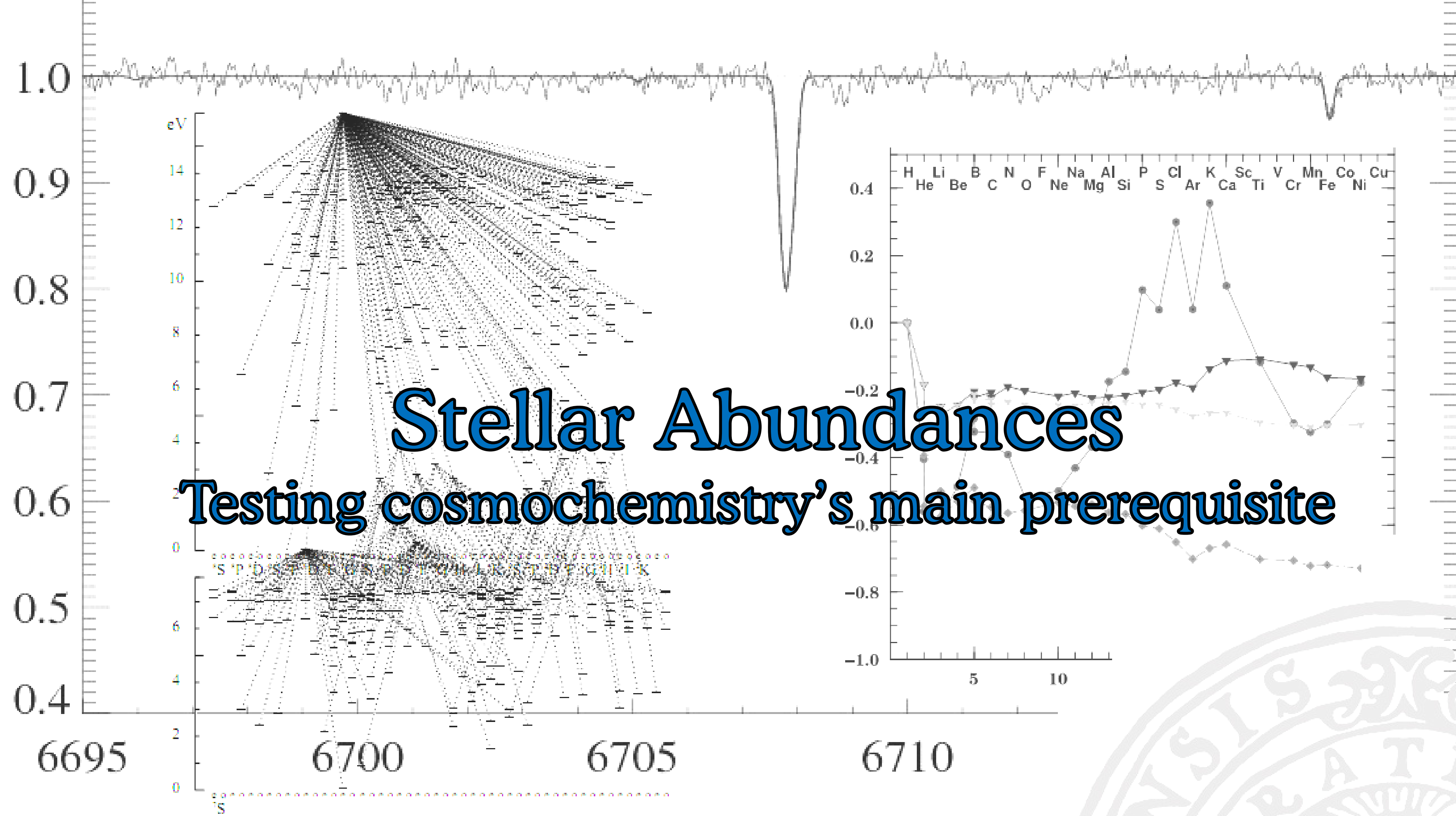

Stellar Abundances

Testing cosmochemistry’s main prerequisite

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Observational Stellar Astrophysics

Moletai, 2008-08-15

What will be covered

I. Some results of population studies

the local volume

the *eternal* assumption in cosmochemistry

testing the *eternal* assumption

II. A fresh look at *eternity*

a reanalysis

an application and a reapplication

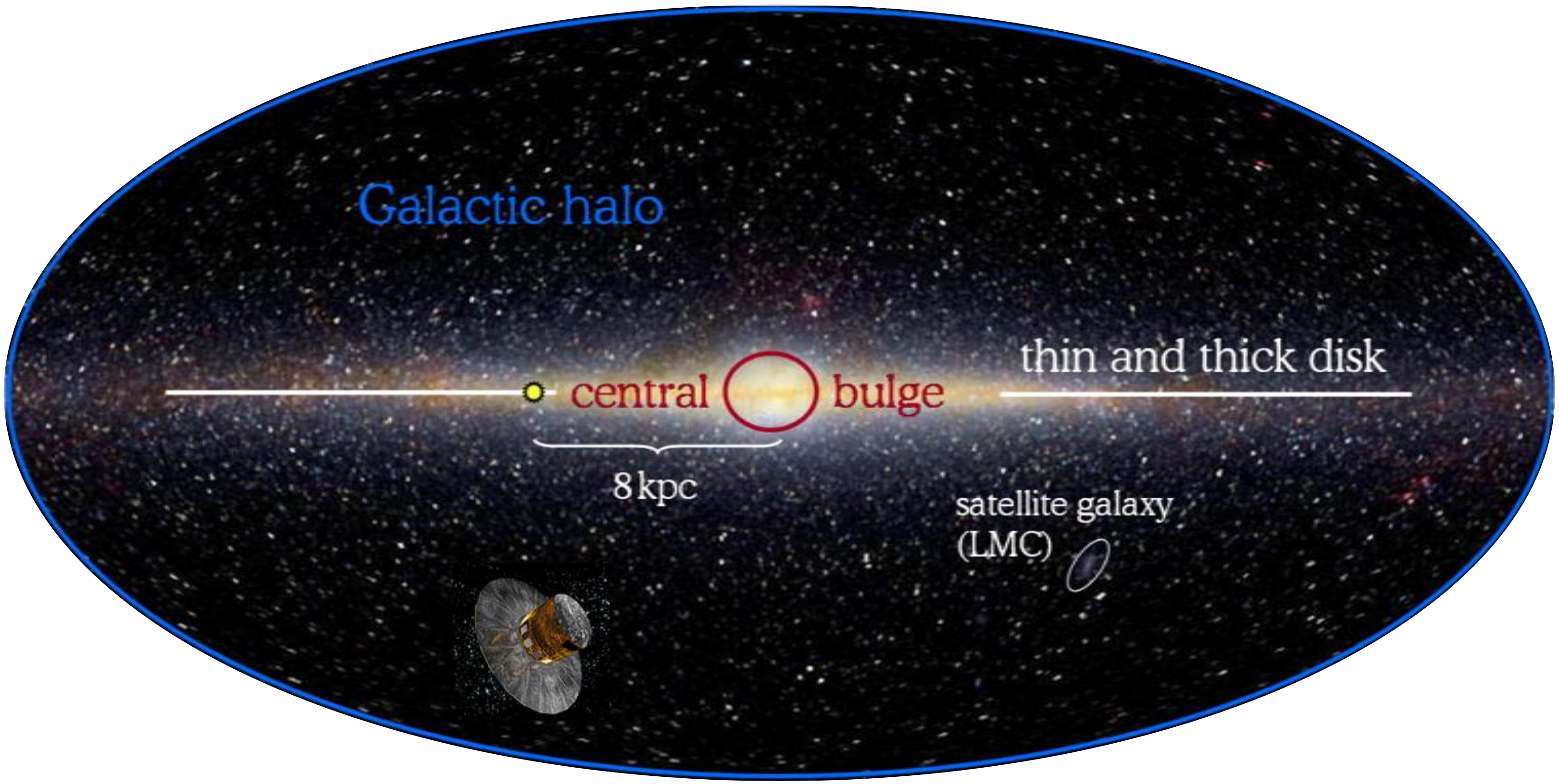
a discovery

III. Implications

Galactic demography

Halo: old, metal-poor, α-rich

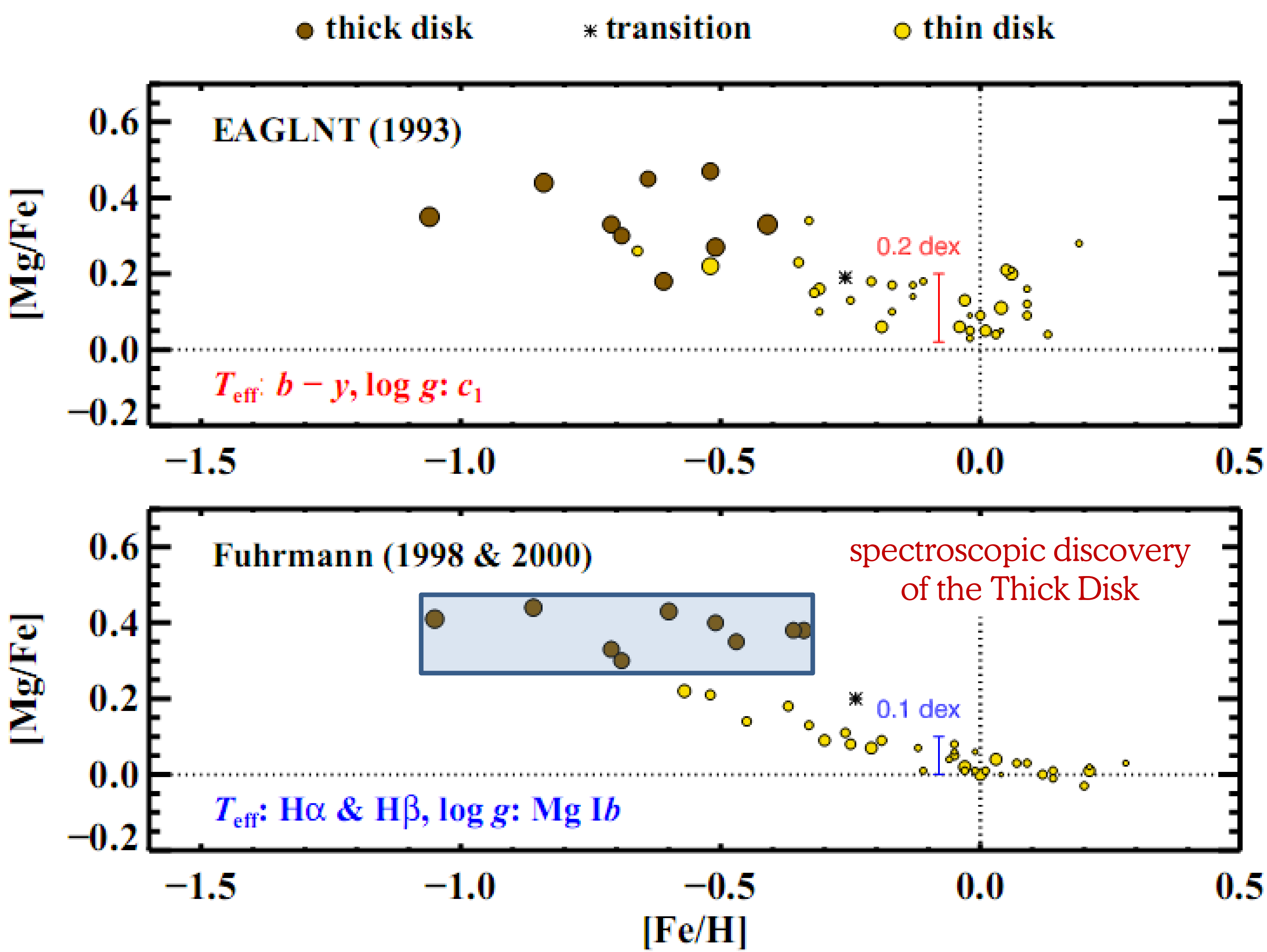
Thin Disk: young, metal-rich, α-poor



Bulge: old, metal-rich, α-rich

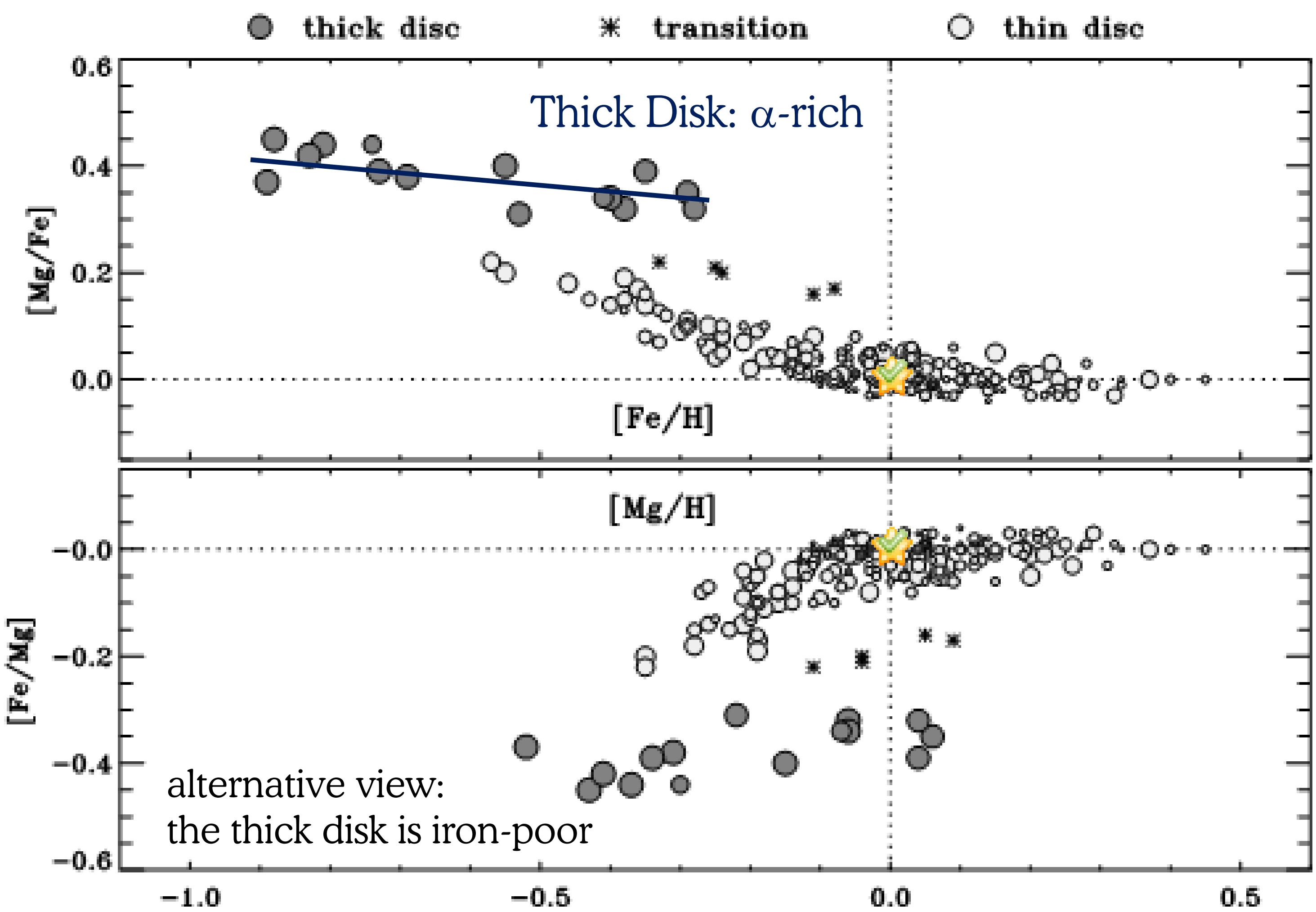
Thick Disk: old, slightly metal-poor, α-rich

EAGLNT 1993 vs. Fuhrmann 1998/2000



the same 44 stars!

The complete picture



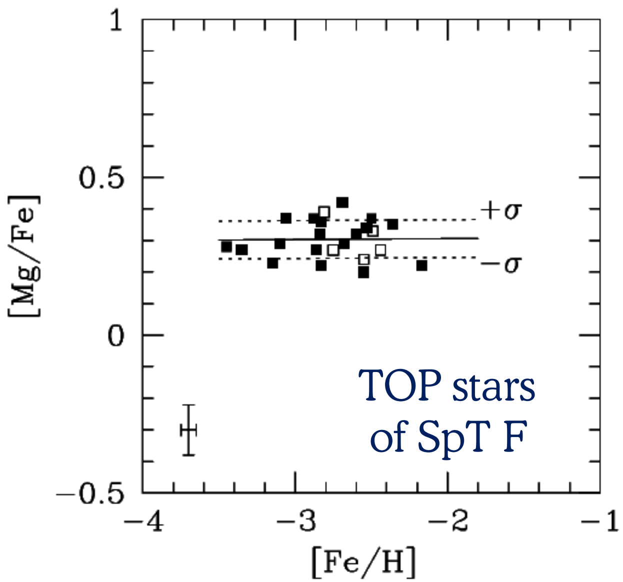
volumne-limited sample of F/G/K stars
within 25 pc
Fuhrmann (2008)

What about the halo?

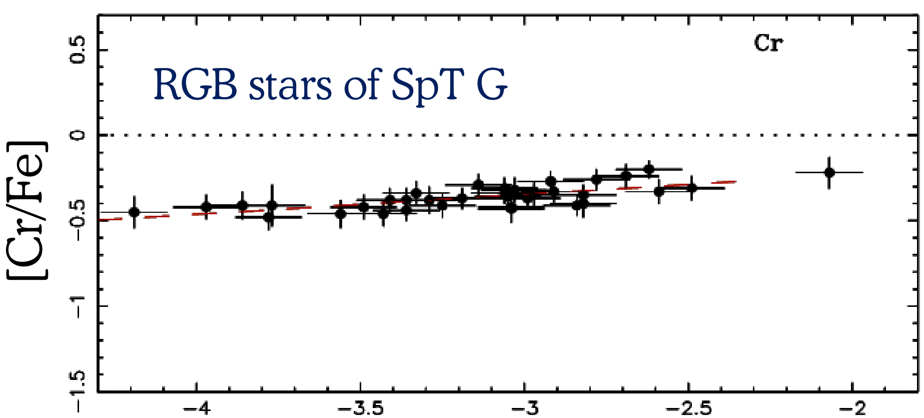
Recent studies of halo stars in the range –4.5 < [Fe/H] < –2.0 reveal a surprising absence of cosmic scatter.

Stellar-parameter **challenge**:
as metallicity decreases, fewer and **fewer spectral features** are available, also for deriving abundances. One needs to understand the line formation of these features well to draw valid conclusions.

Example: Ca I/II imbalance in extremely metal-poor stars can be understood in terms of NLTE (Mashonkina *et al.* 2007)



Arnone *et al.* (2005)

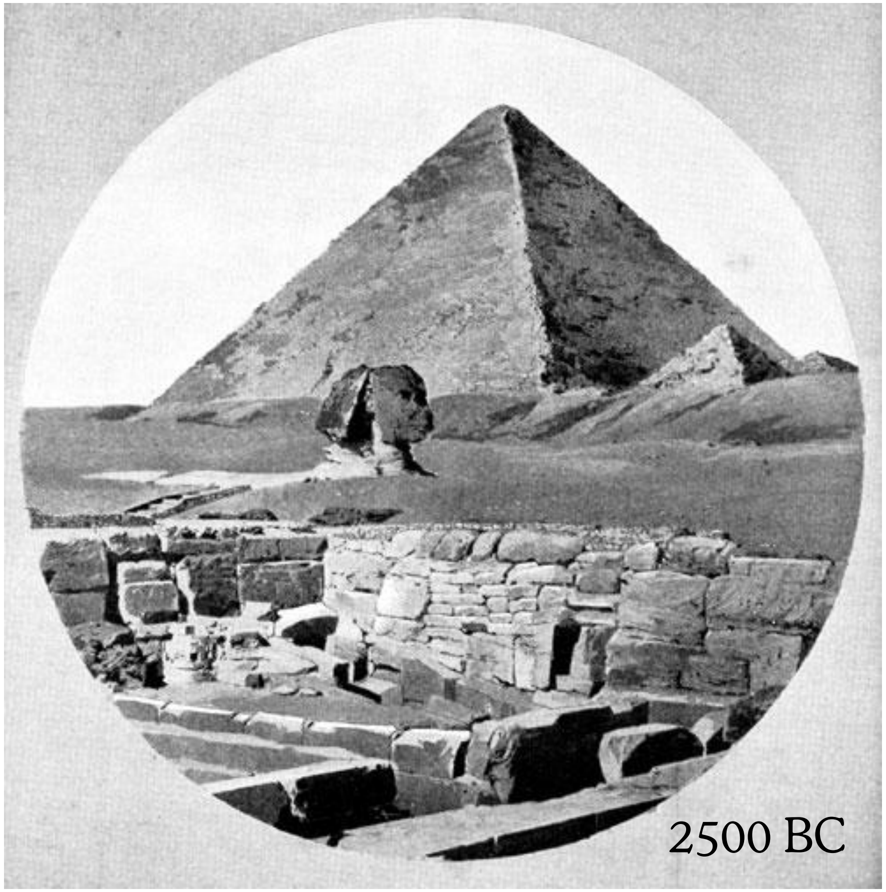


Cayrel *et al.* (2004)

The *eternal* assumption

When we study the Galactic inventory of long-lived F/G/K stars, we assume that these **stars retain** in their atmospheres the **composition of the gas they once formed** from, be it 1 Gyr or 13 Gyr ago.

This implies that we assume the **atmosphere** to be **eternally unchangeable**, i.e., there are no internal or external effects that alter the atmospheric chemical abundances.

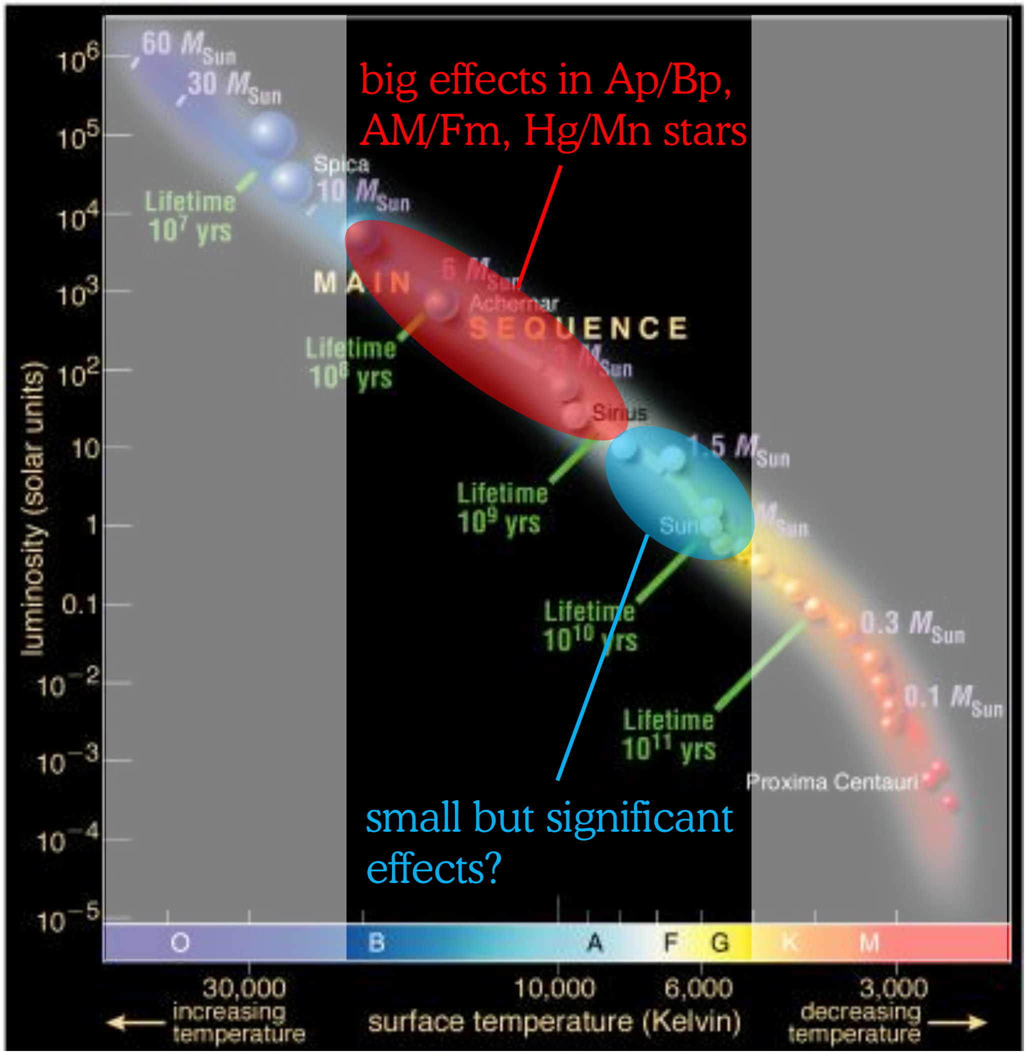


Atomic diffusion throughout the HRD

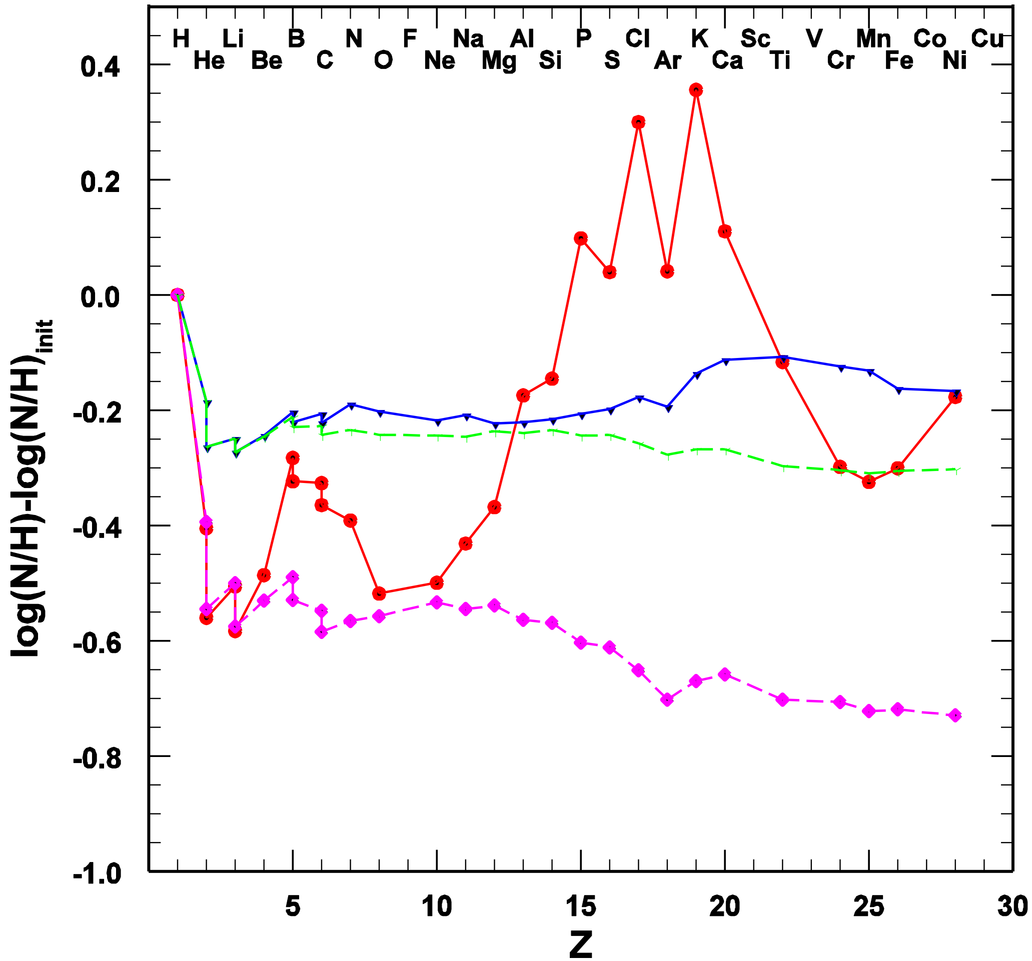
Atomic diffusion is a **slow** process which is efficiently **counteracted by** macroscopic mass flows, e.g. **convection**.

On the hot side of the HRD, time scales are generally short and other effects dominate, e.g. rotation.

On the cool side of the HRD, the convective envelopes are deep inhibiting diffusion.



How to test theoretical AD predictions



abundance variations for a TOP star ([Fe/H] = −2) after 13.5 Gyr **with respect to the original abundances**

from Korn *et al*. (2006), The Messenger 125 (astro-ph/0610077)

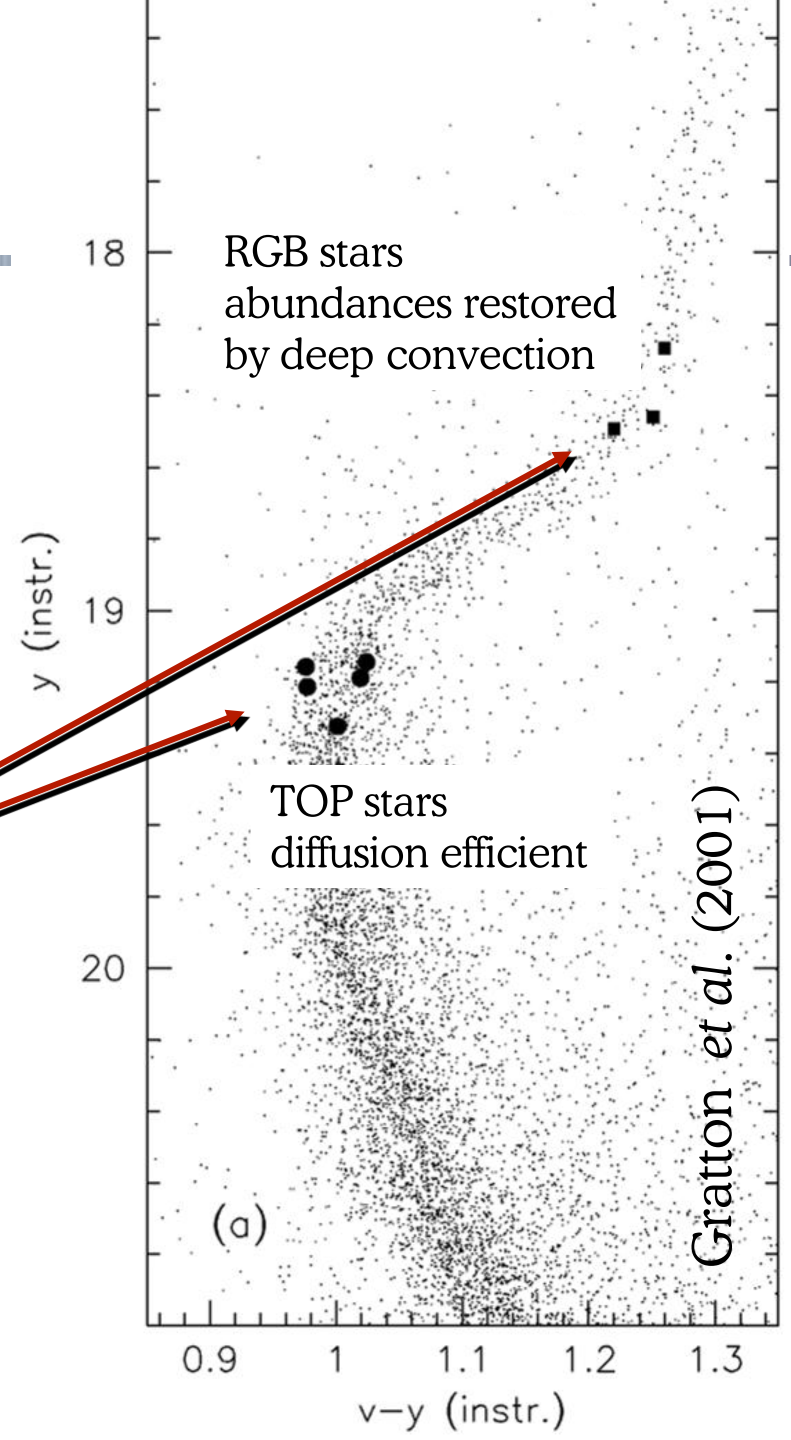
- – – grav. settl. only
- – – grav. settl. + turb. mix.
- —— grav. settl. + rad. lev.
- —— grav. settl. + rad. lev. + turb. mix.

Observing AD

compare abundances in TOP stars
to those in stars at the base of the RGB,
all drawn from a single population
⇨ GCs are ideal objects for this purpose

$$\Delta\, T_{\rm eff} \simeq 1000 \text{ K}$$
$$\Delta \log g \simeq 0.7 \text{ dex}$$

How can one distinguish between
atomic diffusion and
modelling deficits?



AD not operational!

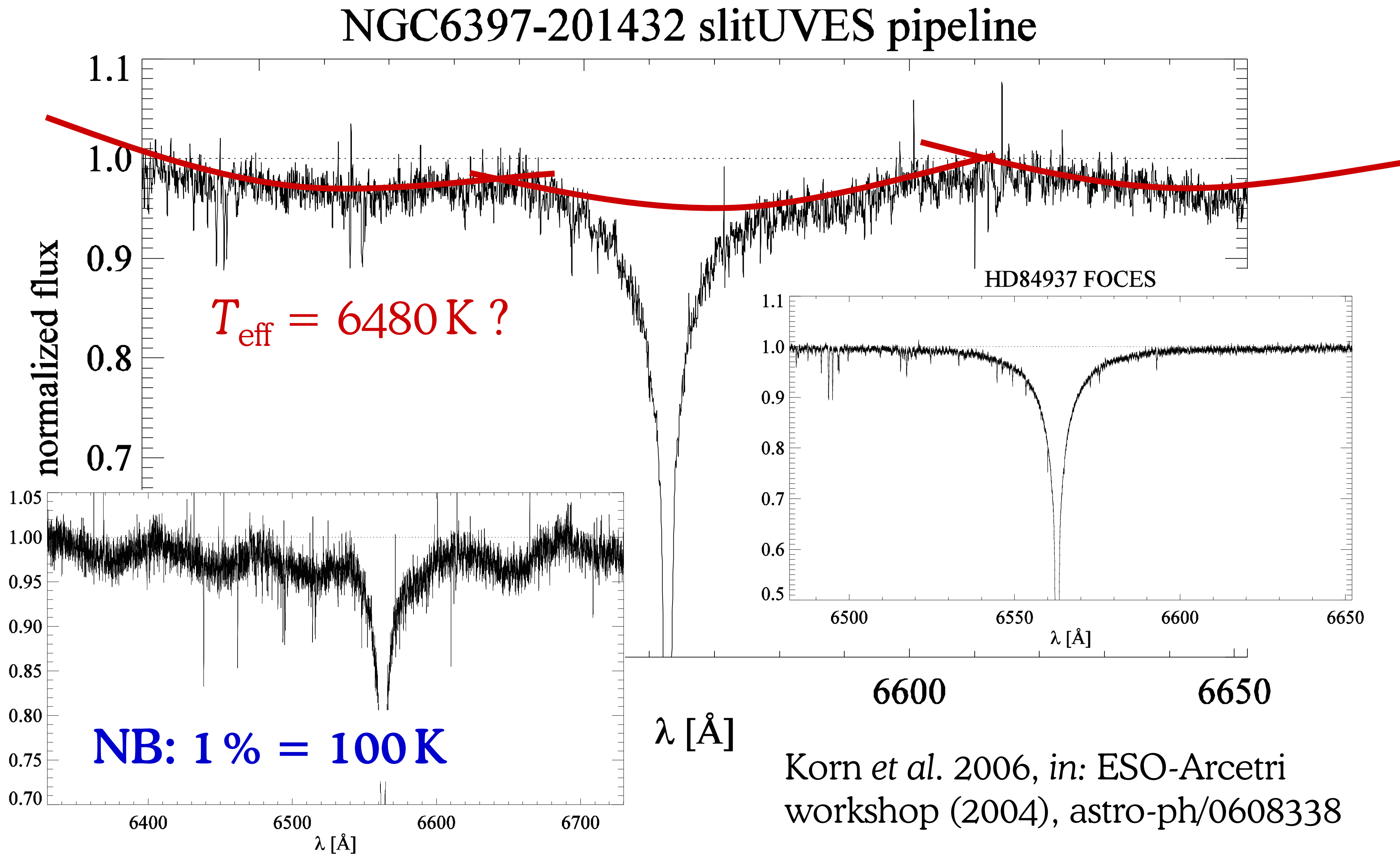
"In both clusters the [Fe/H]'s obtained for TO-stars agree perfectly (within a few percent) with that obtained for stars at the base of the RGB."

The O-Na and Mg-Al anticorrelations in turn-off and early subgiants in globular clusters*

R. G. Gratton[1], P. Bonifacio[2], A. Bragaglia[3], E. Carretta[1], V. Castellani[4], M. Centurion[2], A. Chieffi[5], R. Claudi[1], G. Clementini[3], F. D'Antona[6], S. Desidera[1,7], P. François[8], F. Grundahl[9], S. Lucatello[1,7], P. Molaro[2], L. Pasquini[8], C. Sneden[10], F. Spite[11], and O. Straniero[12]

Abstract. High dispersion spectra ($R \gtrsim 40\,000$) for a quite large number of stars at the main sequence turn-off and at the base of the giant branch in NGC 6397 and NGC 6752 were obtained with the UVES on Kueyen (VLT UT2). The [Fe/H] values we found are $-2.03 \pm 0.02 \pm 0.04$ and $-1.42 \pm 0.02 \pm 0.04$ for NGC 6397 and NGC 6752 respectively, where the first error bars refer to internal and the second ones to systematic errors (within the abundance scale defined by our analysis of 25 subdwarfs with good Hipparcos parallaxes). In both clusters the [Fe/H]'s obtained for TO-stars agree perfectly (within a few percent) with that obtained for stars at the base of the RGB. The $[O/Fe] = 0.21 \pm 0.05$ value we obtain for NGC 6397 is quite low, but it agrees with previous results obtained for giants in this cluster. Moreover, the star-to-star scatter in both O and Fe is very small, indicating that this small mass cluster is chemically very homogenous. On the other hand, our results show clearly and for the first time that the O-Na anticorrelation (up to now seen only for stars on the red giant branches of globular clusters) is present among unevolved stars in the globular cluster NGC 6752, a more massive cluster than NGC 6397. A similar anticorrelation is present also for Mg and Al, and C and N. It is very difficult to explain the observed Na-O, and Mg-Al anticorrelation in NGC 6752 stars by a deep mixing scenario; we think it requires some non internal mechanism.

Problems in the Gratton *et al.* analysis

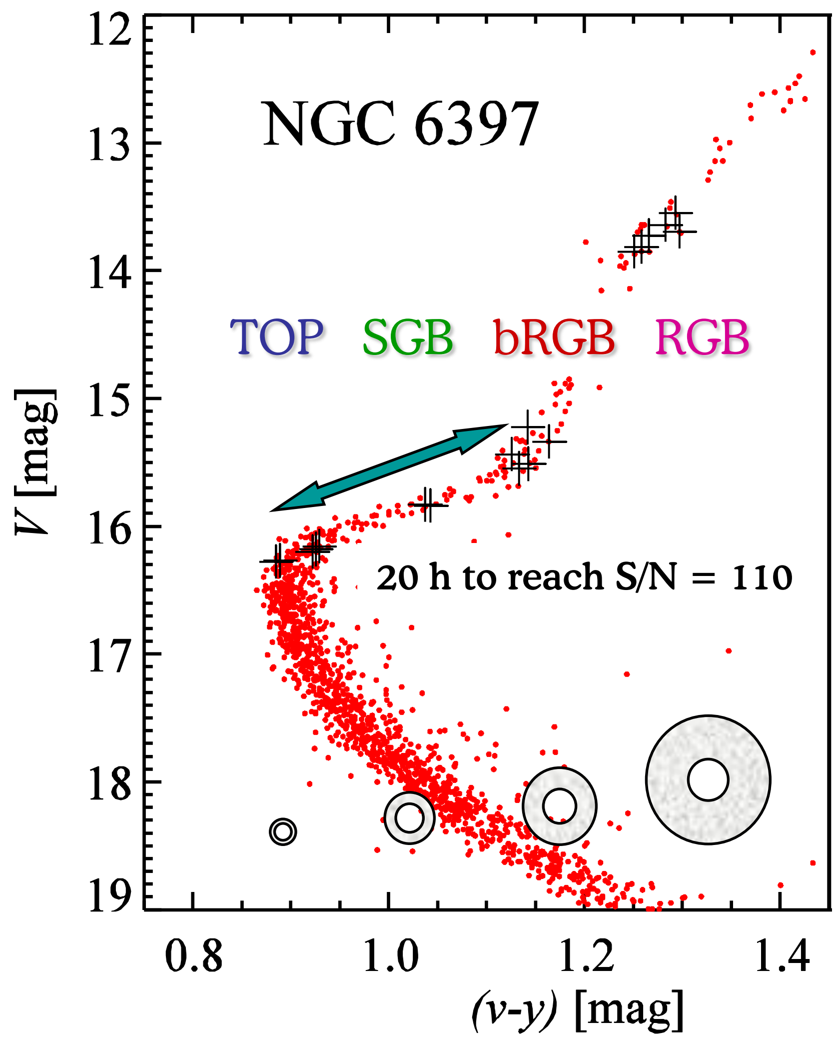


Korn *et al.* 2006, *in:* ESO-Arcetri workshop (2004), astro-ph/0608338

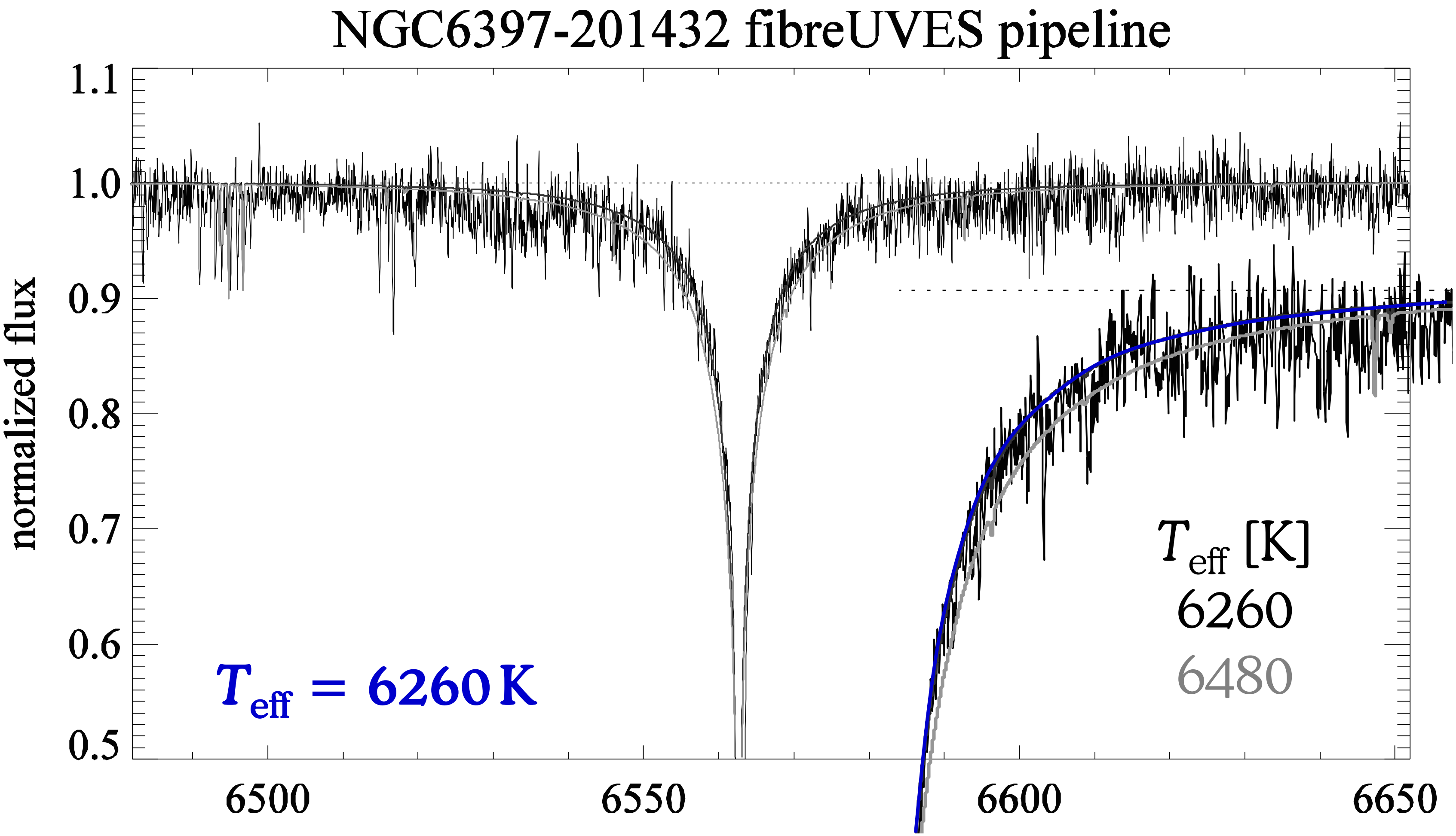
Re-Reapplying for a reanalysis of AD

observations with VLT UT2 and FLAMES+UVES
~~(6/2004 (VM)~~ & 4/2005 (SM); Korn, Gustafsson, Piskunov, Barklem & Grundahl):

- re-observe some of Gratton's targets with FLAMES+UVES: 5 bRGB and 5 TOP stars;
- additionally, observe 2 SGB and 6 RGB stars;
- fill the 130 MEDUSA fibres with targets along the SGB to look for abundance trends at somewhat lower resolution

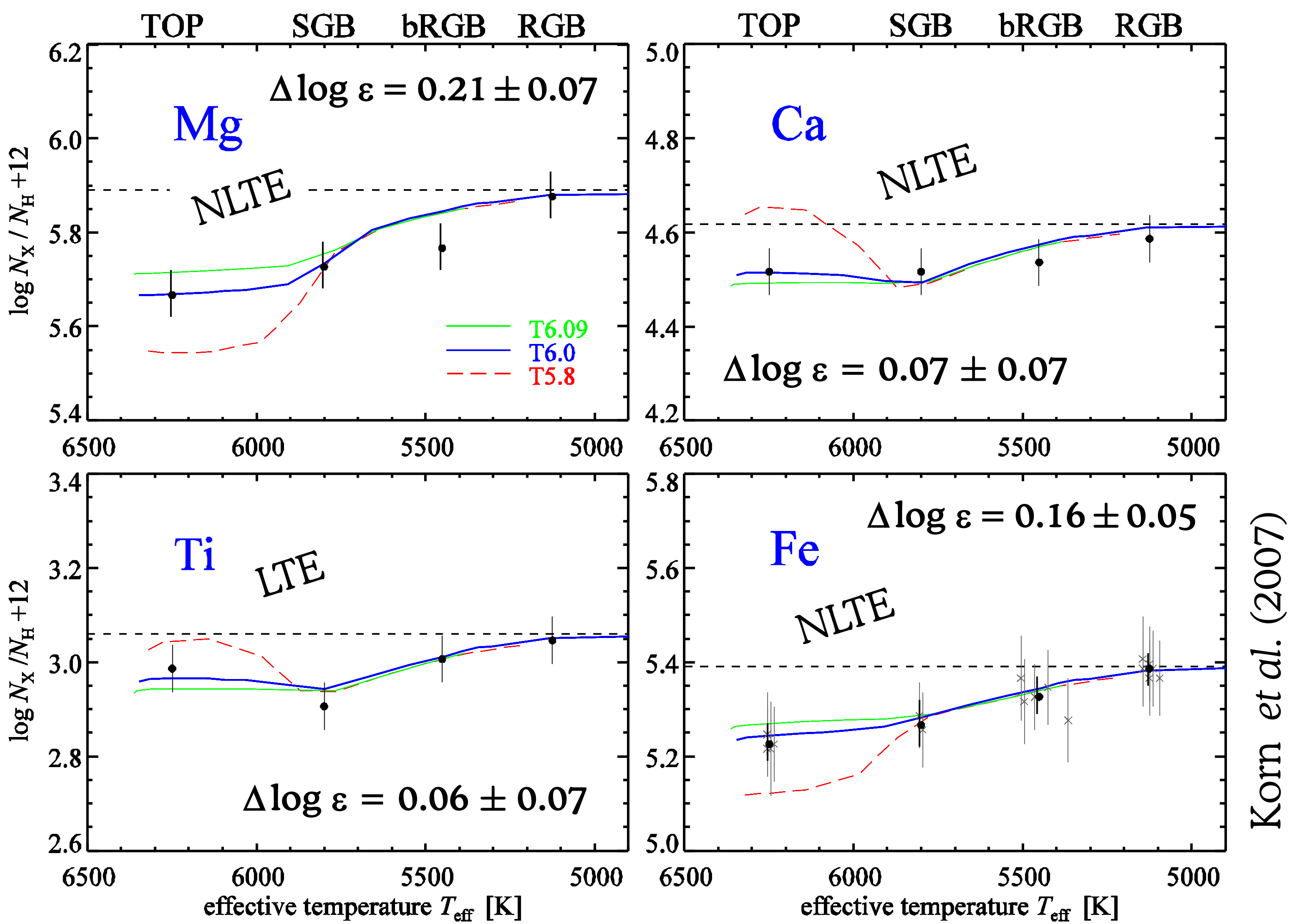


FLAMES+UVES: UVES goes fibres



fibres (FLAMES+UVES) ⇒ more reliable blaze
⇒ more reliable order merging ⇒ more reliable T_{eff} values

Abundance trends!



A cosmological implication

Correcting for diffusion, the stellar lithium abundances can be reconciled with the CMB+BBN prediction:

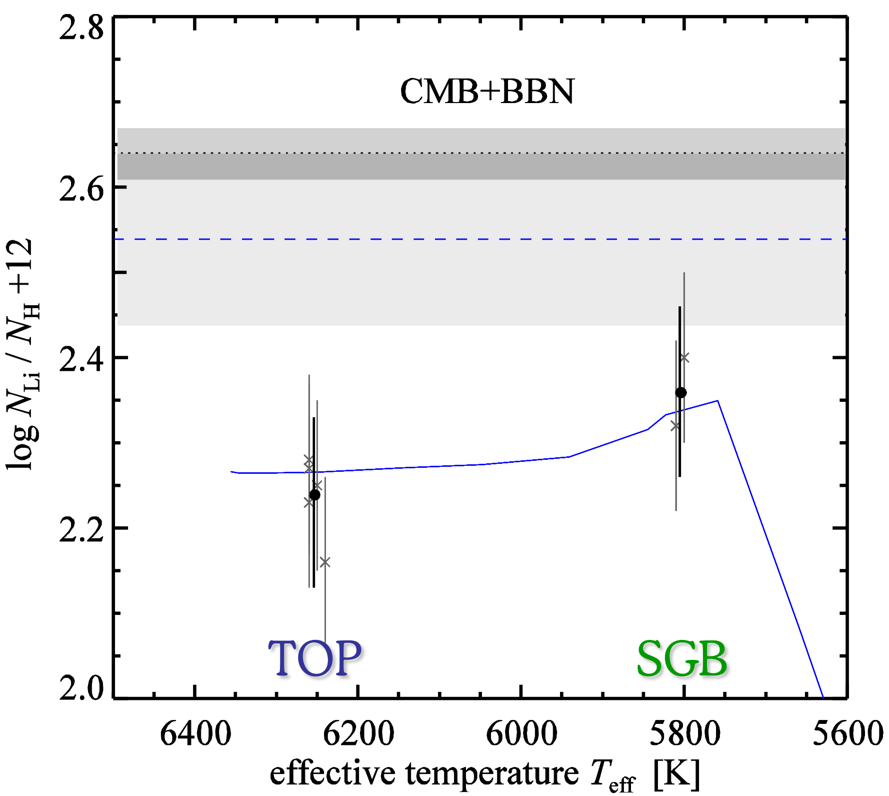
$\log \varepsilon(\mathrm{Li})_{\mathrm{NGC\,6397}} = 2.54 \pm 0.10$

vs. **$\log \varepsilon(\mathrm{Li})_{p} = 2.64 \pm 0.03$**

(Spergel *et al.* 2007)

predicted by Michaud *et al.* (1984)

shown to be compatible with observations by Richard *et al.* (2005)



Korn *et al.* (2006)

NGC 6397: the MEDUSA view

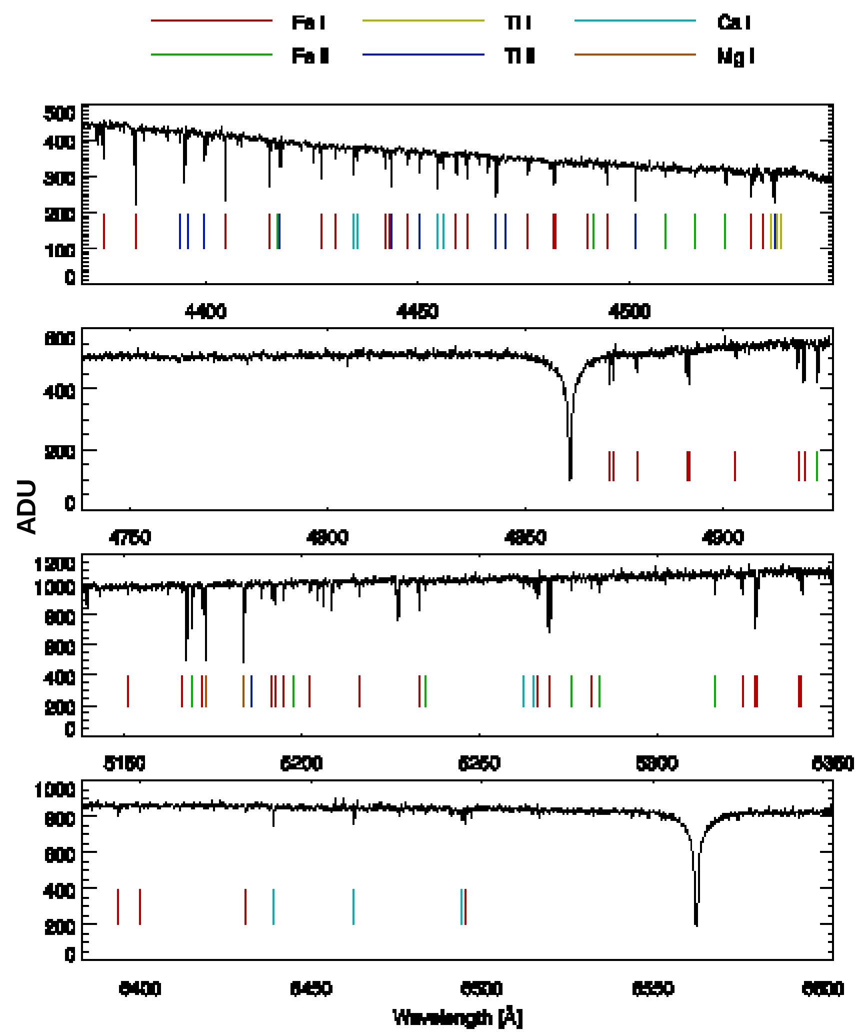
FLAMES-GIRAFFE:
medium-resolution spectrograph
on the VLT UT2

130 MEDUSA fibres giving 200 Å per exposure @ $R \approx 26\,000$.

We observed 130 subgiants in four settings (S/N > 70 per pixel) to derive effective temperatures and abundance for Mg, Ca, Ti and Fe.

MEDUSA advantages:

- FSR > 200 Å (for Balmer lines!)
- can go bluer than FLAMES-UVES

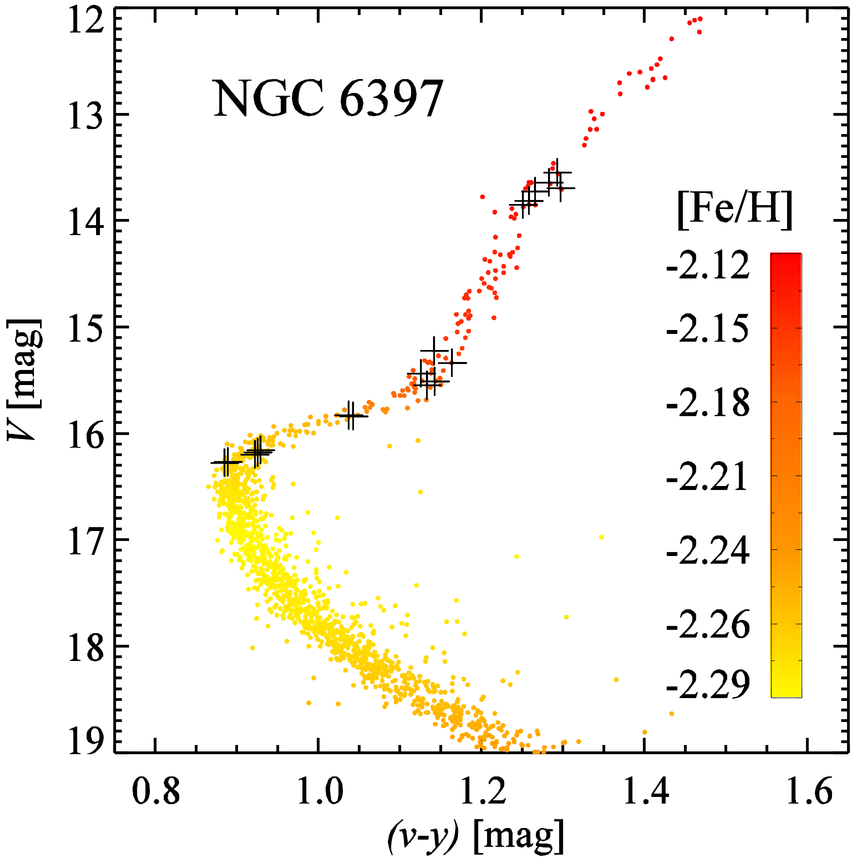


Lind *et al.*, A&A submitted

Say Good bye to the eternal assumption

ADiOS™

Martin Asplund, Paul Barklem, Lionel Bigot, Corinne Charbonnel, Remo Collet, Frank Grundahl, Bengt Gustafsson, A.K., Karin Lind, Lyudmila Mashonkina, Georges Michaud, Nikolai Piskunov, Olivier Richard, Suzanne Talon and Frédéric Thévenin



Korn *et al.* 2006, The Messenger 125, 6

Projects underway

NGC 6752 ([Fe/H] ≈ −1.5) @ VLT (PI Korn):

FLAMES, replicating the methodology applied to NGC 6397

46 hours in 2007, 6 of 30 observing blocks observed;

49 hours in 2008 (t_{exp} = 30 h for the TOP stars!)

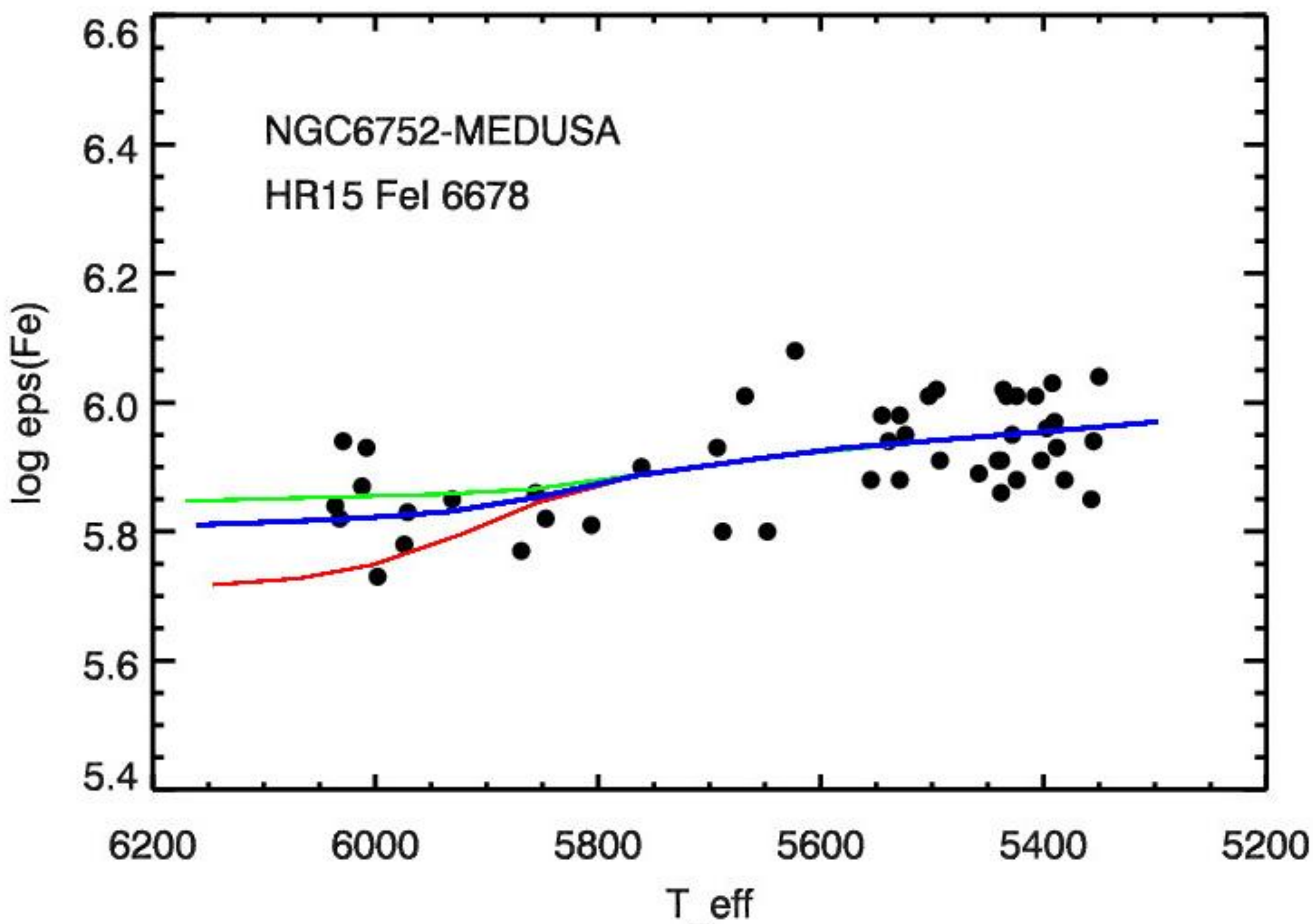
M92 ([Fe/H] ≈ −2.4) @ Keck (PI Cohen):

5 nights in June/July/August

M67 (solar [Fe/H]) @ VLT (PI Gustafsson)

P82, 25 h

A first look at AD in NGC 6752

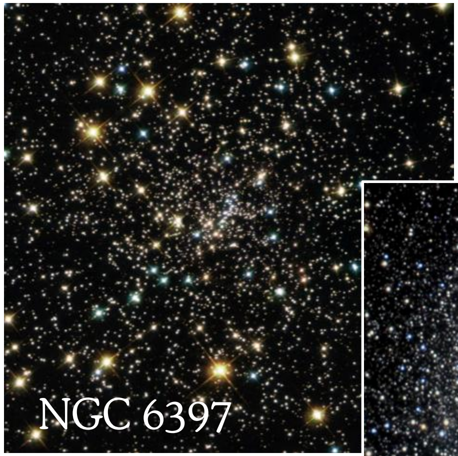


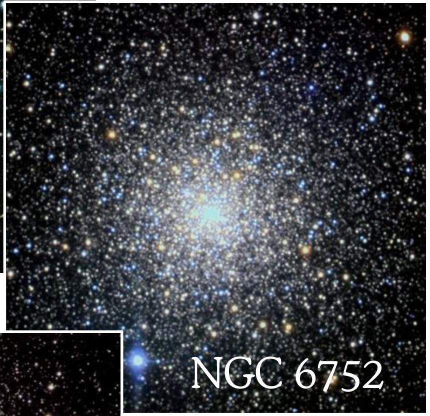
So why not abandon dwarf stars?

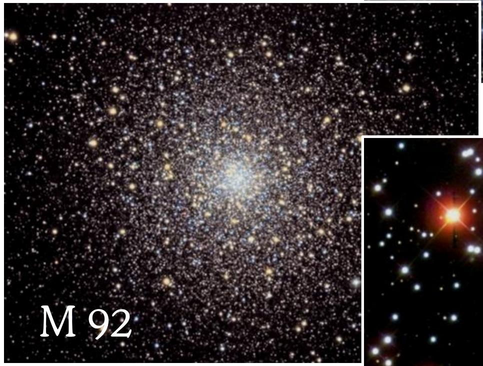
Not an option, as

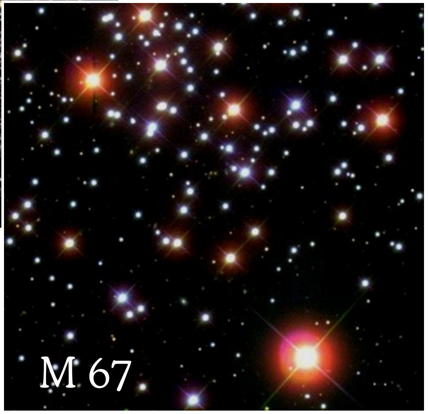
- ★ they give us access to abundances unaltered by stellar evolution
- ★ the only source for unaltered LiBeB and CNO abundances (primordial lithium!)
- ★ AD effects are interesting in their own right

We would now like to understand **what gives rise to the extra mixing at the bottom of the convection zone**.
Rotation? Mass loss? Internal gravity waves?









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