Li isotopes in metal-poor halo dwarfs

M. & F. Spite

1981 - 2009

a more and more complicated story

the very metal-poor stars are born at the very beginning of the Milky Way

the lithium abundance in their atmosphere must reflect the pristine value

Formation of Li

In the early times…

the matter could be enriched only by

- **BBN** primordial nucleosynthesis → ^{7}Li
- **Cosmic rays**

  spallation reactions in superbubbles (SN) } → mainly ^{6}Li

  $\alpha + \alpha \rightarrow {}^{7}\mathrm{Li} + \mathrm{p}$

  $\alpha + \alpha \rightarrow {}^{6}\mathrm{Li} + \mathrm{D}$

  $^{16}\mathrm{O} + \mathrm{p} \rightarrow {}^{6}\mathrm{Li} \ldots$

  $^{12}\mathrm{C} + \alpha \rightarrow {}^{6}\mathrm{Li} \quad {}^{7}\mathrm{Li}$

- SN II (ν process) ??? → ^{7}Li

$$^{4}\mathrm{He}(\nu_x, \nu'_x \mathrm{n})^{3}\mathrm{He}(\alpha,\gamma)^{7}\mathrm{Be}, ^{4}\mathrm{He}(\nu_x, \nu'_x \mathrm{p})^{3}\mathrm{H}(\alpha,\gamma)^{7}\mathrm{Li}$$

$$^{3}\mathrm{He}(\mathrm{n},\mathrm{p})^{3}\mathrm{H}(\alpha,\gamma)^{7}\mathrm{Li}$$

- ~~AGB Novae…~~

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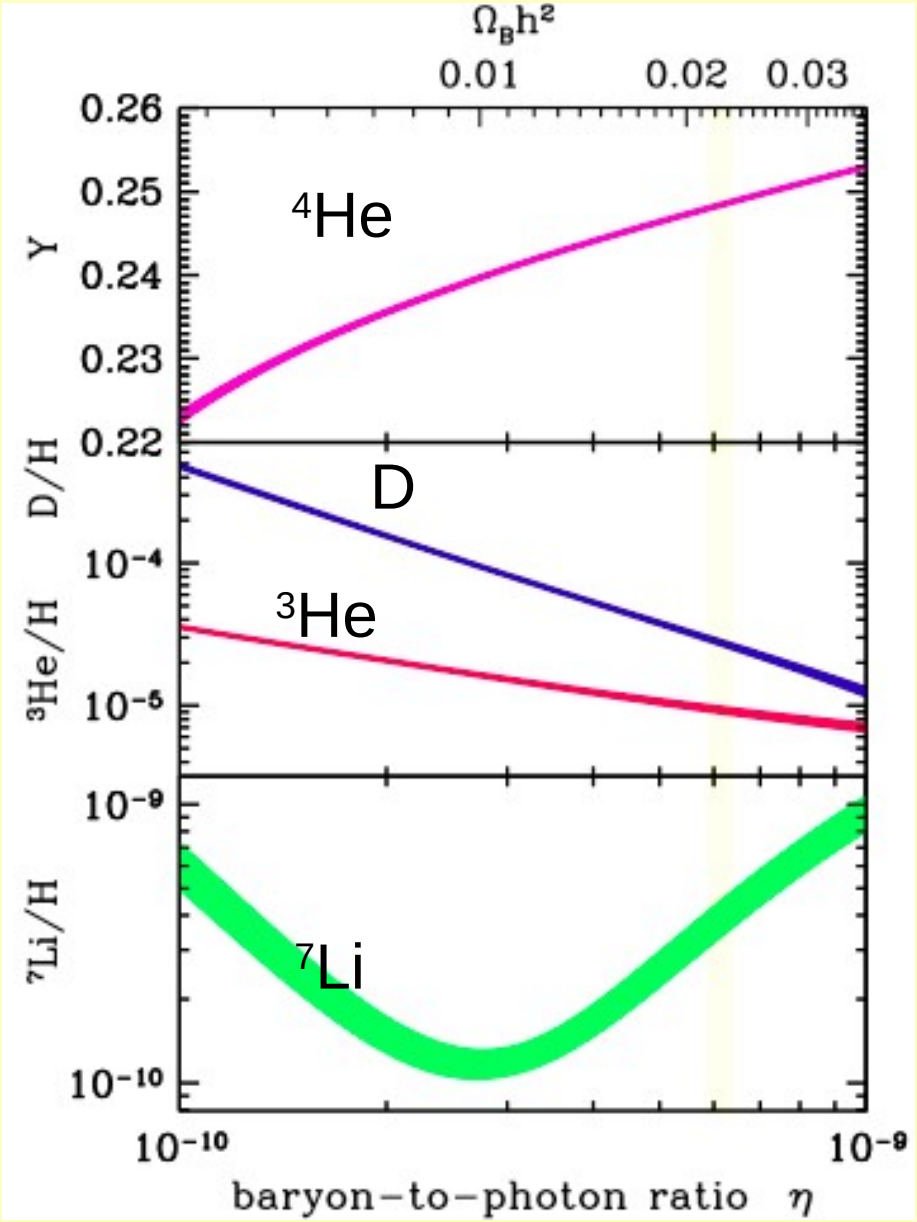
In the early times
^{7}Li ← Big Bang

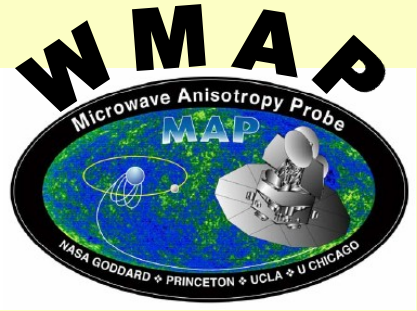
The primordial nucleosyntesis depends only on

baryons to photons ratio

η



see also: Iocco et al. 2009



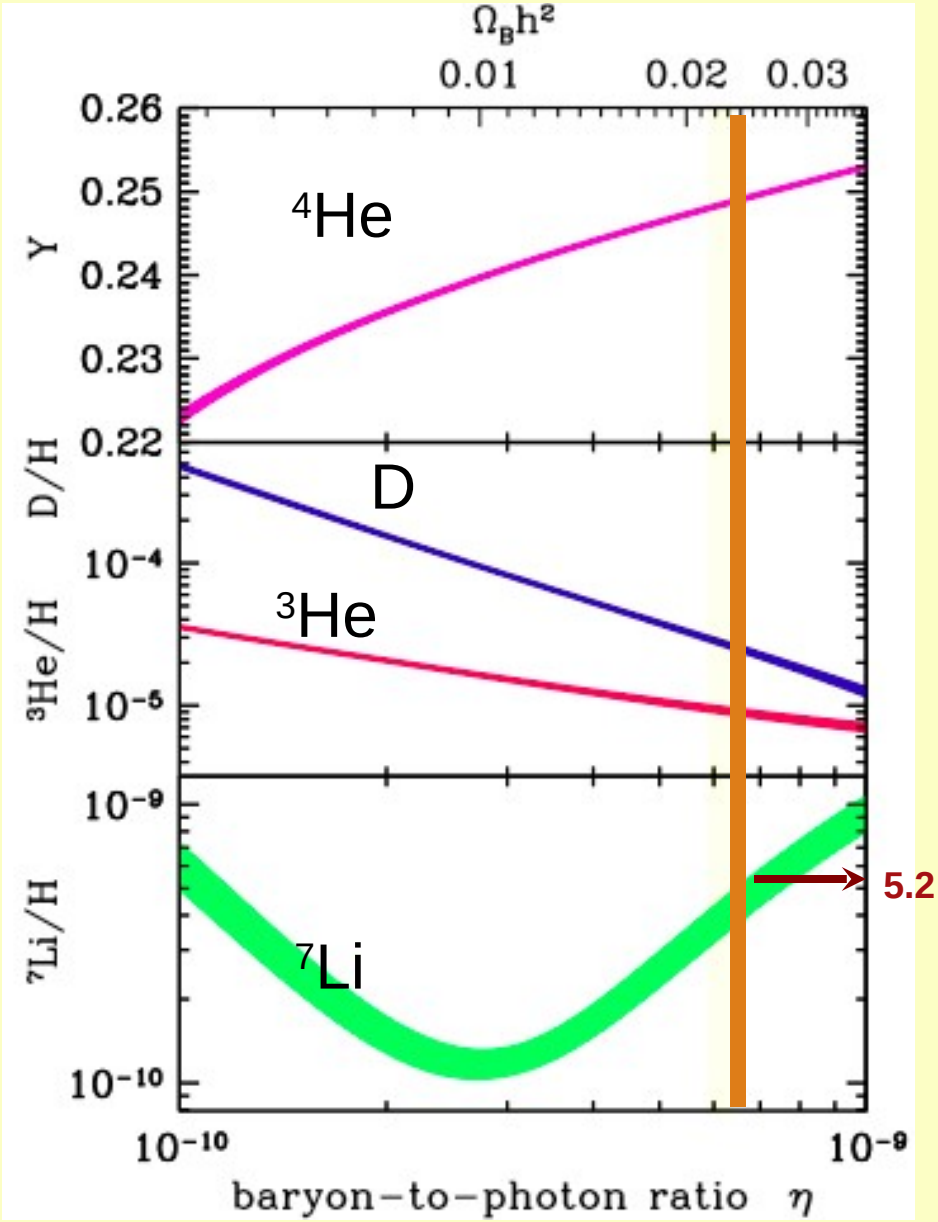
$\eta = 6.23 \pm 0.17\ 10^{-10}$
(Cyburt et al. 2008)

➔**Primordial abundances of 4He 3He D Li**

$^{7}Li/H = 5.24\ 10^{-10}$

log A(Li) = 2.72
for log A(H)=12

see also: Iocco et al. 2009



Lithium is a very fragile element

destroyed :

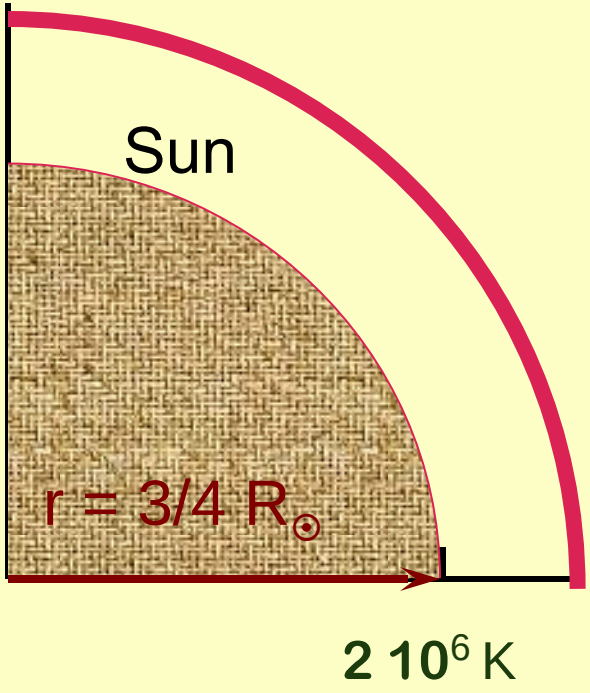
^{7}Li T>2.5 10^{6} K

$^{7}Li + p \rightarrow {}^{4}He + {}^{4}He$

^{6}Li T>2.0 10^{6} K

$^{6}Li + D \rightarrow {}^{4}He + {}^{4}He$

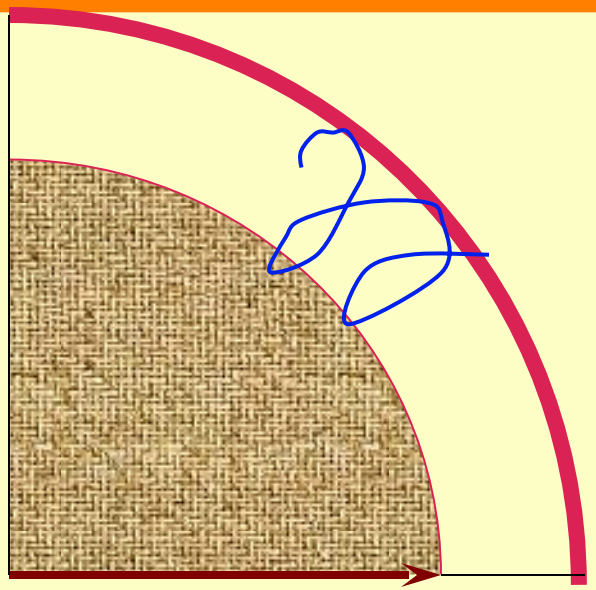
$^{6}Li + p \rightarrow {}^{4}He + {}^{3}He$ ...



However in the MW the Li abundance ↗ with time…

if mixing between
- atmosphere
- layers with T>2.5 10^6K

➔lithium is destroyed
little by little in the atmosphere



In Pleiades: log A(Li)=3.3 age: 0.1 x 10^9 yr

In the Sun: log A(Li)=1.03 age: 5 x 10^9 yr
(see the poster of E.Caffau)

In giants lithium is depleted after the first dredge up

if mixing between
- atmosphere
- layers with T>2.5 10^6K

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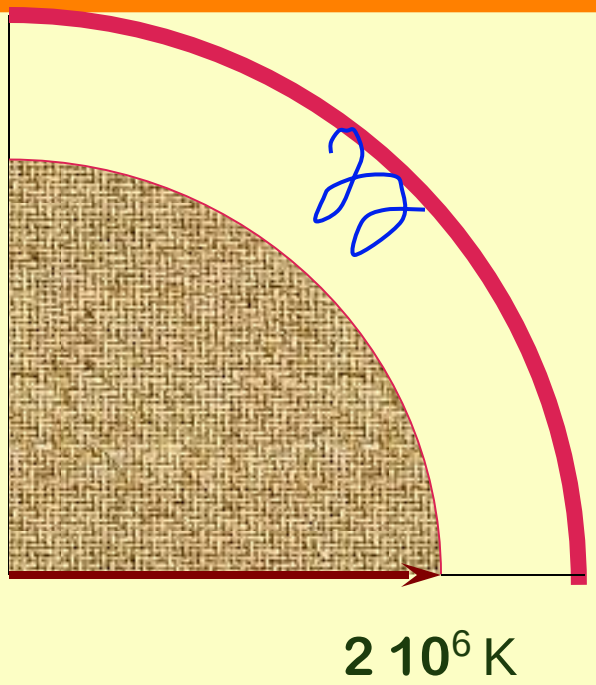


In Pleiades: log A(Li)=3.3 age: 0.1 x 10^9 yr

In the Sun: log A(Li)=1.03 age: 5 x 10^9 yr
(see the poster of E.Caffau)

A priori lithium is preserved in warm metal-poor stars (turnoff)
(mixing is not as deep)

In giants lithium is depleted after the first dredge up

^{7}Li

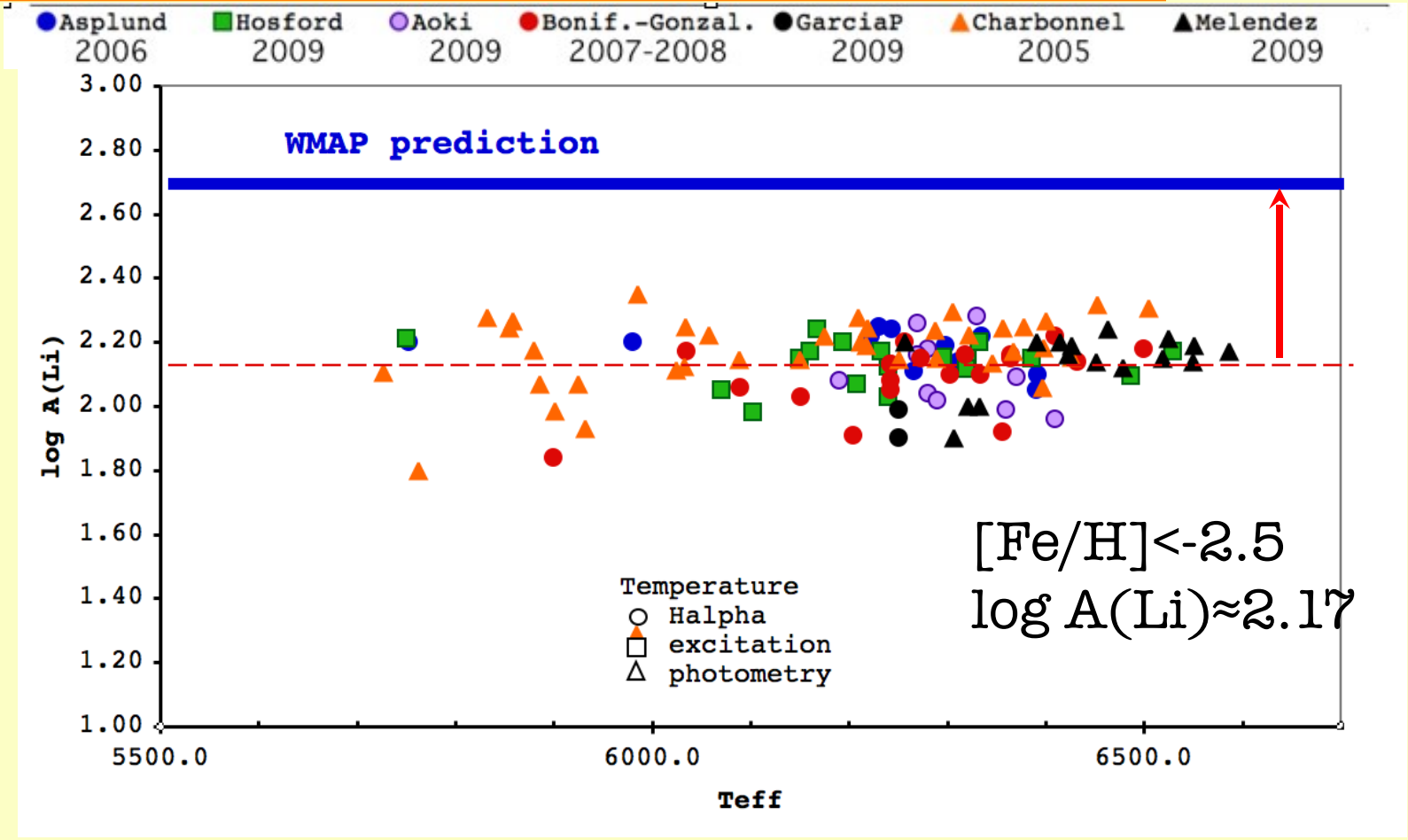
What is observed ?

Abundance of ^{7}Li in the atmosphere of the warm metal-poor dwarfs (turnoff stars)

Teff phot	Teff Hα	Teff (exc)
Charbonel&Primas 2005, Melendez et al. 2009	Asplund et al. 2006, 2007, Bonifacio et al. 2007, Gonzalez Hernandez et al. 2008, García-Pérez et al. 2009,	Hosford et al. 2009

Lithium abundance in metal-poor stars

Poster at the IAU Symp 265



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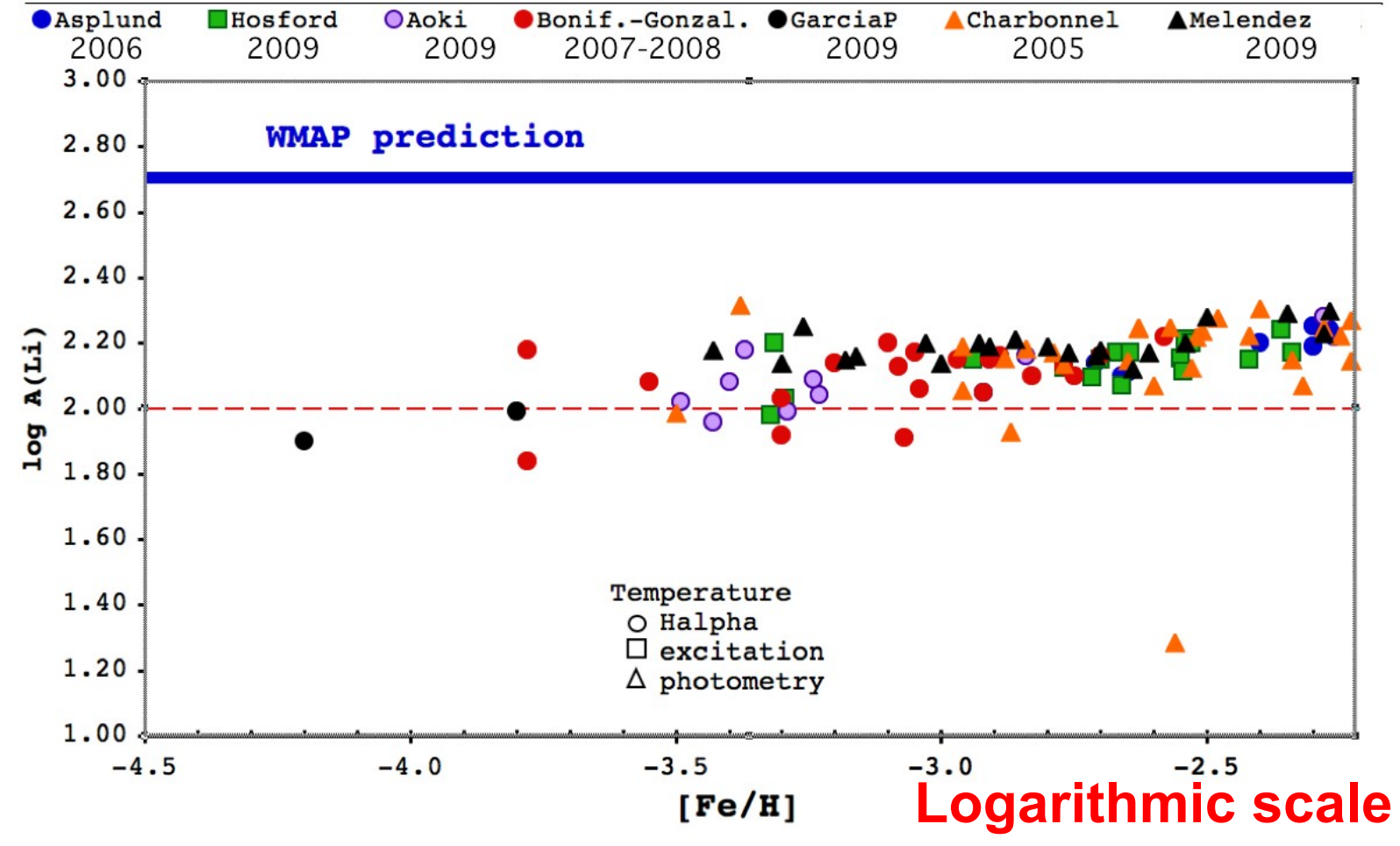
Lithium abundance in metal-poor stars

Poster at the IAU Symp 265



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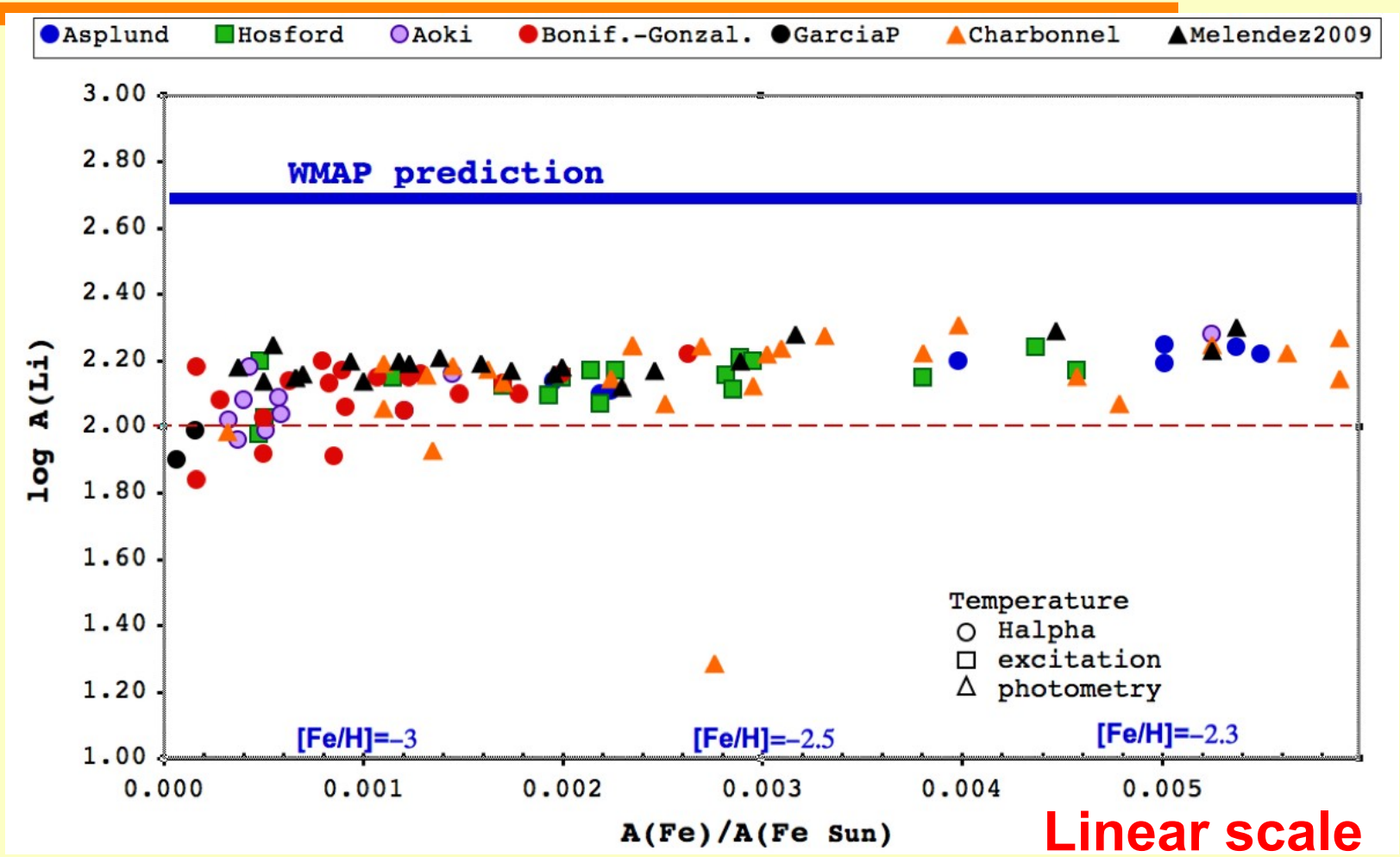
Lithium abundance in metal-poor stars



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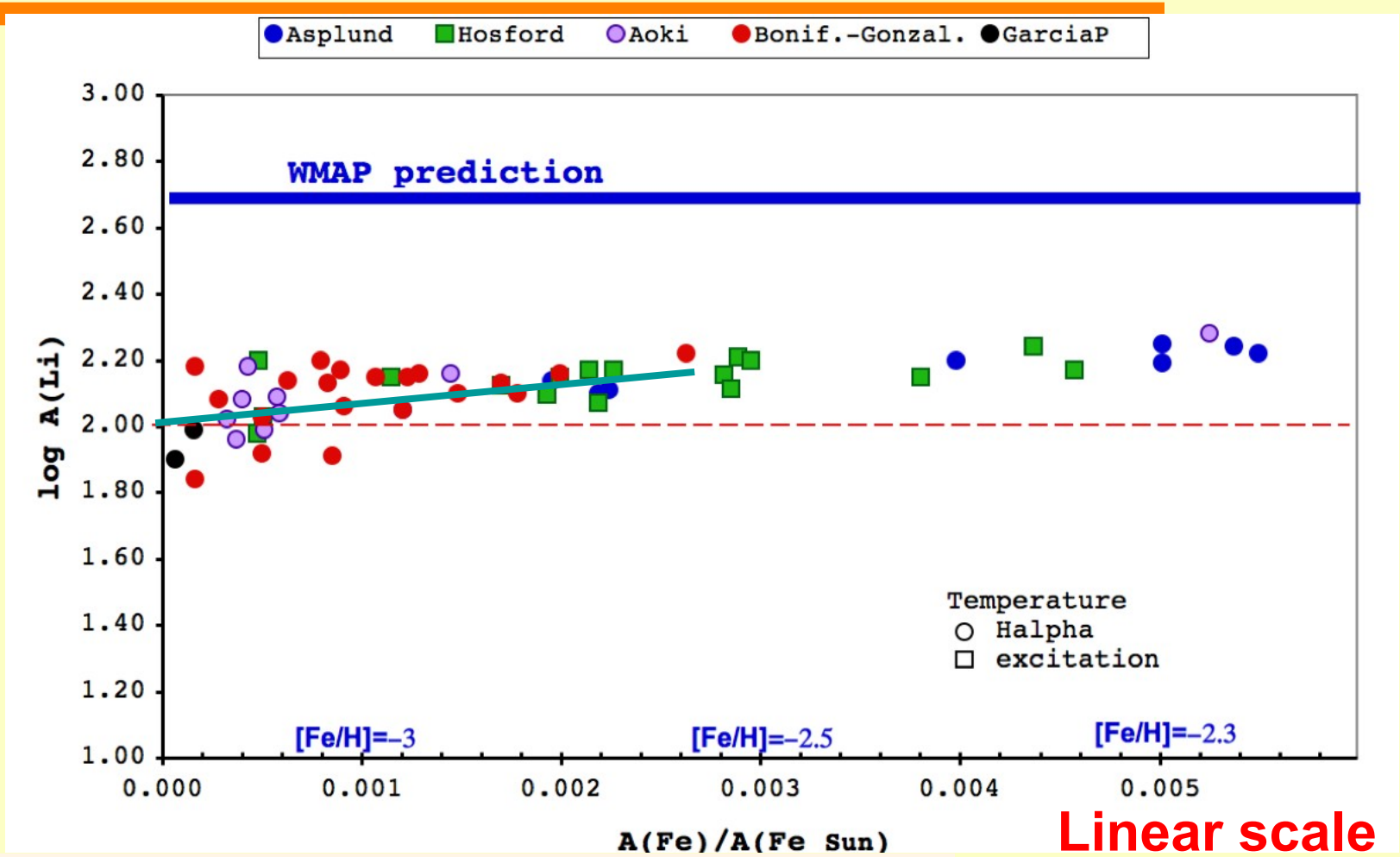
Lithium abundance in metal-poor stars

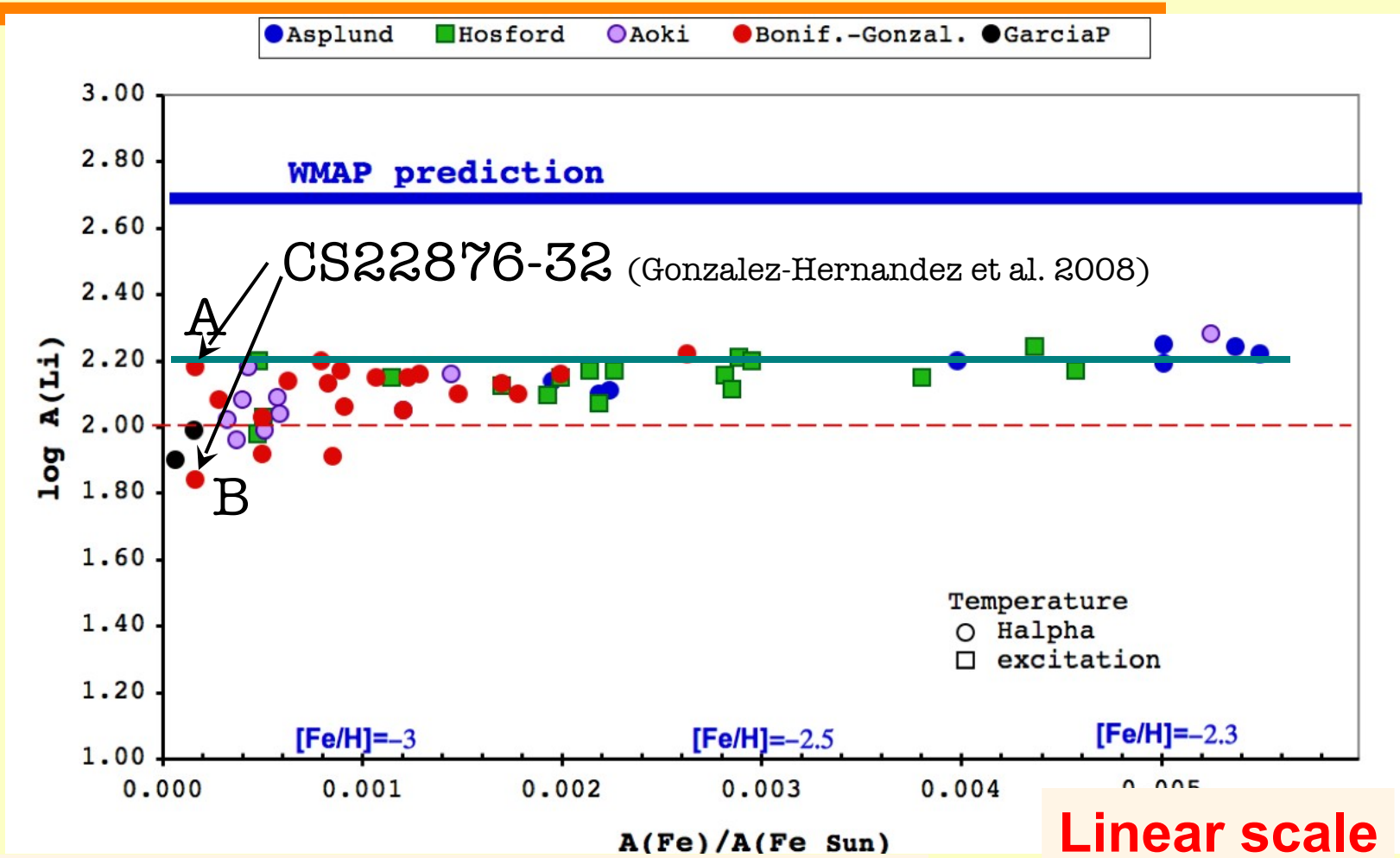
See also the poster of L.Sbordone



Extrapolated primordial Li abund. **log A(Li)$_0$ ≈ 2.0**

Lithium abundance in metal-poor stars

See also the poster of L.Sbordone



Linear scale

Extrapolated primordial Li abund. **log A(Li)$_0$ ≈ 2.2**

^{7}Li

Summary of the observations

- **Pristine abundance of ^{7}Li in the Milky Way**

  = abundance observed in the atmosphere of the most metal-poor dwarfs extrapolated toward Fe/H=0.0

log A(Li) ~ 2.0 dex **+** log A(Li) ↘ Fe/H ↘

increase of the scatter for [Fe/H]<-3

or

log A(Li) ~ 2.2 dex **+** Li more often depleted in the most metal-poor stars

^{6}Li

What is observed ?

Abundance of ^{6}Li in the atmosphere of the warm metal-poor dwarfs

(since ^{6}Li is more fragile than ^{7}Li, if ^{6}Li has survived it is probable that ^{7}Li has not been depleted…)

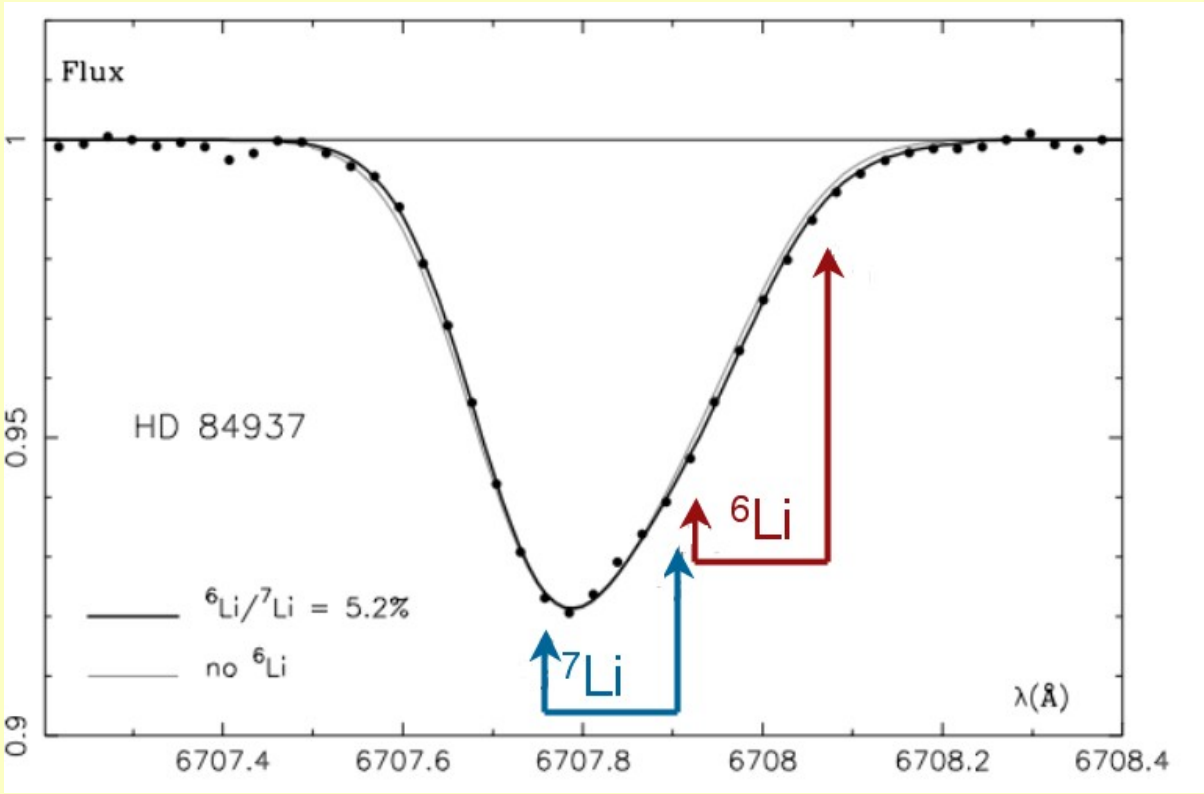
^{6}Li is supposed to be formed by Cosmic rays before the birth of the observed star

Resolution ~100 000 S/N ~ 500

^{7}Li 6707.761
6707.912

^{6}Li 6707.921
6708.072

moreover hyperf ne structure !



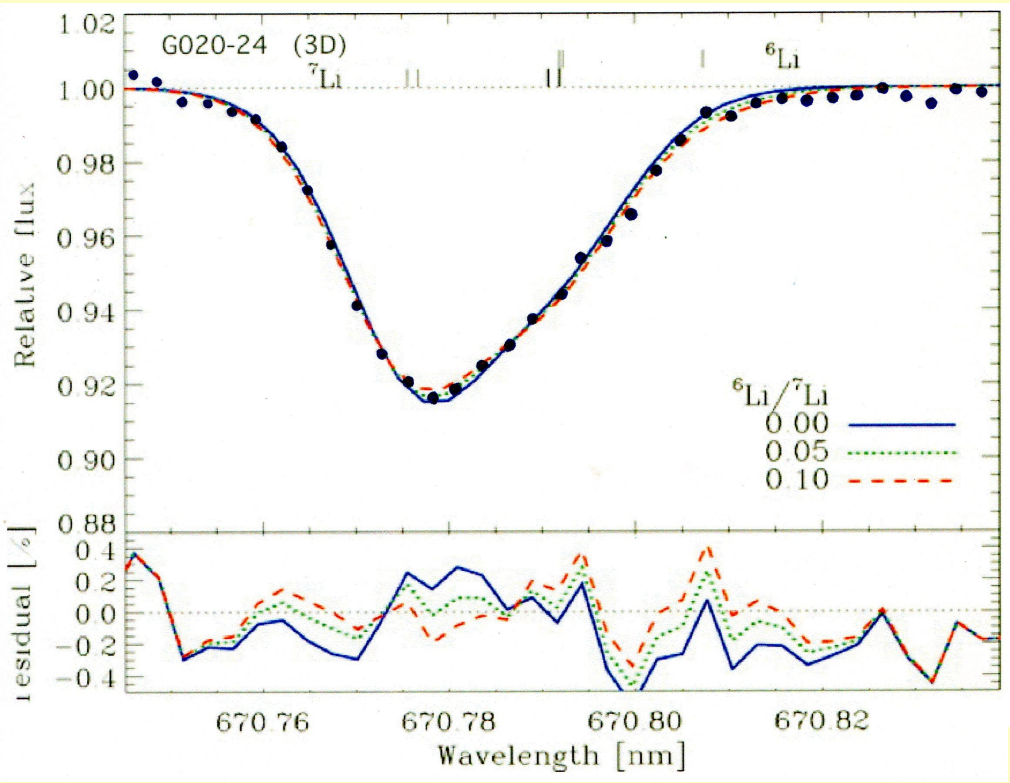
not easy to disentangle ^{6}Li and ^{7}Li ...

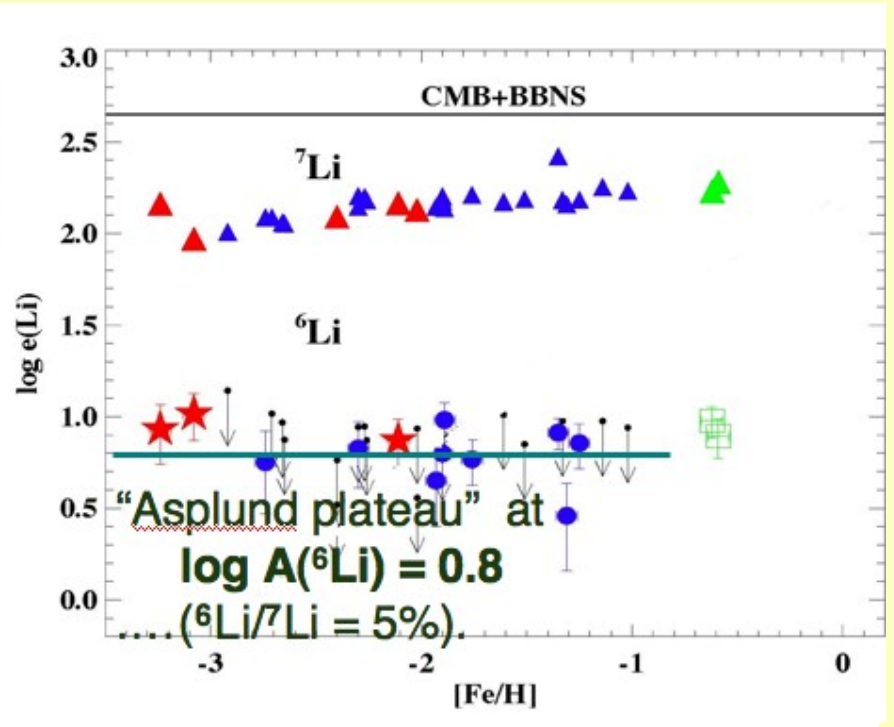
Several groups have recently measured ^{6}Li in metal-poor halo stars:

Asplund
Cayrel - Steffen
Garcia Perez - Aoki - Ryan
…

Asplund et al. (2006, 2007) [VLT, Keck]

Detection of ^{6}Li in 12 metal-poor turnoff stars (27 observed)





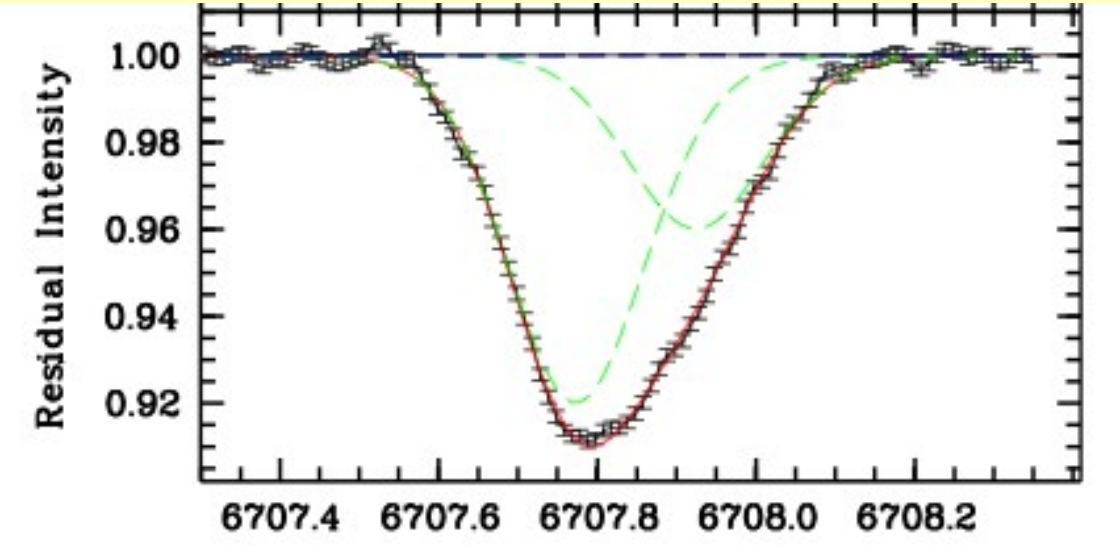
^{6}Li/^{7}Li≈ 0.04

Cayrel et al. 2007 (A&A 473, 37)
see also Steffen et al. 2009 (IAU Symp 265)

Line asymmetries generated by convective Doppler shifts in stellar atmospheres of metal-poor stars. (generally neglected)

➔ **1D** asymetry of similar Fe I lines
➔ **3D NLTE** analysis of the $^{6}Li + ^{7}Li$ blend:

HD74000 classical analysis $^{6}Li / ^{7}Li = 0.04$



BUT
if asymetry is taken into account
compatible with
$^{6}Li / ^{7}Li = 0\%$

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Ana García Perez et al. 2009 (A&A 504, 213)

The error of the ^{6}Li measurement is underestimated (continuum, residual fringes etc…)

		^{6}Li/ ^{7}Li	error
G64-37	Asplund (2008)	0.111	0.032
G64-37	GarcíaPerez (2009)	0.006	0.039

Have we really detected ^{6}Li in some metal-poor turnoff stars

???

If no ^{6}Li in EMP stars →
maybe ^{7}Li in EMP stars is not pristine…

^{6}Li

Summary of the observations

- Abundance observed in the atmosphere of the most metal-poor dwarfs:

^{6}Li

log A(^{6}Li) ~ 0.8 dex "Asplund plateau"

or

^{6}Li is not detectable ???? ^{6}Li/^{7}Li ~ 0.0

Is it possible to explain the behaviour of ^{6}Li and ^{7}Li in the early Galaxy ?

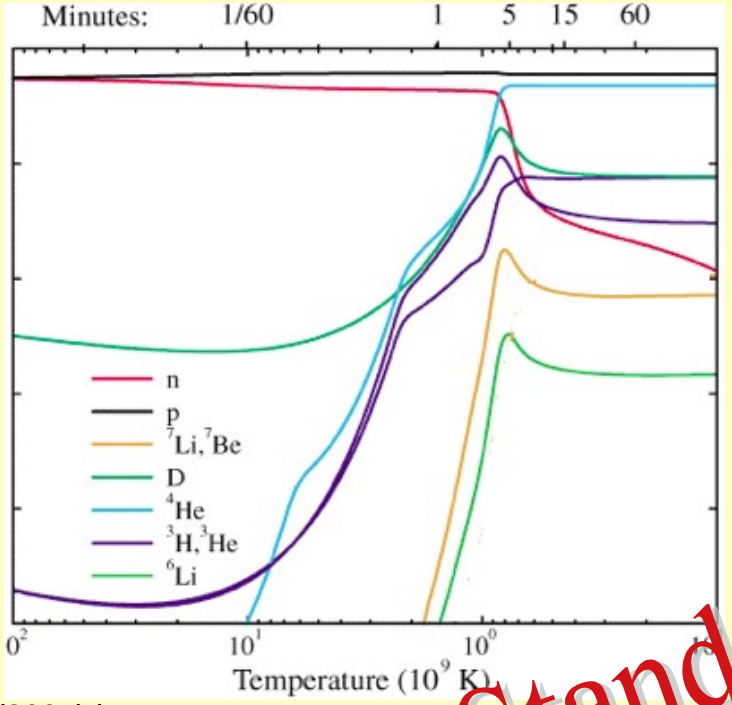
1/ Asplund plateau log A(^{6}Li)=0.8

^{6}Li/^{7}Li= 4%

^{6}Li formed by the BB nucleosynthesis ?

First Nucleosynthesis in the cooling Universe

Standard BIG-BANG:



Gallagher (2004) lecture

Standard BB build 10000 times less ^{6}Li than ^{7}Li

Standard Big-Bang impossible

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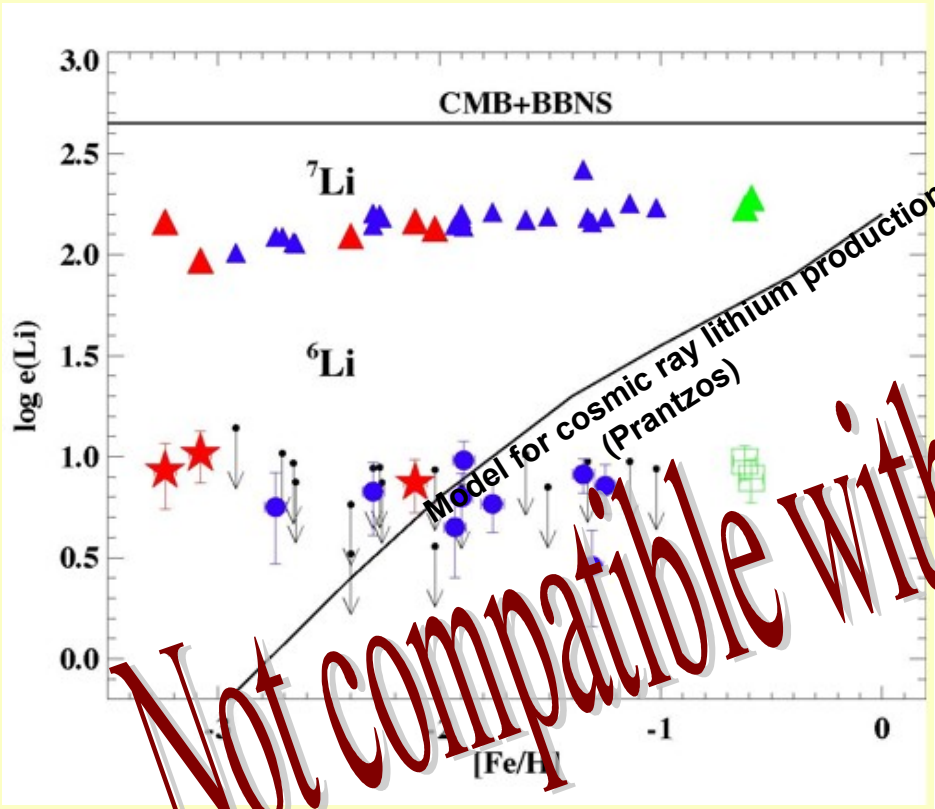
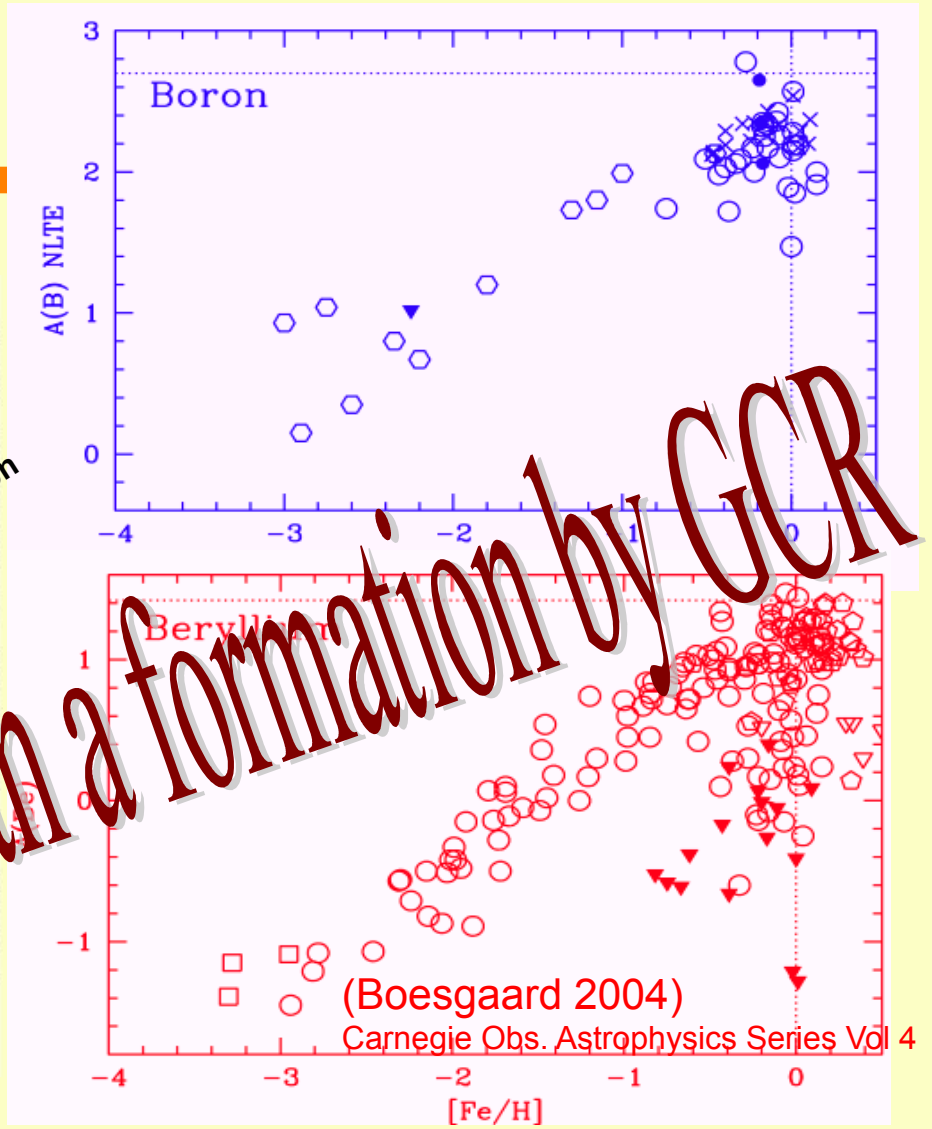
1/ Asplund plateau log A(^{6}Li)=0.8

^{6}Li formed by GCR
+ spallation in superbubles ?





Not compatible with a formation by GCR

2/ logA(^{7}Li)≈ 2.2 in metal poor turnoff stars and BBN ➔ logA(^{7}Li)≈ 2.72

^{7}Li has been partially destroyed <u>before</u> the formation of the old metal-poor stars ?

-astration in a first generation of (only) massive PopIII stars, 10-40 $M_\odot$ (Piau 2006).

They would have destroyed 2/3 of the primordial lithium…
But all these stars would have produced heavy elements (oxygen …) and the resulting metallicity would be much higher than the one observed in the EMP stars… (Prantzos 2007)

2/ logA(^{7}Li)≈ 2.2 in metal poor turnoff stars and BBN ➔ logA(^{7}Li)≈ 2.72

^{7}Li could have undergone depletion through hydrodynamic processes. Diffusion inside the star?

(Korn et al. 2006, Lind et al. 2008, 2009, also GonzalezHernandez et al. 2009)

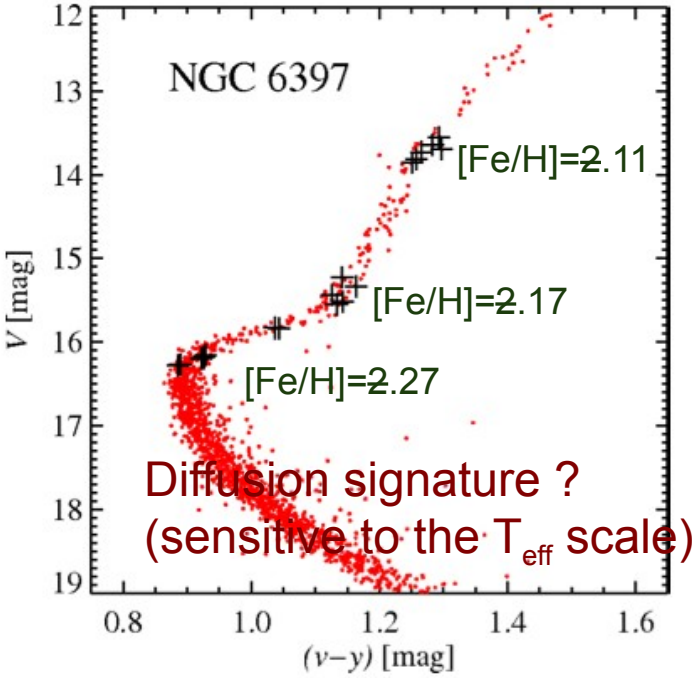


FIG. 2.— Colour-magnitude diagram of NGC 6397 with the four groups of stars (from left to right TOP, SGB, bRGB and RGB stars) marked by crosses.

Correction of the Li abundance 0.26 dex

Pristine value logA(^{7}Li)≈ 2.46 ?

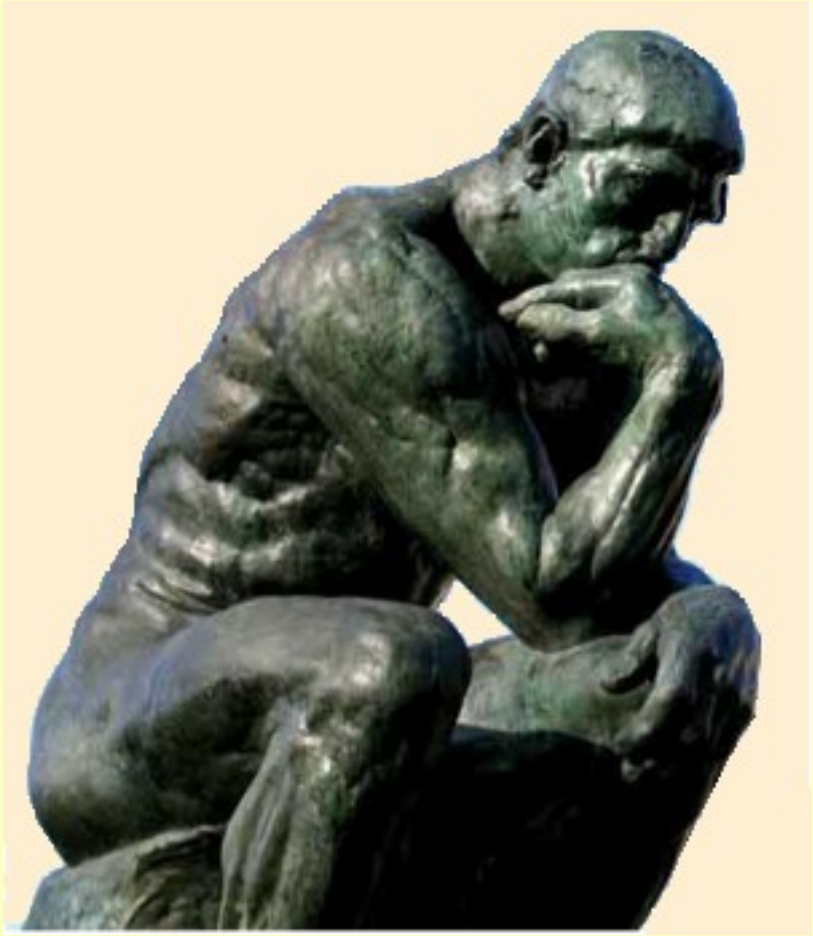
2/ logA(^{7}Li)≈ 2.2 in metal poor turnoff stars and BBN ➔ logA(^{7}Li)≈ 2.72

less ^{7}Li formed ?

-e.g. decaying supersymetric particles (Jedamzik)

Is it the end of the Standard Big Bang ?

Many questions



Few definite answers