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Lithium in Globular Clusters

Dip, Diffusion and Dredge-up

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Gaia
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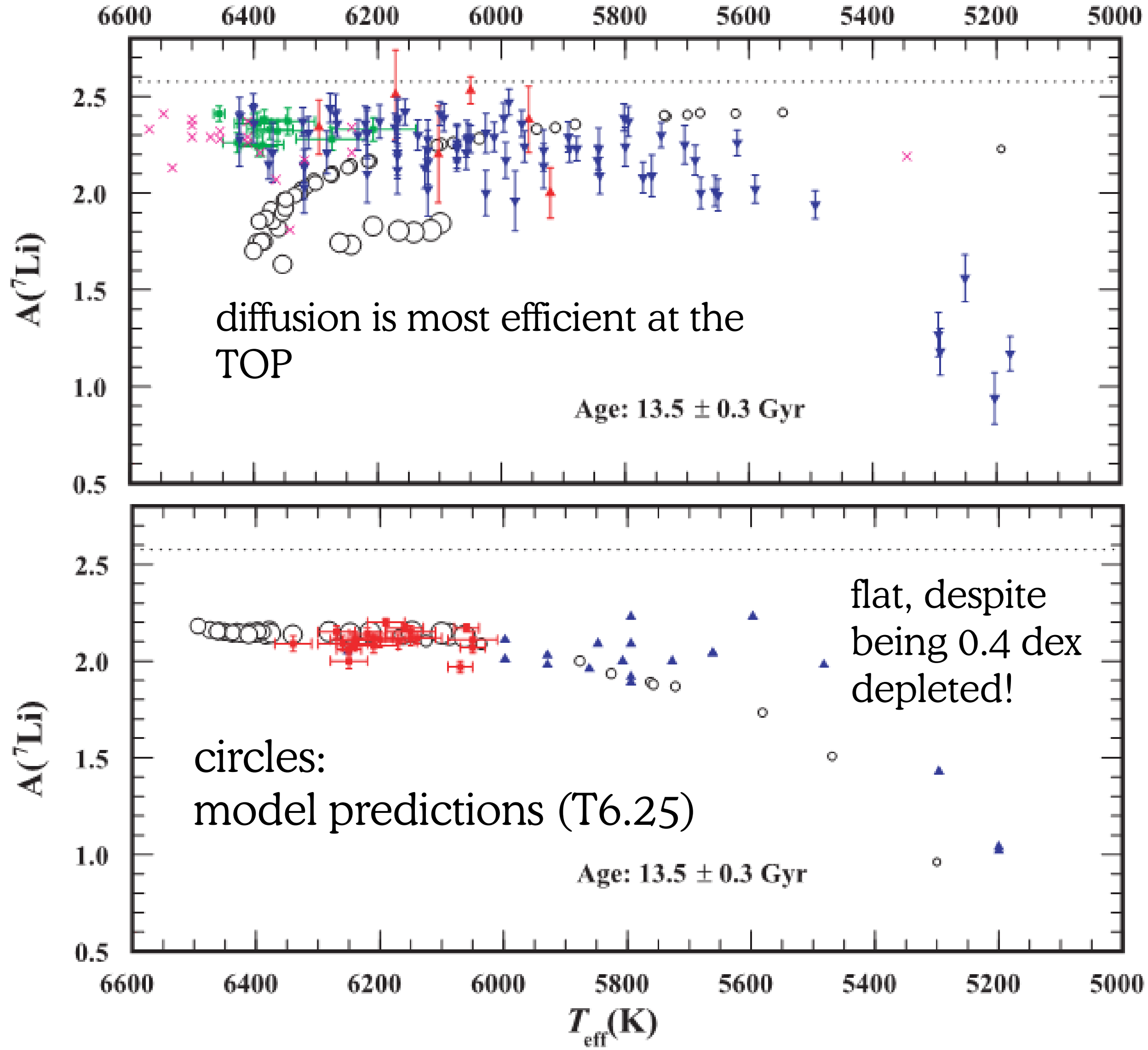
Where we were in 2005



Richard, Michaud & Richer (2005)

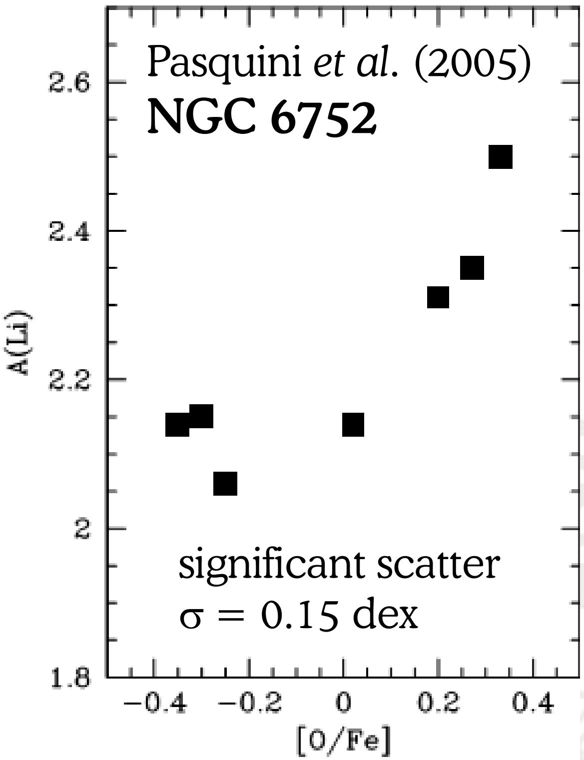
Introductory remarks

GCs are distant objects (2+ kp)

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

⇒ 8-10m telescope science

(Boesgaard *et al.* @ Keck, Gratton *et al.* @ VLT)



Lithium in GCs suffers from pollution

Boesgaard *et al.* (1998) vs. Bonifacio (2002);

⇒ no place to study its evolution?

Most GCs are homogeneous, regarding iron-peak elements.

One can thus use GC stars to study lithium *indirectly*!

The canonical view

Evolution of the surface abundance of lithium for a 0.8 $M_\odot$ non-rotating, non-magnetic model star with [Fe/H] = –2, ML convection and no mass loss:

1.0

RGB bump
no further dilution
expected

SGB
surface dilution
in connection with
the 1st dredge-up

TOP
convective envelope
is at its thinnest

1.0

2.7

base of RGB
surface dilution
completed

2.7
2.7
2.7
2.7
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MS
12 Gyr of hydrostatic
evolution

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2.7 2.7 2.7 2.7 2.7

Luckily, nature is not this boring.

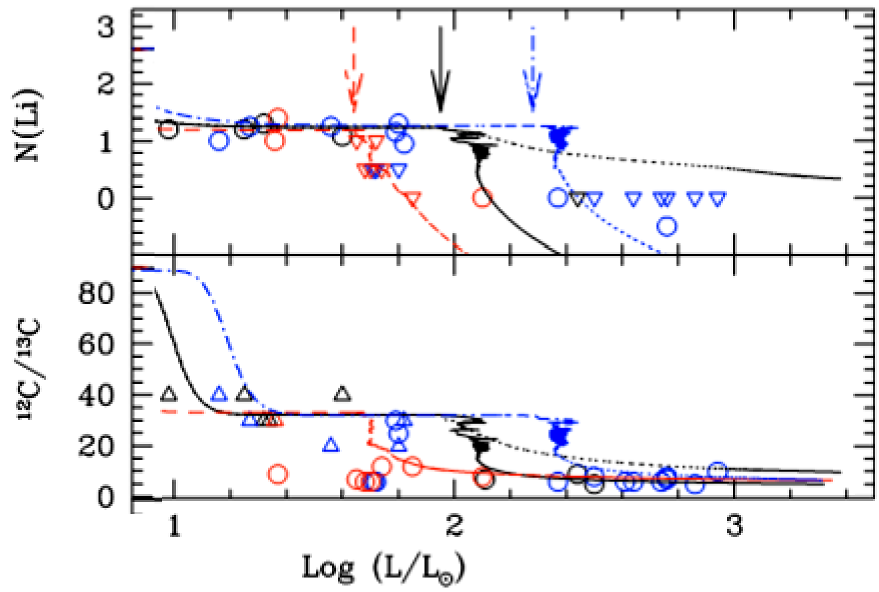
Non-canonical mixing at the bump

Changes in C, N, $^{12}C/^{13}C$ and Li abundances around the RGB bump clearly point towards a non-canonical mixing process (Gratton *et al*. 2000, Recio-Blanco & de Laverny 2007).

Charbonnel (1995) explained these observations using **rotational mixing** (meridional circulation + shear turbulence).
Refined modelling has challenged this view (Palacios *et al*. 2006).

The currently favoured process is **thermohaline mixing** (caused by a μ inversion), see Eggleton *et al*. (2006).

Open issues: **getting the mix** of all processes **right** (without introducing [too many] free parameters)



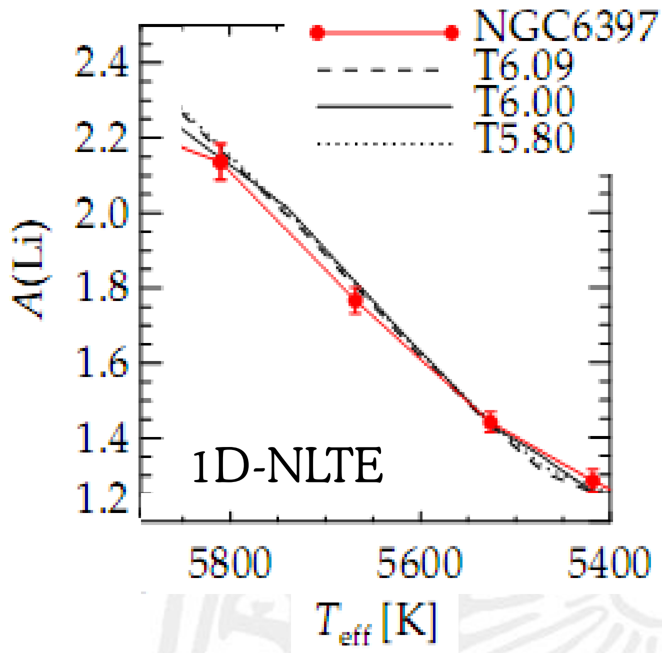
Charbonnel & Zahn (2007)

The 1st dredge-up

Surface dilution by a factor > 20, as the convective envelope progressively eats itself into lithium-free layers.

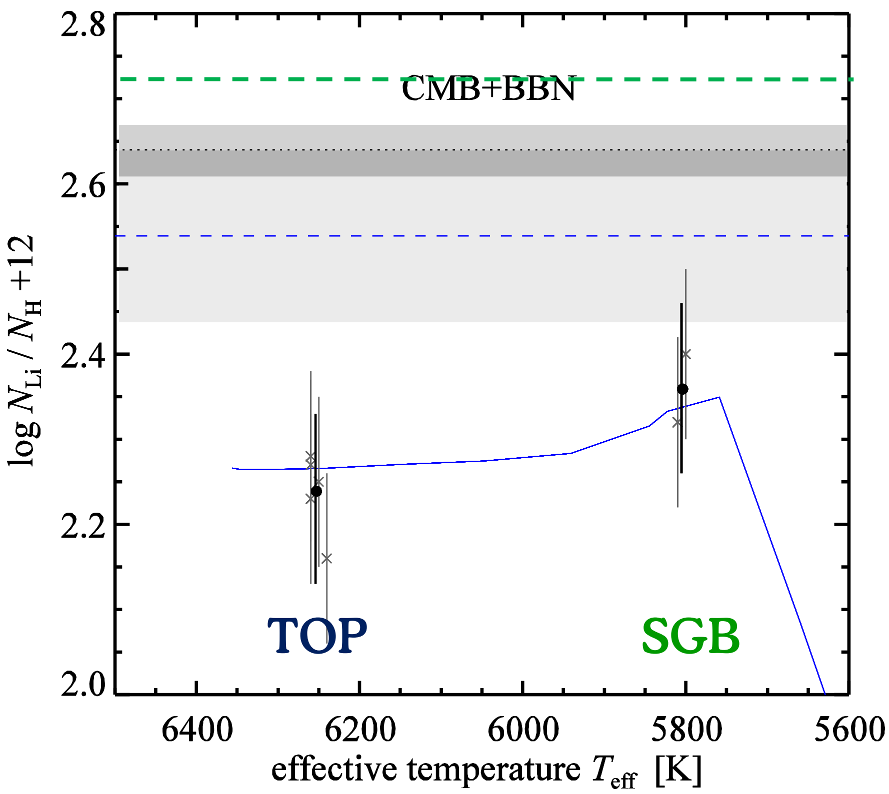
Open issues:

No rigorous comparison between hydrodynamic stellar-structure model predictions and observed abundances based on hydrodynamic model atmospheres with NLTE. (3D-NLTE studies of lithium have been done for Spite plateau stars.)



Lind *et al.* (2009)

Constraining lithium diffusion I



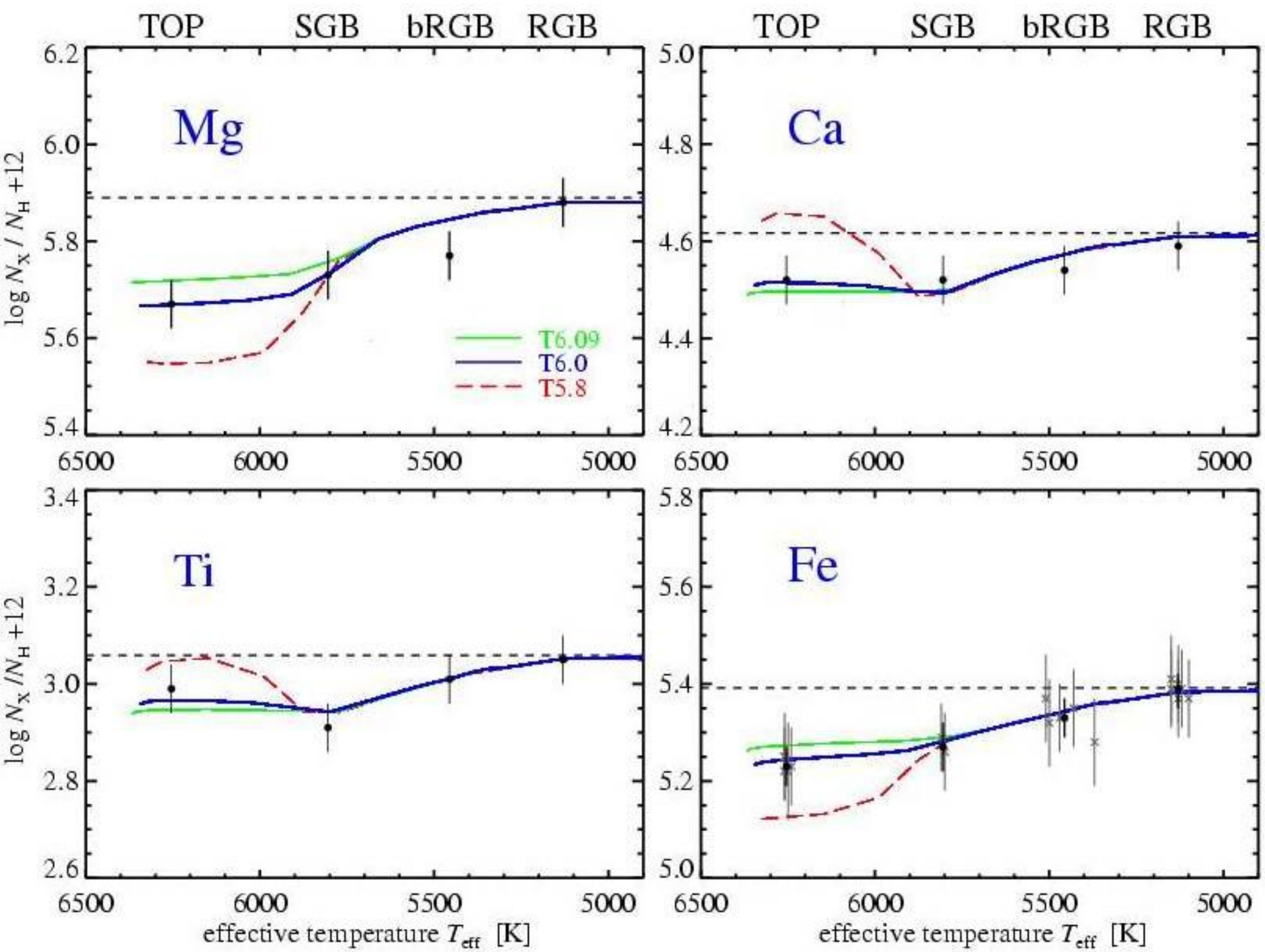
Korn *et al.* (2006)

Diffusion signature in lithium in models with turbulent mixing

Lithium settles out of the convective envelope during the MS phase. When the star evolves along the SGB, the convective envelope expands inward and encounters Li-rich layers. This lithium can is thus brought to the surface (Li ⬀). Subsequently, surface dilution of lithium sets in, as the convective envelope encompasses lithium-free layers.

cf. Zahn 2005, IAU 228

Constraining lithium diffusion II



Korn *et al.* (2007)

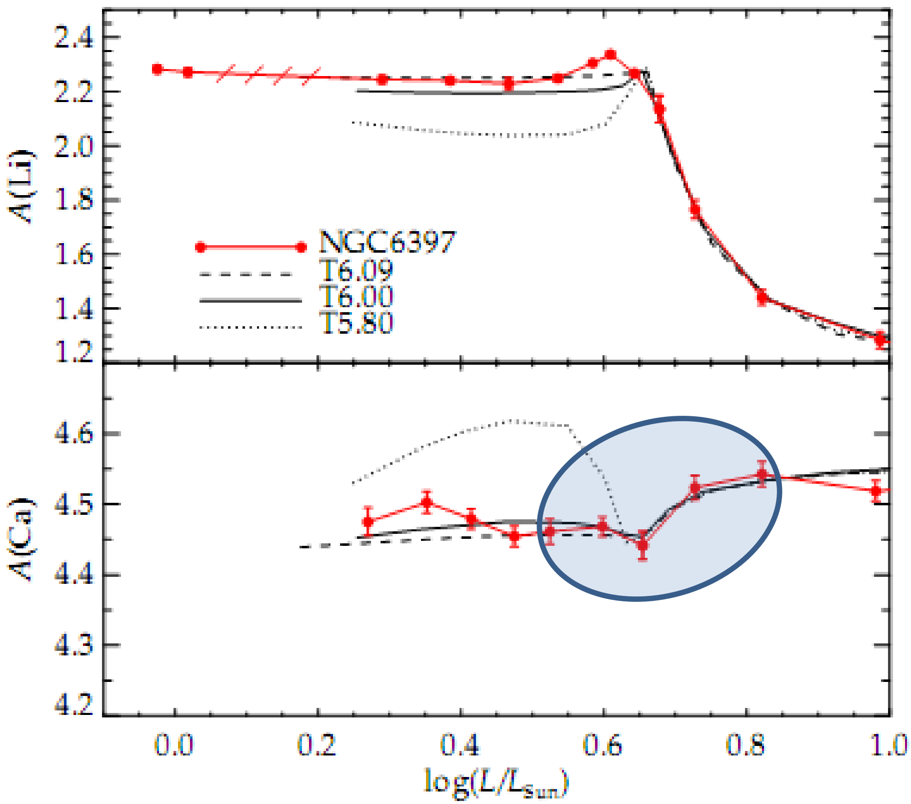
Noteworthy:
Balmer-line T_{eff} scale, confirmed by IRFM and synthetic photometry.

Mg I, Ca I and Fe I lines are T_{eff}-sensitive; Ti II and Fe II lines are log *g*-sensitive.

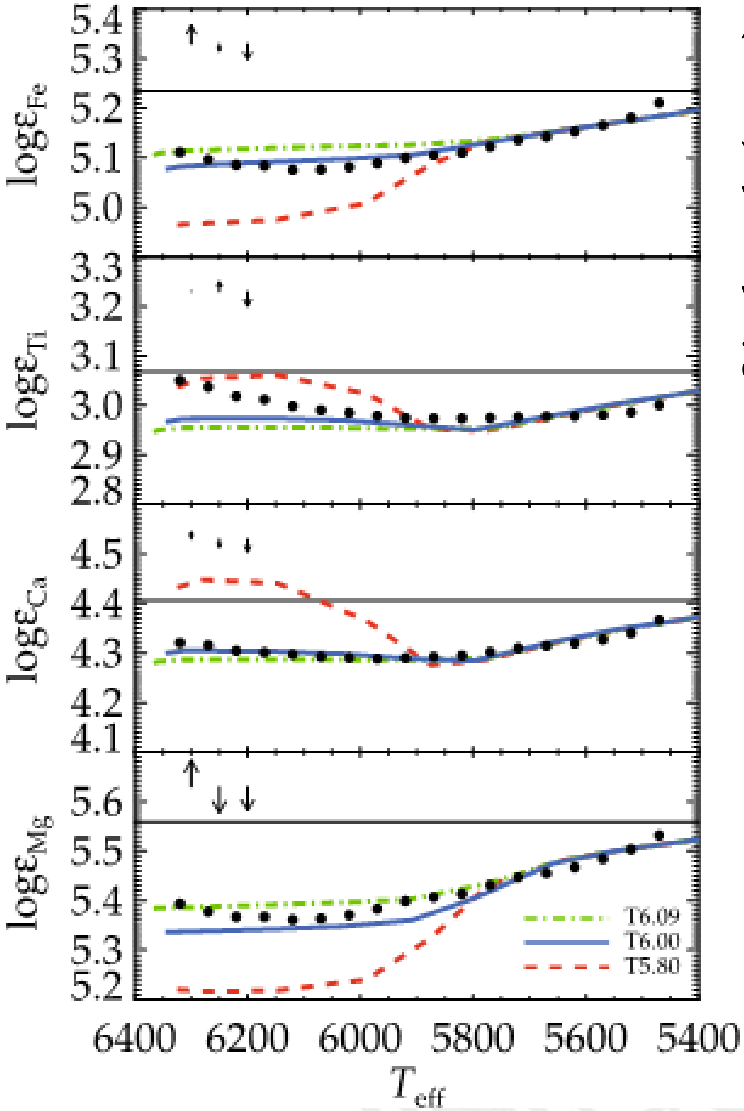
Mg, Ca and Fe lines are modelled in NLTE.

Note the behaviour of the red T5.8 model: it is above the observations in two cases, below in the two others (interplay between sedimentation, levitation and mixing).

Constraining lithium diffusion III



Lind *et al.* (2009)



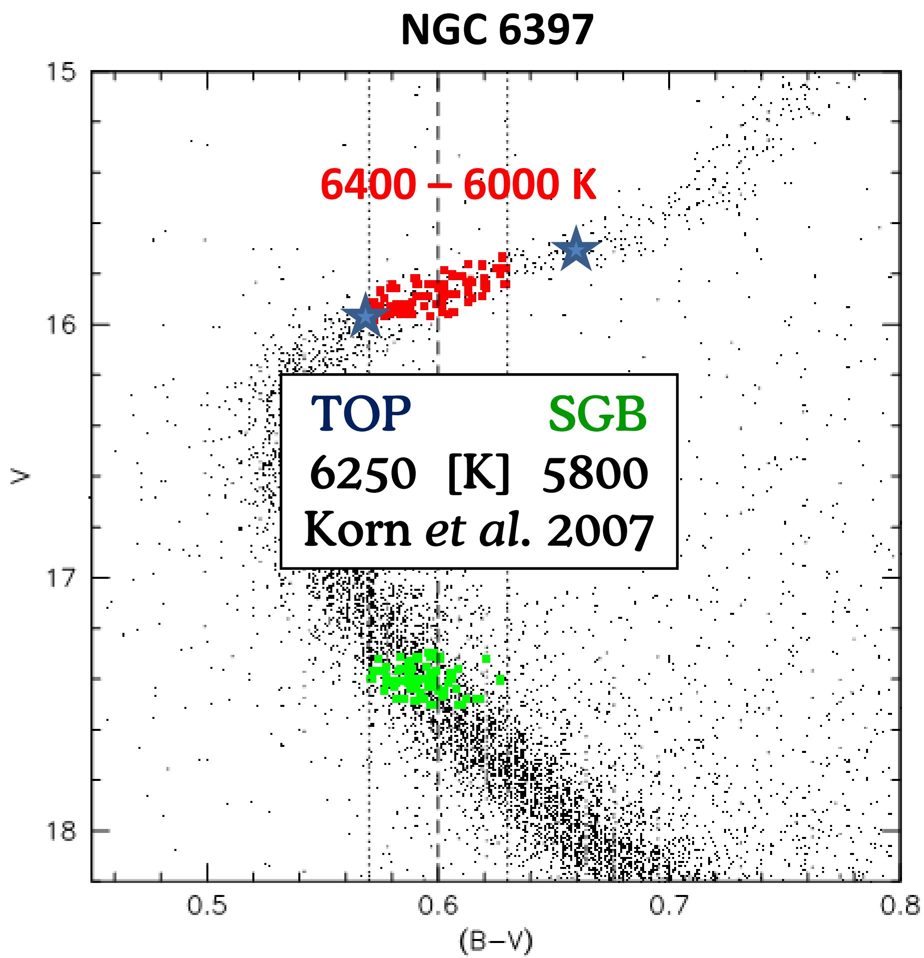
Lind *et al.* (2008)

More diffusion constraints

González Hernández *et al.* (2009): "vertical" diffusion study (Li only) using a significantly different (hotter and expanded) T_{eff} scale based on 3D-LTE Hα line wings.

Two results:

- A(Li, SGB) = A(Li, MS) + 0.07 (even larger difference in 1D)
- A(Li) increases with T_{eff} for both groups in rough agreement with a **T6.25 diffusion model** (as seen by Lind *et al.* 2009 for the SGB stars)



New constraints for models: **yes!**
Principle problem for diffusion: **no!**
Awaiting reanalysis of the Lind *et al.* (2008/09) data for Li, Ca, Fe, … on this new T_{eff} scale.

NGC 6752 @ [Fe/H] = –1.6

Gratton *et al.* (2001):

Δ [Fe/H] (TOP – bRGB) = 0.00 ± 0.03

We find small by rather systematic abundance trends between groups of stars along the evolutionary sequence of NGC 6752.

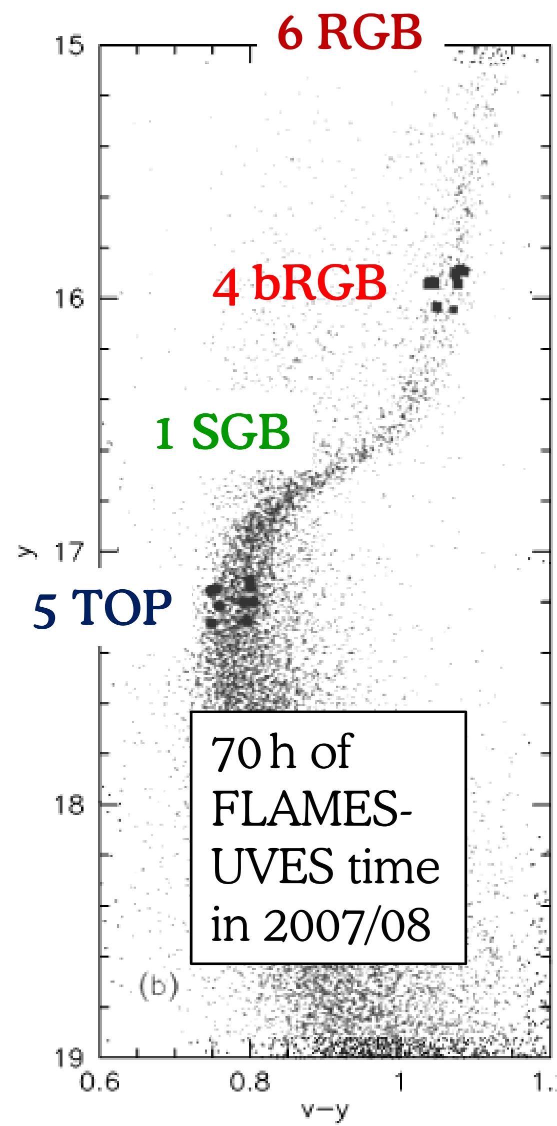
Δ [Fe/H] (TOP – bRGB) = –0.08 ± 0.02

and

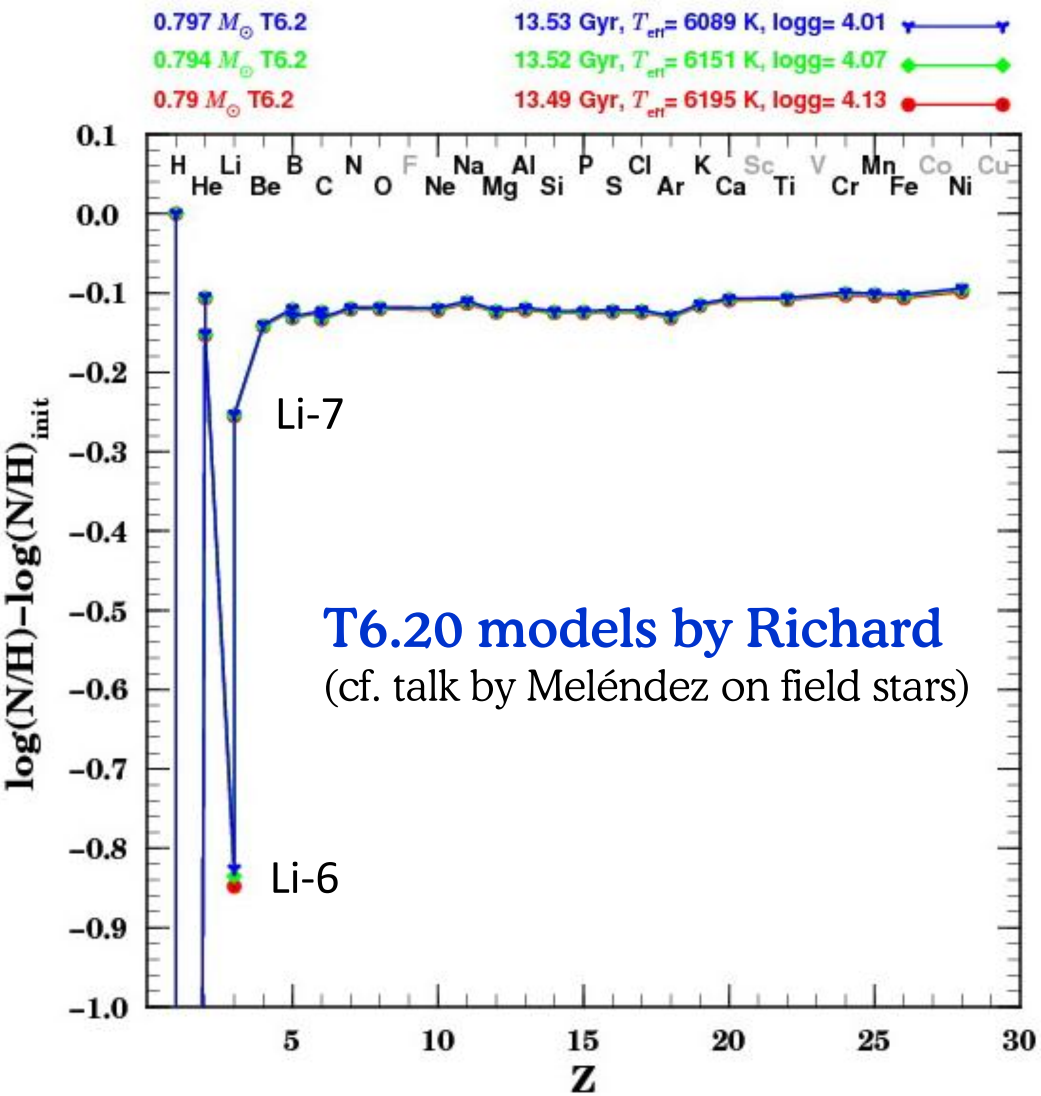
Δ [Fe/H] (TOP – RGB) = –0.10 ± 0.03

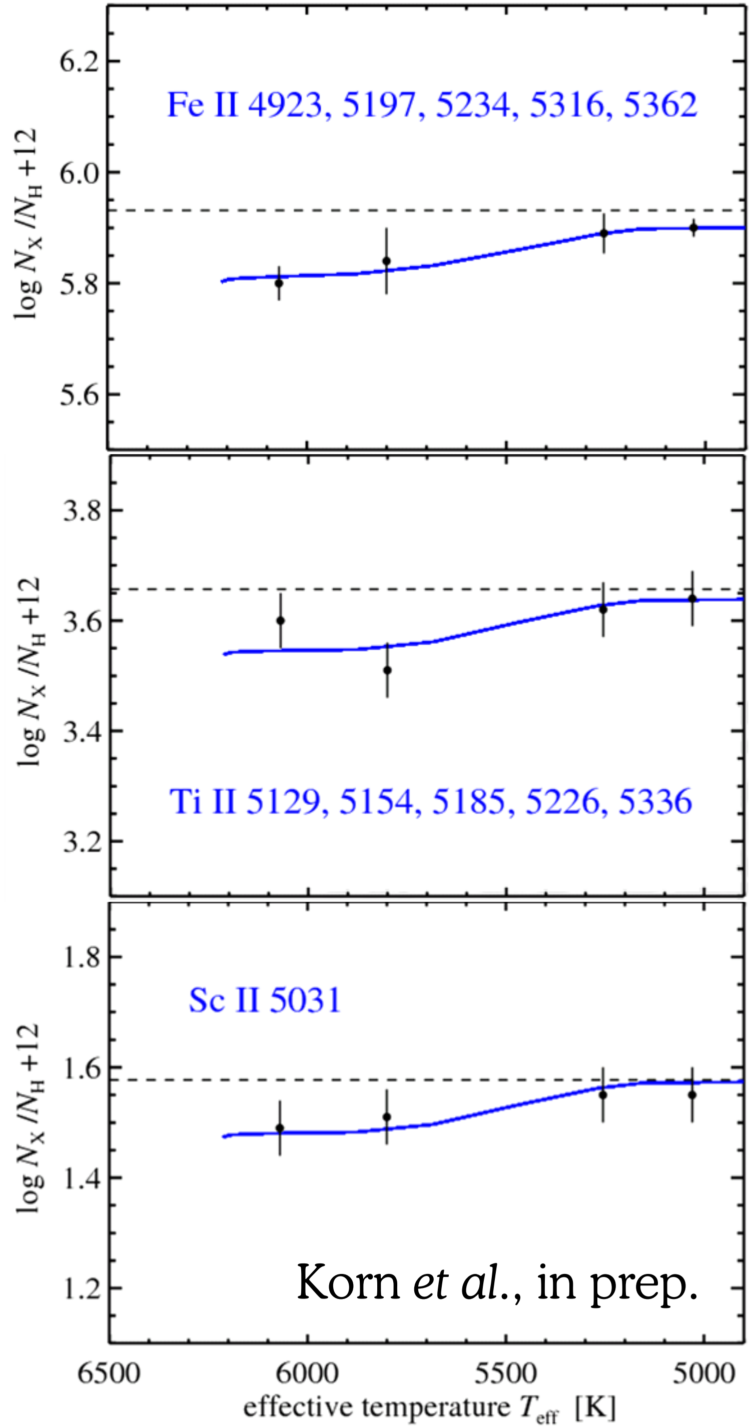
Both 3D and NLTE effects are expected to be small for lines of Fe II (Ti II, Sc II).

Korn *et al.*, in prep.



NGC 6752 @ –1.6


0.797 M☉ T6.2
0.794 M☉ T6.2
0.79 M☉ T6.2
13.53 Gyr, Teff= 6089 K, logg= 4.01
13.52 Gyr, Teff= 6151 K, logg= 4.07
13.49 Gyr, Teff= 6195 K, logg= 4.13
H He Li Be B C N O F Ne Na Mg Al Si P S Cl Ar K Ca Sc Ti V Cr Mn Fe Co Ni Cu
Li-7
Li-6
log(N/H)–log(N/H)init
Z
T6.20 models by Richard
(cf. talk by Meléndez on field stars)


Fe II 4923, 5197, 5234, 5316, 5362
Ti II 5129, 5154, 5185, 5226, 5336
Sc II 5031
log NX /NH +12
effective temperature Teff [K]
Korn et al., in prep.

A stellar solution…

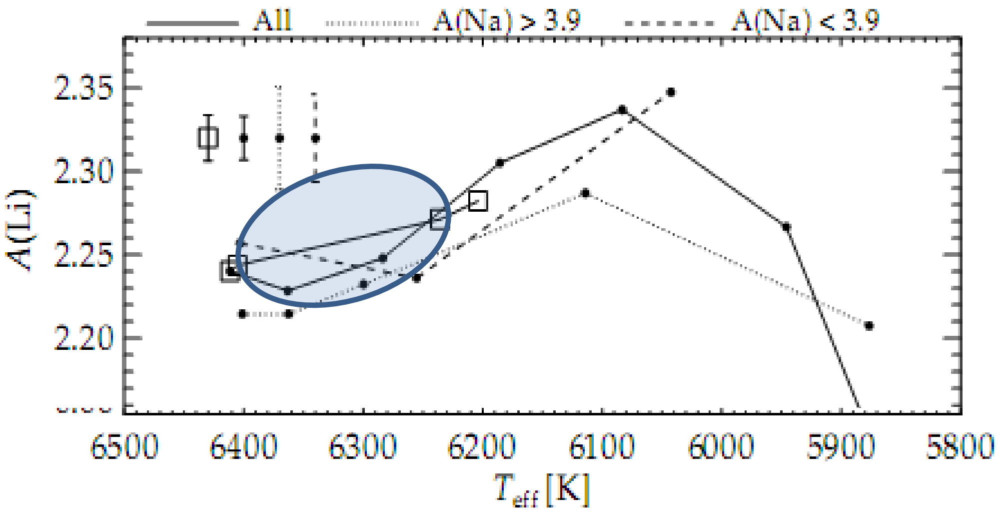
- **effective temperatures T_{eff}** ⇗
  (Lind *et al*. 2009, González Hernández *et al*. 2009)
- **surface temperatures of 2nd generation 3D hydro models** ⇗
- **mixing efficiency T.6.x** ⇗
  (González Hernández *et al*. 2009, Korn *et al*., in prep.)

… to the cosmological lithium-7 problem is (still) likely.

(cf. talk by Meléndez, but also by Jedamzik, Spite, González Hernández, Lind and arXiv:0911.0960)

Necessary consequence: The lithium-6 detections are not real.

The final D: dip



Lind *et al.* (2009)

For details on the Pop I dip, see talk by Randich.

In NGC 6397: highly speculative at present, but dip signatures should be more likely to trace, if a hotter T_{eff} scale turns out to be correct.

Conclusions

GCs can add to our understanding of the ***mixed evolution*** of stellar lithium in several ways

- 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 $T_{\rm eff}$ scale can be obtained
- The common distance means that surface-gravity differences and gravity-sensitive abundance differences can be determined very precisely
- The diffusion signature for lithium (or its absence) can be connected to other elements
  caution: the abundance trend of Li, and several other elements, is often affected by intra-cluster pollution
- Surface lithium of Spite-plateau stars is lowered by ≥ 0.25 dex
- The role and properties of outliers can be quantified

Stellar mixing processes are...

... a Fountain of Youth.

Not only in Geneva.