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The first stars and the early lithium history.

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Abstract

The constant ^{7}Li abundance in halo stars near turn-off ($T_{eff}\simeq$6300 K) and below [Fe/H]=-1.3 is referred as the lithium Spite Plateau. It has been attributed a cosmological origin. However the Big Bang Nucleosynthesis (BBN) predictions supported by the Wilkinson Microwave Anisotropies Probe (WMAP) suggest that these stars have been depleted by 0.4 dex with respect to the primordial ^{7}Li abundance. Part of this depletion may have occurred through astration in the Population III stars. This idea is fueled by the lingering difficulties of the halo stars models to explain the properties of the Plateau and in particular its extremely small scatter. We show it is supported by the most recent observations concerning ^{7}Li both in Plateau stars around [Fe/H]=-2.5 and in the most metal poor star known to date: HE1327-2326. In the framework of this new paradigm we estimate the level of astration of the Galactic halo necessary to bring the observations on the Spite Plateau in agreement with the BBN predictions to be between 1/3 and ½ of the halo (baryonic) mass. We show that the amount of ^{7}Li depletion due to Population III stars might provide indications on the reionization of the Universe or the early production of ^{6}Li. Finally a significant amount of astration in Population III stars has a strong impact on the early metal production in the Galactic halo. This work is available on astro-ph/0603553 presently submitted to ApJ

Three constrains on ^{7}Li

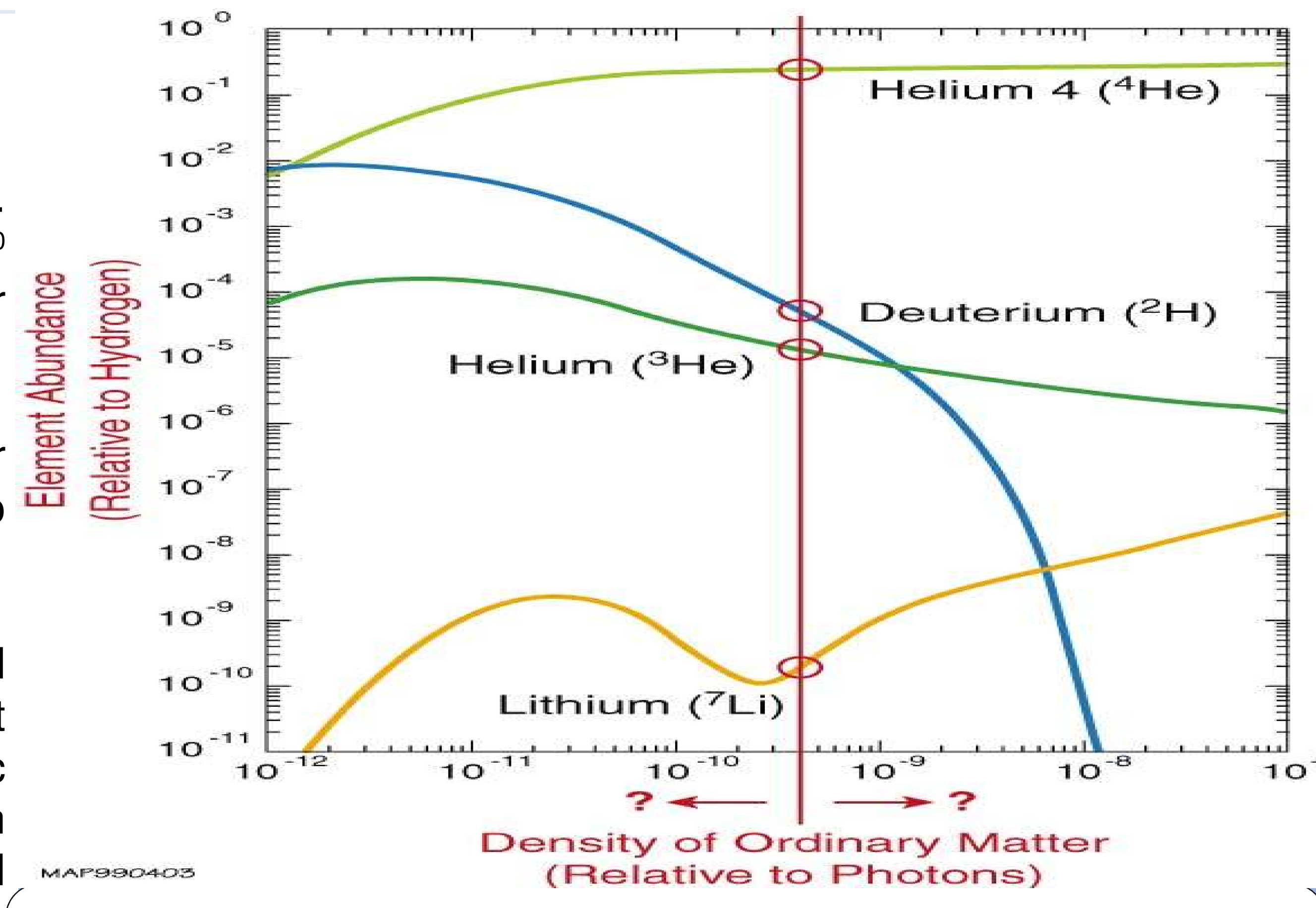
➢The Big Bang Nucleosynthesis computations presently suggests A(^{7}Li)=2.6 i.e. ^{7}Li/^{1}H=4.10^{-10} (Coc et al. 2004). This result relies on the baryonic number η =6 10^{-10} infered from the cosmological background anisotropies measured by WMAP after three years of observations (Spergel et al. 2006).

➢The average lithium Plateau abundance observed today is A(^{7}Li)$\simeq$2.2. The scatter of the abundances on the Plateau is extremely small $\sigma\simeq$ 0.05-0.03 dex (Bonifacio et al. 2006; Asplund et al. 2006).

➢The models of turn-off halo stars suggest a ^{7}Li surface depletion between 0.1 and 0.2 dex during the 13 billions years lifetime of these stars (Piau 2006, Pinsonneault et al. 2002, Richard et al. 2005). The depletion mostly stems from the microscopic diffusion. The absence of scatter on the Plateau would be difficult to explain with a larger depletion induced by nuclear reactions through mixing of surface material down to layers where the temperature exceeds 2.5 10^6 K. The presence of ^{6}Li in some Plateau stars (Asplund et al. 2006) reinforce such a scenario.

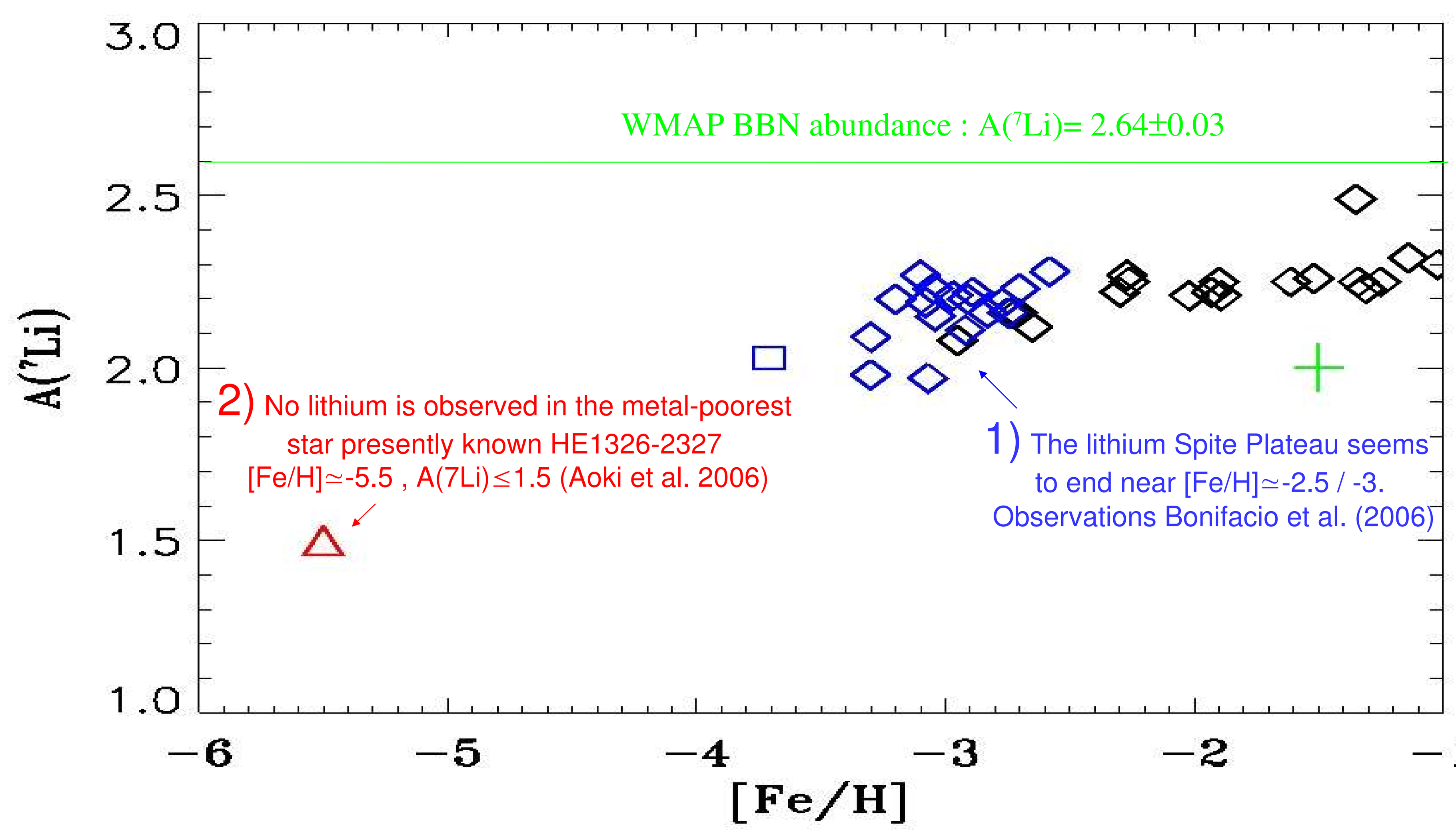
There is a discrepancy Δ^7Li=0.2 to 0.3 dex between BBN computations and predictions of initial Population II stars composition.

A possible and simple solution to the BBN/halo stars ^{7}Li discrepancy is to assume it is induced by astration of the primordial matter inside Population III stars.



Schematic view of the Big Bang Nucleosynthesis where the ratios of the light elements produced are displayed as a function of the baryonic number (Image Credit : NASA).

Two observational confirming clues



Lithium depletion in halo dwarfs is insufficient

We computed Population II models of halo stars including both microscopic diffusion and various prescriptions for the turbulence in the upper radiation zone. Turbulent mixing in the radiation zone is supported by the lithium history in solar analogs (Piau et al. 2003) and the lithium Plateau features (Piau 2006).

The models are initiated with A(^{7}Li)=2.6 and evolve until they reach 13.5 Gyr. The mass is set so that T_{eff}=6200 K at this age.

Under these conditions Population II models do not reproduce the abundance of ^{7}Li observed today for [Fe/H]=-3.5 and typical halo star metal repartition or the HE1326-2327 composition.

Composition and mass	Tachocline prescription for turbulence	Richard et al. (2005) prescription for turbulence
[Fe/H]=-3.5, [O, α/Fe]=0.35 0.69 $M_\odot$ & 'usual' halo star composition	A(^{7}Li)=2.38	A(^{7}Li)=2.26
[Fe/H]=-5.5, [O/Fe]=2.6, [C/Fe]=3.9 0.41 $M_\odot$ & composition of HE1326-2327	A(^{7}Li)=1.83	A(^{7}Li)=2.36

The astration in the first stars

In stellar conditions, ^{7}Li is destroyed by proton capture as soon as T>2.5 10^6 K. The first stars destroy lithium by this process on the largest part of their mass fraction. Using zero age main sequence models of zero metallicity stars we estimate that lithium is preserved over m_7= 7 10^{-5} to 7 10^{-3} $M_\odot$ for every solar mass processed. This range of values is determined by the initial mass function and the mass cuts adopted for the lower and upper limits of mass range. In any case m_7 is very small.

A simple calculation shows that the fraction of matter astrated in the first generation of stars x_{PopIII}, m_7 and Δ^7Li are related by x_{PopIII}= (1-10$^{-\Delta 7Li}$) / (1-m_7)

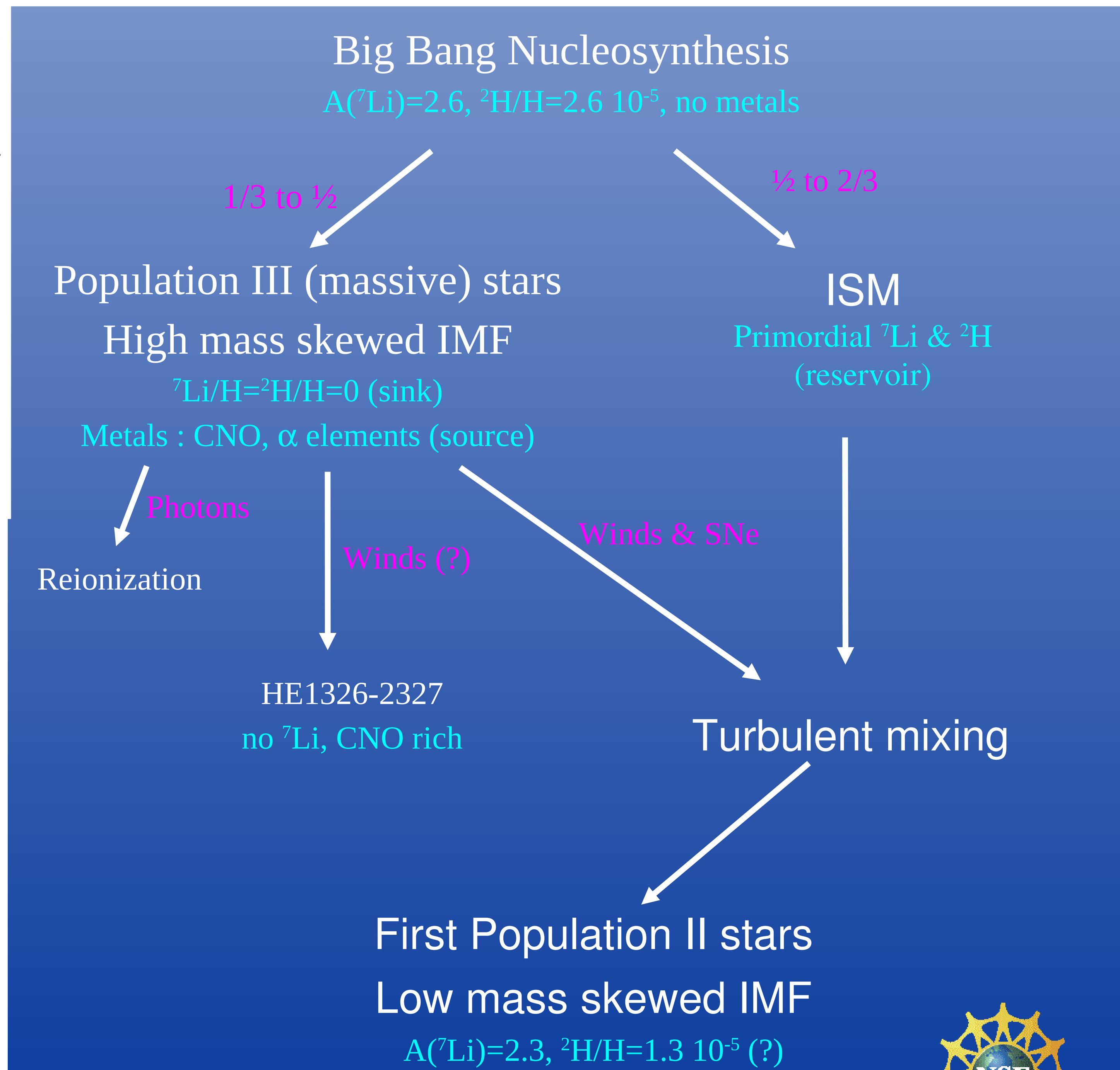
In turn this formula indicates that the mass fraction of the Galatic halo baryonic matter required lies between 1/3 and ½ if we assume Δ^7Li=0.2 and 0.3 respectively.

The level of astration has implications for :

➢Estimating the ionizing efficiency of the first stars. The luminosity of quasars decreases for redshifts higher than 3 (Hopkins et al. 2006). Therefore the first stars are serious candidates for the episod of reionization of the Universe occuring at redshifts higher than 5 and that is presumably responsible for the optical depth of the Universe measured by WMAP.
➢The stellar nucleosynthesis in the first stars. Present supernovae yields for Population III stars and a level of astration of ½ suggest the early halo nearly reached the solar metallicity after the first stellar generation. These explosive yields however are in complete disagreement with the observations of [C/O] or [N/O] ratios in the halo stars. The abundances resulting only from the winds of models including rotation (Hirschi 2006) are in better agreement with these ratios and the total metal abundances observed in the most metal poor stars. Carbon and nitrogen enriched extremely metal poor stars were probably formed through winds of massive Population III progenitors. Therefore the peculiar chemical patterns observed below [Fe/H]= -2 (Beers et al.) receive a simple explanation in the framework of significant initial astration in Population III stars.
➢The early interstellar medium mixing and nucleosynthesis induced by the first supernovae explosions. An important number of first SNe may induce an efficient initial mixing of the halo capable of explaining the small of scatter in chemicals below [Fe/H]= -2 e.g. in α–elements. Furthermore these SNe are candidates to the production of the energetic particles presumably responsible for the ^{6}Li plateau (Asplund et al. 2006).

Summary

The scheme we suggest for matter from BBN to the Population II stars



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