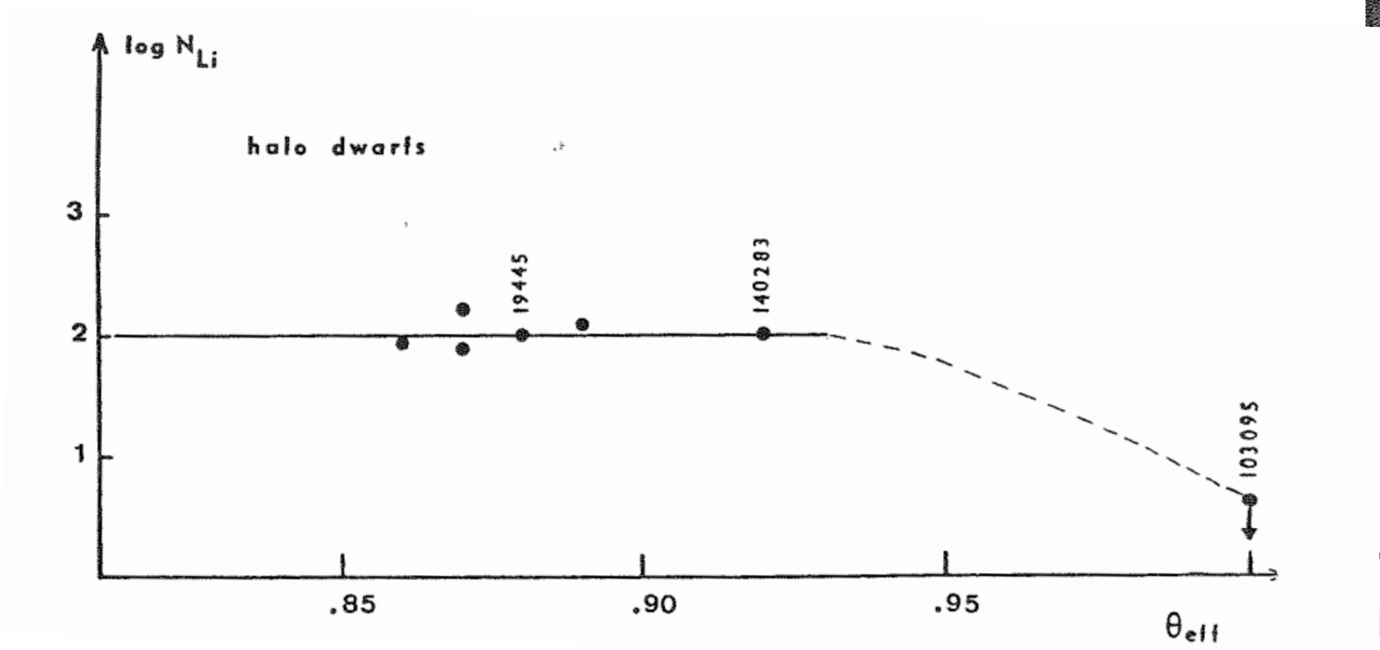
Spite & Spite (1981)



Naturally it would be very important to confirm the value of the abundance of lithium at the beginning of the life of the Galaxy; in particular an evaluation of the lithium abundance in the atmosphere of the dwarf stars in globular clusters would be of great interest.

in: IAU colloquium 68 "Astrophysical Parameters for Globular Clusters",
Schenectady, NY, October 1981

Lithium in the Cosmos
February 27-29, 2012

Shedding Light on Lithium Evolution

the Globular Cluster Perspective

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SETTING SCIENCE AGENDAS FOR EUROPE

Gaia DPAC
Data Processing & Analysis Consortium

RYMDSTYRELSEN
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Introductory remarks

GCs are distant objects (2+ kp)

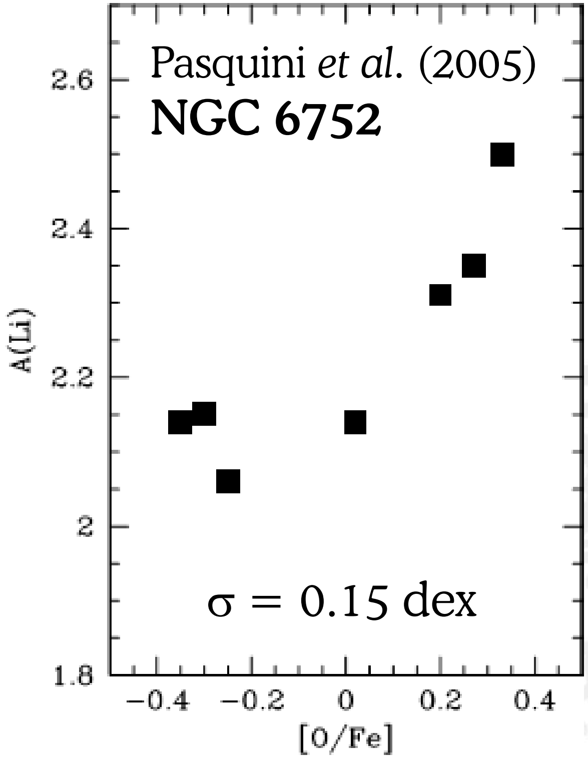
⇒ unevolved stars are faint
(m_V (turn-off point) ≥ 16.5)

⇒ 8-10m telescope science

Lithium in GCs suffers from pollution

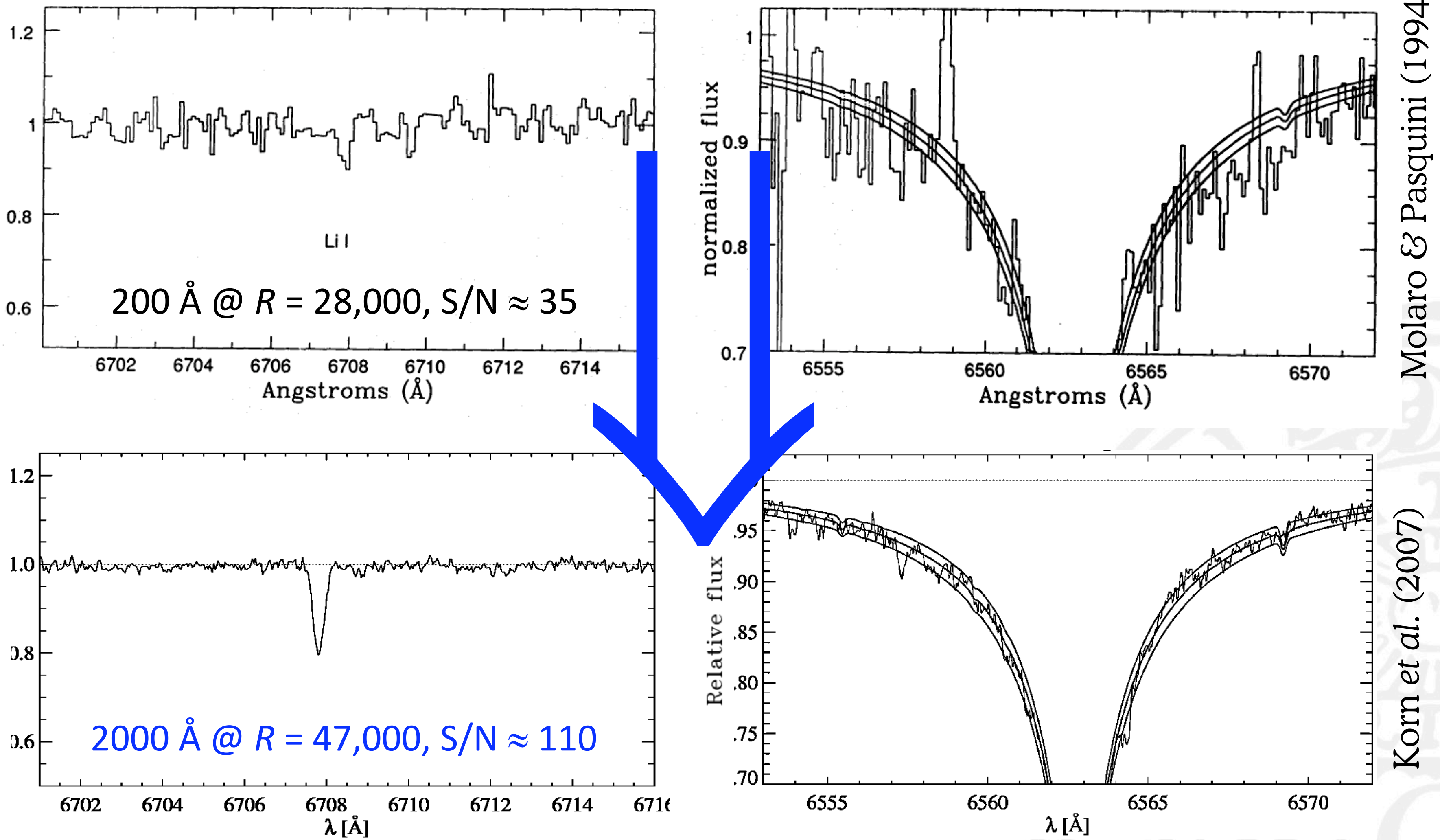
Pasquini *et al.* (2005)

⇒ no place to study its evolution?



Harder to disentangle the physical processes at work, but well worth a detailed look! Lots to learn!!

From a 1st spectrum to routine work



200 Å @ *R* = 28,000, S/N ≈ 35

Molaro & Pasquini (1994)

2000 Å @ *R* = 47,000, S/N ≈ 110

Korn *et al.* (2007)

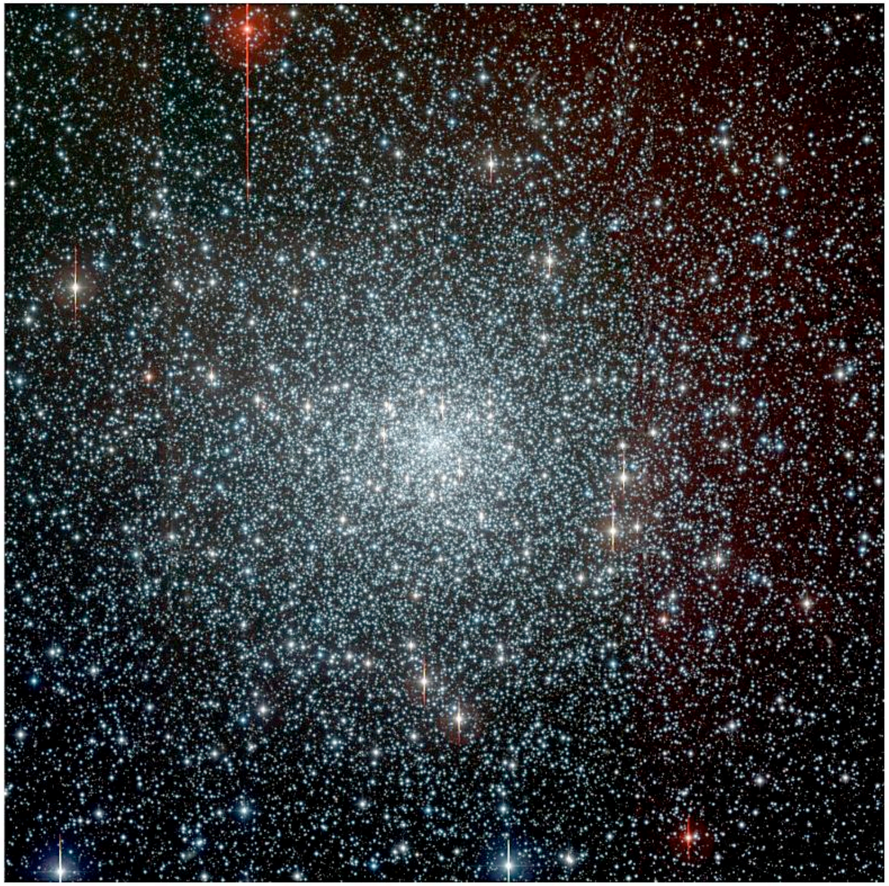
The cluster of choice

NGC 6397: one of the most nearby, low-reddening, metal-poor globular clusters (t = 12 Gyr, [Fe/H] = –2.1)

Lithium from individual *plateau* stars (12-scale abundance):

2.35 ± 0.25 (Molaro & Pasquini 1994)
2.28 ± 0.10 (Pasquini & Molaro 1996)
2.23 ± 0.07 (Thevenin *et al*. 2001)
2.34 ± 0.06 (Bonifacio *et al*. 2002)
2.24 ± 0.05 (Korn *et al*. 2007)
2.25 ± 0.01 (Lind *et al*. 2009)
2.37 ± 0.01 (González Hernández *et al*. 2009)

Differences arise from T_{eff} and (N)LTE.

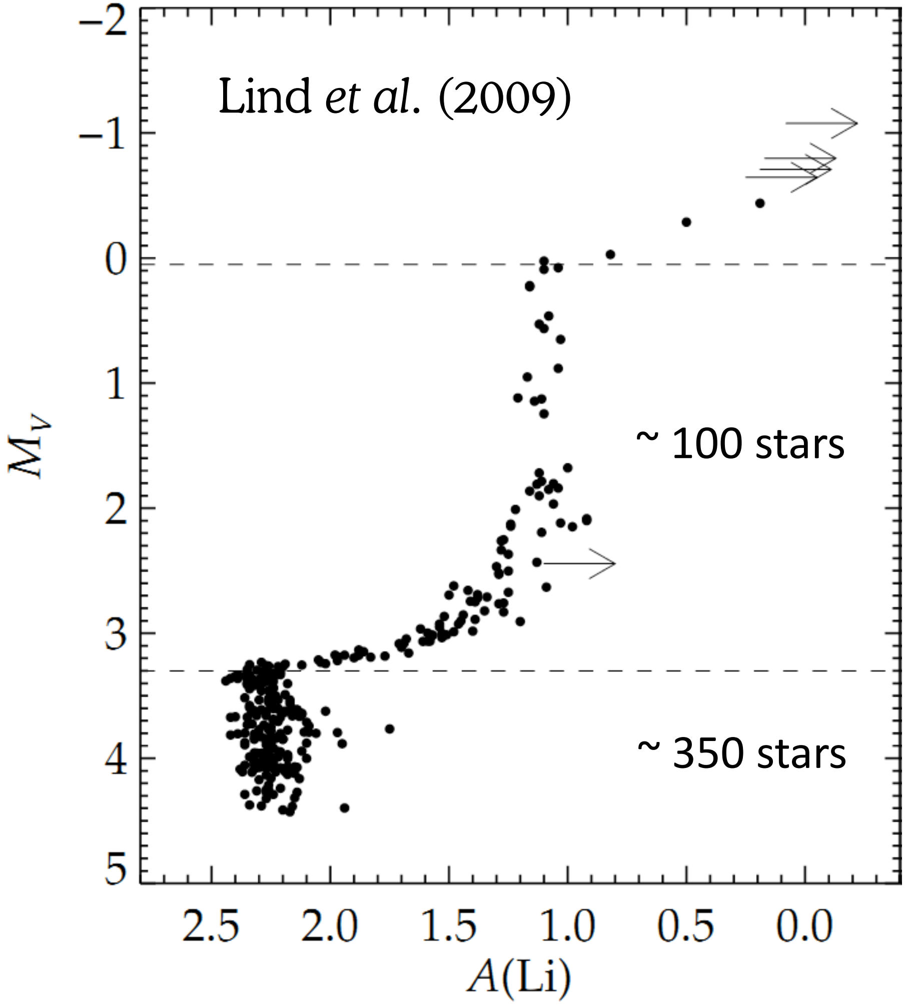


Globular Cluster NGC 6397
(ESO/MPI 2.2-m + WFI)

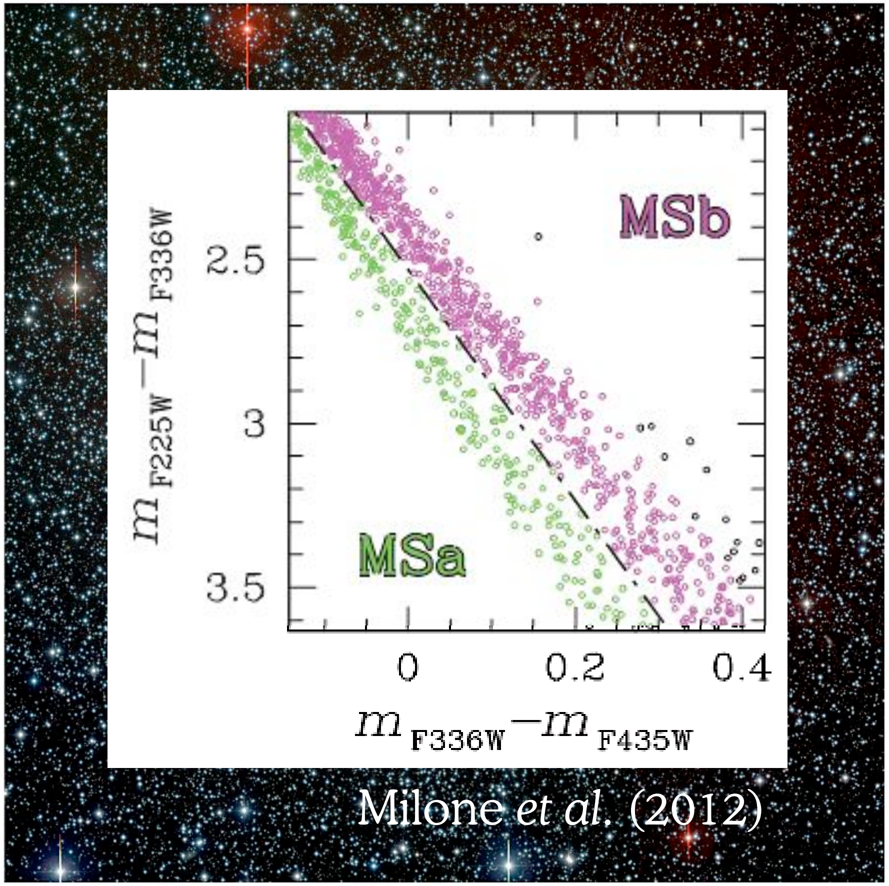
ESO PR Photo 23a/04 (17 August 2004)

© European Southern Observatory

More on NGC 6397



Lind *et al.* (2009)



Milone *et al.* (2012)

Globular Cluster NGC 6397
(ESO/MPI 2.2-m + WFI)

ESO PR Photo 23a/04 (17 August 2004)

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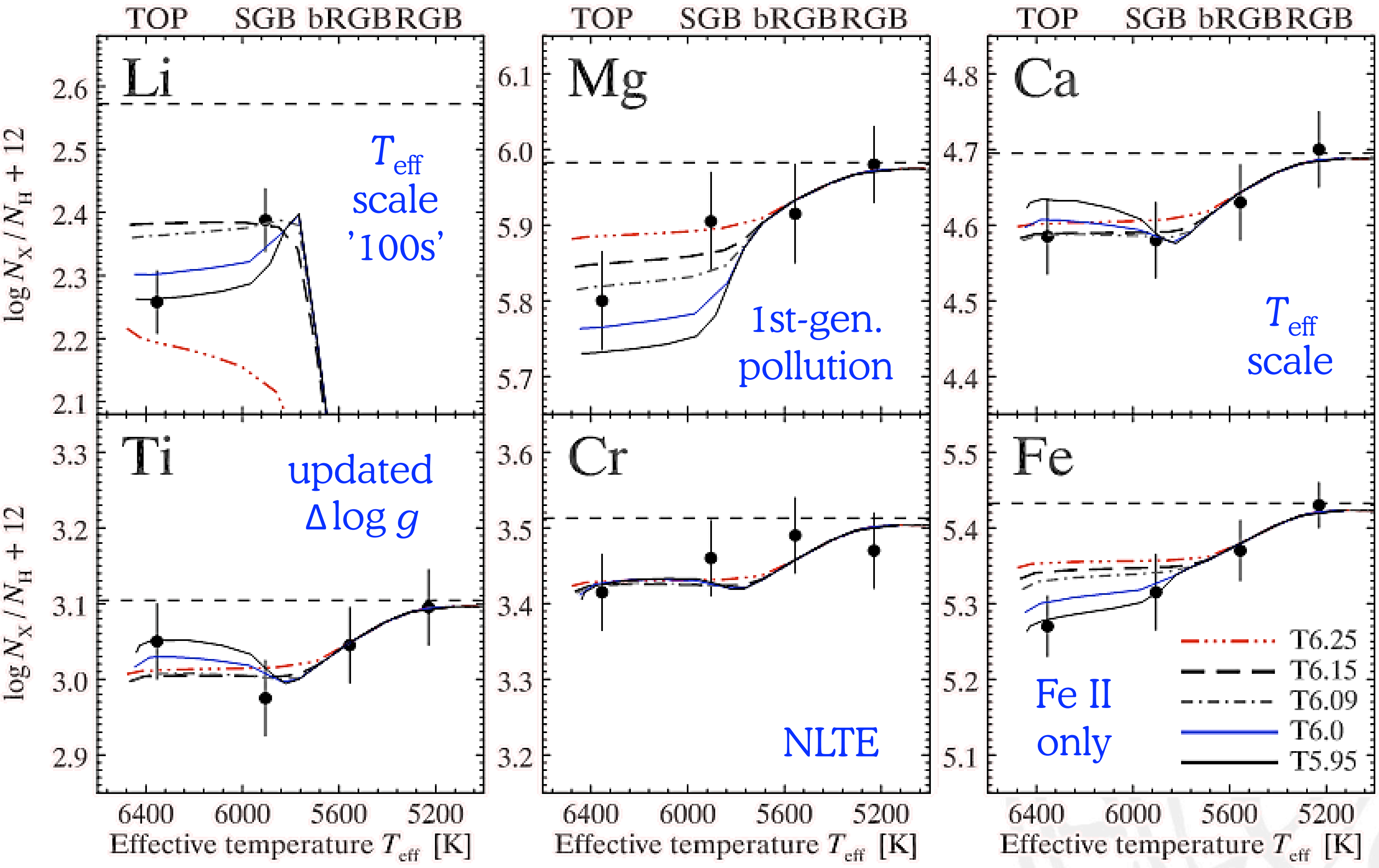
Abundance trends in NGC 6397



T_{eff} scale '100s'

1st-gen. pollution

T_{eff} scale

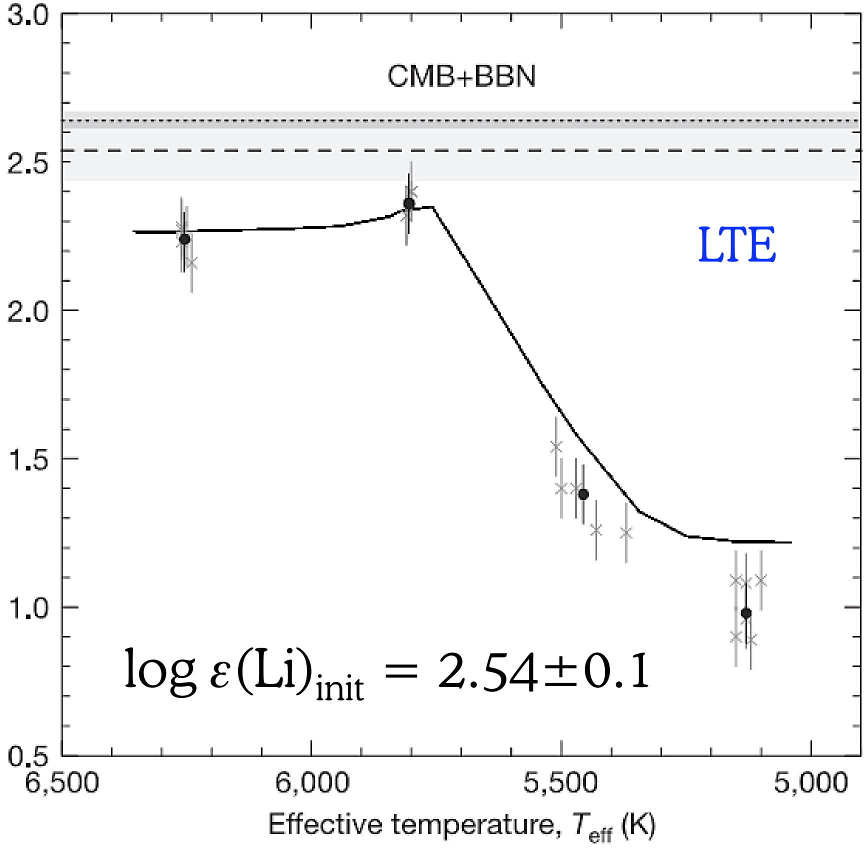
updated $\Delta \log g$

NLTE

Fe II only

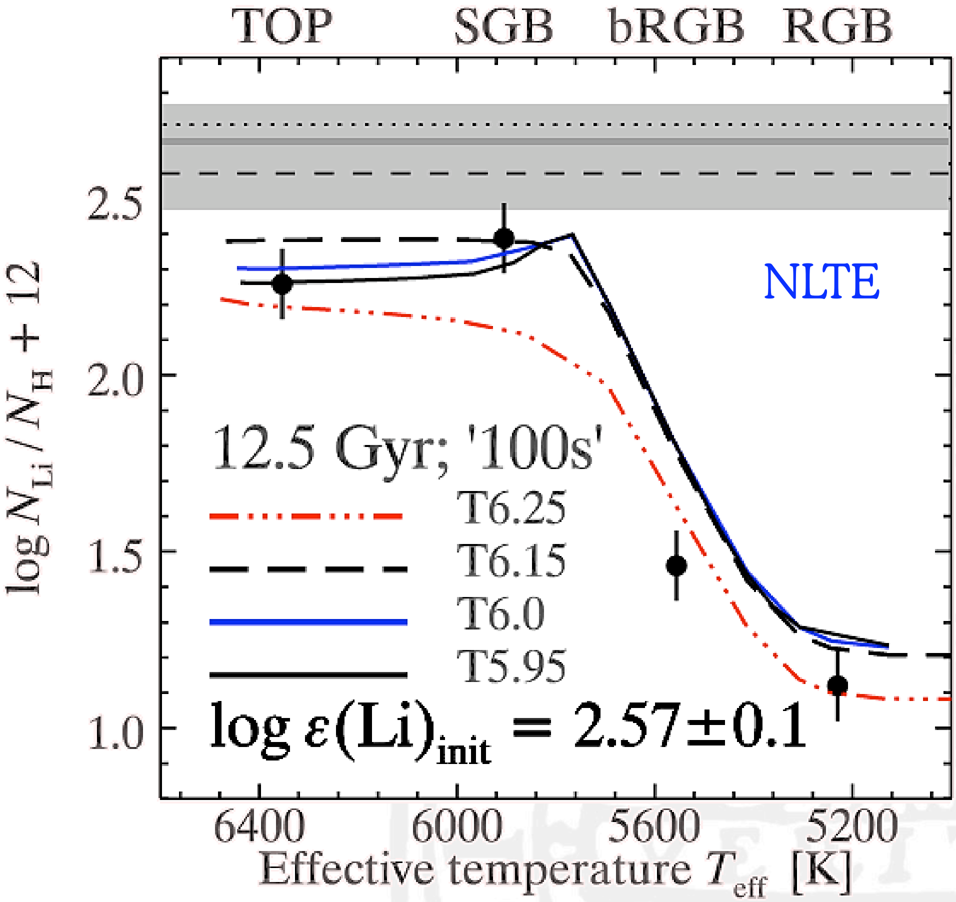
Nordlander *et al.* (2012)

Bridging the gap to $\mathrm{Li}_{\mathrm{BBN}}$ at [Fe/H]=−2



$\log \varepsilon(\mathrm{Li})_{\mathrm{init}} = 2.54 \pm 0.1$

Korn *et al.* (2006)



$\log \varepsilon(\mathrm{Li})_{\mathrm{init}} = 2.57 \pm 0.1$

Nordlander *et al.* (2012),
see poster for details

Should we reject atomic diffusion…

… because it involves an ad-hoc formulation of mixing?

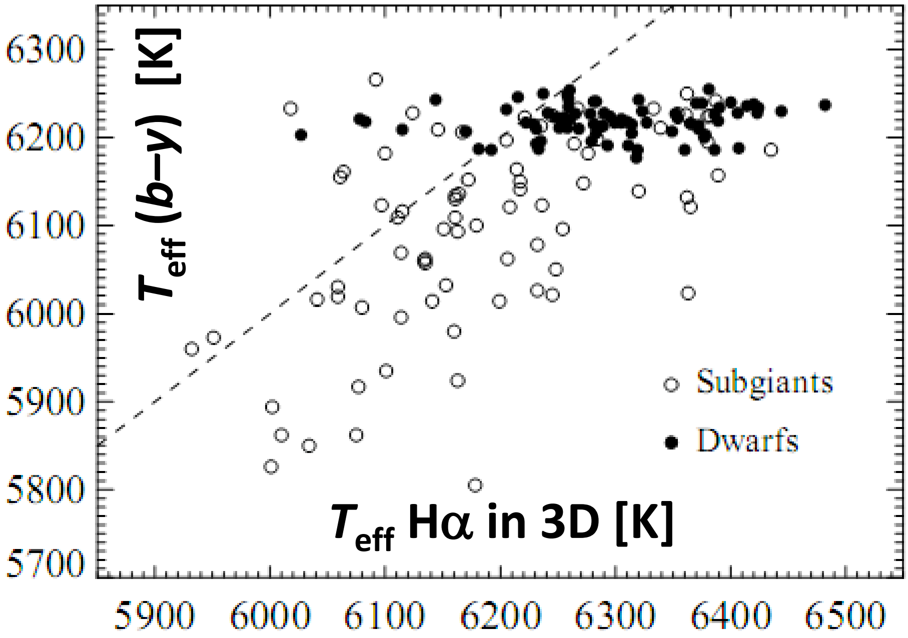
If we do this, then we should also reject
Theory of stellar structure for its use of α_{MLT};
Theory of model atomspheres for ξ_{mic}/ Ξ_{mac};
Theory of NLTE line formation for S_{H};
Hydrodynamic modelling for numerical viscosity;
you name it.

Let's make an effort to understand the processes that give rise to the mixing needed to moderate atomic diffusion!

Li and the $T_{\rm eff}$ -scale

Surface lithium explicitly depends on the adopted $T_{\rm eff}$ values, at the level of 0.07 dex / 100 K.

Despite major efforts in recent years, there is still no agreement to better than 100 K.



González Hernández *et al.* (2009)

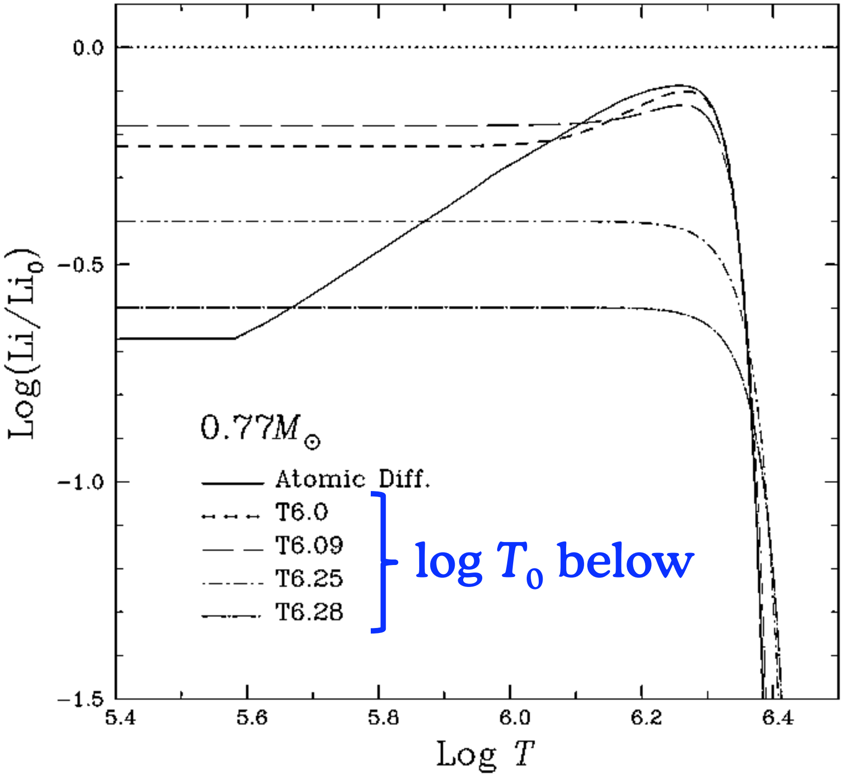
Will photometric calibrations, synthetic photometry, excitation equilibria and Balmer lines agree (better) in 3D-NLTE modelling?

An even worse T_{eff}-scale issue

There is a perfidious aspect of atomic-diffusion models with high mixing efficiency (e.g. T6.25):

they give the largest correction to surface lithium (–0.4 dex) with very small signatures for heavy elements (≈ –0.1 dex).

Depending on study design, the *indirect* impact of the T_{eff} scale on the diffusion correction for lithium can be rather large.



Richard *et al.* (2005)

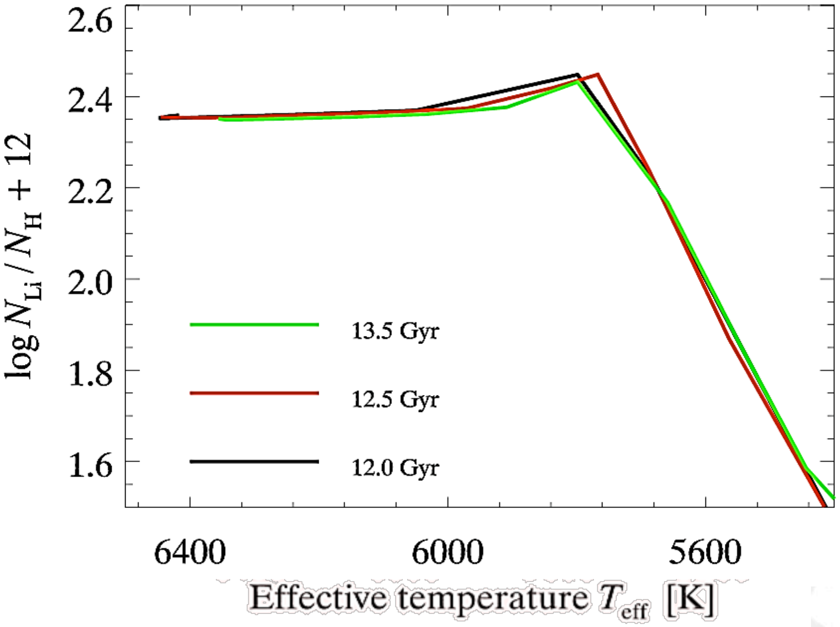
$$D_T = 400 D_{\mathrm{He}}(T_0)\left[\frac{\rho}{\rho(T_0)}\right]^{-3}$$

Lithium as a function of age

Atomic diffusion is a slow, time-dependent process.

How can halo stars with different ages thus have uniform surface lithium?

There is an interplay between age, mass, T_{eff} (TOP) and M(convection zone):
younger stars ⇔ hotter TOP ⇔ more efficient surface depletion *per unit time*.



Thin Spite plateau possible in the presence of atomic diffusion!

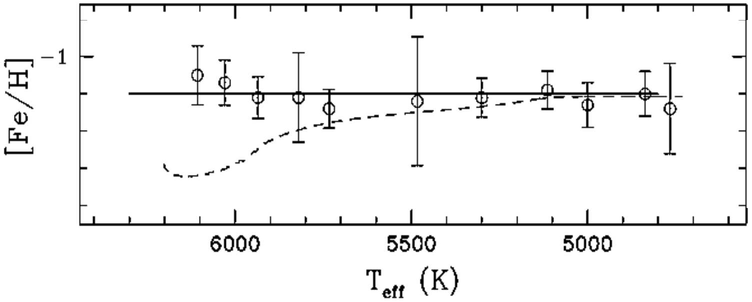
Studies in additional GCs

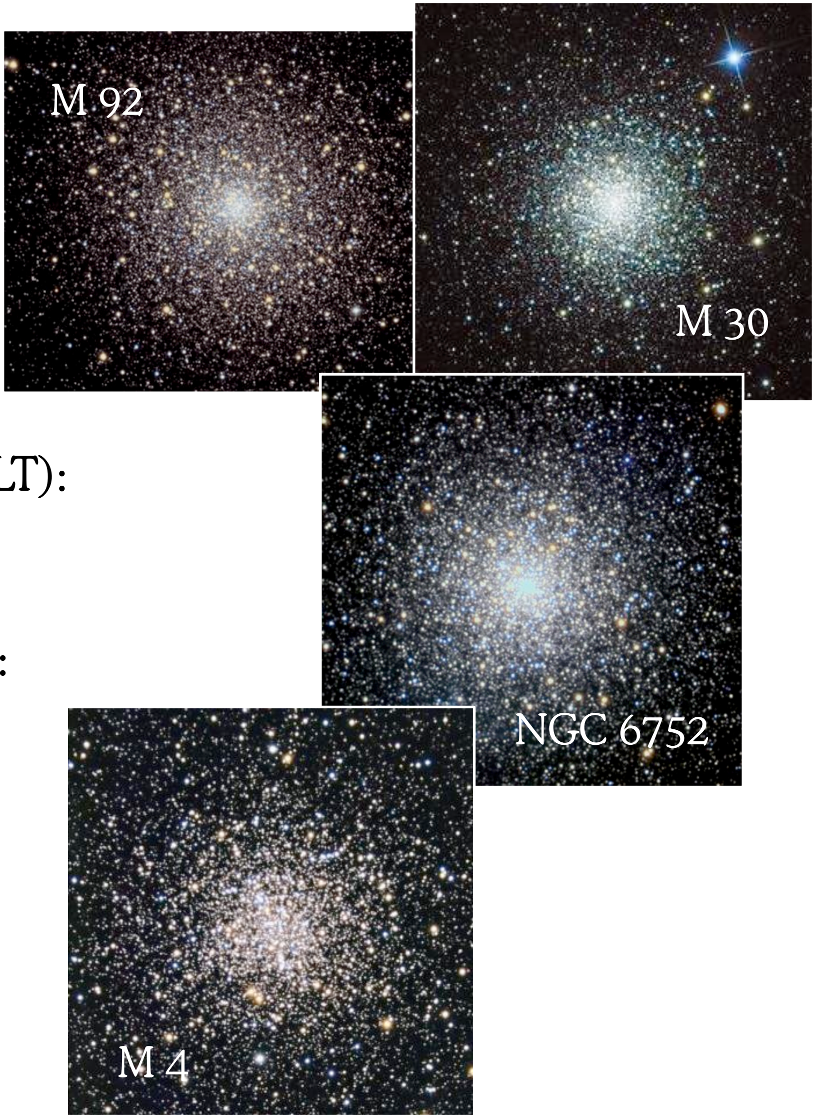
M 92 at [Fe/H] = −2.5 (Cohen @ Keck): difficult ($V_{\mathrm{TOP}} > 18$)!

M 30 at [Fe/H] = −2.5 (Lind *et al.* @ VLT): lithium only (in progress, cf. Lind's talk)

NGC 6752 at [Fe/H] = −1.6 (Korn *et al.* @ VLT): see next slide

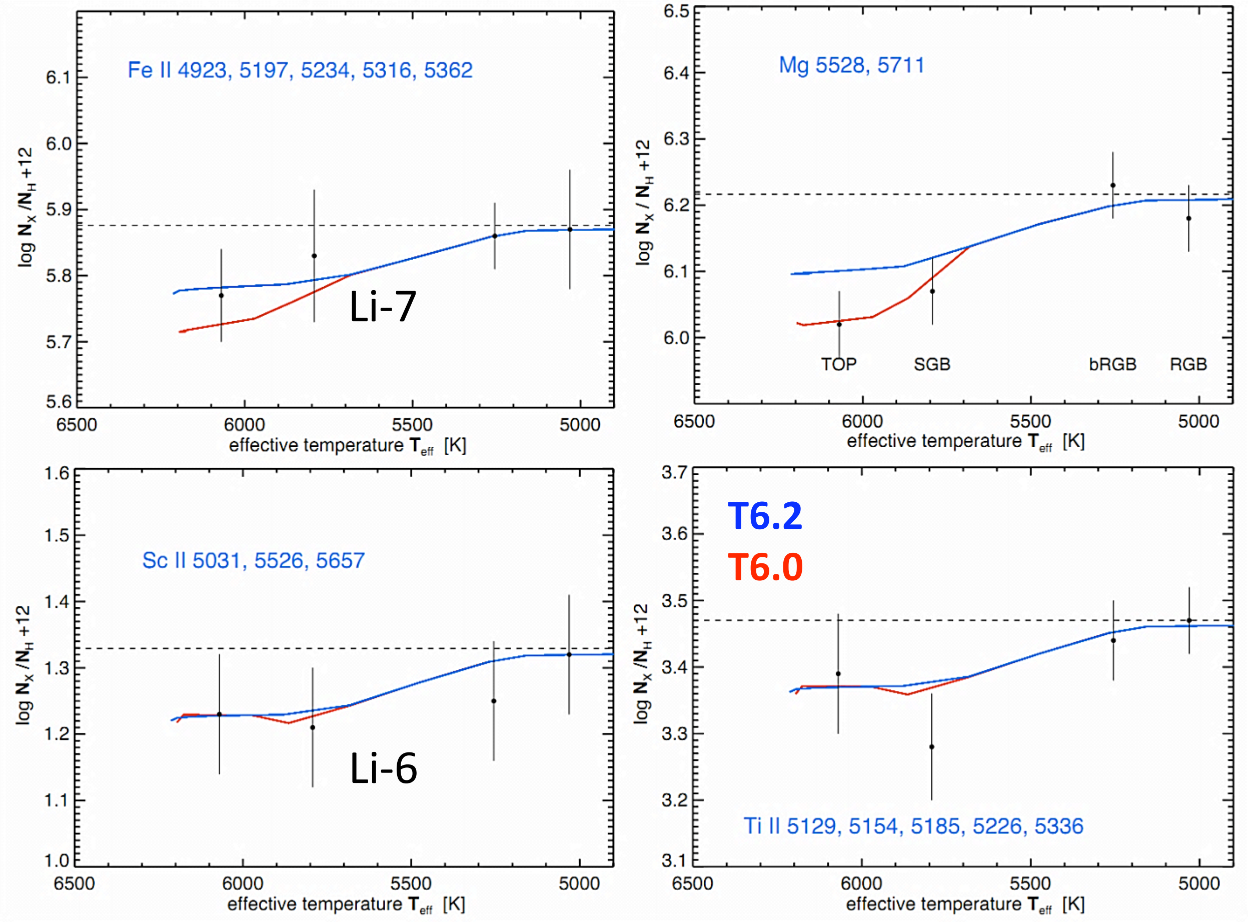
M 4 at [Fe/H] = −1.1 (Mucciarelli *et al.* 2011): no trend in iron; matching lithium to SBBN requires diffusion + efficient mixing (T6.25)

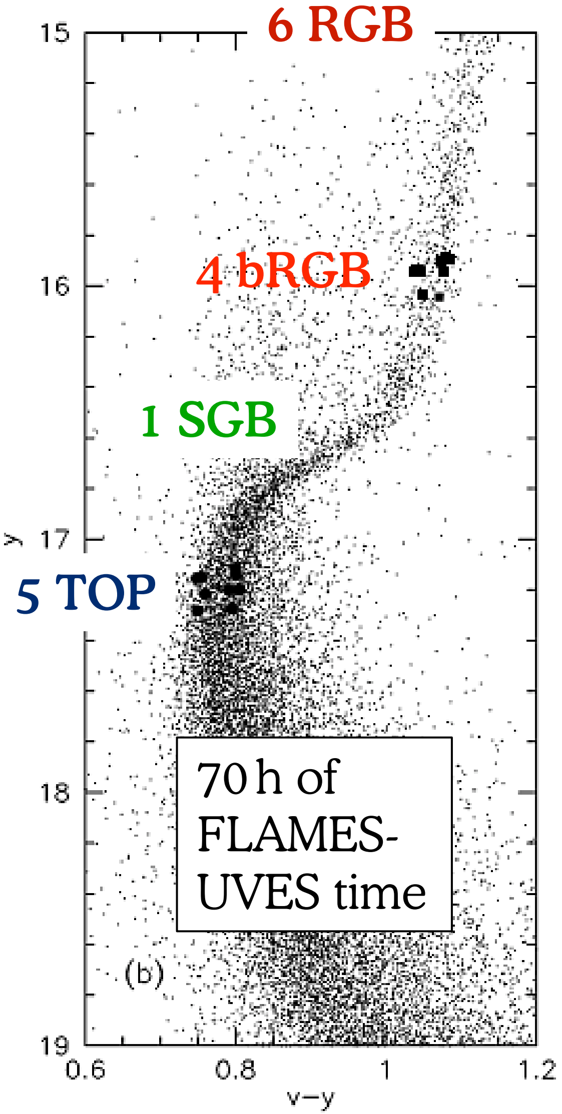




NGC 6752 @ [Fe/H]=−1.6

Shallow trends compatible with T6.20 model predictions

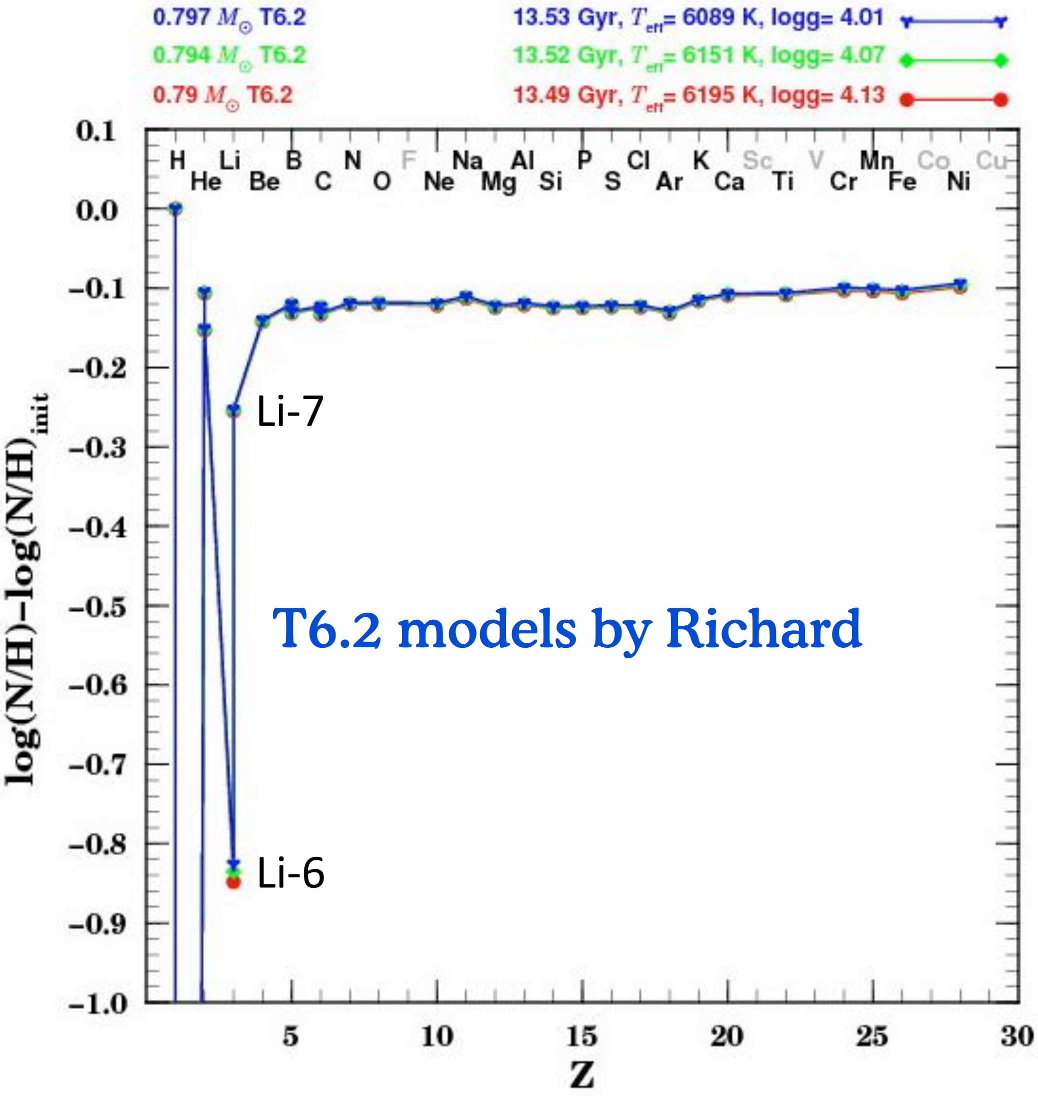




70 h of FLAMES-UVES time

Gruyters *et al.*, in prep.

T6.2 predictions for NGC 6752



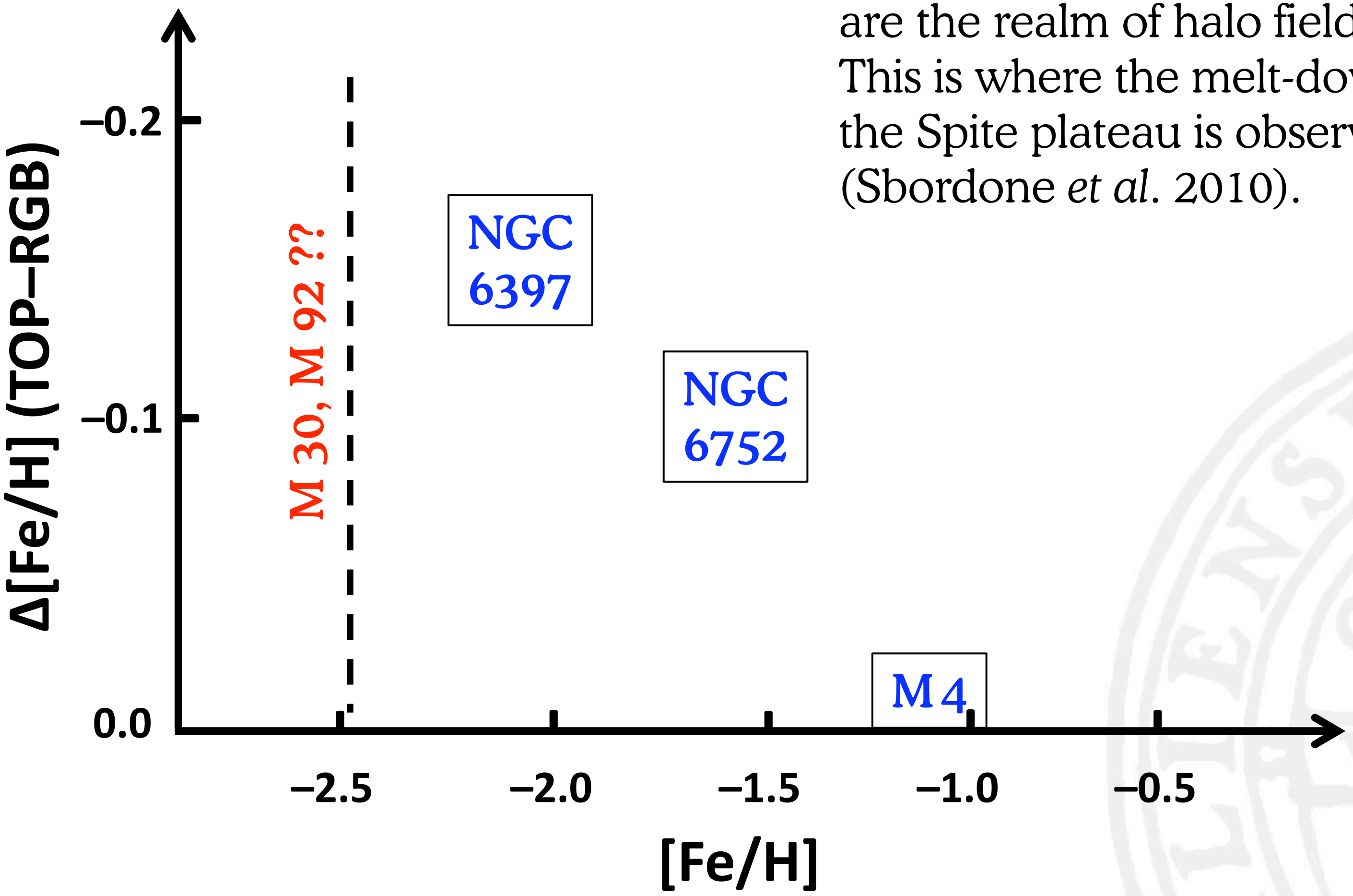
T6.2 models by Richard

Contrary to the T6.0 model employed to explain NGC 6397, the T6.2 model essentially shows no element-specific signatures for heavy elements (Δ (TOP–RGB) ≈ –0.1).

In TOP stars, Li-7 is depleted by 0.25 dex, Li-6 by 0.85 dex, relative to the original abundance.

Li-6 detected in field TOP stars at 5 % implies $(\text{Li-6/Li-7})_{\text{init}} \approx 0.2$.

Mixing as a function of [Fe/H]

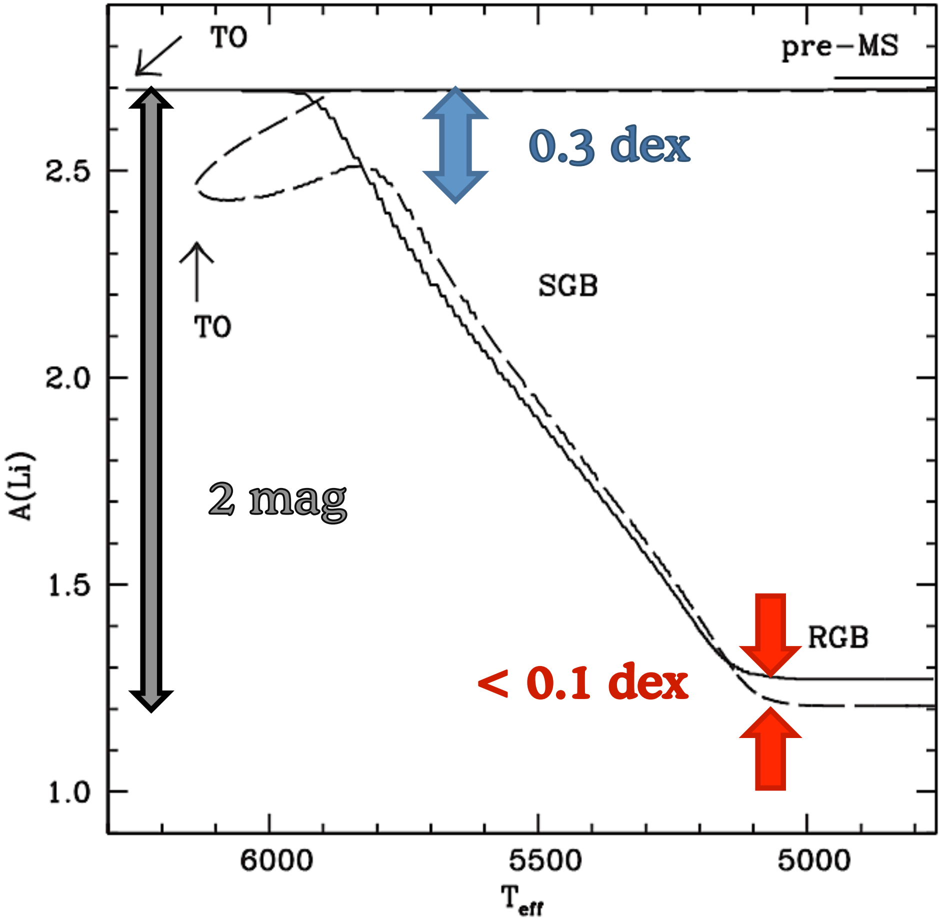


Metallicities below [Fe/H] ≈ –2.5 are the realm of halo field stars. This is where the melt-down of the Spite plateau is observed (Sbordone *et al*. 2010).

Studying lithium on the RGB

Studying lithium after the 1st dredge-up seems to diminish the impact of modelling uncertainties related to atomic diffusion.

One also wins 1+ magnitude (nominally 2 mag, but the Li doublet is weaker in the RGB stars). This may allow to take this research extragalactic.



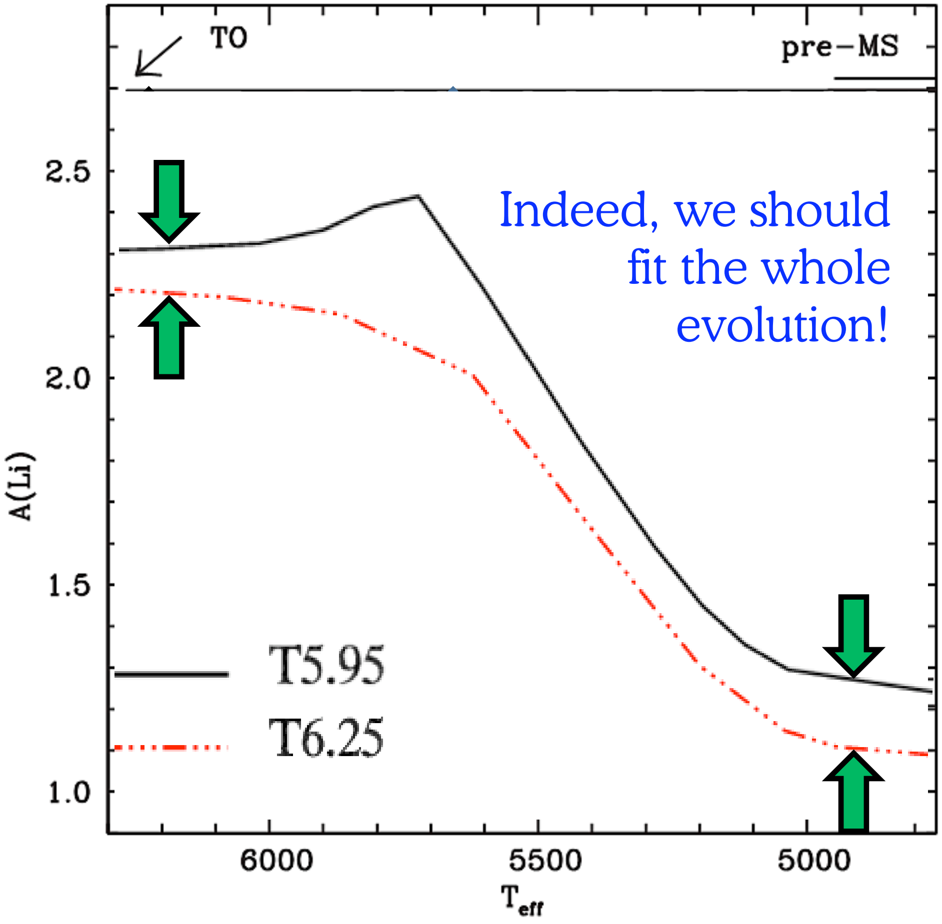
Mucciarelli *et al.* (2012)

Studying lithium on the RGB

Studying lithium after the 1st dredge-up seems to diminish the impact of modelling uncertainties related to atomic diffusion.

However, this does not do away with the uncertainty stemming from the choice of mixing efficiency Tx.y.

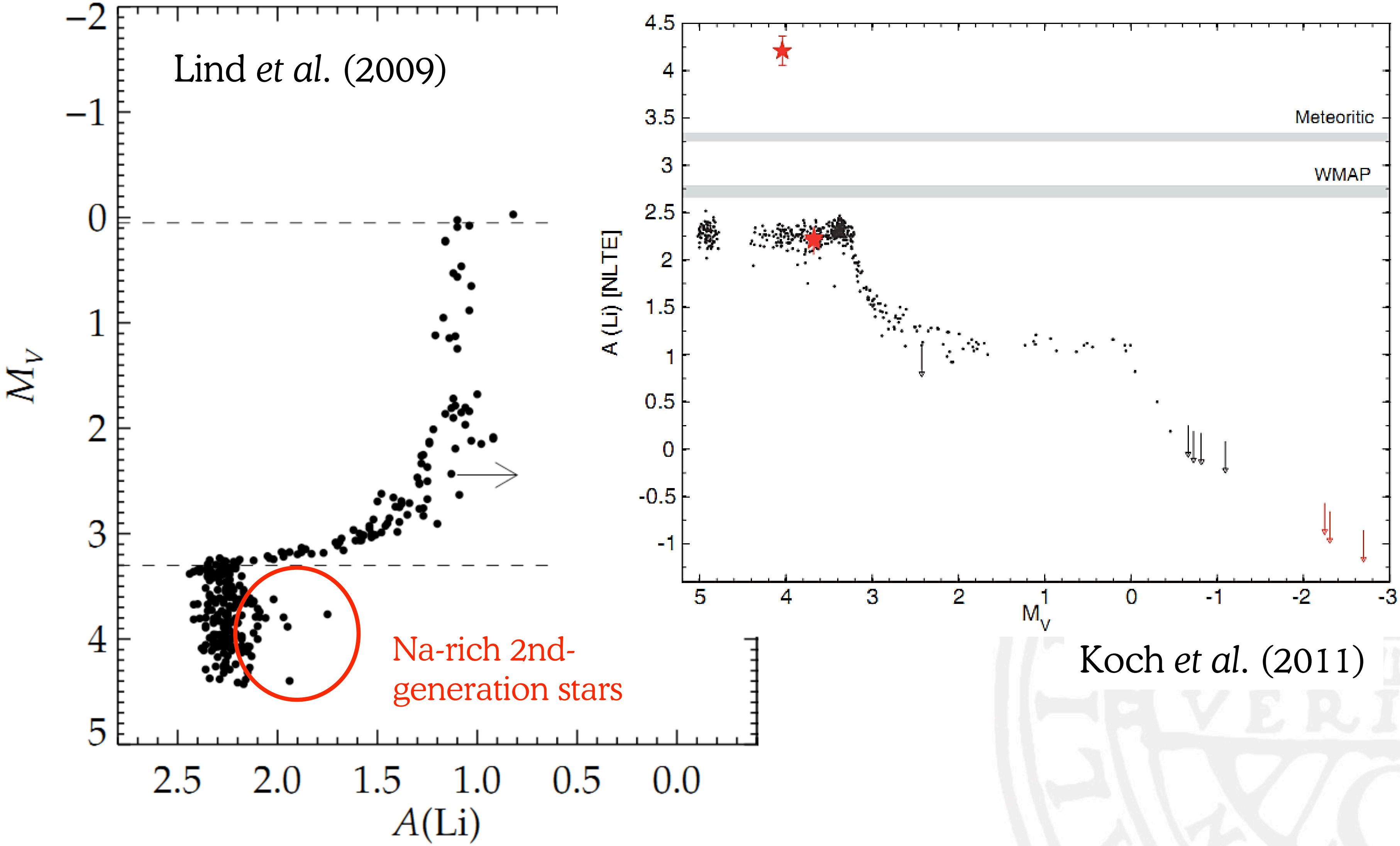
How do we determine Tx.y from giants alone?



Indeed, we should fit the whole evolution!

Mucciarelli *et al.* (2012)

Outliers: trash or treasure?



Lind *et al.* (2009)

Na-rich 2nd-generation stars

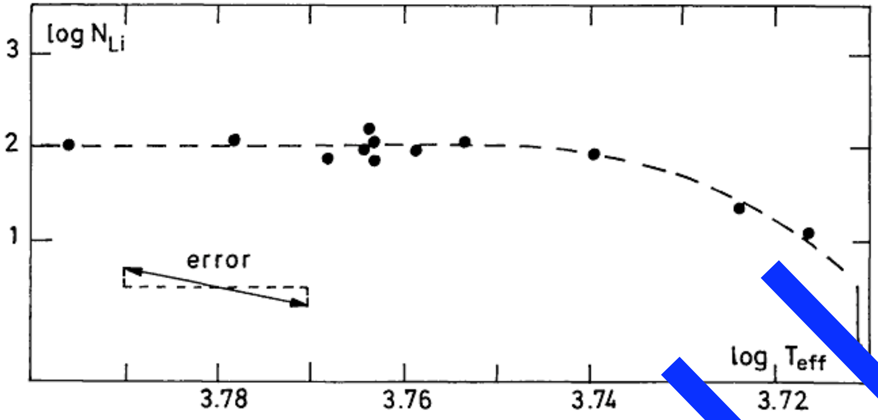
Koch *et al.* (2011)

Conclusions

GC studies can significantly enhance our knowledge of the ***mixed* evolution of stellar lithium**

- Despite multiple stellar generations within a GC, the stars observable today are coeval and their age can be determined $\Rightarrow$ constraints on the Pop II T_{eff} scale (e.g using the WDCS age)
- Make best possible use of the common distance of GC stars: you know ΔL and $\Delta \log g$ very precisely!
- Atomic diffusion connects the surface evolution of lithium to other elements. Intra-cluster pollution has to be dealt with.
- The role and properties of outliers can be quantified
- Surface lithium of Spite-plateau stars is lowered by ≥ 0.2 dex

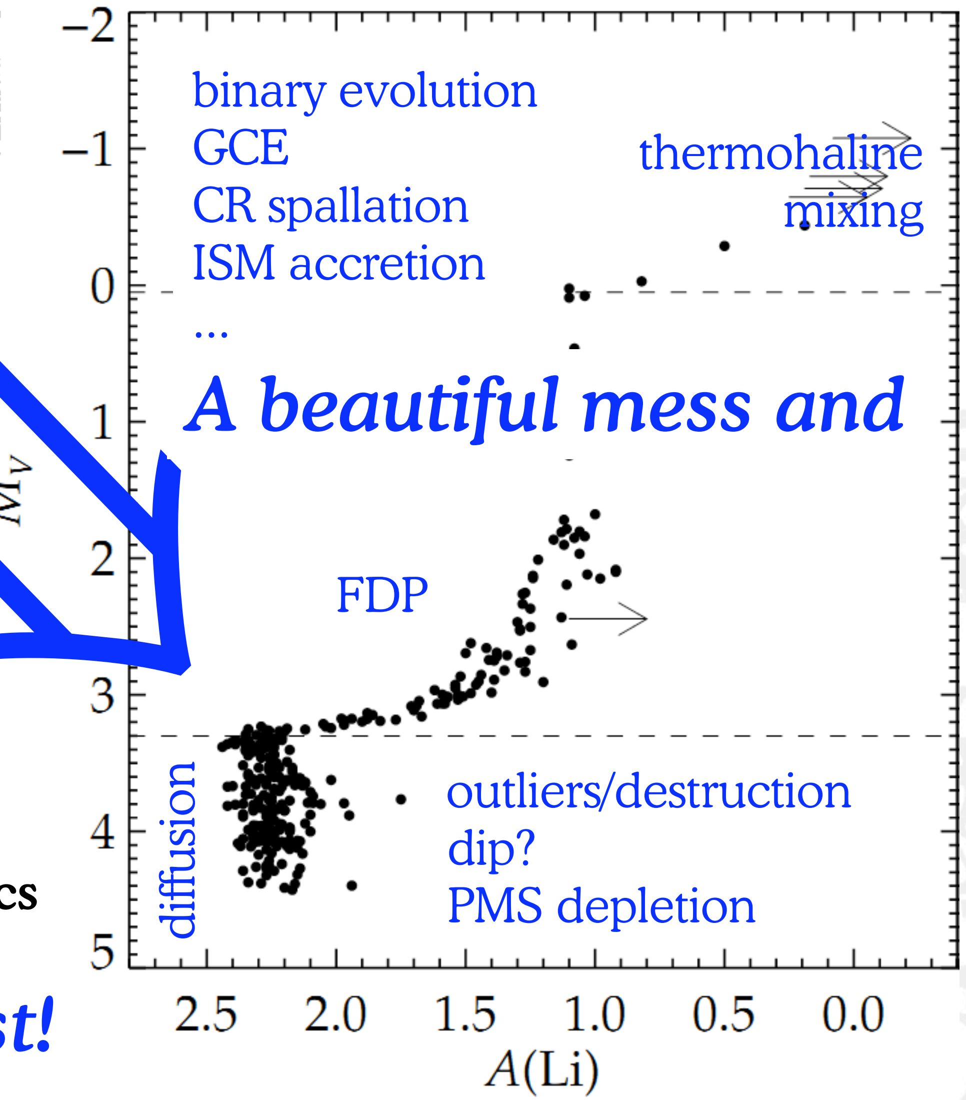
30 years of lithium in halo stars



A discovery by two scientists
$\Rightarrow$ The work of **dozens of scientists**

A 10-star analysis
$\Rightarrow$ Studies with **300+ stars** in *one* GC

Focus on Ω_b $\Rightarrow$ Focus on **stellar physics**



A beautiful mess and

… a rich scientific harvest!