The lithium problem and the role of open clusters

The discrepancy between lithium primordial values as dervied from cosmology and stellar astronomy,

and how observations in open clusters can help in solving the dilemma.

Giancarlo Pace &

Sofia Randich, Paola Sestito, Angela Bragaglia, Livio Pastori

Lithium primordial value

- COSMOLOGY: it is computed by BBN models. The value is a function of η
- STELLAR ASTRONOMY: it is computed from the abundances of old stars.

AND …… they do not match.

Well, they do but not perfectly.

Sun: factor of ~100 depletion with respect to initial, meteoritic abundance

OC observations will help us understanding

The physics behind lithium depletion in stars

OUTLINE

- Brief “history” of lithium: its primordial production, and its depletion in stars.
- Lithium in halo stars, Spite plateau
- The lithium problem: shall we revise BBN or stellar models?
- Observations in open clusters and our current understanding of lithium depletion.

Formation of the primordial elements

$$\mathrm{H, D, {}^3He, {}^4He, {}^7Li, {}^7Be}$$

$T > 10^{12}$ $\Rightarrow$

$$n + e^+ \longleftrightarrow p + \bar{\nu}$$

$$p + e^- \longleftrightarrow n + \nu$$

$$\gamma + \gamma \longleftrightarrow e^+ + e^-$$

$$n \longrightarrow p + e^- + \bar{\nu}_e$$

T Ü 10^{10} ⇒ $n/p = \exp(-\Delta mc^2/KT_{fr})$

Ü 1 sec

$10^9 > T > 10^8$

$D + n \rightarrow \gamma + {}^3H$	$D + D \rightarrow p + {}^3H$
$D + p \rightarrow \gamma + {}^3He$	$D + D \rightarrow n + {}^3He$
${}^3He + n \rightarrow p + {}^3H$	${}^3H \rightarrow He + e^- + \bar{\nu}_e$
${}^3H + D \rightarrow n + {}^3He$	${}^3He + n \rightarrow \gamma + {}^4He$
${}^3He + D \rightarrow p + {}^4He$	${}^3He + {}^3He \rightarrow 2p + {}^4He$

$$Y_p=(2\cdot n/p)/(1+n/p)$$

$$^4He+^3H \Rightarrow \gamma+^7Li$$

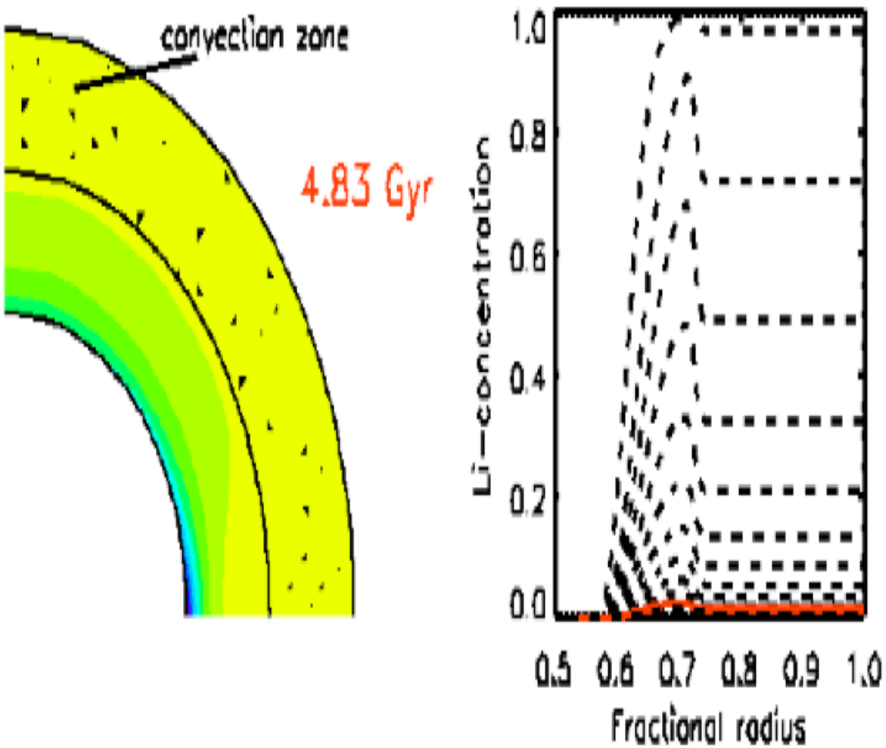
$$^4He+^3He \Rightarrow \gamma+^7Be$$

Governing parameters:

- The baryon to photon ratio, η: formation of D $\Rightarrow$ onset of nucleosynthesis
- The number of neutrino families: energy density $\Rightarrow$ freeze out time/temp

Lithium depletion

STELLAR STRUCTURE



http://www.aip.de/

- In stars Lithium is destroyed by proton captures, at 2.5 MK
- If the convective zone is deep enough then Li depletion occurs
- Different stars deplete different amount of Li depending on: mass, age, metallicity ….

lithium formation

1

In the ISM, by spallation, i.e. interaction between cosmic rays and CNO nuclei.

2

In stars, after some acrobacy :

$$^{4}He+^{3}He \rightarrow \gamma+^{7}Be$$ (p-p chain)

Be shoud be then brought to low-T layers

$$^{7}Be+e^{-} \rightarrow ^{7}Li + \nu_e + \gamma$$

It may happen in AGB thermal pulses.

Li-rich AGB and RG stars exist.

Other possibility:
By explosive H burning:
nova outburst
explosion of massive stars

$A(Li) = \log(N(Li)/N(H)) + 12$

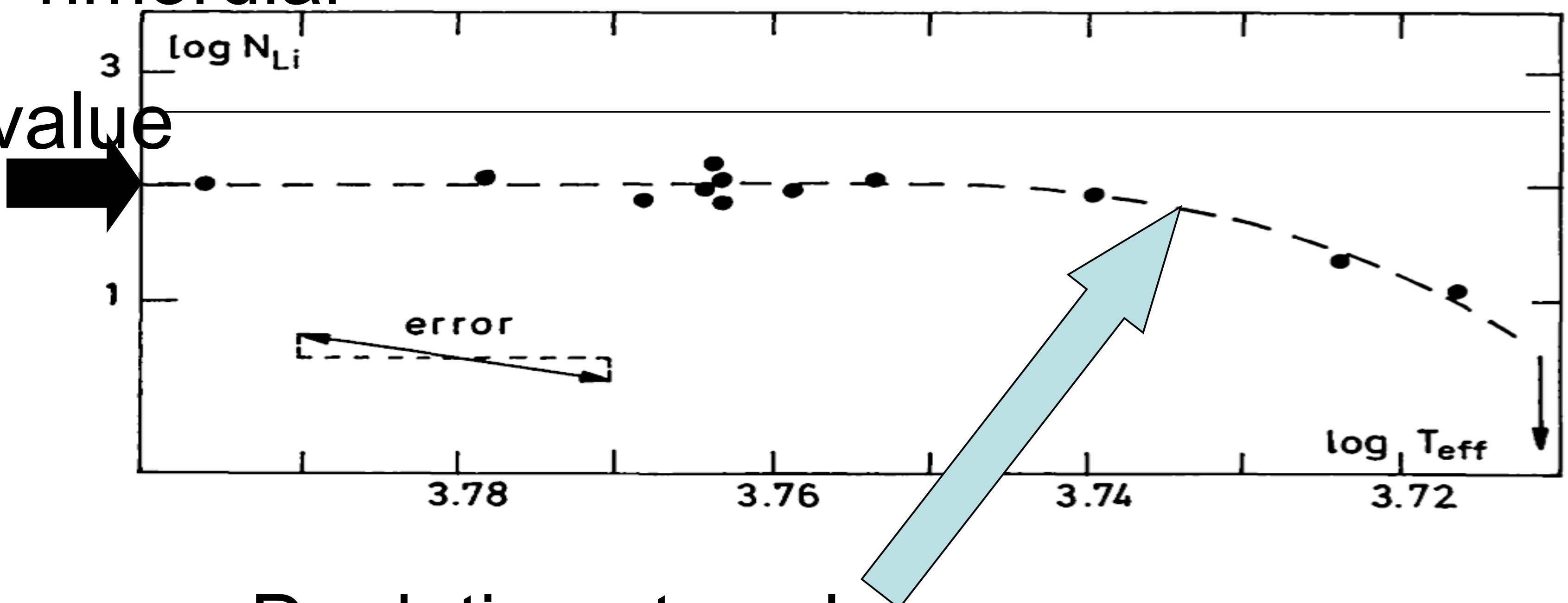
Meteoritic A(Li)
[= ISM A(Li)]
is indeed higher than the primordial one

Observations of halo stars

Spite and Spite, 1982

Primordial

value



Depletion at work

Disk enhanced

WMAP gives higher primordial values

WE NEED TO UNDERSTAND MIXING

What value is the real primordial value?

KORN et al: the lithium in the Spite Plataeu is not primordial!!!!

Kumberbatch et al: we have updated the BBN, and it is now compatible with the stellar value!!!!

We need to understand mixing by means of more observations in Pop I stars

open clusters

Standard models

- Li is depleted during the PMS
- Once on the MS, depletion stops
- Li depletion is strongly metallicity and temperature dependent
- Same age, mass and initial chemical composition =>

  same A(Li) =>

  no scatter in OC for a given T_{eff}

Observations up to 2000

Zappalà (1972): *If the Pleiades Li abundances represent ZAMS values, then the smaller Hyades abundances must be indicative of depletion on the MS*

More modern Li measurements in open clusters:

MS deplet

↓

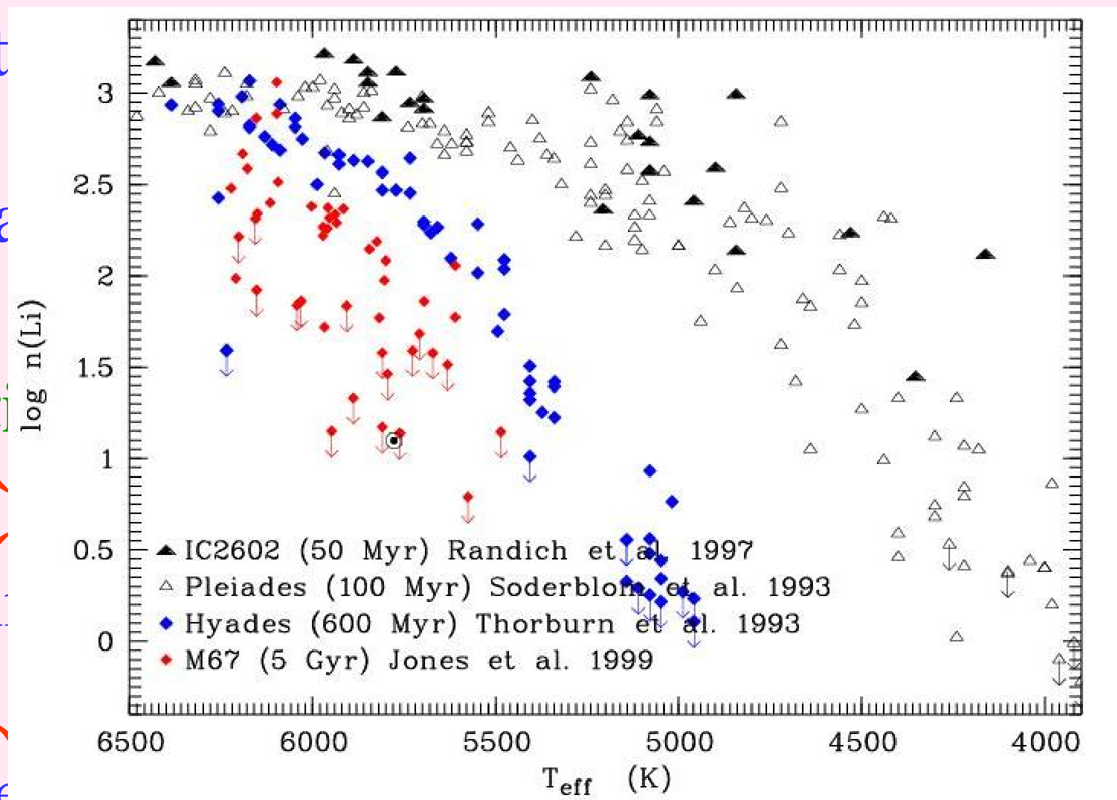
Different a a factor of
10 spread

→ **additi**

↕

Extra-mix

New models & Observations



New FLAMES/Giraffe Observations (Randich et al. 2005)

Cluster	Age (Gyr)	[Fe/H]	R_{GC} (Kpc)
NGC 6475	0.25	+0.13	8.3
NGC3960	0.9	+0.02	8.0
NGC2324	0.9	-0.17	11.6
NGC2477	1.0	+0.07	8.9
NGC2660	1.1	+0.04	9.2
To2	2.5	-0.20	13.1
NGC6253	3.0	+0.36	7.0
Be29	4.0	-0.31	22.0
Be20	4.9	-0.30	16.4
Be32	7.2	-0.29	11.3
Pallavicini et al. (2006)			
NGC2506	2.0	-0.20	10.38
Mel 66	4.0	-0.33	10.2
Cr 261	8.0	+0.13	7.5

Lithium in Berkeley 32

EW measurements of the Lithium resonance line @6708 Angstrom

Fe line contribution, computed with Spectral synthesis

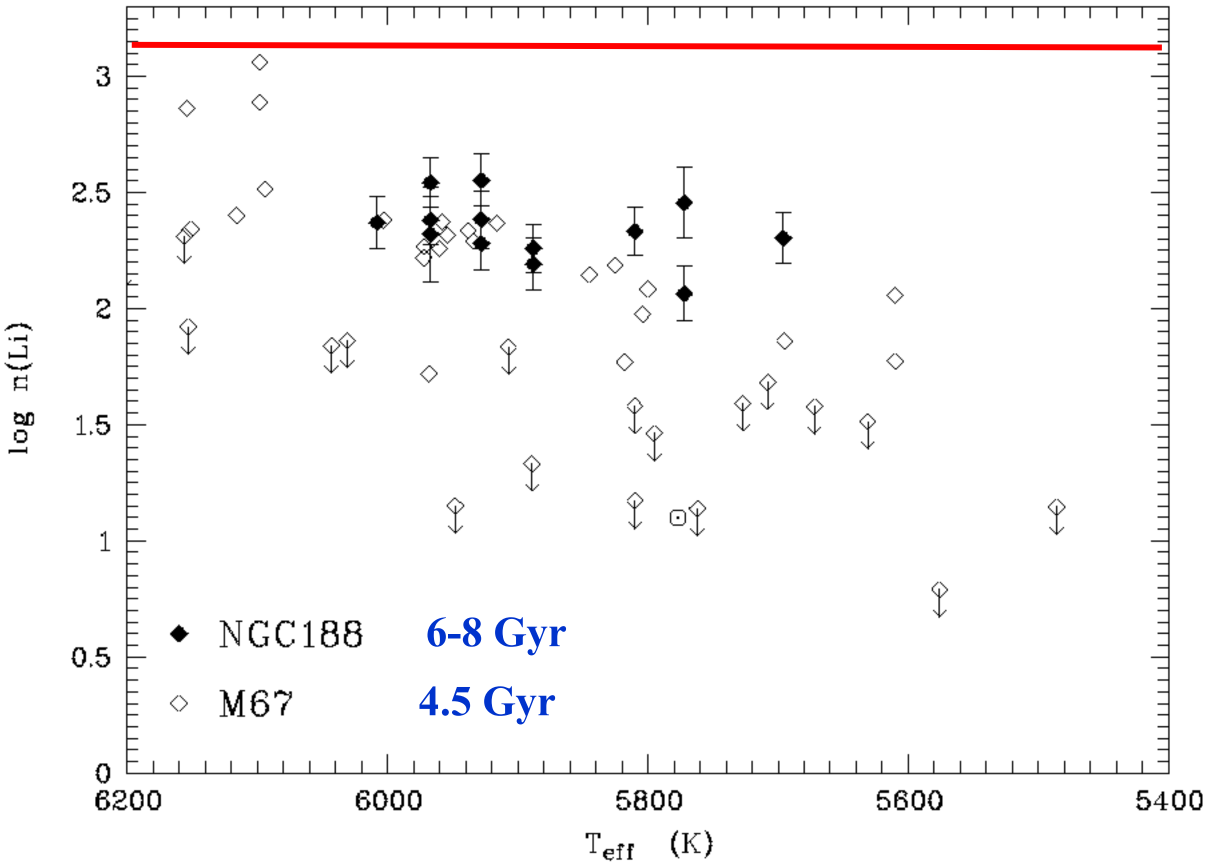
Temperature determination by means of photometry (Richtler and Sagar 2001, D'Orazi et al 2006)

& colour-T calibrations by Soderblom

Curve of growth by Soderblom

New observations: 1. Timescales

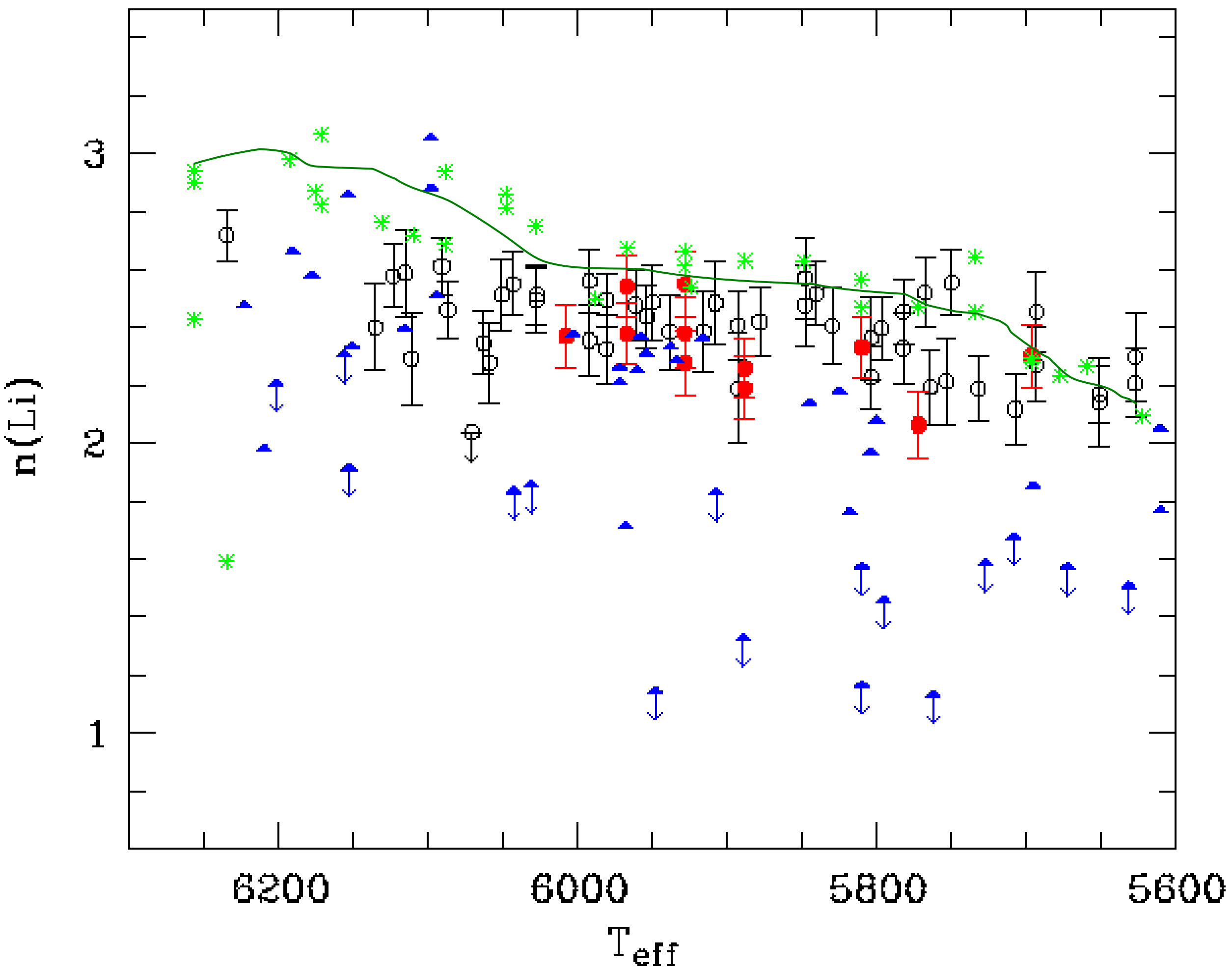
Main result: convergence of Li abundances at old ages



NGC 188 no more Li depleted than upper envelope of M67

Randich et al. (2003)

New observations: 1. Timescales



○ **Be 32: 5-6 Gyr**

▲ **M67: 4.5 Gyr**

• **NGC188: 6-8 Gyr**

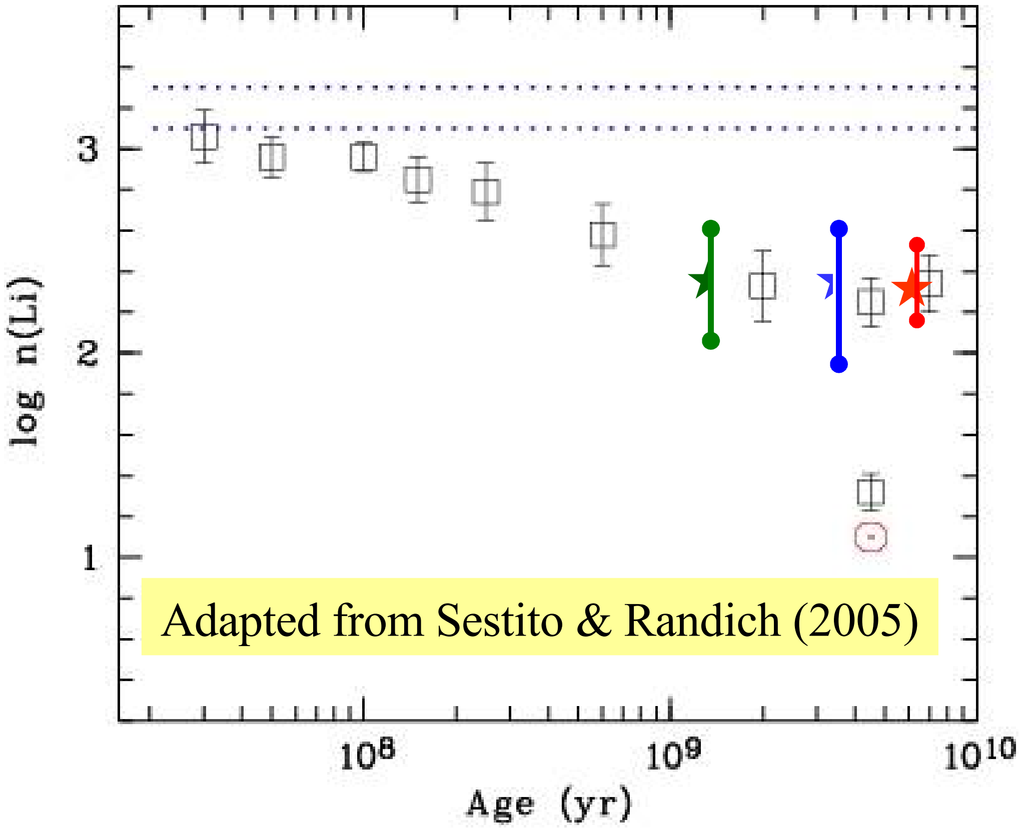
* **Hyades: 0.6 Gyr**

Be 32 pattern very similar to that of NGC 188

Randich et al. (2007)

Observations: 1. Timescales

3 new OCs (>30 members/cluster) from the FLAMES survey of Randich et al. (2005):



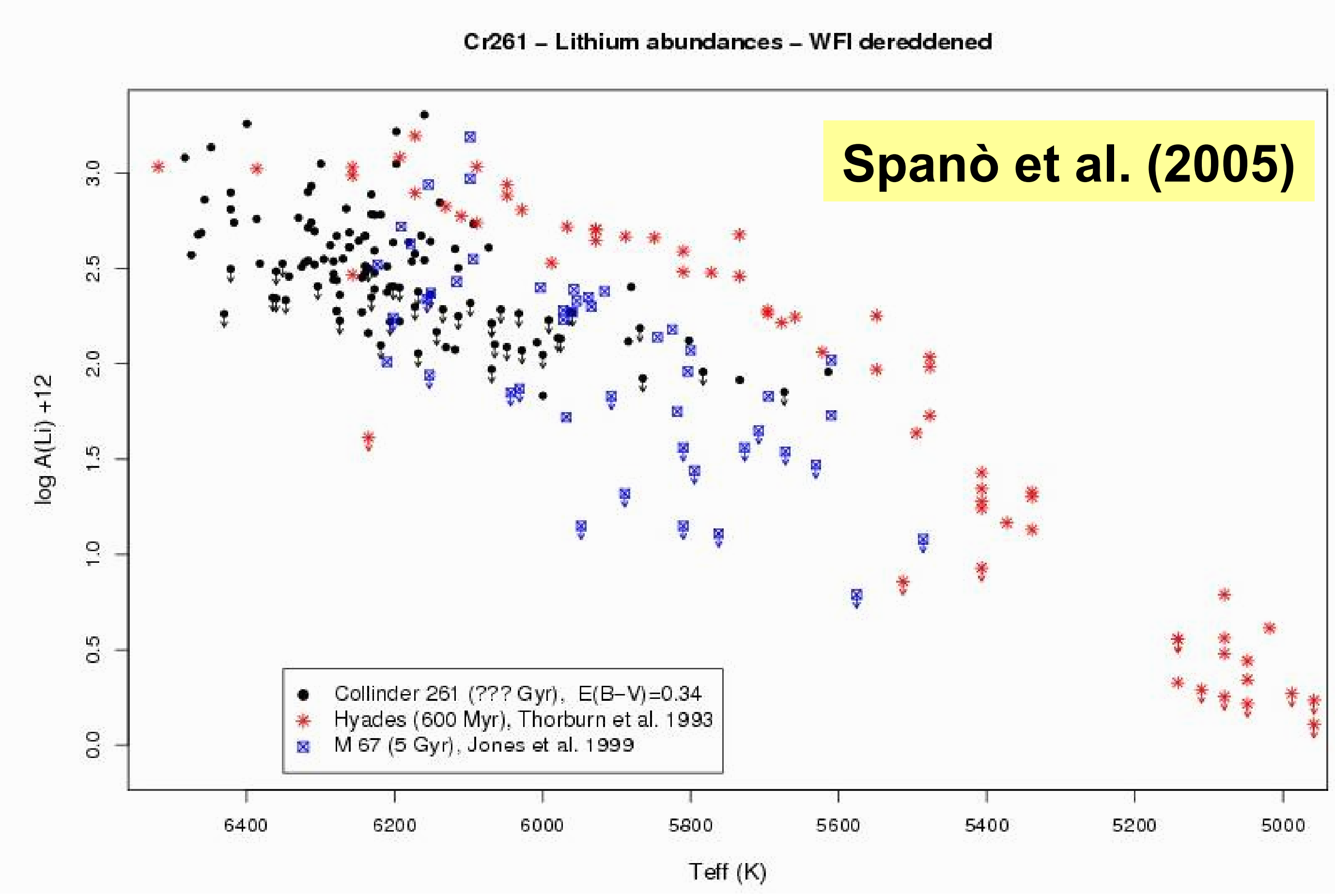
NGC3960 (1 Gyr, 0.02 –Prisinzano & Randich (2007)

NGC6253 (3 Gyr, 0.35 –Randich et al. 2008)

Be 32 (5 Gyr, -0.32 –Randich et al. 2008)

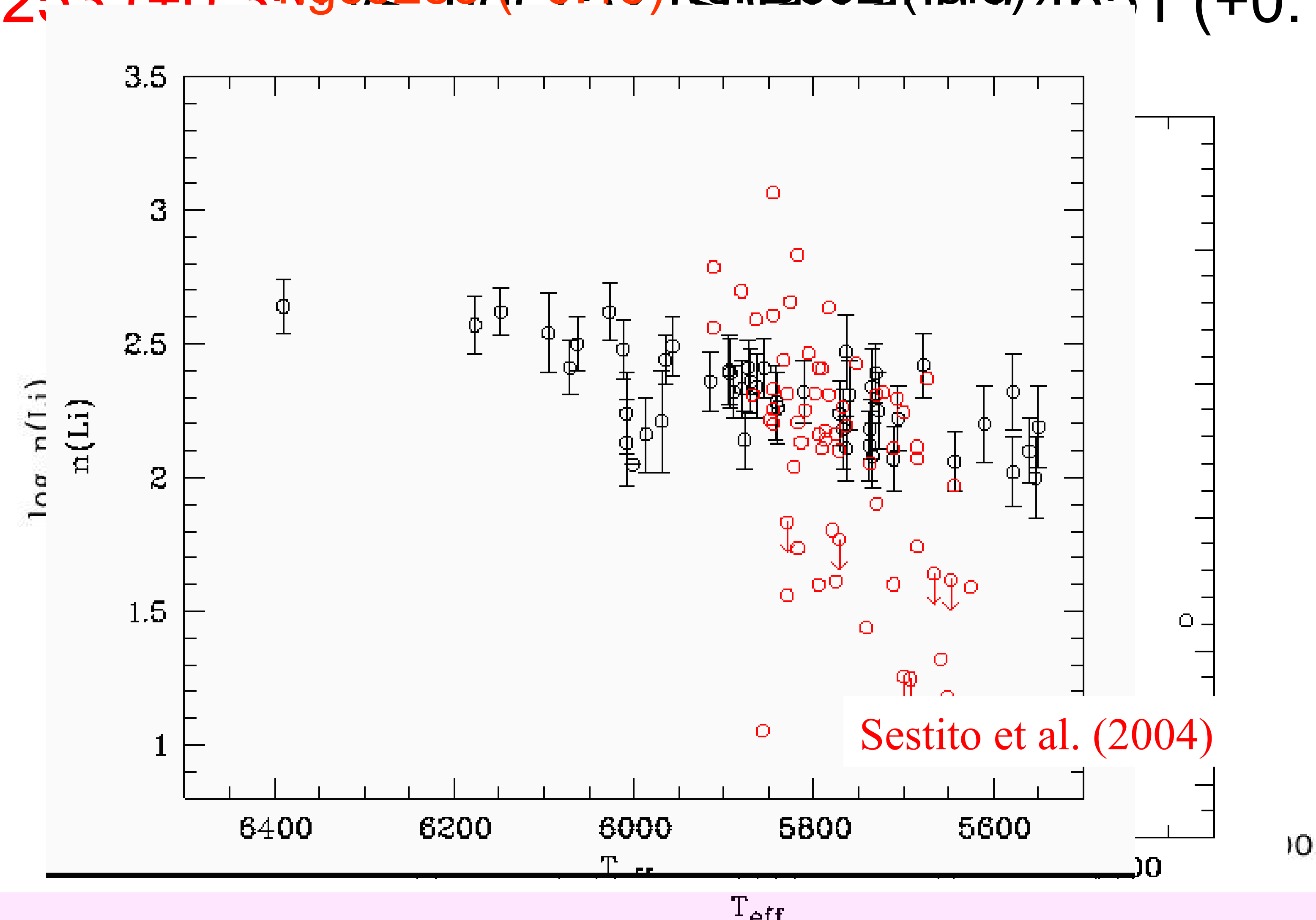
New observations: 2. Dispersion

Out of **9 OCs** with t ≥ 1 Gyr only **3** show a large (> errors) **dispersion:** **M67, NGC6253 (3 Gyr, +0.35), Cr261 (7 Gyr, ~solar).** No dependence of dispersion on age and metallicity.



New observations: 3. Dependence on [Fe/H]

ngc6253 (+0.15) vs. Be32 (-0.3)



Average depletion does not depend on [Fe/H]

Summary of open cluster observations

- Lithium is hardly depleted during the PMS
- Lithium is strongly depleted on the MS
- Metallicity plays a small role
- Stars otherwise similar do sometimes differ in Li abundance (other parametrs involved)
- The depletion “saturates” after one Gyr

Models: Non standard processes

- Atomic Diffusion (element separation) – e.g., Michaud et al. (1986), Chaboyer et al. (1995), Michaud et al. (2004)
- Slow mixing driven by rotation (mer. circulation, angular momentum loss, + other) – Eddington (1925!), Zahn (1974,1992), Charbonnel & Talon (1999), Shatzmann & Baglin (1991), Pinsonneault et al. 1992, Deliyannis & Pinsonneault (1997)
- Gravity waves -García López & Spruit (1991), Montalban & Schatzmann (2000)
- Tachocline – Brun et al. (199), Piau et al. (2003)
- A combination of these (Charbonnel & Talon 2005)

Constraints from observations

- Timescales of Li depletion
- Dispersion: M67 unique? Dependence on cluster parameters?
- Dependence of depletion on [Fe/H]
- Beryllium depletion? Be vs. Li

Summary of obs.-model comparisons

PROPERTY MODEL	Amount of depletion/ convergence	Dispersion	[Fe/H] dependence
Diffusion	NO/YES	NO	NO
Rotational mixing	YES/NO?	YES	?
Gravity waves	YES/NO	NO	?
Tacochline	YES/NO	NO?	NO
Rot.+ Waves	YES/NO	YES	?

Conclusions

- The lithium primordial value is obtained both by means of cosmology and stellar astronomy.
- Our current understanding of mixing in stellar atmospheres is incomplete
- Although primordial lithium is studied using pop II stars, open cluster observations will help us to understand mixing in stars and solve the dilemma
- New generation telescopes give us an unprecedented opportunity in this regard