PRODUCTION OF LiBeB BY COSMOLOGICAL COSMIC RAYS

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Daigne et al., 2006, ApJ, 647, 773

RVO, 2005, ApJ, 627, 666

RVO, 2006, ApJ, 651, 658

RMVOI, 2008, ApJ, 673, 676

RVMODSV, 2009, MNRAS, 398, 1782

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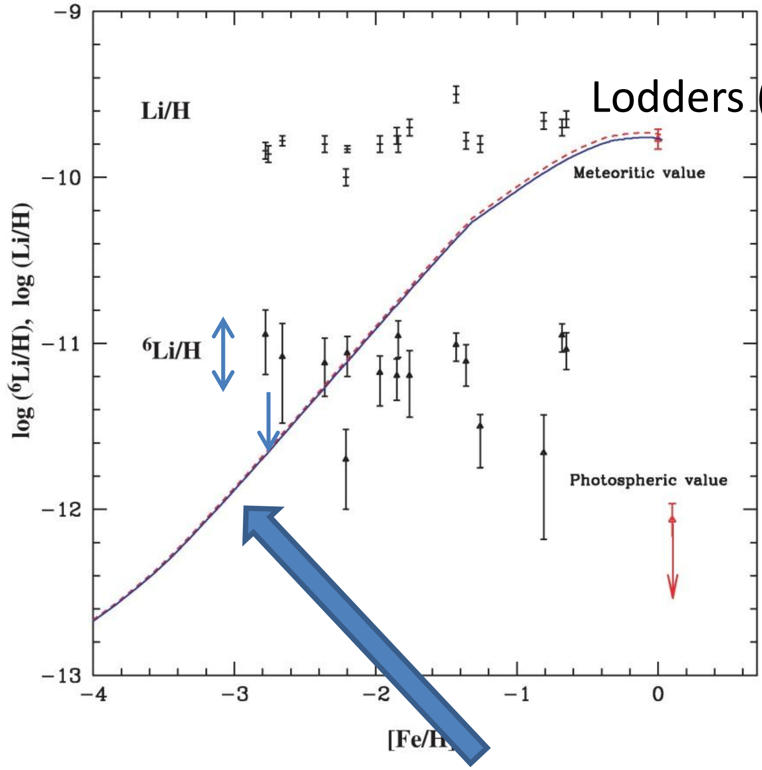
Motivations
$^{6}Li/H$ abundances in MPHS

observed abundance ~ - 11
Asplund et al. 2004
Lambert 2004
Asplund et al. 2006

Log(BBN abundance) = - 14



Lodders (2003)

GCR production
Vangioni-Flam, Cassé & Audouze (2000)
Mercer et al. (2001)

OUTLINE

Motivation : Li6 abundance

- BBN
- Non-thermal production

A Cosmological perspective

- Hierarchical model and PopIII stars
- Main successes

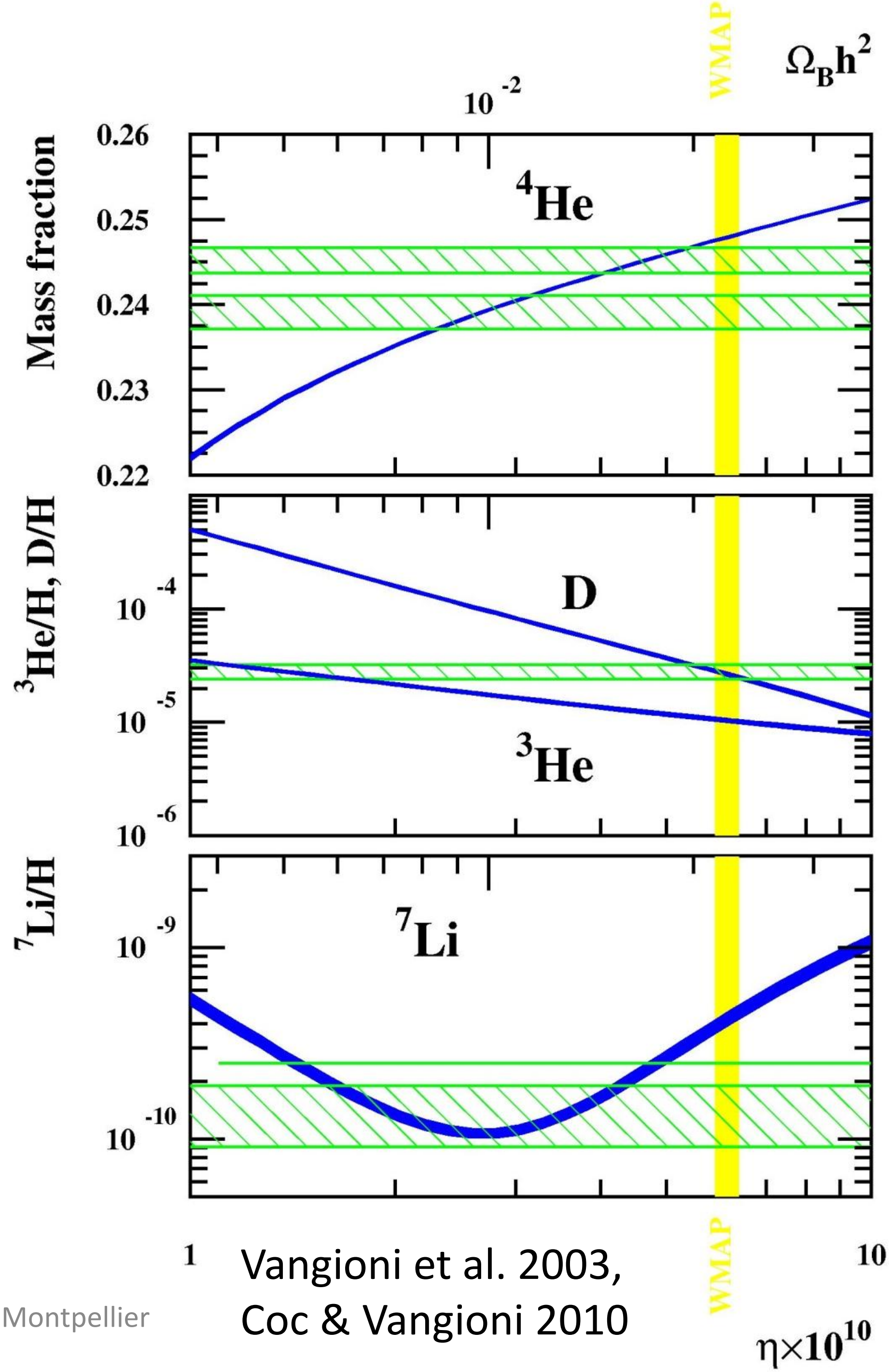
CCR production

- CR ejection spectrum
- LiBeB production
- Gamma ray flux

Conclusion

Primordial Nucleosynthesis:

A link between theoretical BBN (blue curves) and observed abundances (green area)



Vangioni et al. 2003, Coc & Vangioni 2010

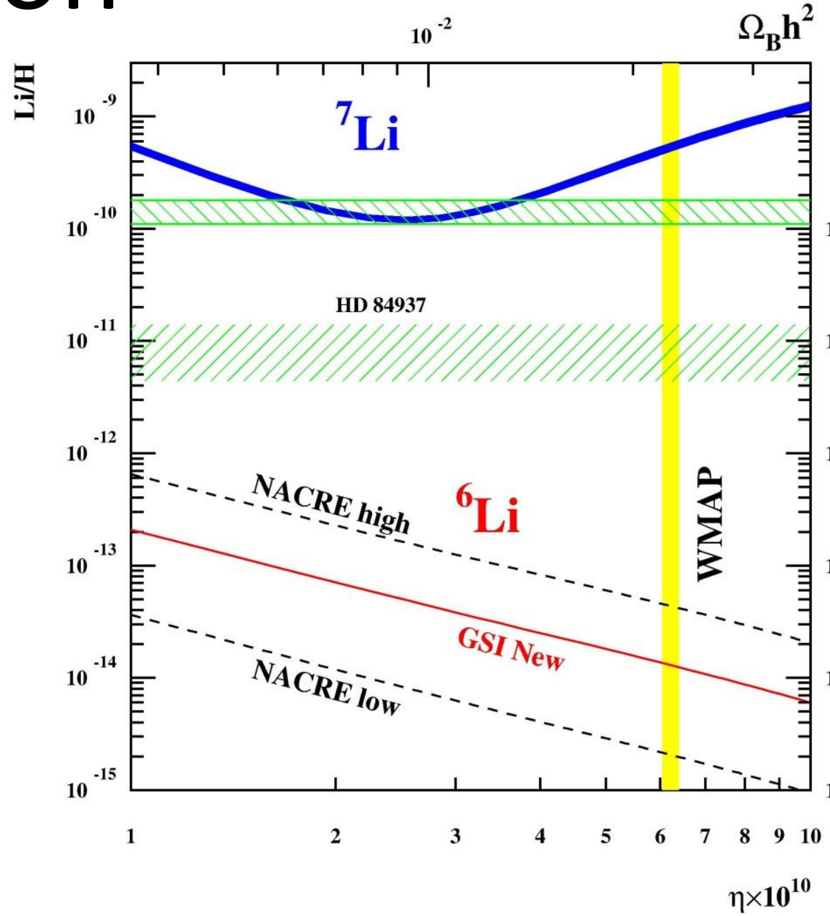
^6Li production

➔ NO… OR MAY BE :
New measures for SBBN $D(\alpha,\gamma)^6Li$
(Hammache et al. 2010)

Modification to SBBN
(Jedamzik et al., Kawasaky, Pospelov… Ellis et al.)

➔ MAY BE :
Shocks during galaxy formation
(Suzuki & Inoue 2002)

CCR – IGM interaction
(Montmerle 1977 ; Rollinde et al. 2005, 2006, 2008)



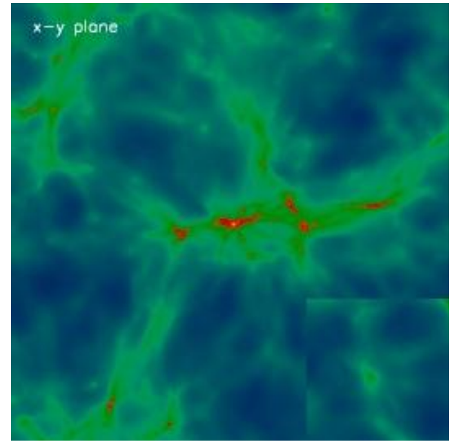
Hammache et al. 2010

Nucleosynthesis in a Cosmological context

❑ Additional constraints :
Be, B; T(z) ; Ig ; CNO ; reionisation

COSMOLOGICAL CONTEXT
A UNIFORM HIERARCHICAL MODEL

Formation of the first (Massive) Stars



Greif, Johnson, Bromm al. 07

0.1 Gyr (z~30)

0.2 Gyr (z~20)

See also Wise & Abel, 2007 ; O'Shea et al 20007 ; Smith et al. 2008; Johnson et al. 2007 ; Yoshida et al. 2007

?

Formation of low mass stars

Observation of halo stars

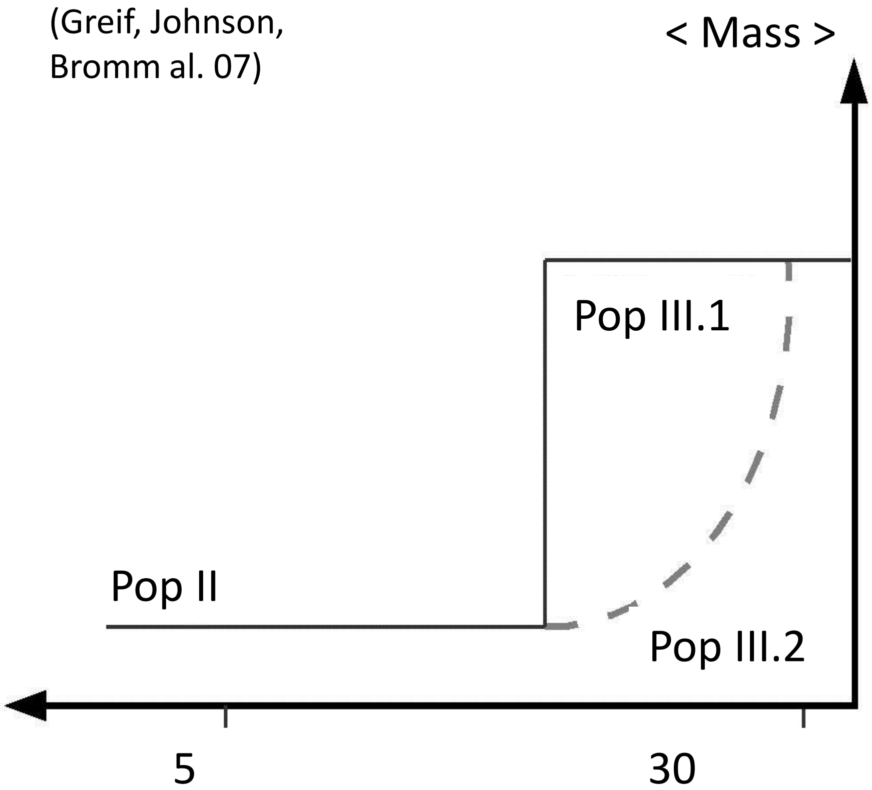
Abundances (H, Fe, C, O, Si…)

13.6 Gyr

HK-HES surveys (Beers et al.1992) ; Hamburg-ESO survey (Christlieb et al. 2002)
ESO-LP "First Stars" (Cayrel et al. 2004) ; Frebel ; Aoki ; Cohen ; Norris…

Different modes of Star Formation

(Greif, Johnson, Bromm al. 07)



Three modes of star formation triggered by metallicity

- Very massive PopIII.1 (>100 Msun)
- Massive PopIII.2 (few 10 Msun)
- PopII (1-100 Msun)

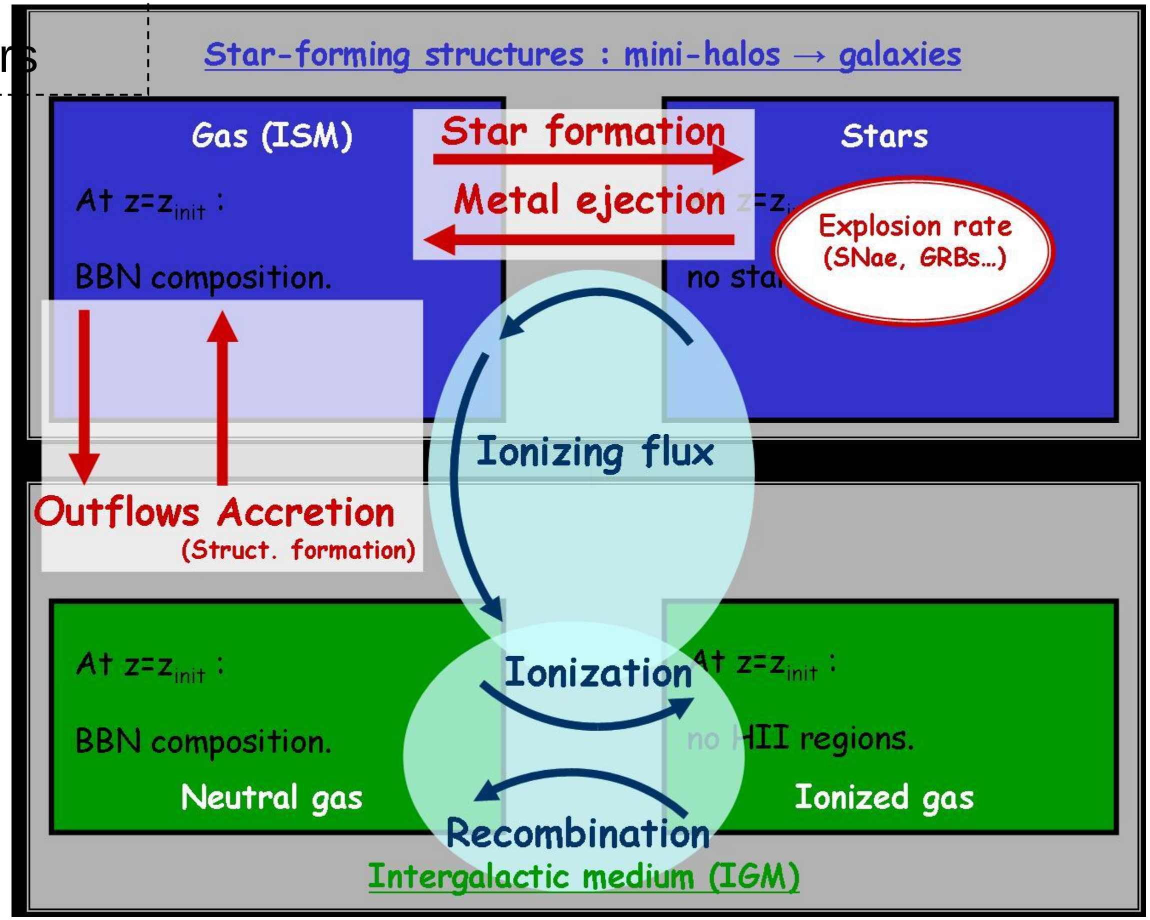
ISM – IGM interaction

1. Structures follow Press Schechter
2. Follow mean IGM / ISM / Stars

(Daigne et al. 2006)

Press Schechter
SFR
IMF
Yields

Abundances
SNR
Fluxes…



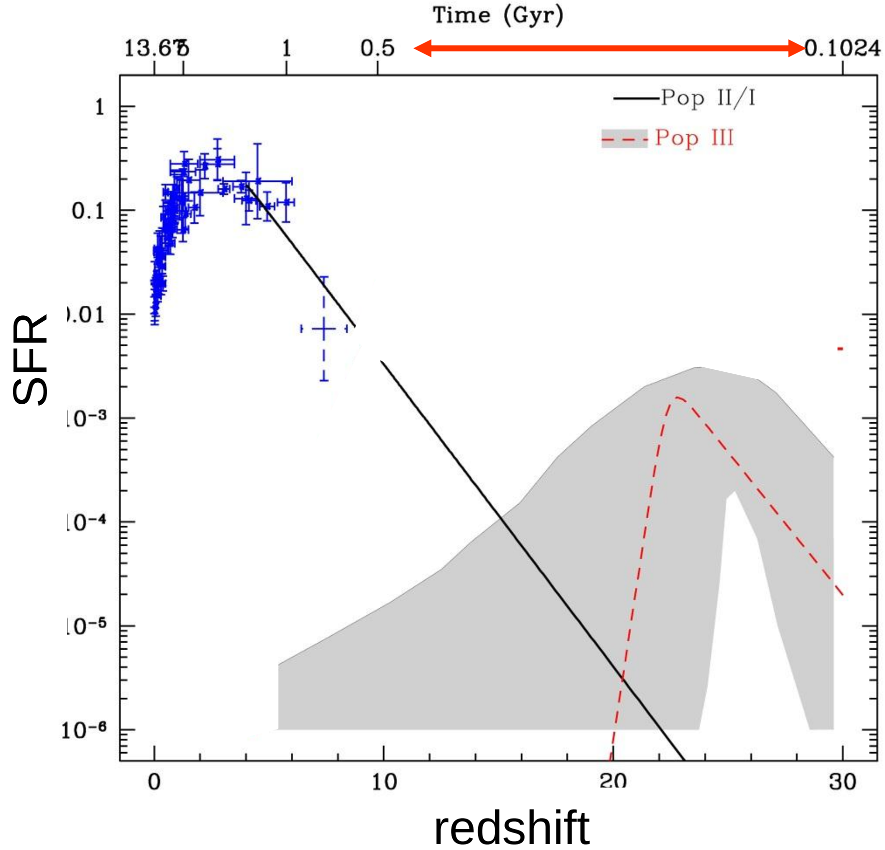
Different modes of Star Formation

Daigne etal. (2006)
Rollinde et al. (2009)

We consider :

- PopI/II stars Salpeter IMF 0.1-100 M Standard yields (WW95)
- PopIII stars

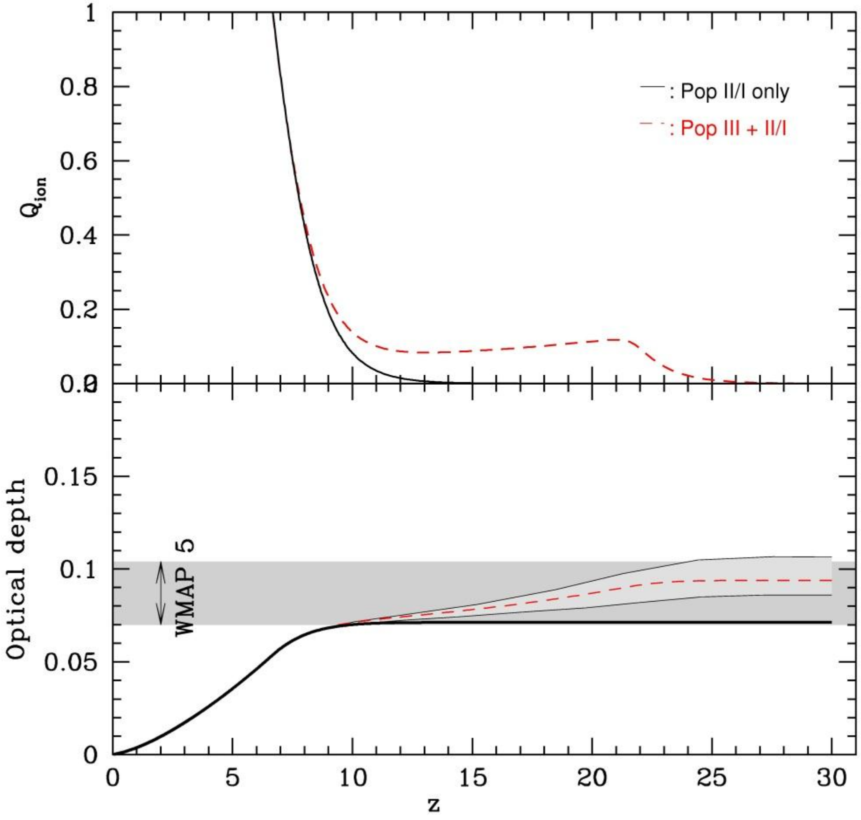
Salpeter IMF 40-100 M (WW95)

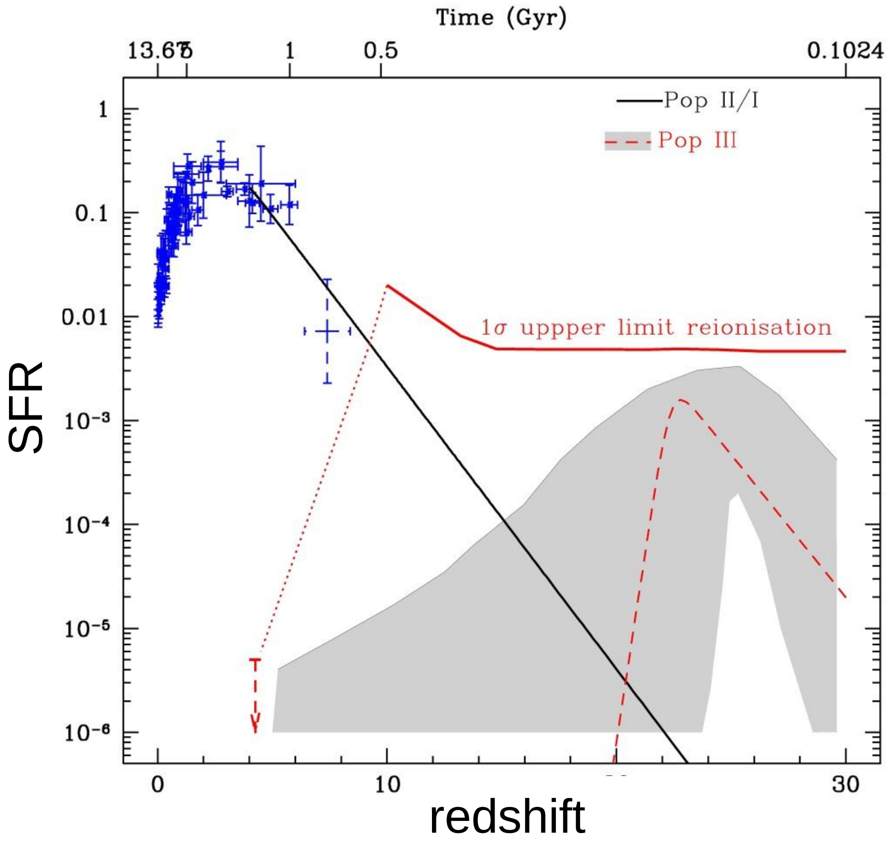


Successfully reproduced :

- Baryonic content
- SNR
- Chemical enrichment of IGM / ISM
- Reionisation

Reionization constraints





Dunkley et al. (2009) - WMAP5

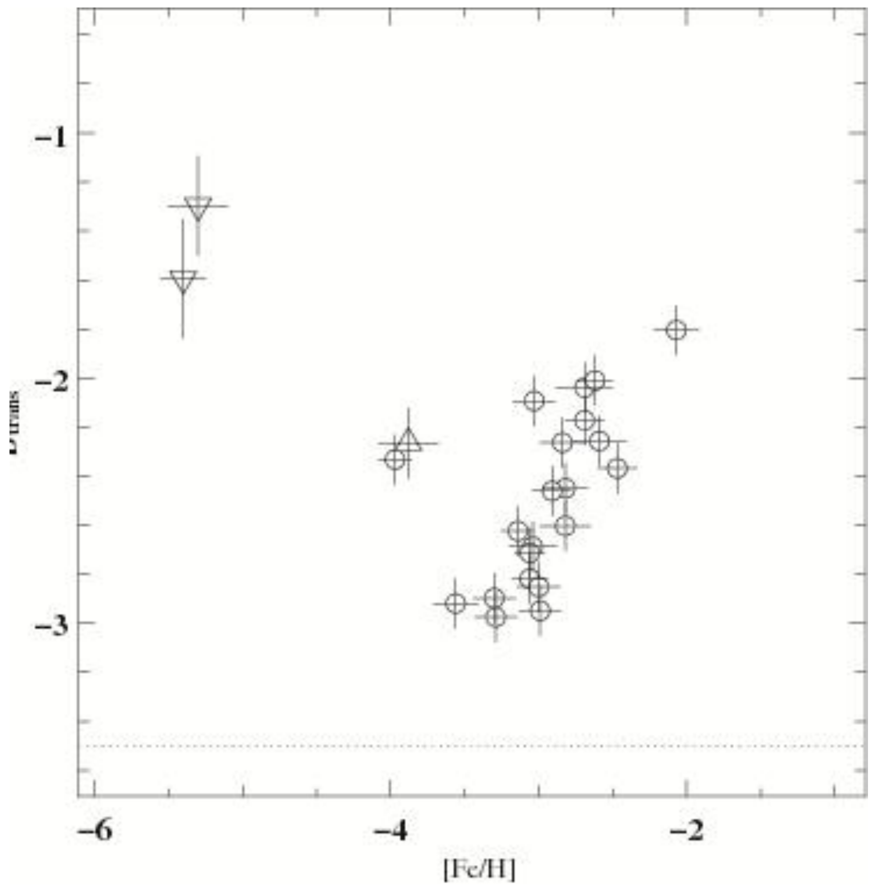
Gradual and consistent with a 2 steps model

Specificity of Ultra-Metal Poor Stars

D_{trans} =
$\mathrm{Log}(10^{[C/H]}+0.3 \times 10^{[O/H]})$

Low-mass criterium :
$D_{trans} > -3.5$
(Bromm & Loeb, 2003
Santoro & Shull, 2006
Frebel et al. 2007)

D_{trans} vs Fe/H



Nucleosynthesis of PopIII stars

Carbon-rich Extremly Metal Poor Stars

If C-EMPs (HMP and UMP)

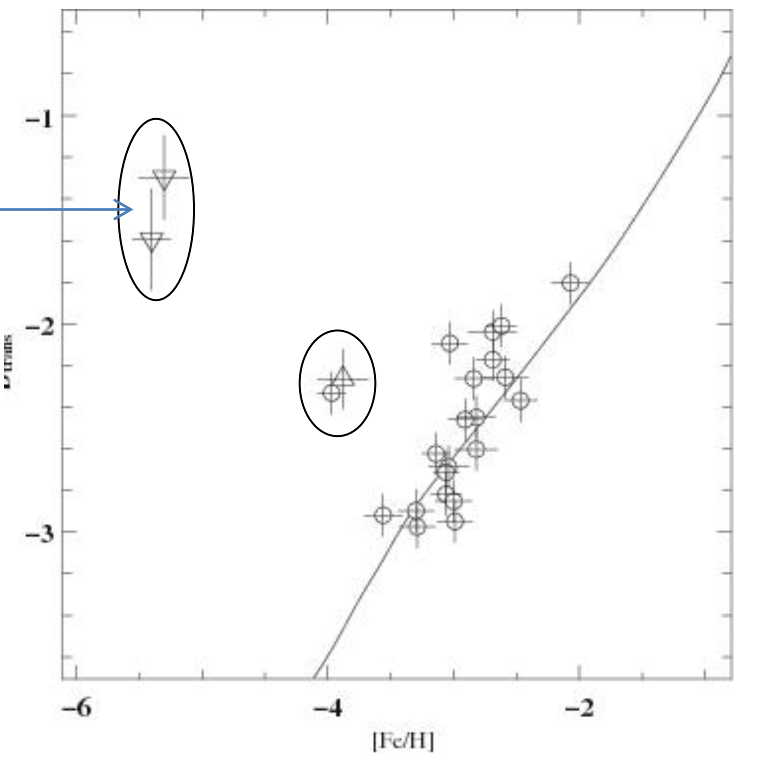
are *cosmologically significant*,

Their abundance pattern *cannot be explained* without massive stars

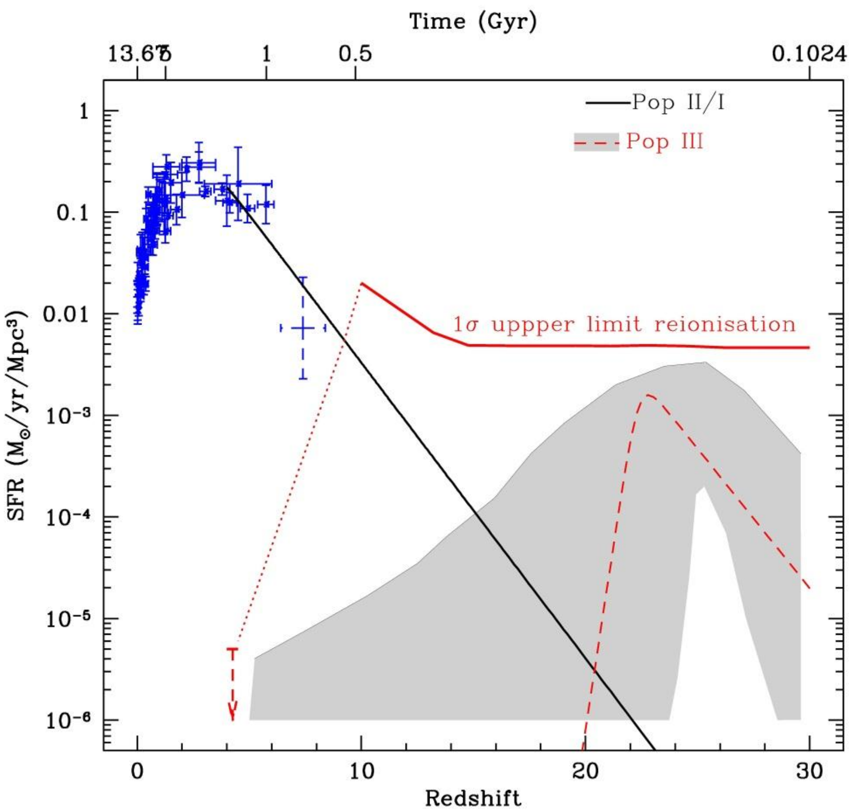
(> 10 Msun and < 100 Msun)

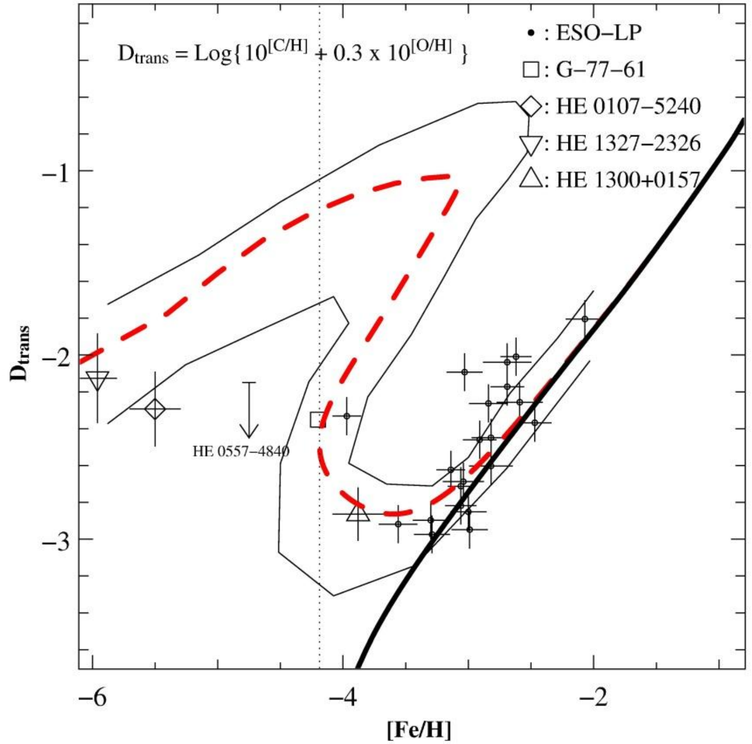
Very massive stars (> 200 Msun) do not modify abundances

D_{trans} vs Fe/H



Constraints on cosmological SFR





LiBeB AND CCRs

CCR ejection and outflows

CR source spectra Propagation

$$\frac{dQ_{C,N,O}}{dp} = \begin{cases} p^{-\gamma_{p,He}} \; if \; E \geq 8 \; GeV/n \\ p^{-\gamma_{CNO}} \; otherwise \end{cases}$$

$$\gamma_{p,He} = 3; \; \gamma_{CNO} = 1.5$$

Based on observed Galactic spectrum
Maurin et al. 2004 ; Hörandel et al. 2007

CNO Abundances

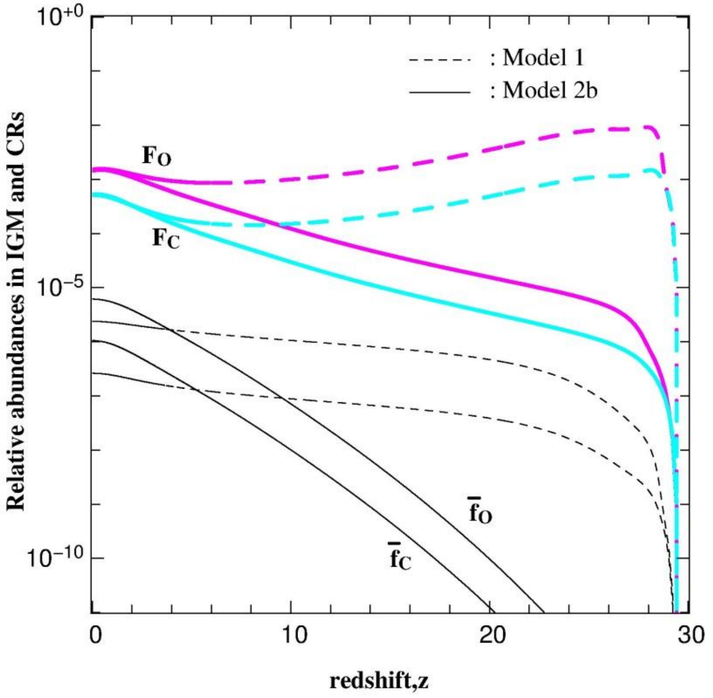
$$F = \frac{\Phi}{\Phi_p} ; f = \frac{n_{ISM}}{n_{ISM,H}} ; \bar{f} = \frac{n_{IGM}}{n_{IGM,H}}$$

Based on model of Daigne et al.
And abundance pattern (Meyer et al. 1998)

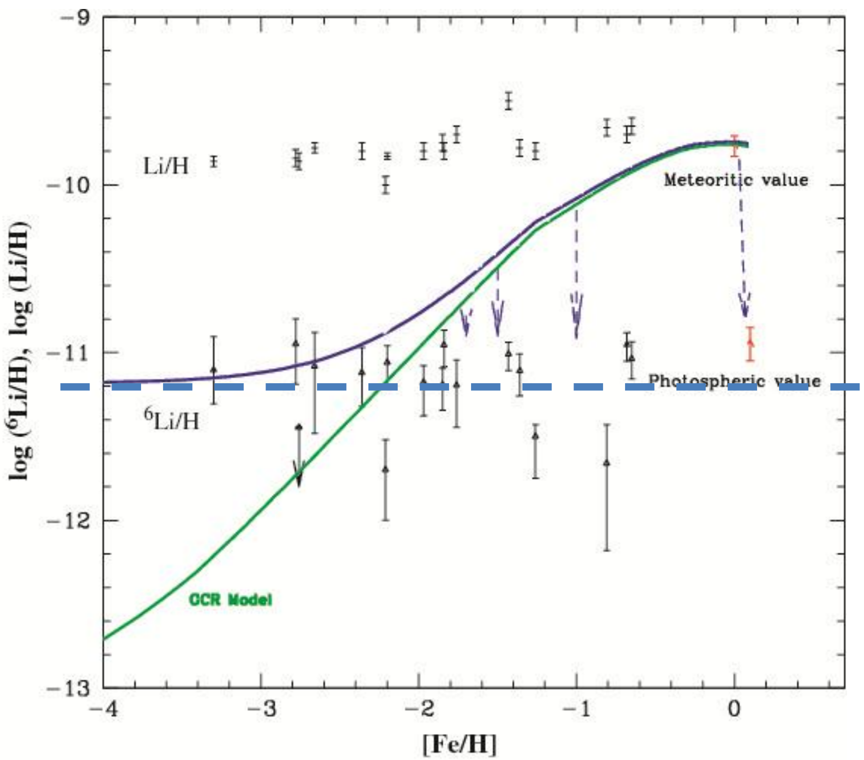
$$F = \eta f$$

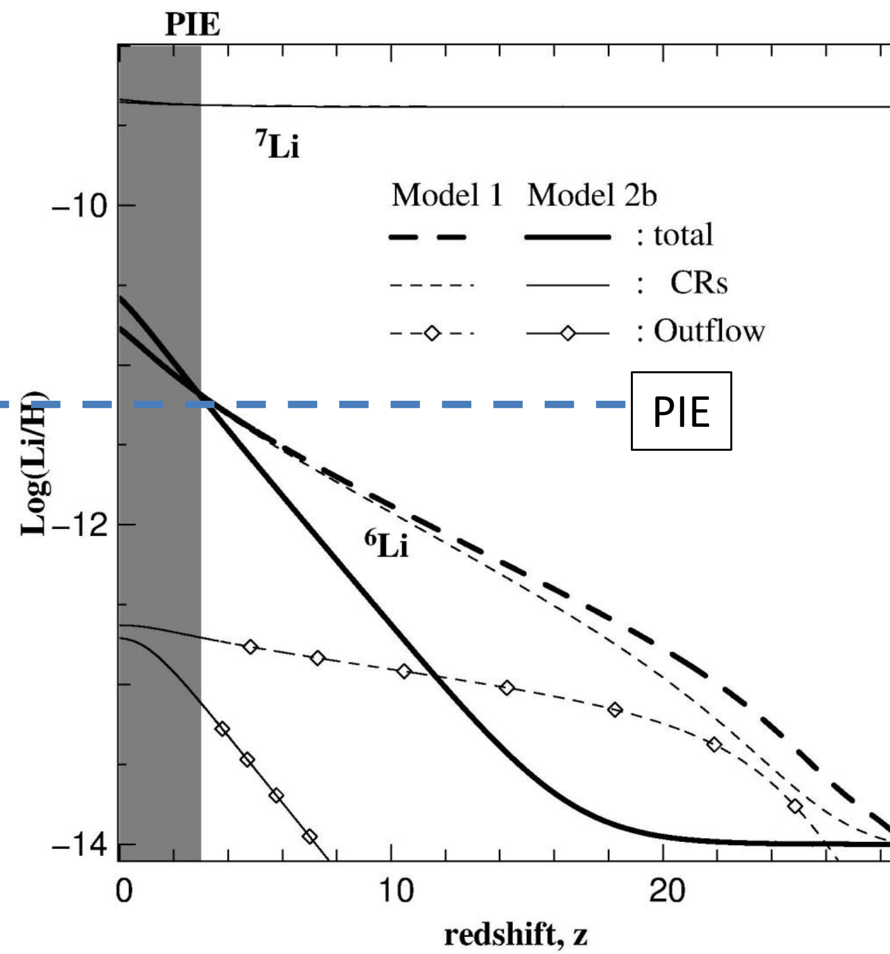
$$f_{He} = \overline{f_{He}} = 0.08$$

1 : PopIII 40-100 Msun
2b : PopIII > 250 Msun (black hole)

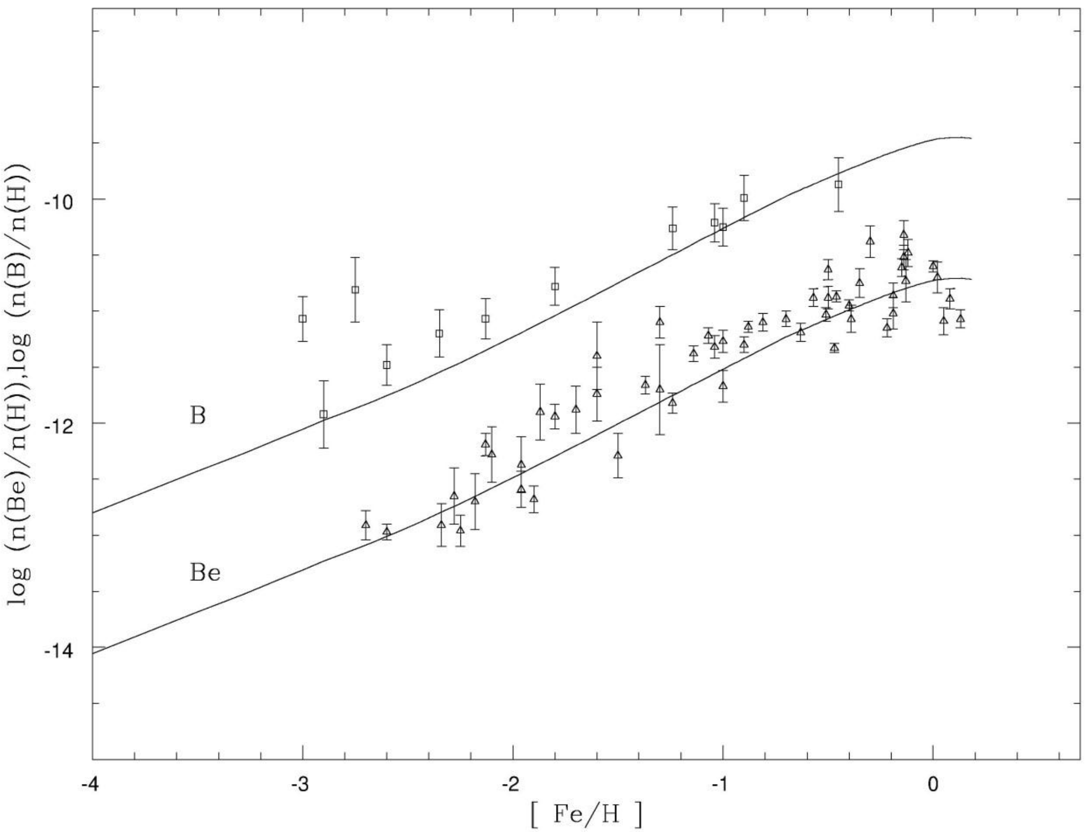


A solution to ^{6}Li abundance





Be, B and D abundances (1)



Vangioni et al. 2000

Observation of BeB ∝ Fe/H
➔ Additional primary process (LEC ; CNO + p)

Existence of a PIE ?

$^{10}B/H_{MPHS} \sim 10^{-11.5}$ (Primas et al. 1999 ;)

$^{9}Be/H_{MPHS} \sim 10^{-13}$ (Primas et al. 2000 ; [Fe/H]=-3.3)

Be. B and D abundances (1)

Most recent SBBN computation with ~ 400 reactions

Coc et al. 2011, in preparation

SBBN of LiBeB does not explain a possible PIE

$^{10}B/H_{MPHS} \sim 10^{-11.5}$ (Primas et al. 1999)

$^{9}Be/H_{MPHS} \sim 10^{-13}$ (Primas et al. 2000)

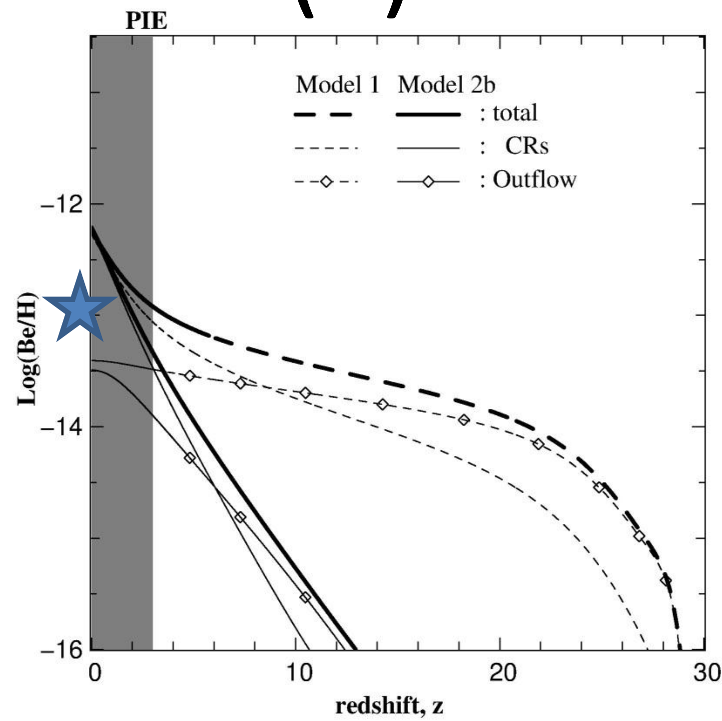
Be, B and D abundances (2)

SIMPLIFIED DESCRIPTION OF CROSS SECTIONS USED IN THE APPROXIMATE CALCULATION

$i + j \to X$	σ_{ij}^{X} (mbarn)	E_1 (GeV nucleon^{-1})	E_2 (GeV nucleon^{-1})
$\alpha + \mathrm{He} \to {}^6\mathrm{Li}$	20	0.01	0.02
$p + \mathrm{H} \to \mathrm{D}$	1	0.4	0.8
$p + \mathrm{He} \to \mathrm{D}$	12	0.05	∞
$p + \mathrm{C} \to {}^9\mathrm{Be}$	6	1.0	∞
$p + \mathrm{O} \to {}^9\mathrm{Be}$	5	0.05	∞
$p + \mathrm{C} \to \mathrm{B}$	90	0.015	∞
$p + \mathrm{O} \to \mathrm{B}$	50	0.04	∞

$D/H_{CCR} \sim 3.1\ 10^{-10} \ll 2\ 10^{-5}$ (O'Meara et al. 2006)

${}^9Be/H_{CCR}\ (z = 3) \sim\ 10^{-12.9/-13.3} \sim 10^{-13}$ (Primas et al. 2000)



Be, B and D abundances (2)

Simplified Description of Cross Sections Used in the Approximate Calculation

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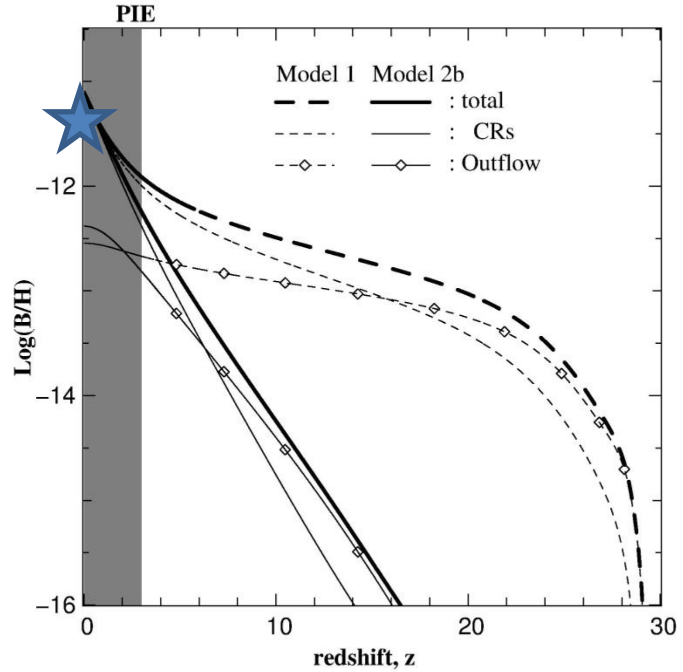

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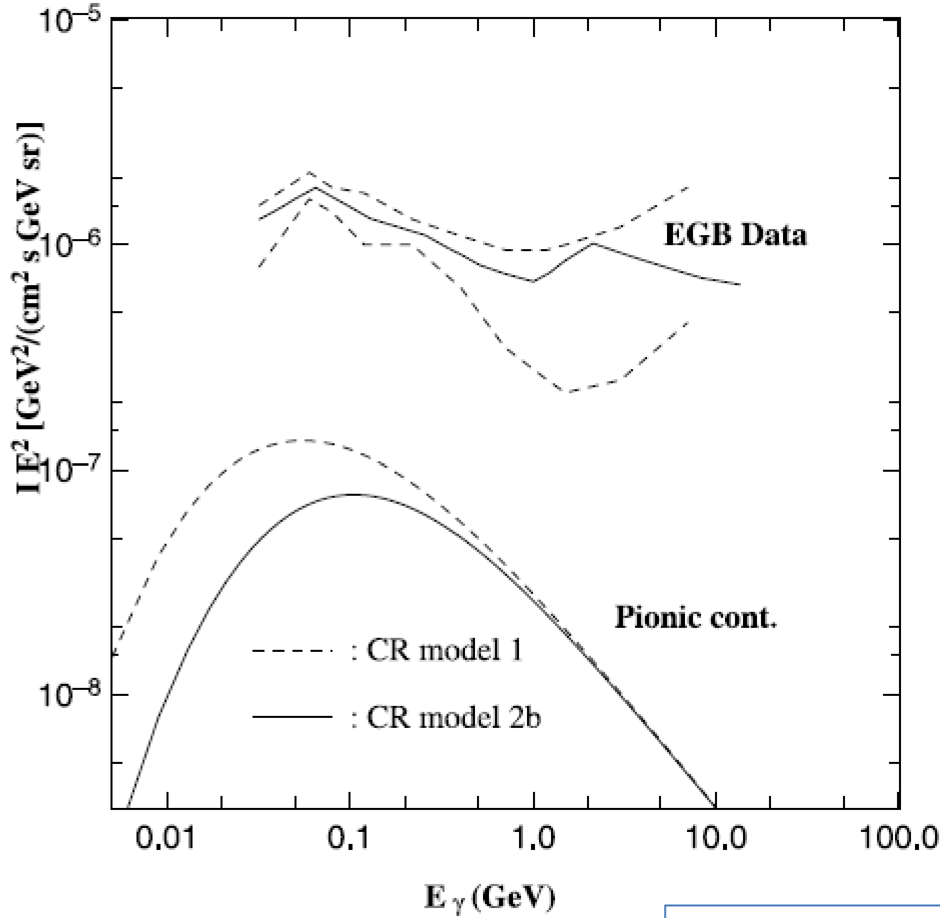
${}^{10}B/H_{CCR}\ (z=3) \sim\ 10^{-11.9/-12.2} \sim 10^{-11.5}$ (Primas et al. 1999)

$\gamma - ray\ flux$



Model from Pavlidou & Fields 2002
Data from Strong et al. 2004, 2007

CONCLUSION

CCRs production by interaction with IGM in a cosmological context

- Explains a possible *plateau* for ^{9}Be, *B* and ^{6}Li
- under-produces *D* and ^{7}Li as compared to primordial abundances
- Under-produces γ ray flux as compared to observed EGBR

Early PopIII episod

- Explains the CNO abundance of a few known MPHS to date
- Is consistent with other cosmological constraints
- Requires **inputs from CRs expert (ejection, confinement *at high redshift*)**

The **observed abundances** of ^{9}Be, *B* and ^{6}Li

- Constrain the SFR evolution at high redshift
- Constrain the shape of CCR spectrum (source and propagation)
- ***Has to be confirmed !!***