Workshop
Lithium in the cosmos
2012

WHY ?

1/

Predictions: (**W**ilkinson **M**icrowave **A**nisotropy **P**robe **WMAP**)

quantity of ^{7}Li and ^{6}Li formed during the primordial nucleosynthesis (standard BBN)

2/

Measurements: Abundance of Li in the matter shortly after the BB

In a perfect world these abundances would be the same...

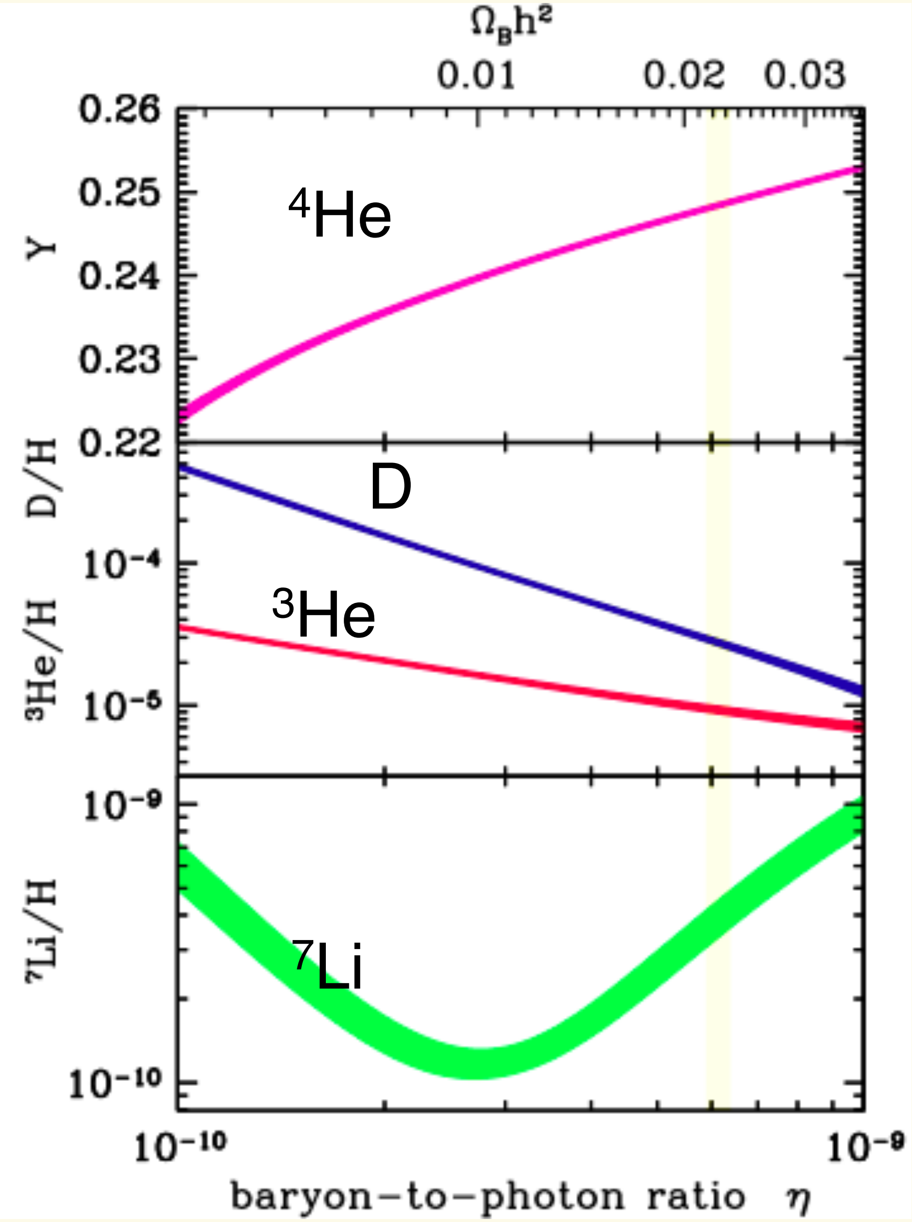
The cosmic lithium problem.
One observer's point of view...

What is the problem ?

In the standard B.B. the primordial nucleosyntesis depends only on

baryons to photons ratio

η



e.g. Coc & Vangioni 2010
Iocco et al. 2009
Cyburt et al. 2008

Wilkinson **M**icrowave **A**nisotropy **P**robe

+ Iocco et al. (2009)

$N^7Li/ N_H = 457 \times 10^{-12}$

$N^6Li/ N_H = 0.01 \times 10^{-12}$

$N^6Li/ N^7Li = 2 \times 10^{-5}$

seven years

of observations

mean baryon density:

$\Omega_b h^2 = 2.249 \times 10^{-2}$ (WMAP 2011)

$A(^7Li) = 2.66$

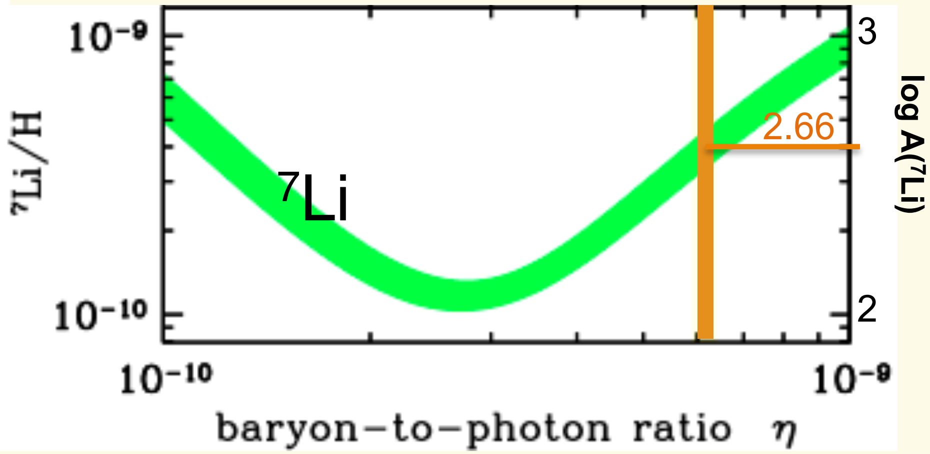
$A(^6Li) = -2.00$

for log A(H)=12

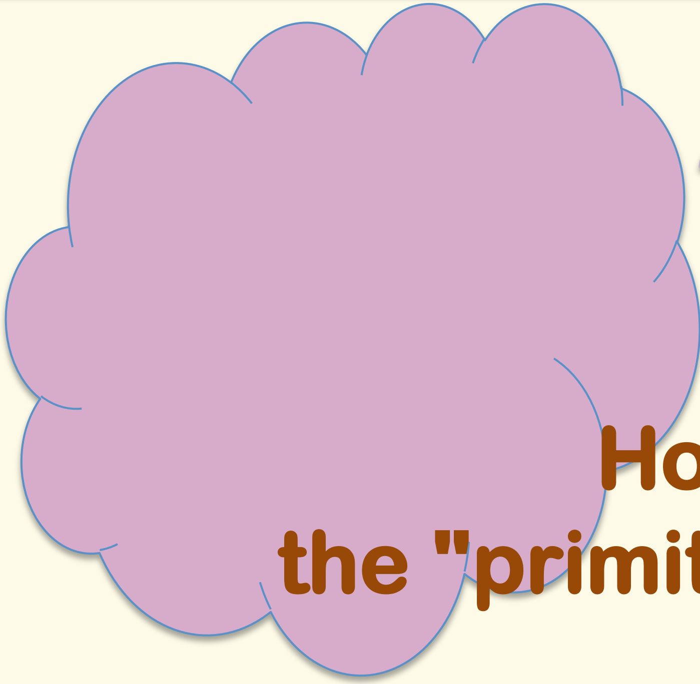
$\eta = 6.16 \times 10^{-10}$

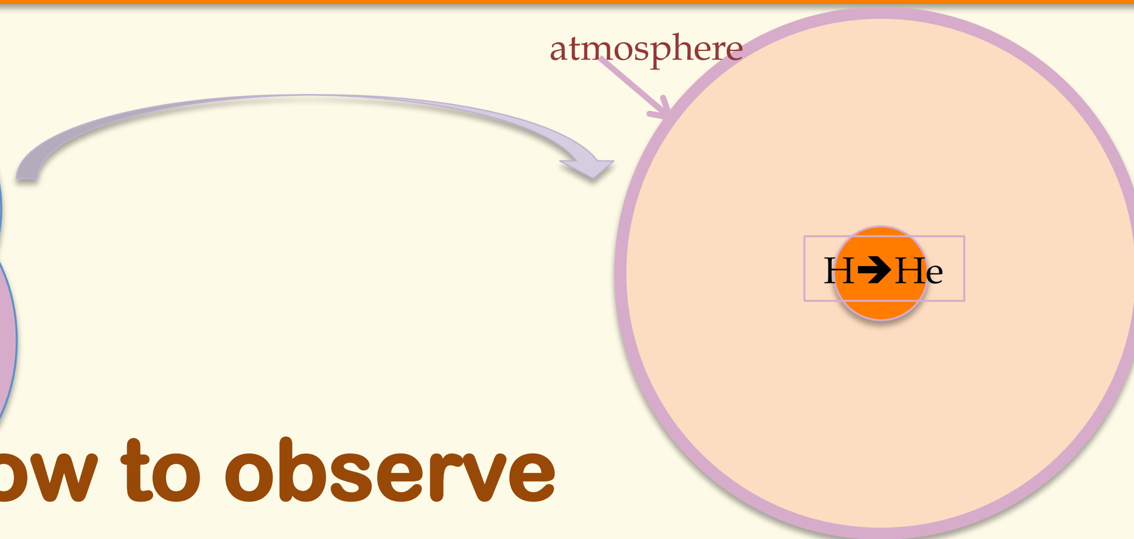
→Primordial abundances

of D ^{4}He ^{3}He Li



What is observed in the primitive galactic matter?





How to observe the "primitive Galactic matter " ?

theory of stellar atmospheres:

The chemical composition of the atmosphere of a dwarf star is a good witness of the matter which formed the star

the chemical composition of the atmosphere does not "change" with time

But...

Lithium is a very fragile element

if mixing between the atmosphere and these hot layers

⇒lithium is destroyed little by little in the atmosphere

destroyed :

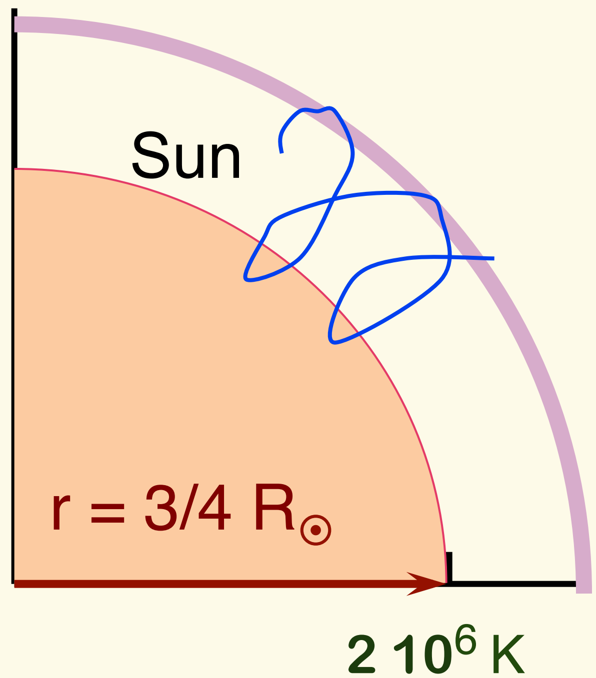
^{7}Li T>2.5 10^{6} K

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

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

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

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

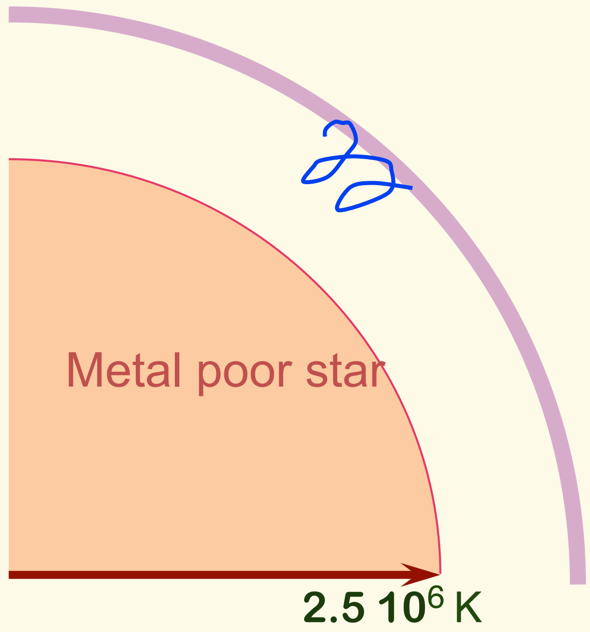


In warm **metal-poor** stars

(turnoff stars: Teff > 5900K)

mixing is not as deep as in solar type stars and

lithium is preserved.



A priori :

Abundance of lithium in old metal-poor turnoff stars =

Abundance of lithium in the primitive galactic matter

^{7}Li

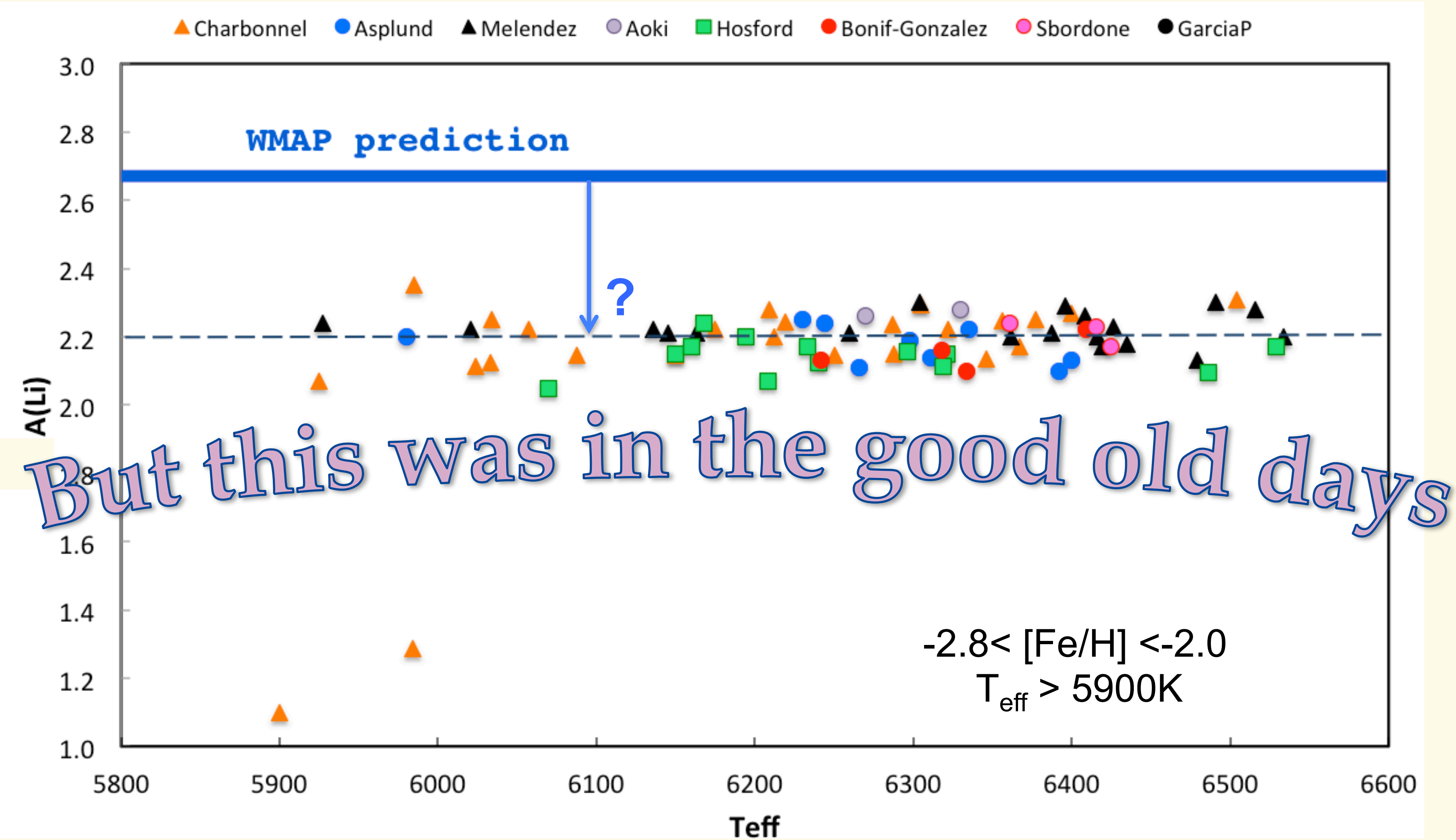
What is observed in field stars ?

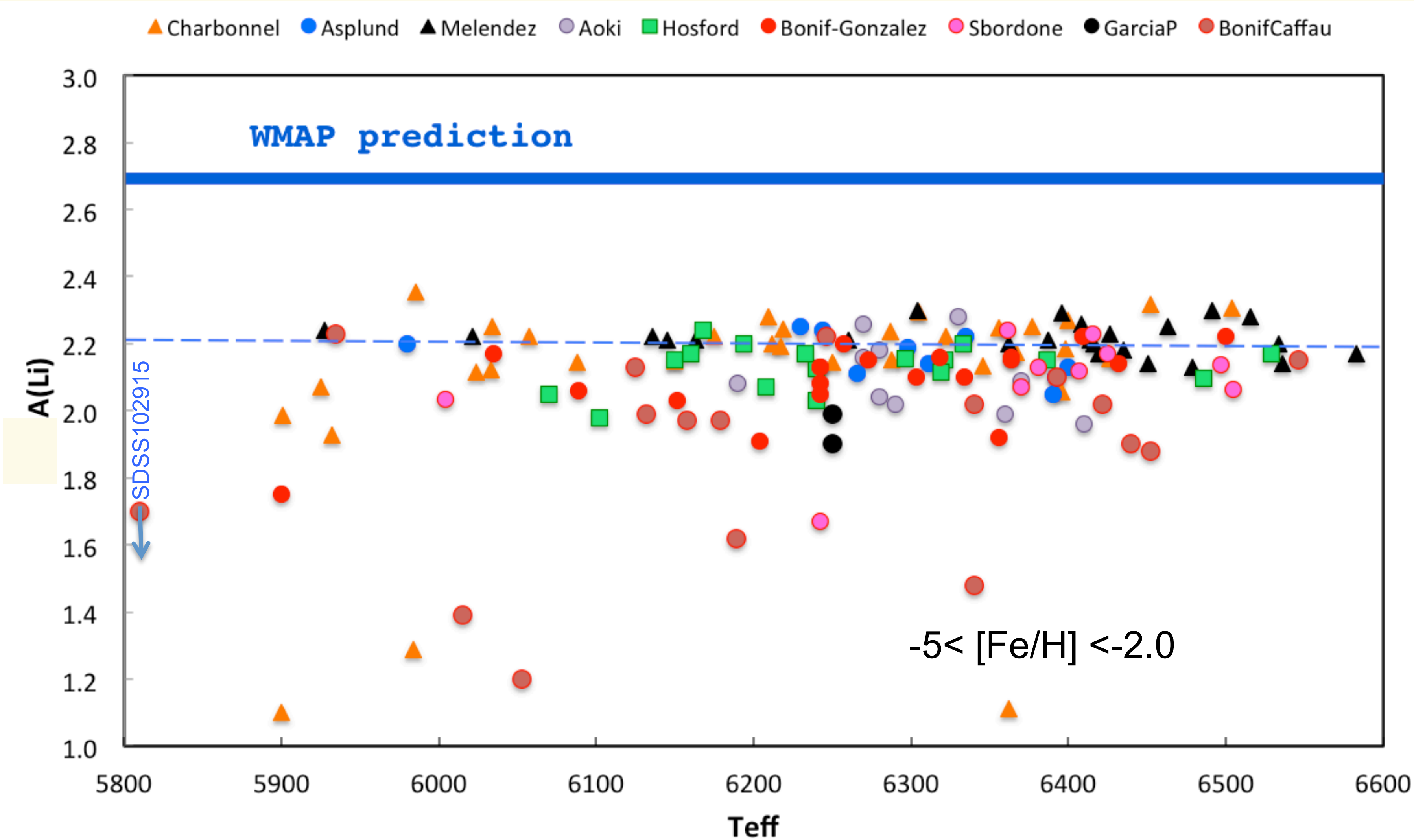
Abundance of ^{7}Li in the atmosphere of the warm metal-poor dwarfs (turnoff stars)

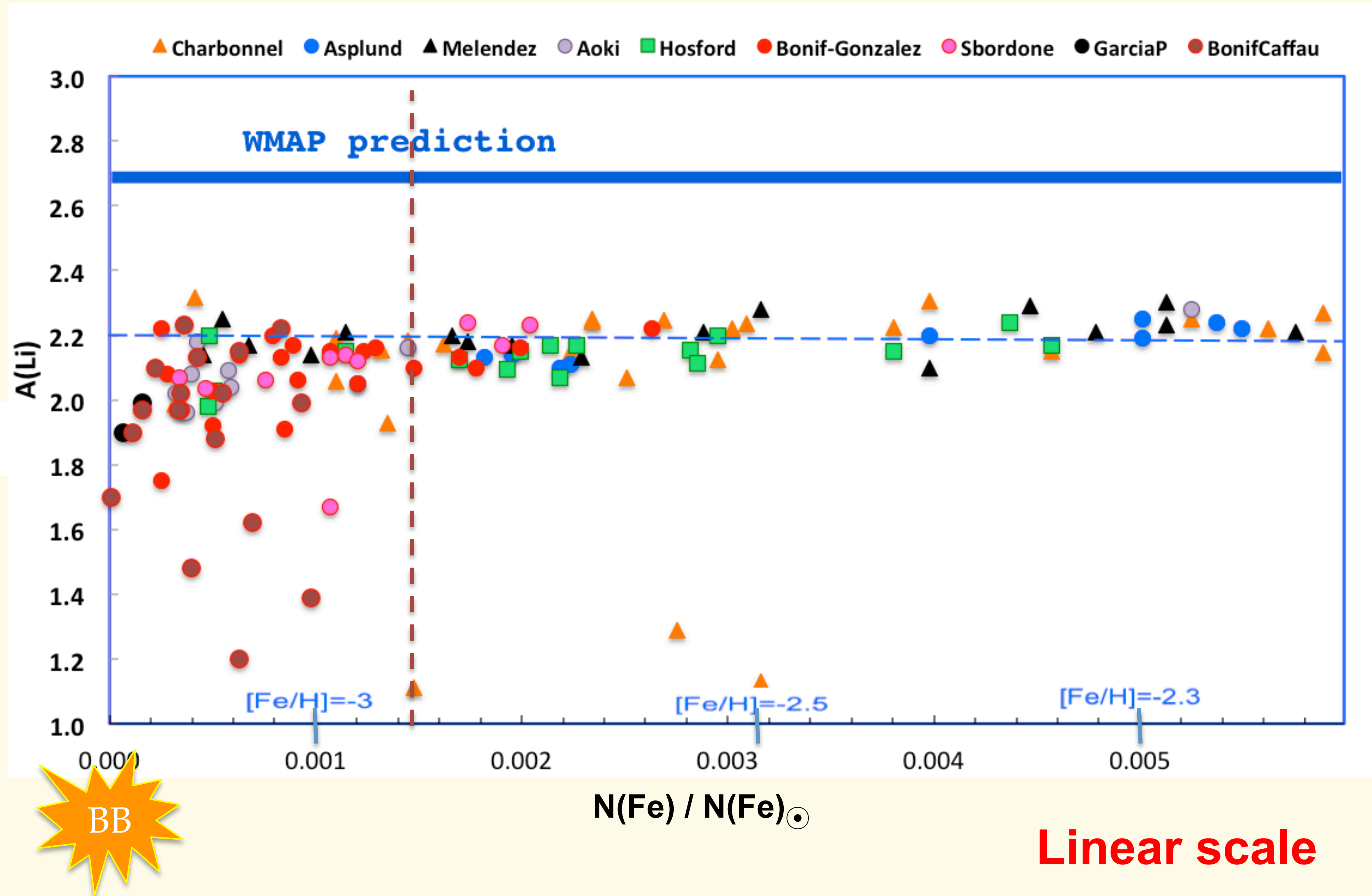
T_{eff} (phot)
Charbonel& Primas 2005,
Meléndez et al. 2010
Schaeuble& King 2012

T_{eff} (Hα)
Asplund et al. 2006, 2007,
Bonifacio et al. 2007,
González-Hernández et al. 2008,
García-Pérez et al. 2008,
Sbordone et al. 2010

T_{eff} (exc)
Hosford et al. 2009


Charbonnel
Asplund
Melendez
Aoki
Hosford
Bonif-Gonzalez
Sbordone
GarciaP
WMAP prediction
?
A(Li)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
5800
5900
6000
6100
6200
6300
6400
6500
6600
Teff
-2.8< [Fe/H] <-2.0
T_{eff} > 5900K
But this was in the good old days


Charbonnel
Asplund
Melendez
Aoki
Hosford
Bonif-Gonzalez
Sbordone
GarciaP
BonifCaffau
WMAP prediction
A(Li)
SDSS102915
-5< [Fe/H] <-2.0
Teff
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
5800
5900
6000
6100
6200
6300
6400
6500
6600



Charbonnel
Asplund
Melendez
Aoki
Hosford
Bonif-Gonzalez
Sbordone
GarciaP
BonifCaffau
WMAP prediction
A(Li)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
[Fe/H]=-3
[Fe/H]=-2.5
[Fe/H]=-2.3
0.000
0.001
0.002
0.003
0.004
0.005
N(Fe) / N(Fe)$_\odot$
BB
Linear scale

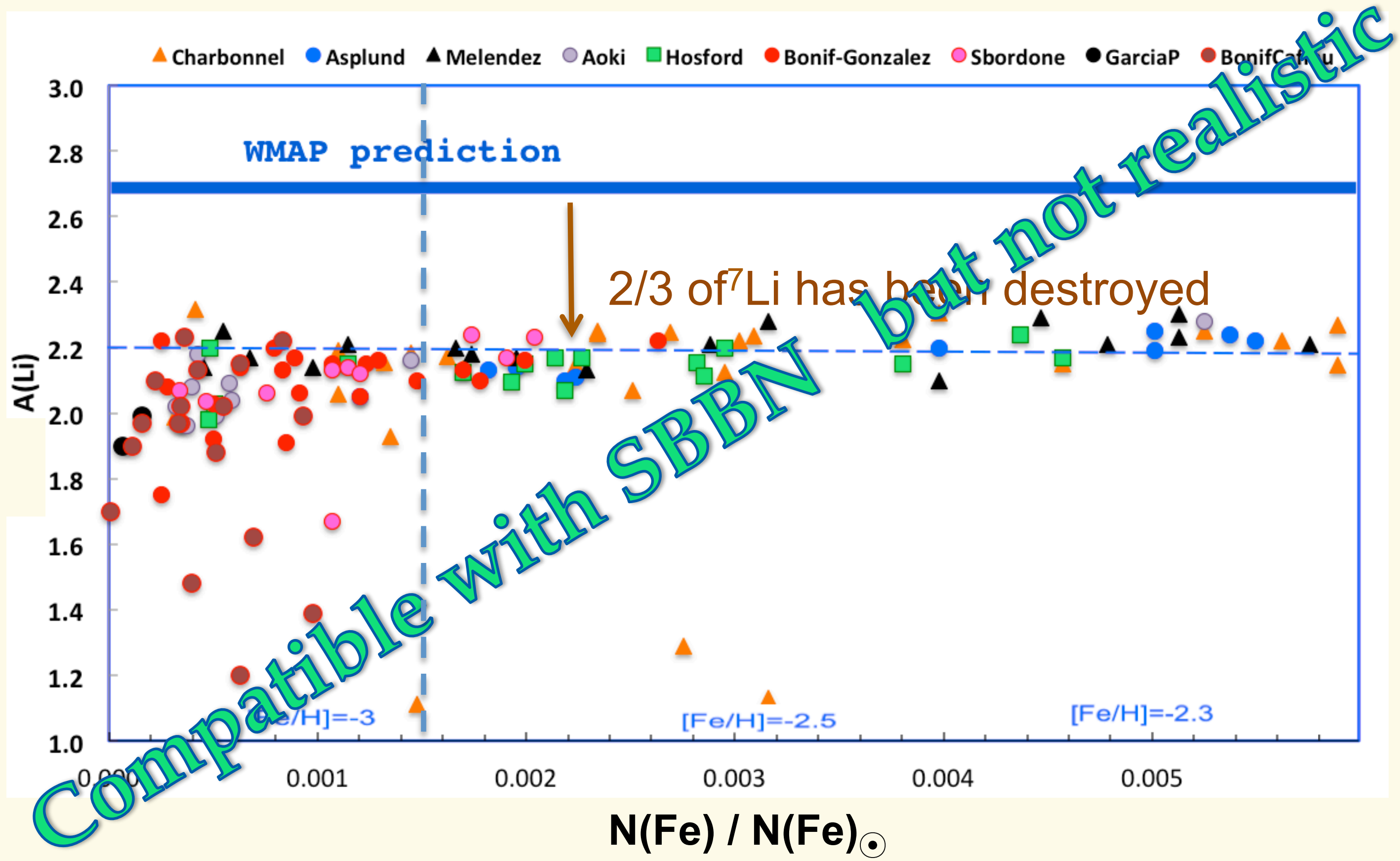
Is it possible to explain the behavior of ^{7}Li by stellar processes ?

-**"plateau"** independent of metallicity and Teff for Teff>5900K
-2.9 <[Fe/H]< -2.0
at a value **3 times lower than the BB predictions**

-**large scatter** (below the plateau) for Teff>5900K
[Fe/H]<3.0

1st interpretation primordial Li abundance 2.7dex

2/3 of the quantity of ^{7}Li has been destroyed in the galactic matter <u>before</u> the formation of the old metal-poor stars.

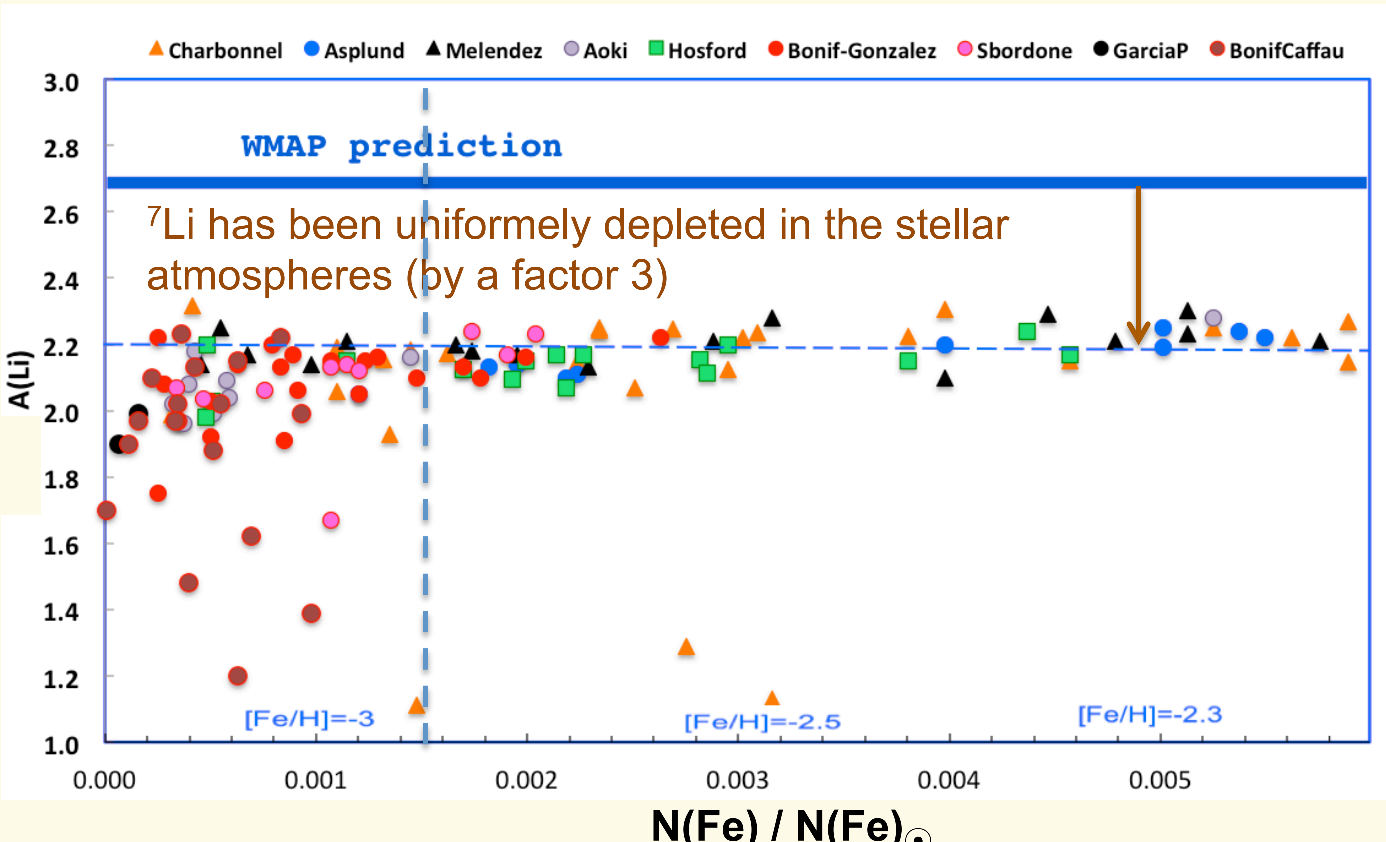


astration in a **first generation of (only) massive Pop III stars (Piau 2006)**

➔they would have produced heav y elements (oxygen …) and the resulting metallicity would be much higher than the one observed in the EMP stars…
(Prantzos 2007)

2nd interpretation primordial Li abundance 2.7dex

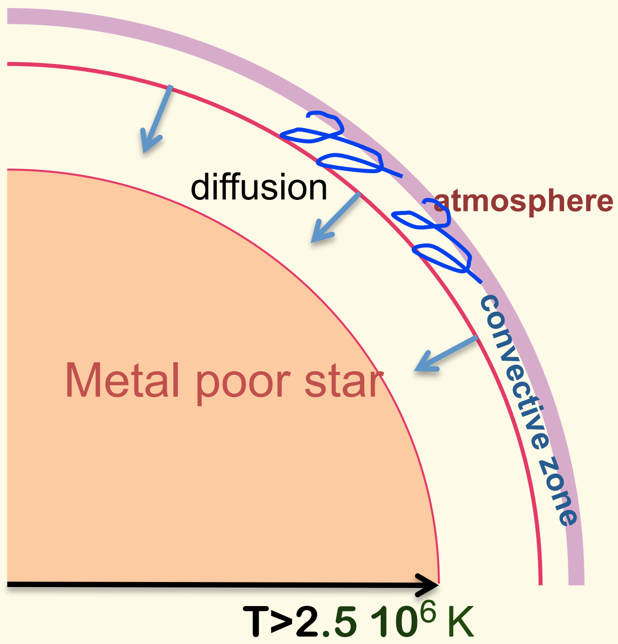
^{7}Li has been depleted in the atmosphere of the old metal-poor stars (uniform depletion for Teff>5900K and -2.8 <[Fe/H]< -2.0)



proposed mechanisms:

-gravitational waves
(Charbonnel & Talon, 2005)

-turbulent diffusion
(gravitational settling)
(Michaud et al. 1984, Richard et al., 2005, Korn et al., 2006)...



Atomic diffusion ?

Atomic diffusion is a slow gravitational settling of the elements below the convective zone.

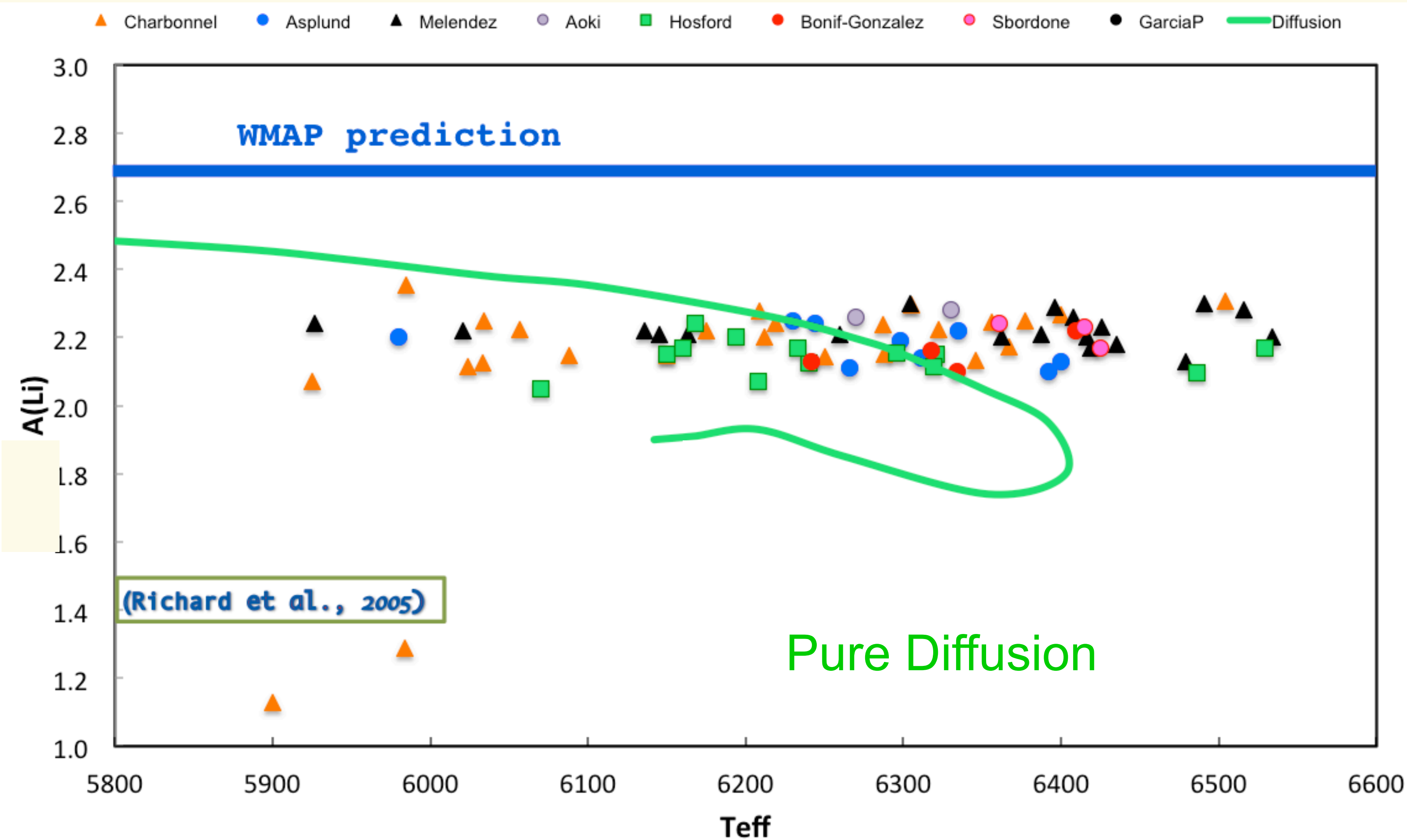
It "is always present in stars. It cannot be turned off. It can only be rendered inefficient by sufficient mass motion either due to meridional circulation or turbulence." (**Michaud et al., 1984**)

If diffusion is efficient, the lithium abundance in the convection zone of a metal-poor dwarf decreases with time because of the settling of Li.

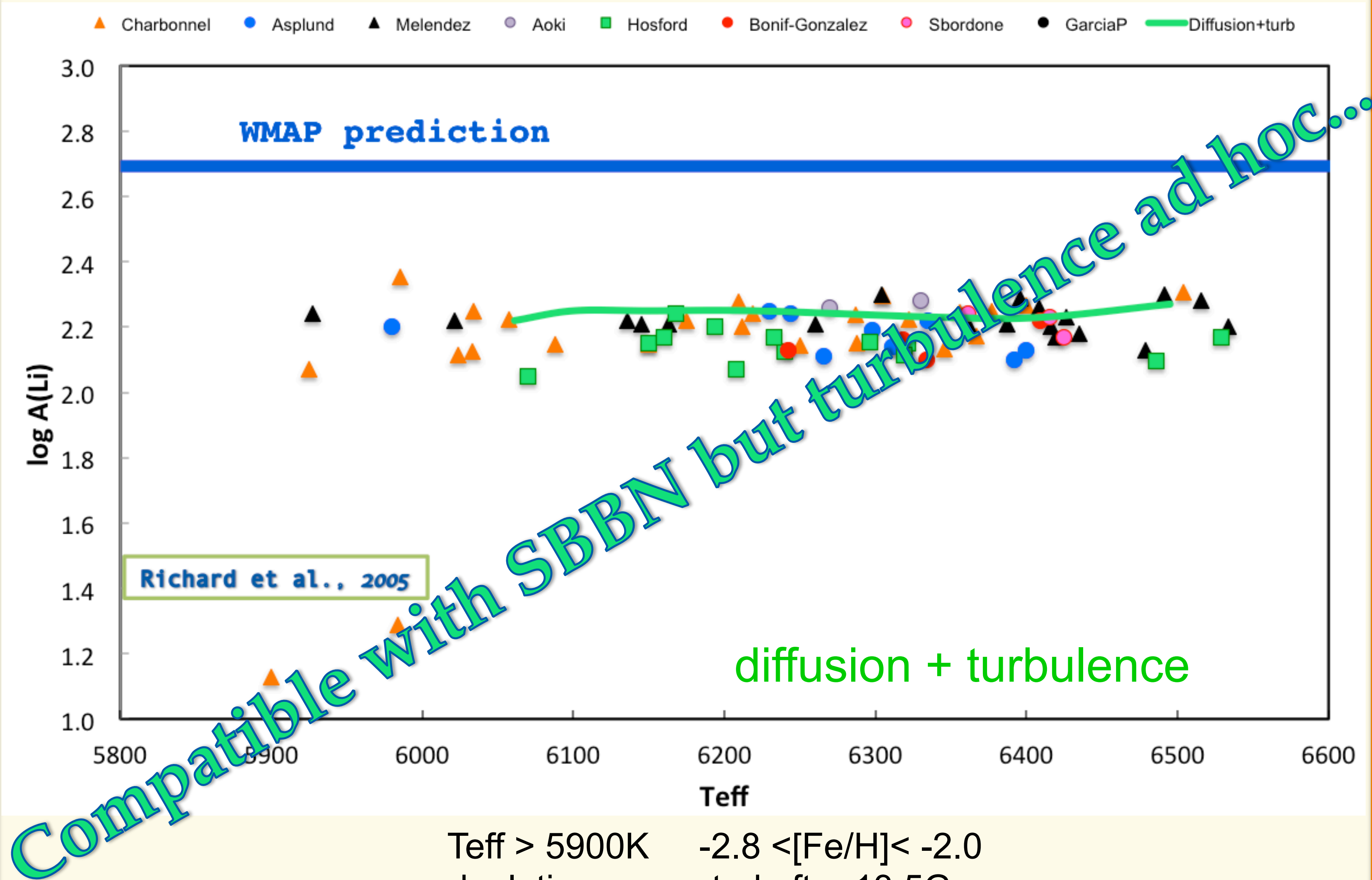
Characteristic time scale:

$$\boxed{1/\tau_{Li} = 2.3\ 10^{-22}\ AT^{3/2}\ M\ /\ Z^2\ M_Z}$$

A atomic mass of Li **M** mass of the star **T** temperature
Z atomic number of Li **M_Z** mass of the mixed zone



Teff > 5900K   -2.8 <[Fe/H]< -2.0
depletion computed after 13.5Gyr



Teff > 5900K -2.8 <[Fe/H]< -2.0
depletion computed after 13.5Gyr

⇒Determination of the "turbulence parameter" ?

Abundance of ^{7}Li in Globular clusters stars

- -same age
- -same metallicity
- -evolutionary stage well known

But !

Sometimes contamination of the star forming gas by processed material ejected by a first generation of massive stars.

In the warm cluster dwarfs of the first generation the lithium abundance is the same as in the old field stars.

NGC 6397

Korn et al. 2006, 2007 found an evolution of [Fe/H] along the HR diagram.
Turnoff stars have a lower iron abundance than giants.

⇒ interpreted in terms of turbulent diffusion this would induce that the lithium abundance in turnoff stars would have been depleted by **0.26 dex** compared to the original value...

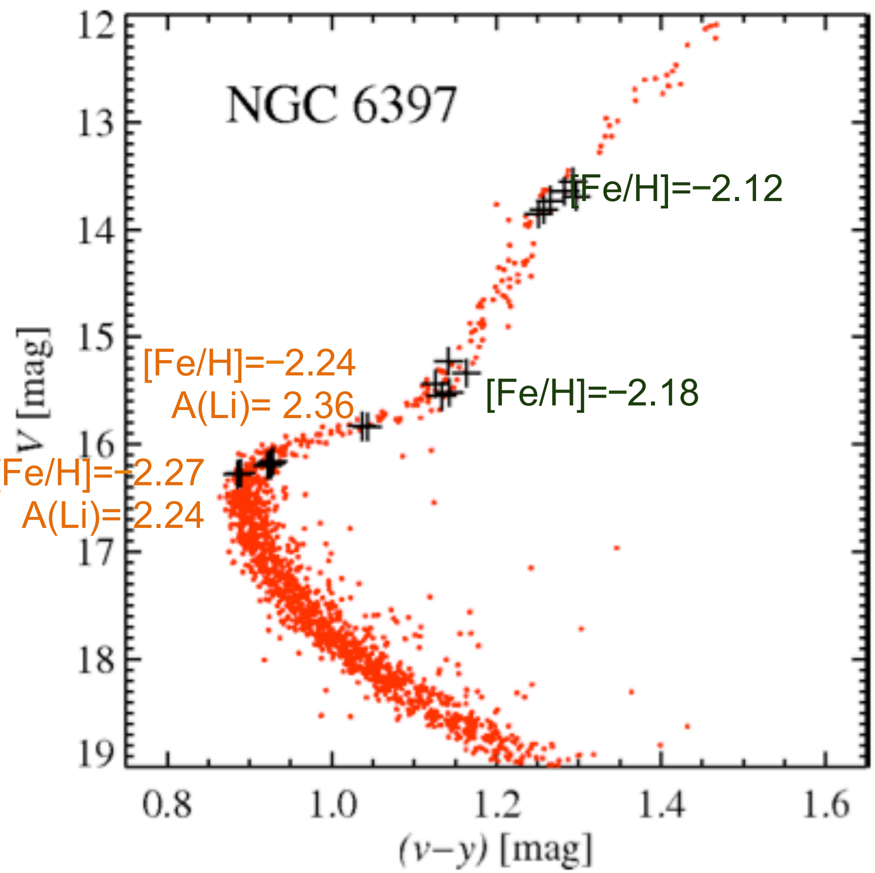
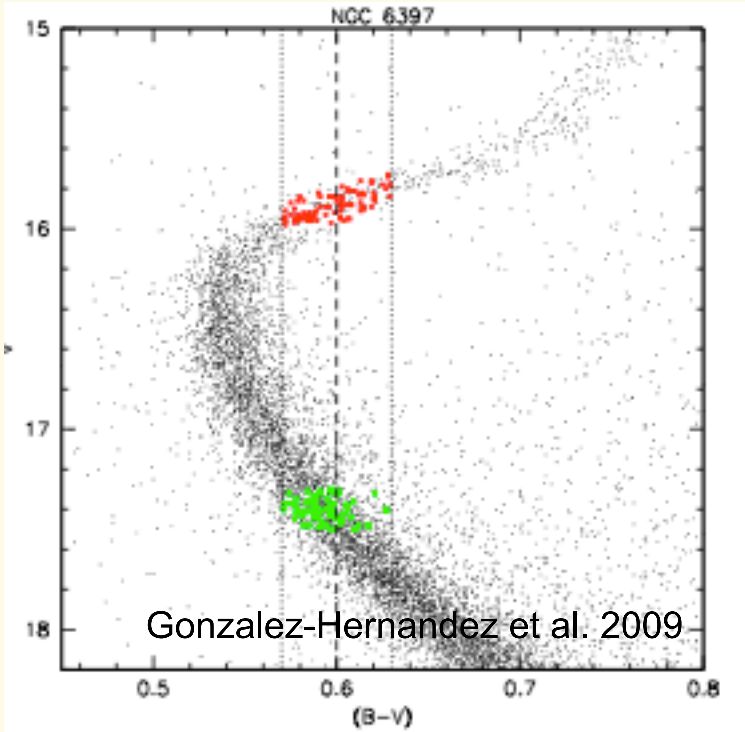
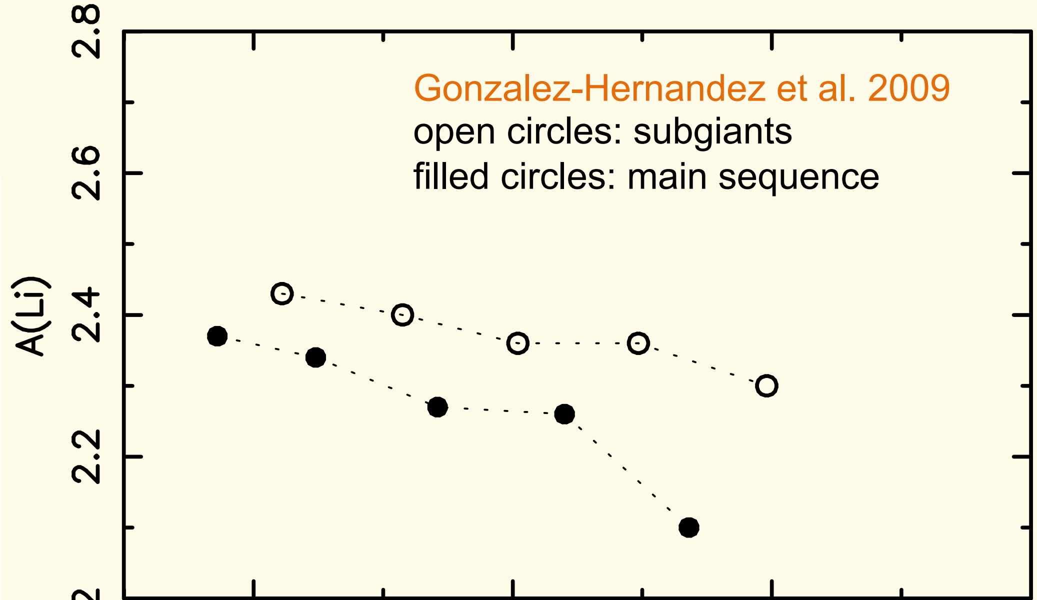


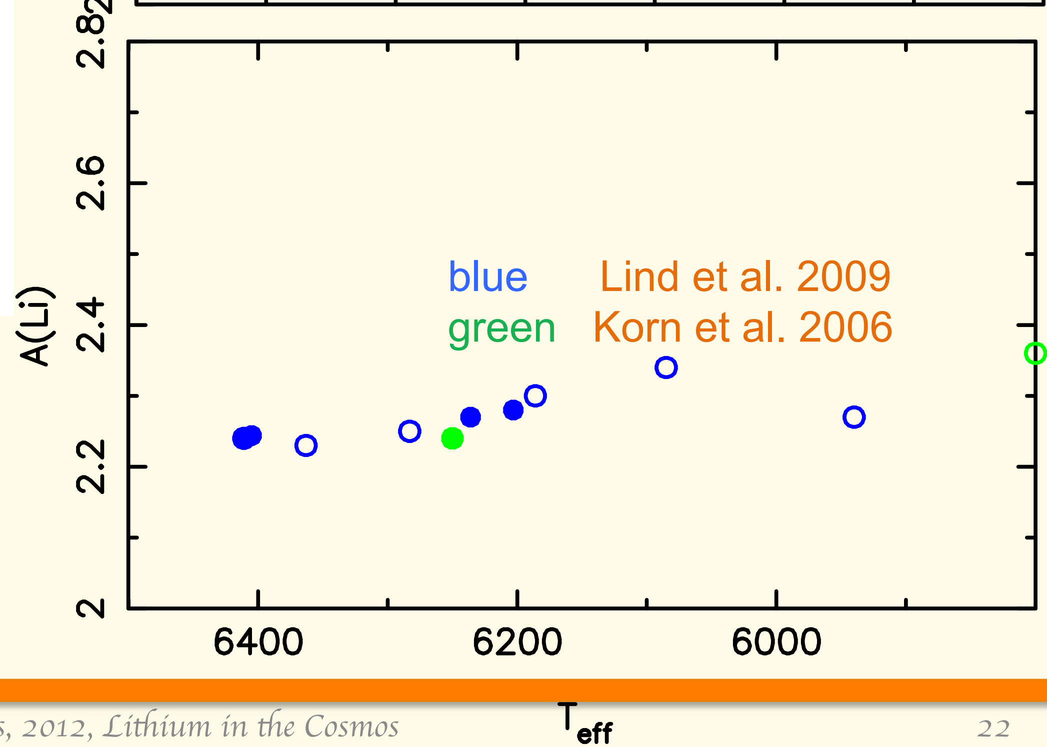
FIG. 2.— Colour-magnitude diagram of NGC 6397 with the four groups of stars (from left to right TOP, SGB, bRGB and RGB stars) marked by crosses.

original lithium abundance
2.24 + 0.26= 2.50 ???

NGC 6397





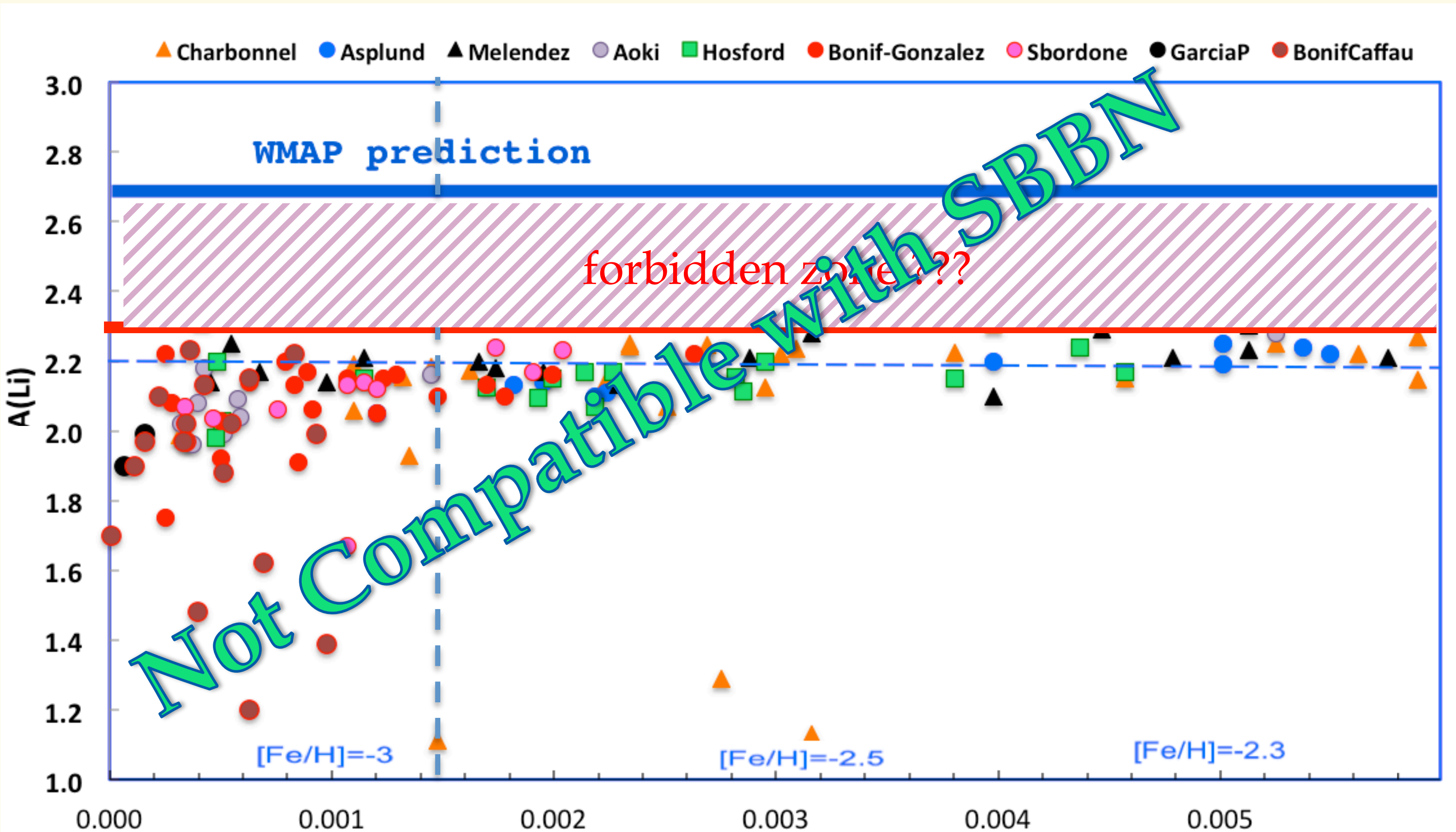


other attempts in M4, ω Cen...

Mucciarelli, Monaco, Bonifacio...

3rd interpretation

primordial Li abundance ≈ 2.2dex
+ some depletion in the most metal-poor stars



N(Fe) / N(Fe)$_\odot$

Linear scale

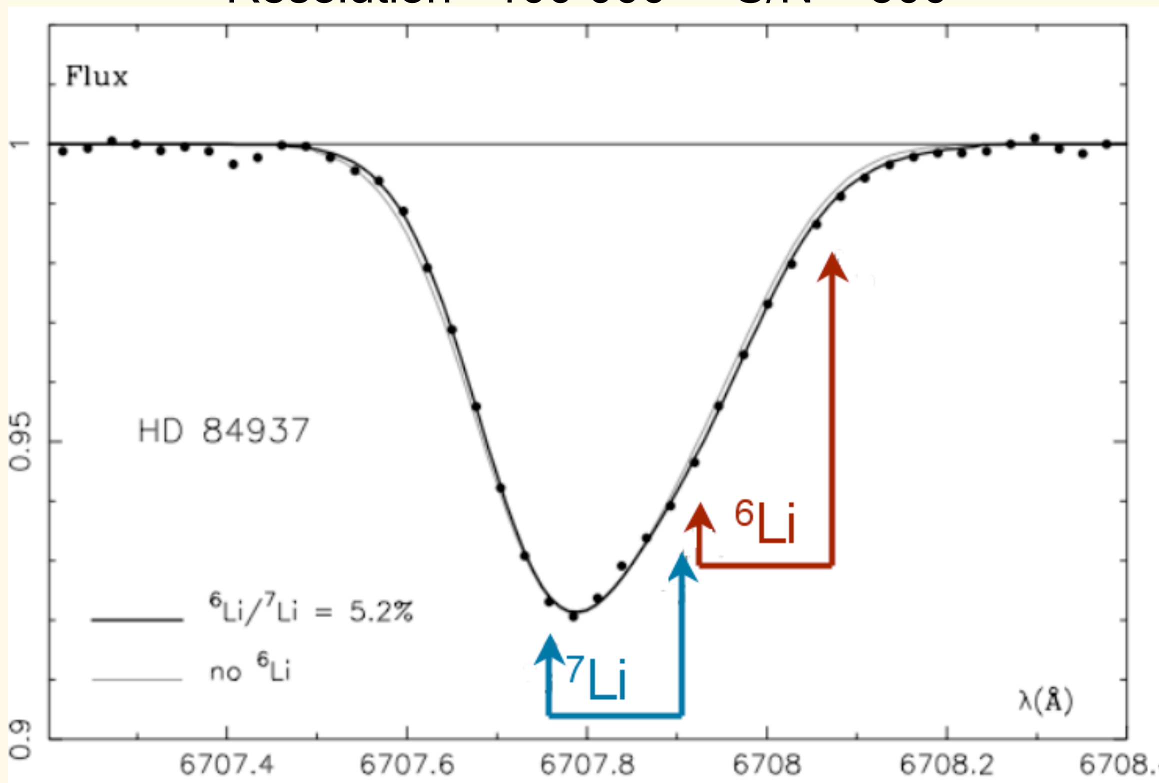
^{6}Li

What is observed in field stars?

Several groups have recently measured ^{6}Li in metal-poor halo stars:
Asplund
Cayrel - Steffen
Garcia Perez - Aoki – Ryan

It is very difficult to disentangle ^{6}Li and ^{7}Li

Resolution ~100 000 S/N ~ 500



^{7}Li 6707.761
6707.912

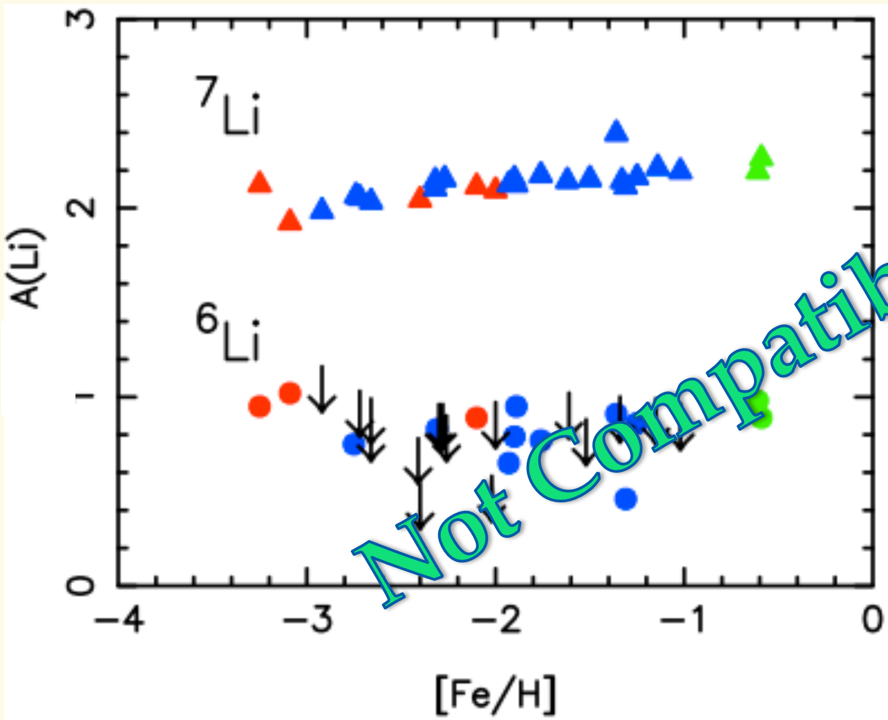
^{6}Li 6707.921
6708.072

moreover hyperfine structure!

Asplund et al. (2006, 2008)   [VLT, Keck]:

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

if ^{7}Li has been depleted by 3 the depletion of ^{6}Li should be at least that much...

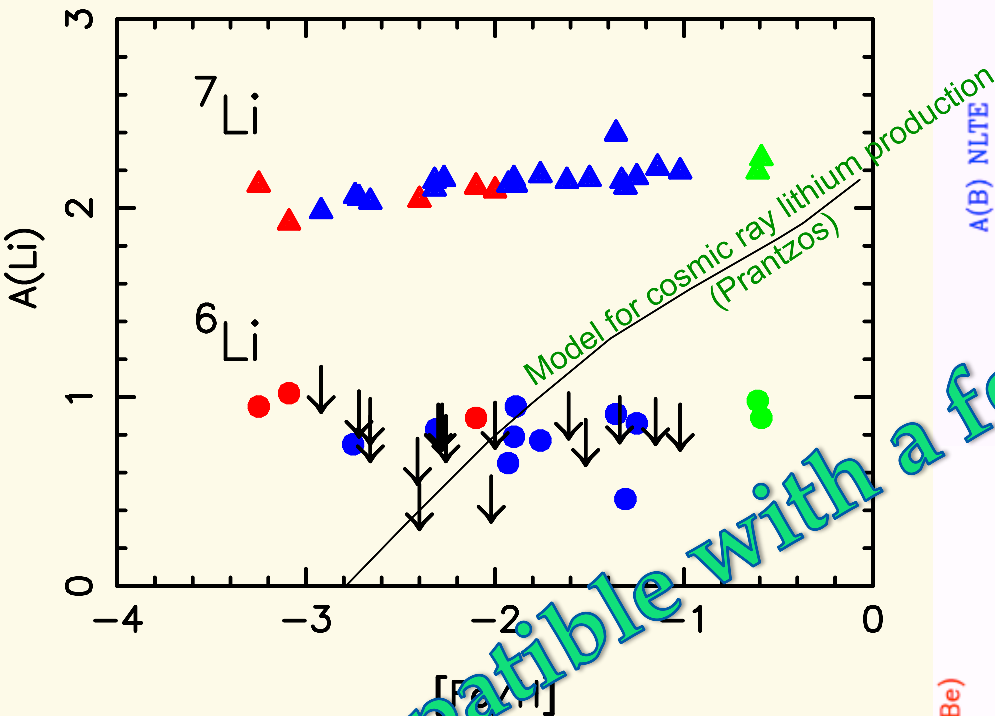


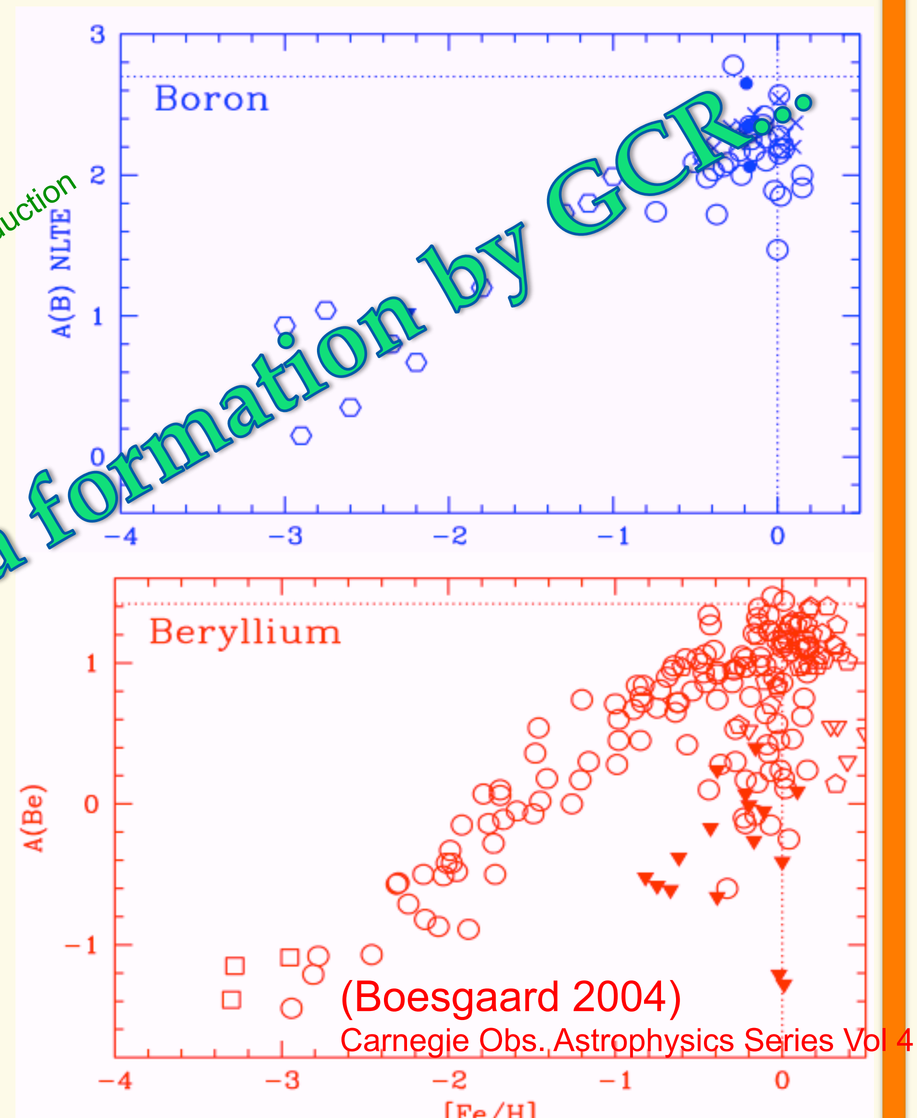
Not Compatible with SBBN

$N_{^6Li}/N_H$ ~ 2 x 10^{-11}

$N_{^6Li}/N_{^7Li}$ ~ 5% ???

Galactic Cosmic Rays ?

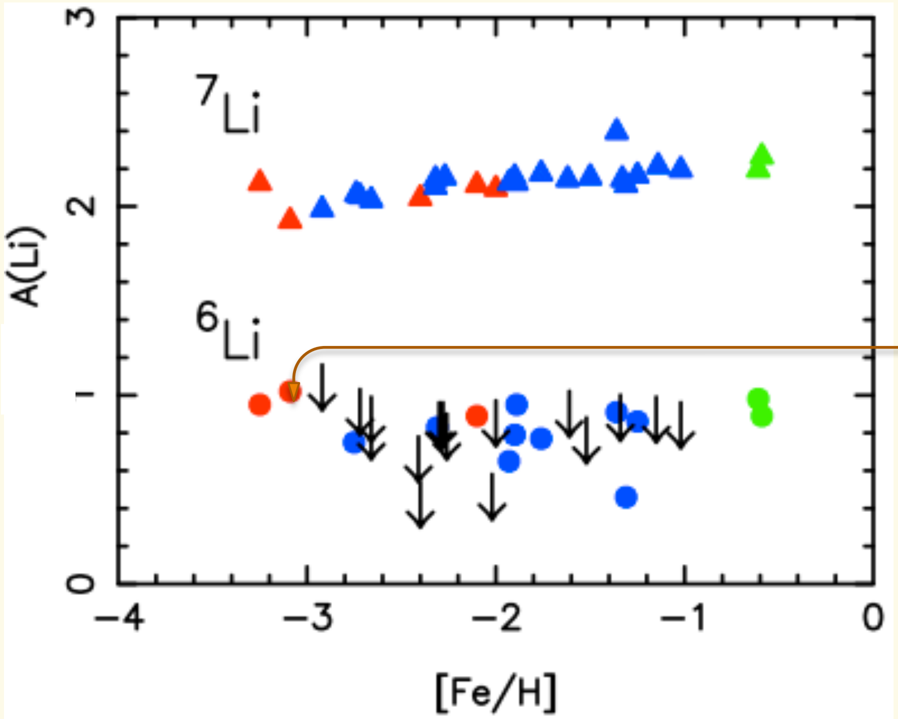




Not Compatible with a formation by GCR...

Asplund et al. (2006, 2008) [VLT, Keck]:

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



Cayrel et al. (2007) Steffen (2009)

If line asymmetries generated by convective Doppler shifts in stellar atmospheres of metal-poor stars is taken into account the abundance of ^{6}Li is strongly reduced... (case of HD74000)....

García-Pérez et al. (2009)

G64-37	^{6}Li/^{7}Li
Asplund (2008)	0.111±0.032
García-Pérez	0.006±0.039

?

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

^6Li

We should
develop efficient theoretical tools to interpret the complex profile of the ^7Li-^6Li feature
but...

better adapted spectrographs will provide better conclusions...

(ESPRESSO at the VLT combining the stability of HARPS with the efficiency of UVES and a resolution R=160000...   ?)

Is there a convincing way to reconcile the predictions of the SBBN and the observations of ^{6}Li and ^{7}Li in the old galactic metal-poor stars ?

This is the aim of this workshop...

Owing to the quality of the participants, significant advances are expected in this meeting from discussions, confrontations...