Main-Sequence and sub-giant stars in the Globular Cluster NGC6397: The complex evolution of the lithium abundance

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(3) Observatoire de Paris-Meudon (GEPI)

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- L. Sbordone (CIFIST, Observatoire de Paris-Meudon)
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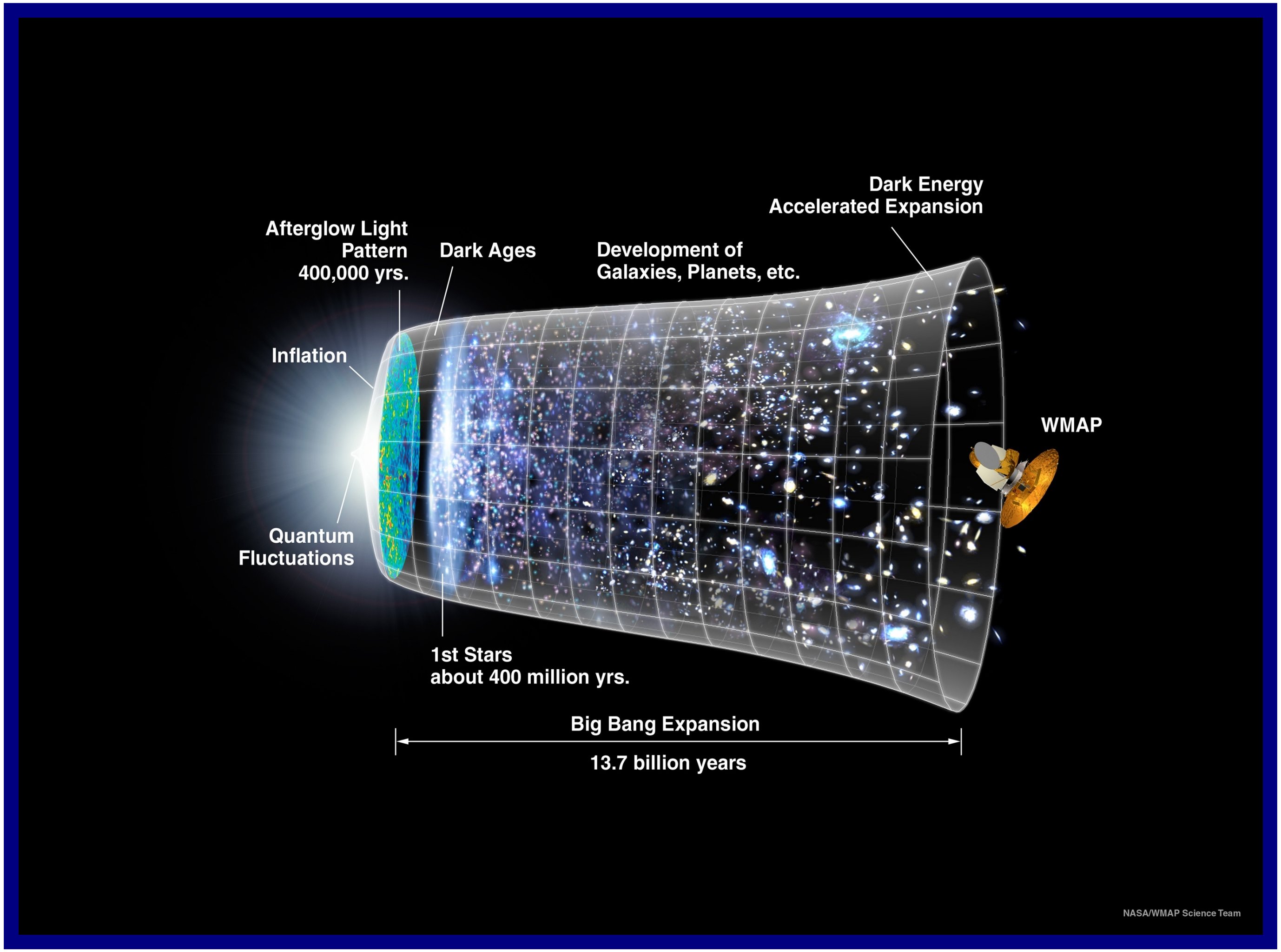
- S. Zaggia (INAF- Osservatorio Astronomico di Padova)

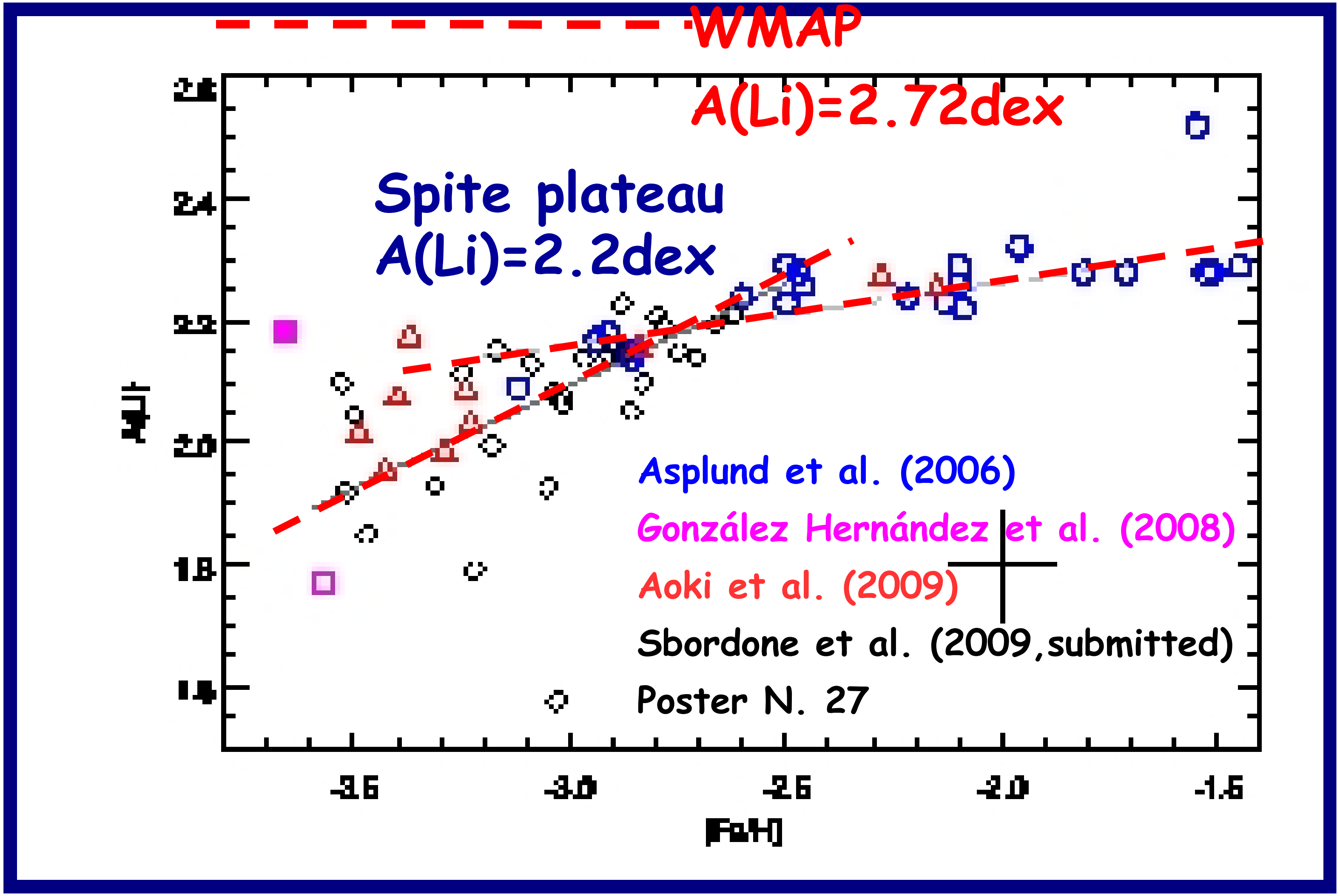
Outline

- Introduction:
  Lithium discrepancy
- 3D model grid
- Observations:
  Globular Cluster NGC 6397
- Stellar parameters
- Lithium Abundances
- Discussion and conclusions

Introduction

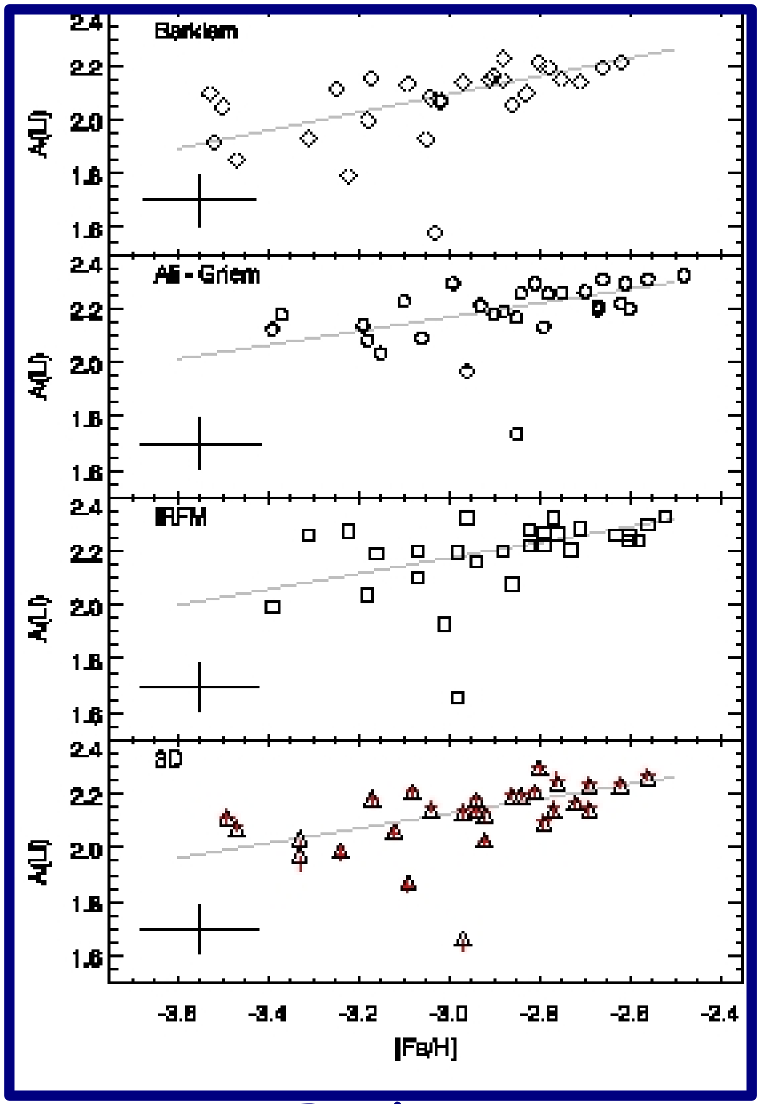


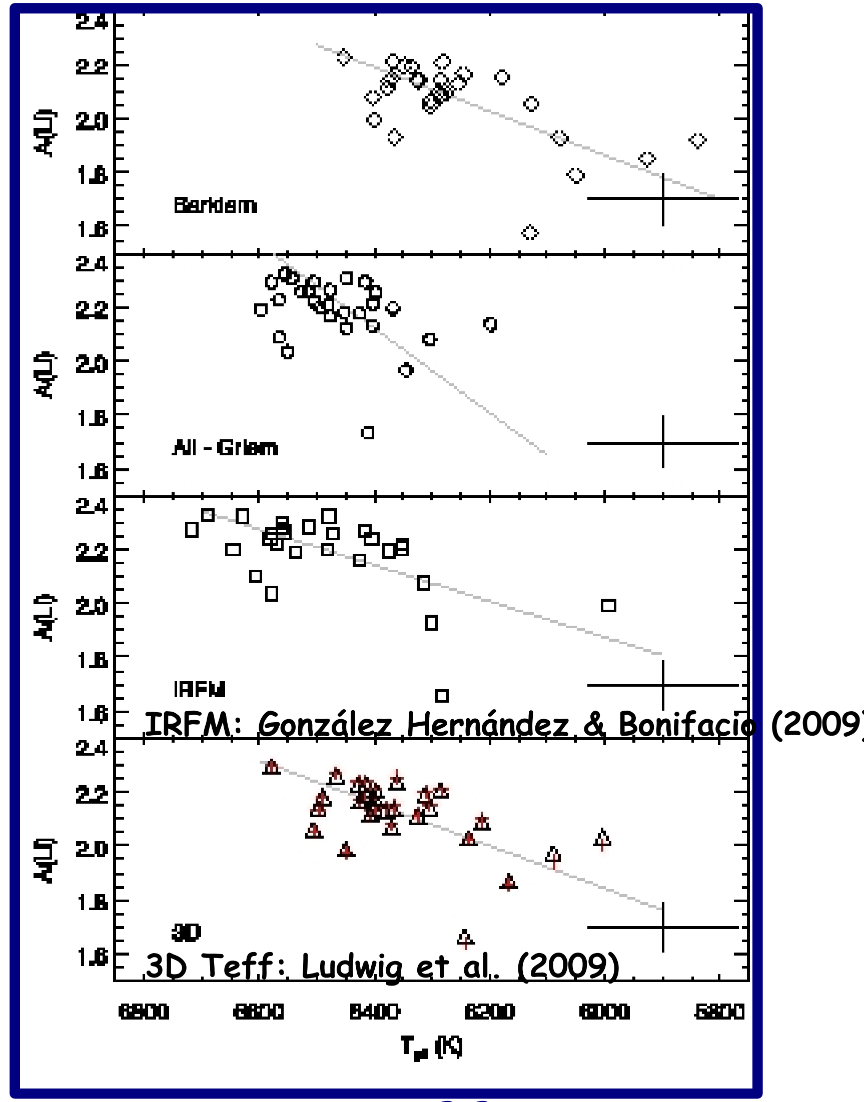
Lithium in metal-poor stars



A(Li) in field metal-poor stars
Sbordone et al. (2009, submitted)

A(Li)





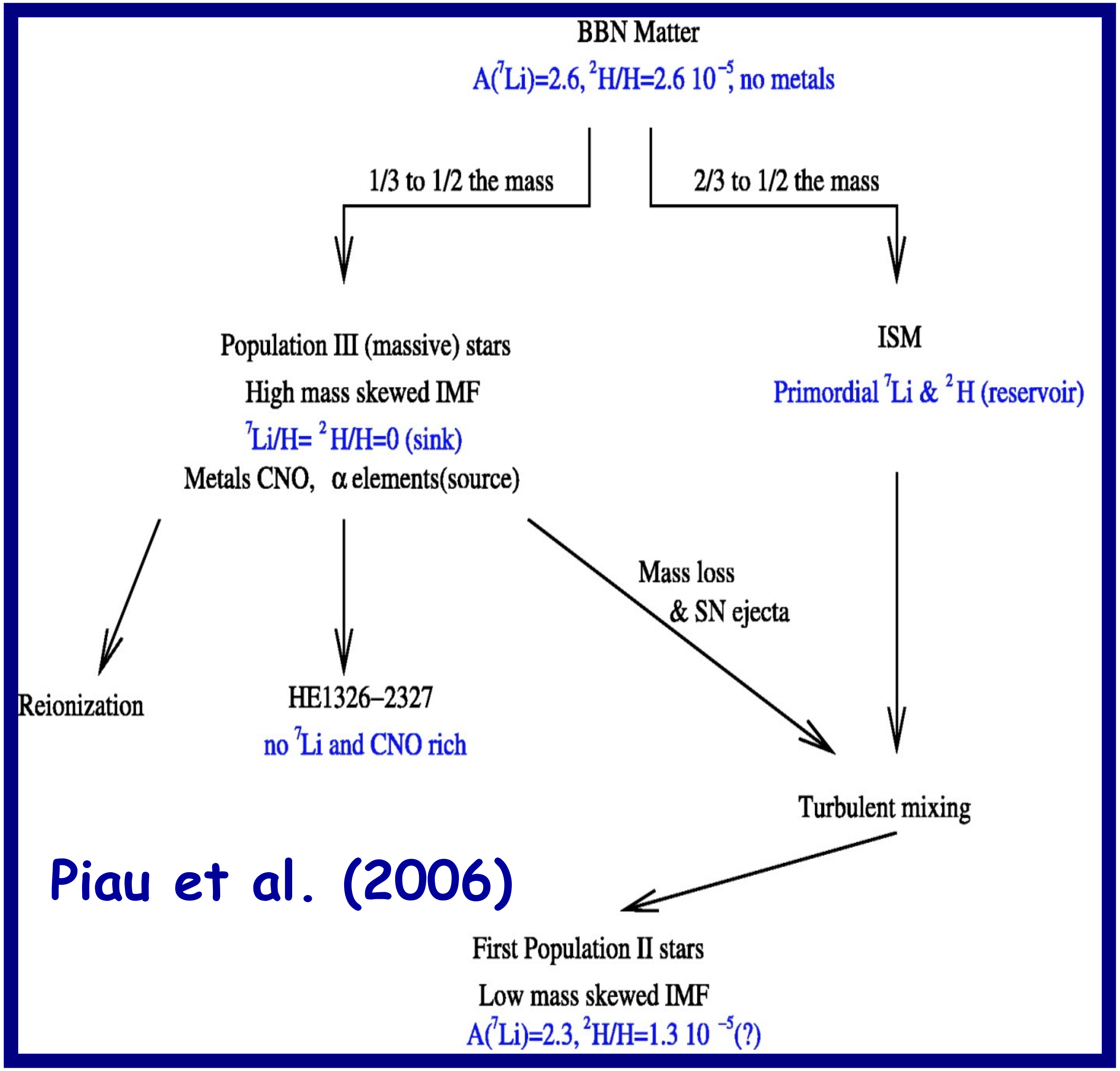
[Fe/H]

Teff

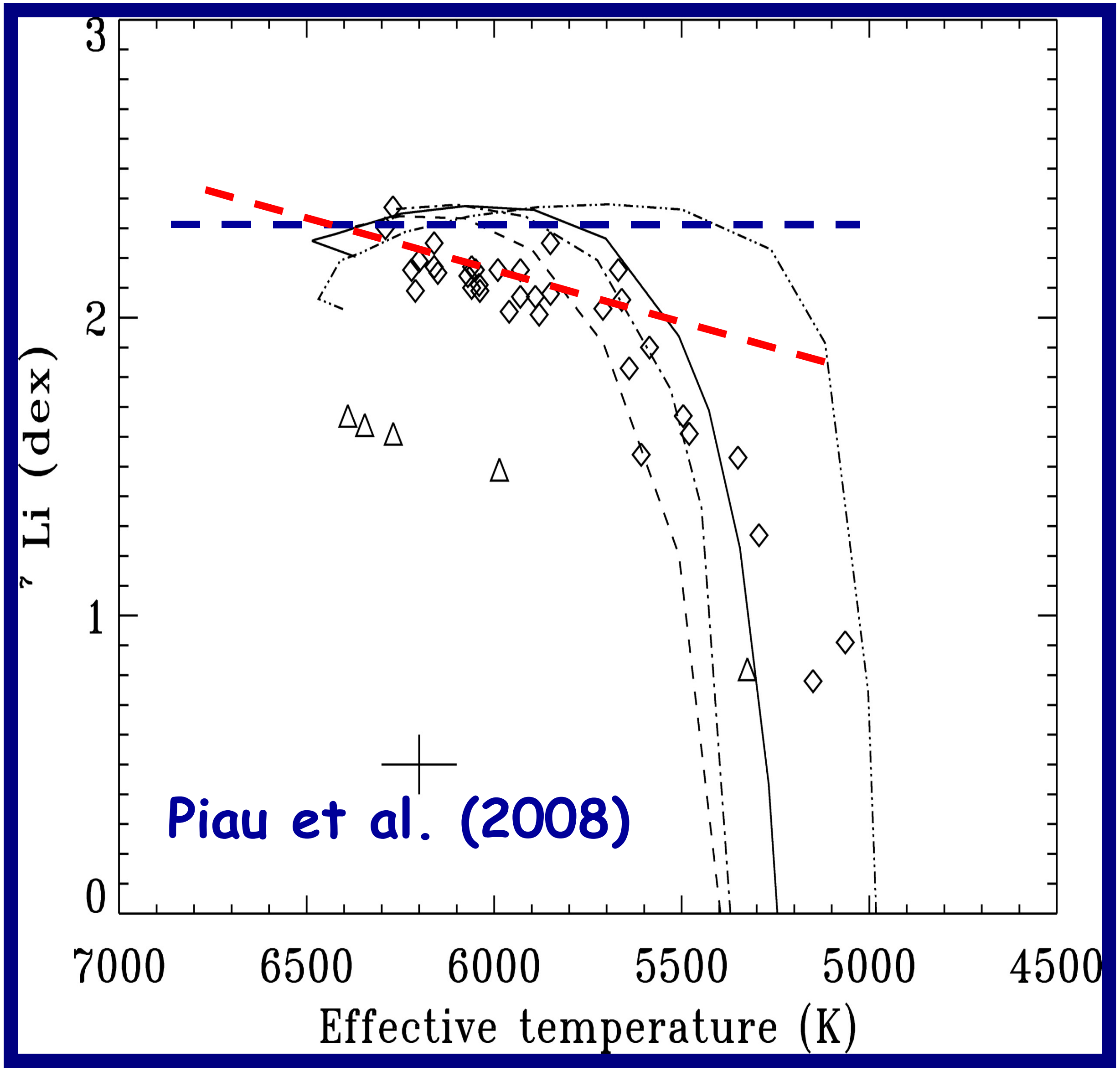
Lithium discrepancy

- The 0.4-0.5 dex of difference between the Spite plateau and WMAP may be explained by:
  - Diffusion with turbulence (Richard et al. 2005)
  - Gravity waves (Talon & Charbonnel 2004)
  - Pre-galactic Li processing (Piau et al. 2006)
  - Tachocline mixing (Piau et al. 2008)
  - Non-standard BBN (Jedamzik 2004, 2006; Jittoh et al. 2008; Hisano et al. 2008)

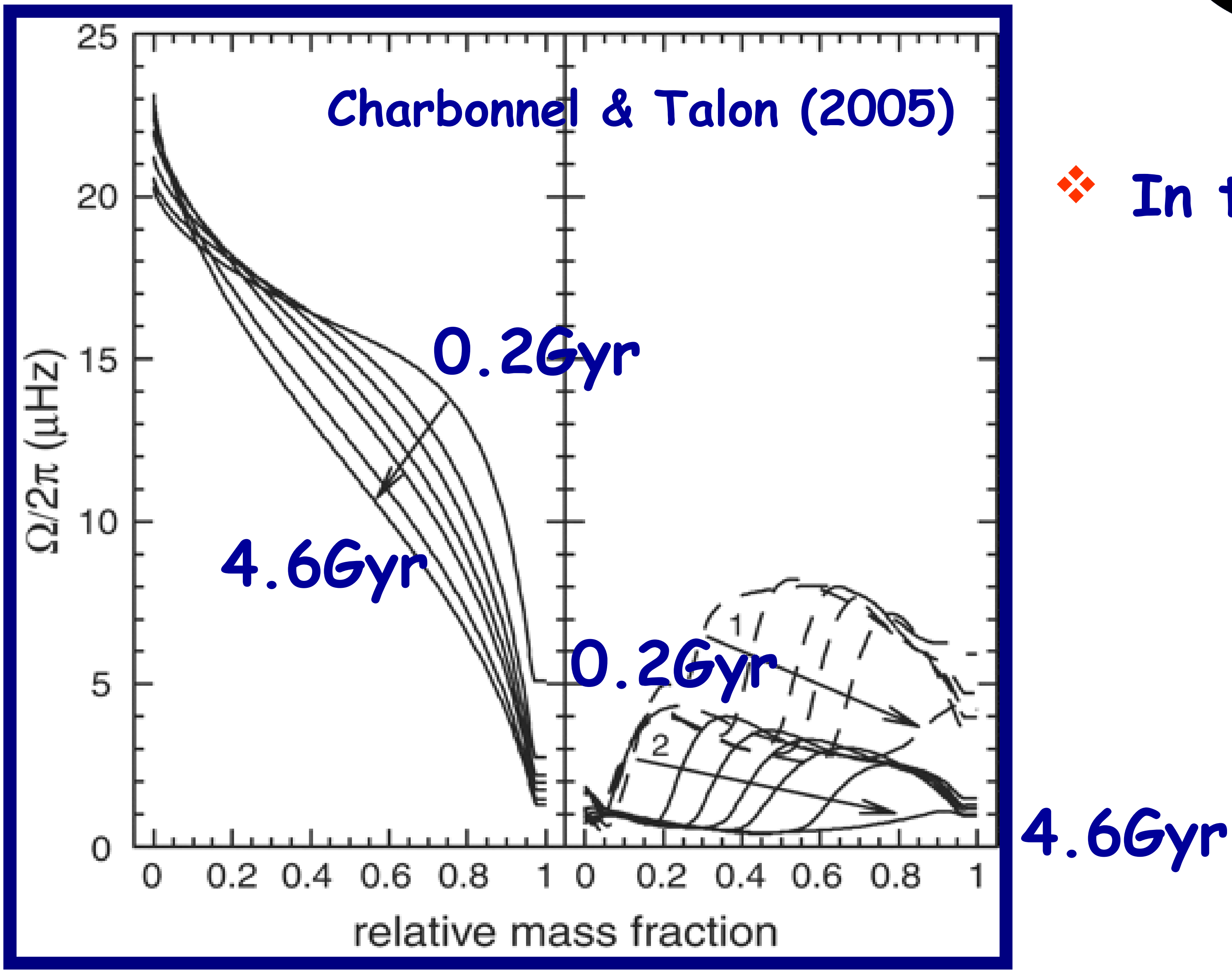
Pre-Galactic Li depletion



Tachocline mixing

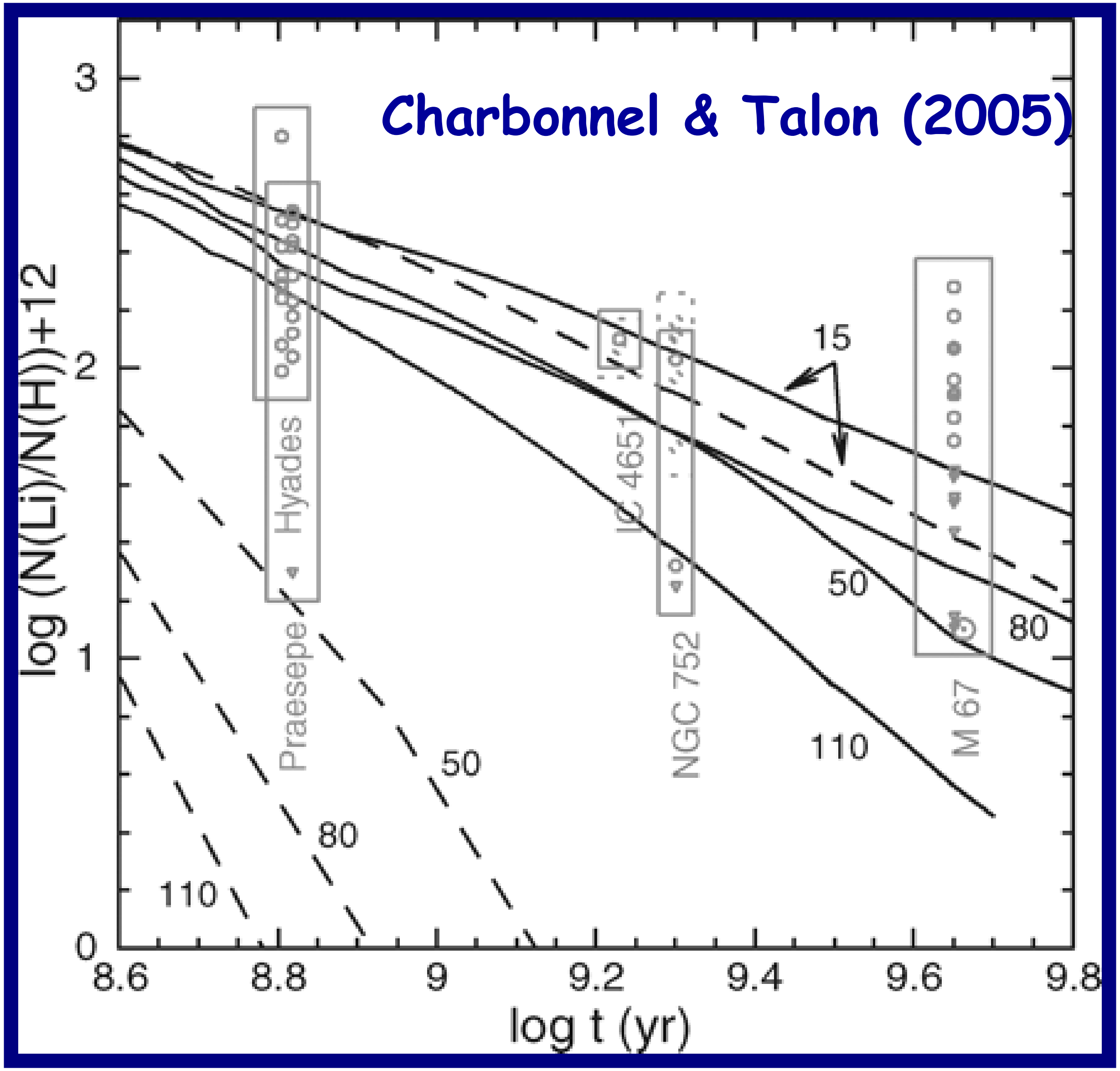


Gravity waves



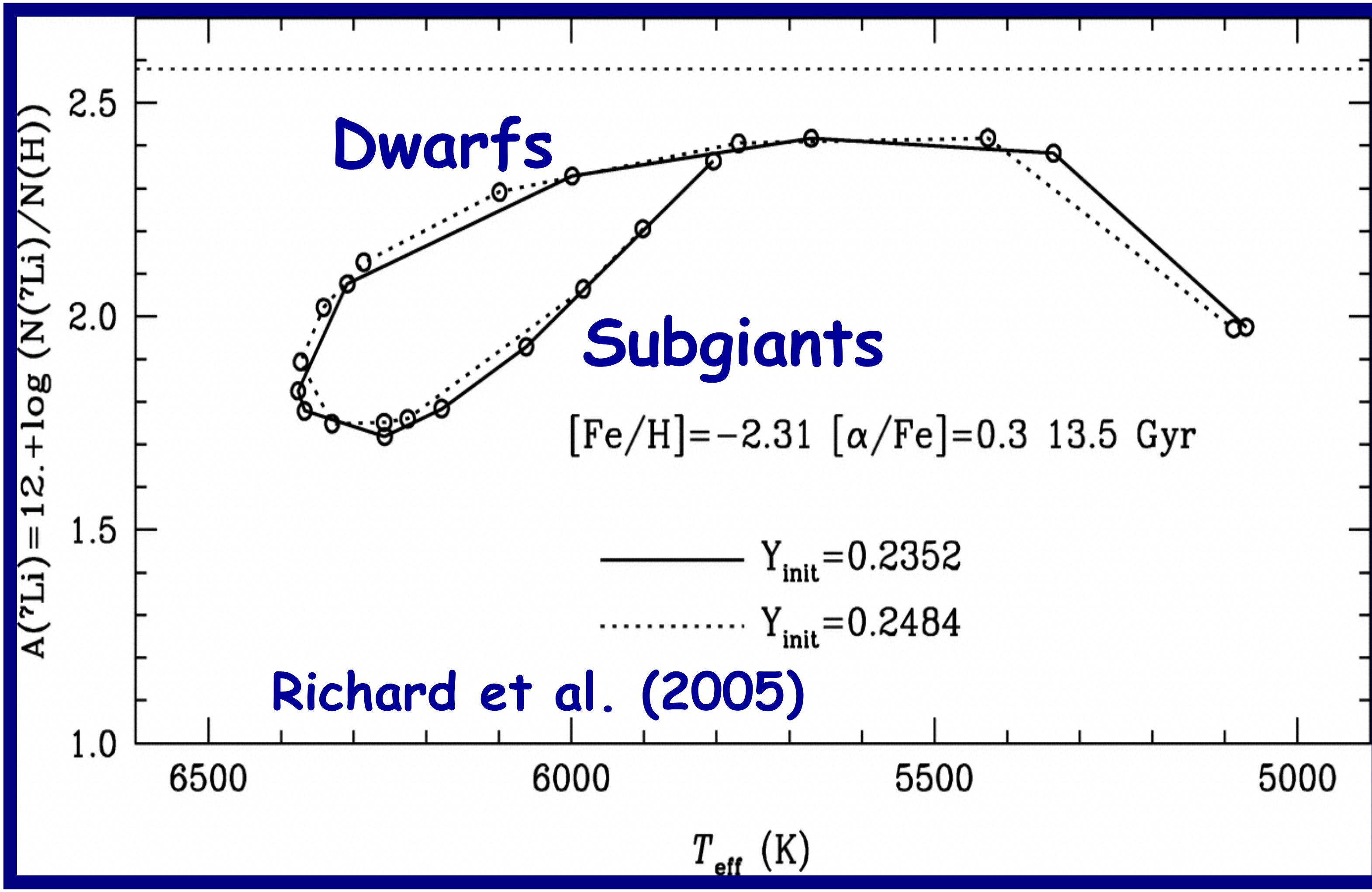
- In the Sun

Gravity waves

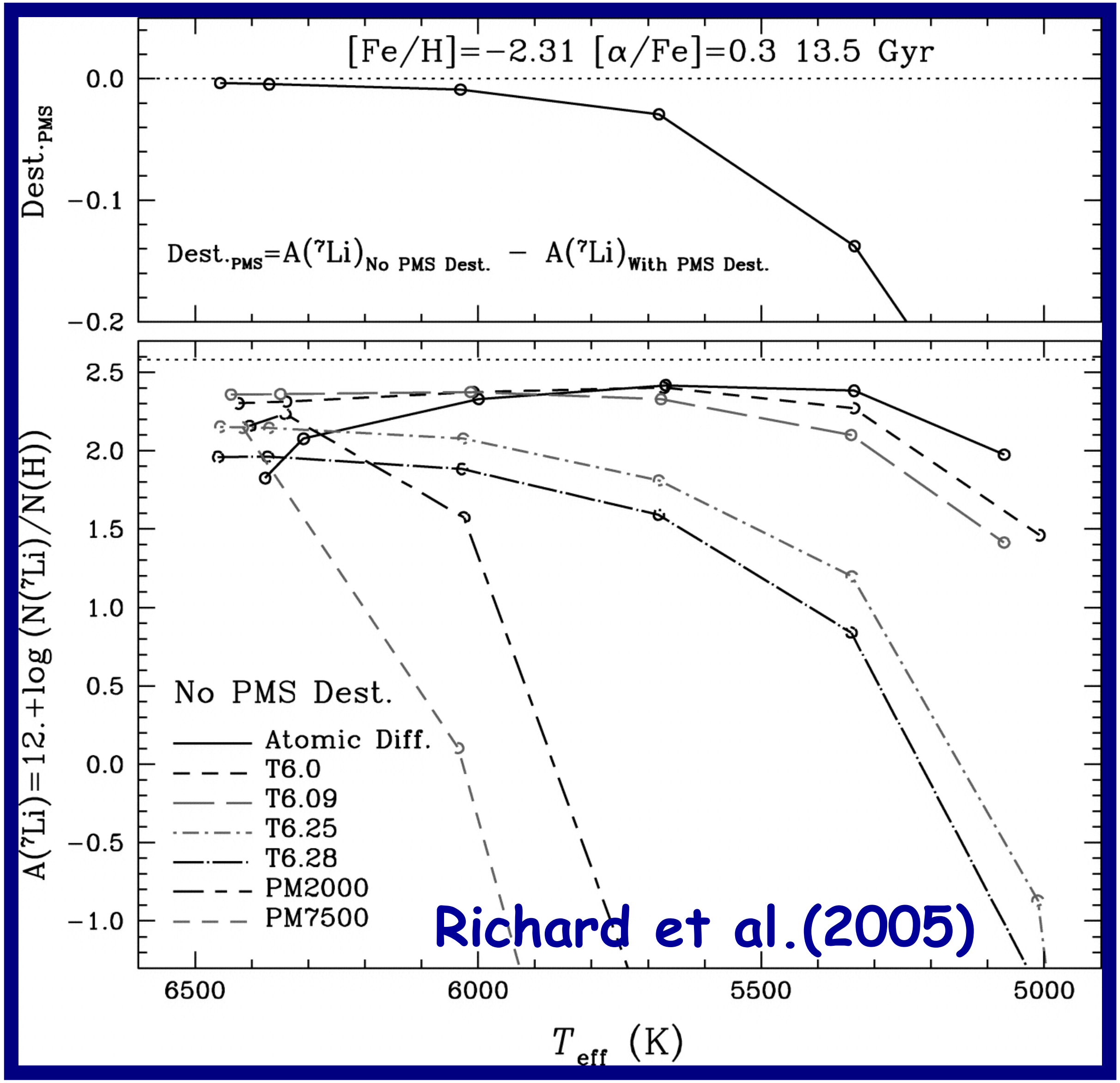


- Only for solar type stars
- This needs to be done for metal-poor stars

Atomic diffusion models

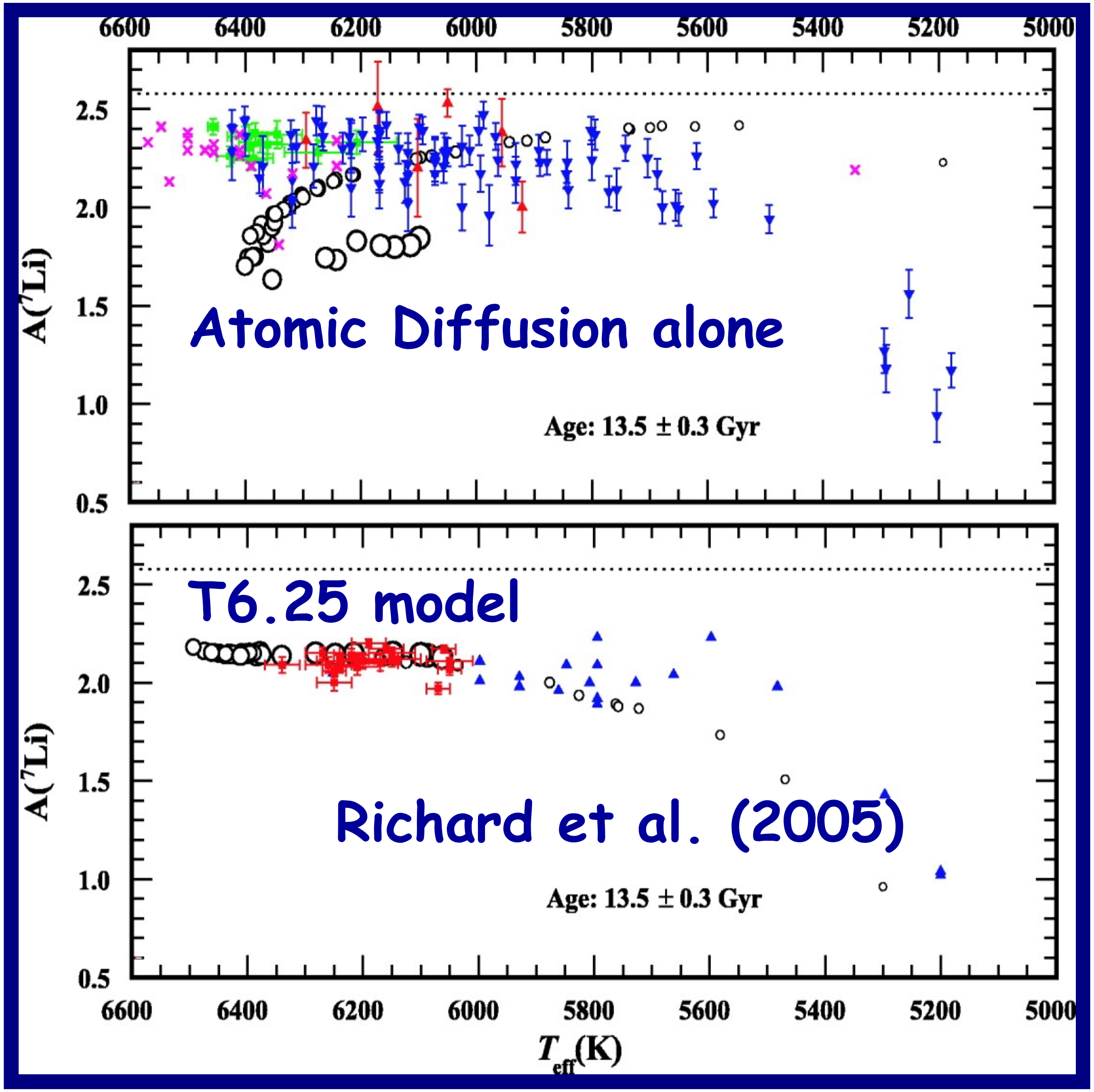


Turbulent diffusion models



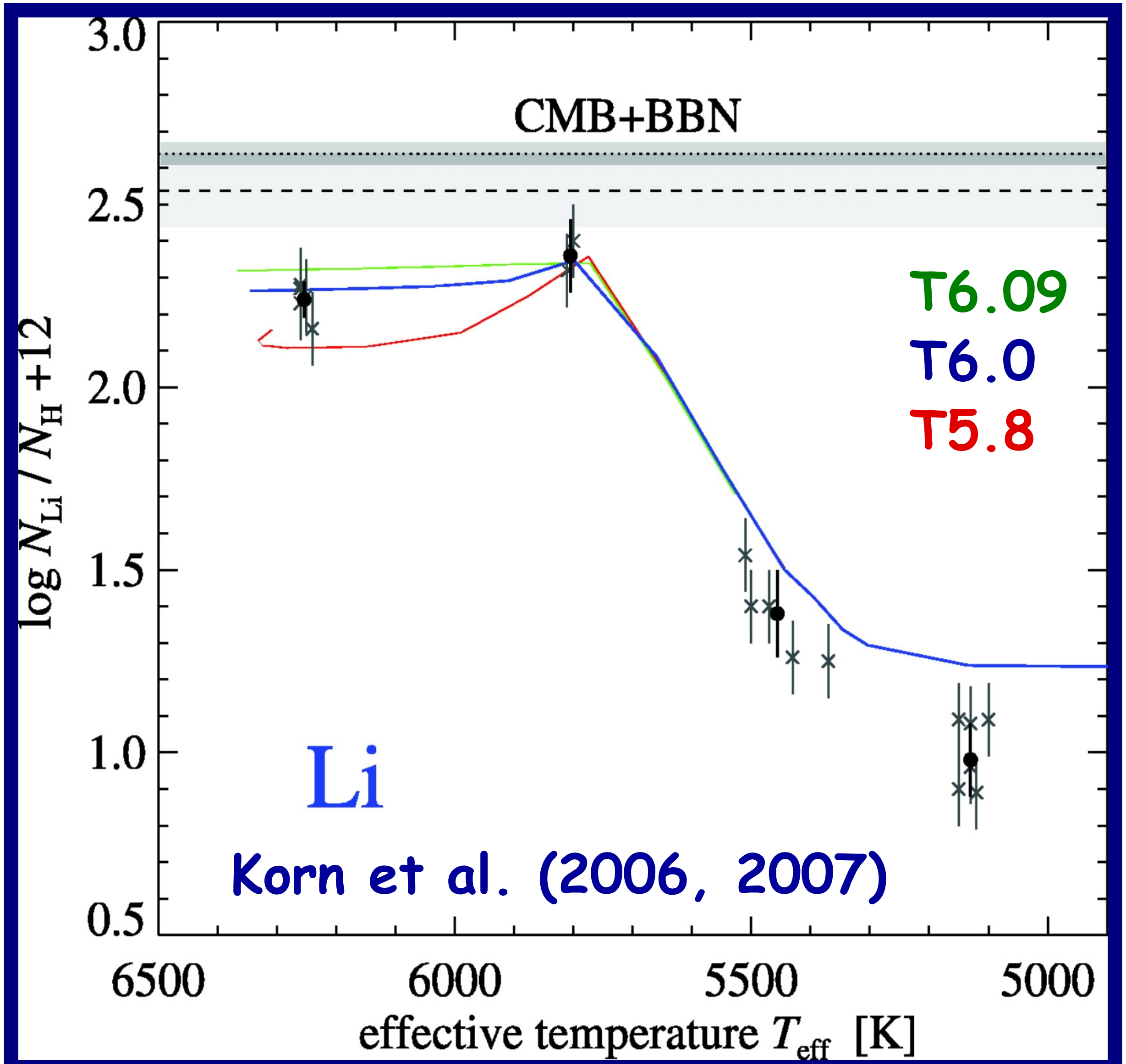
All Dwarfs

Turbulent diffusion models



BUT, the turbulence is included in these models without postulating any physical mechanism responsible for it

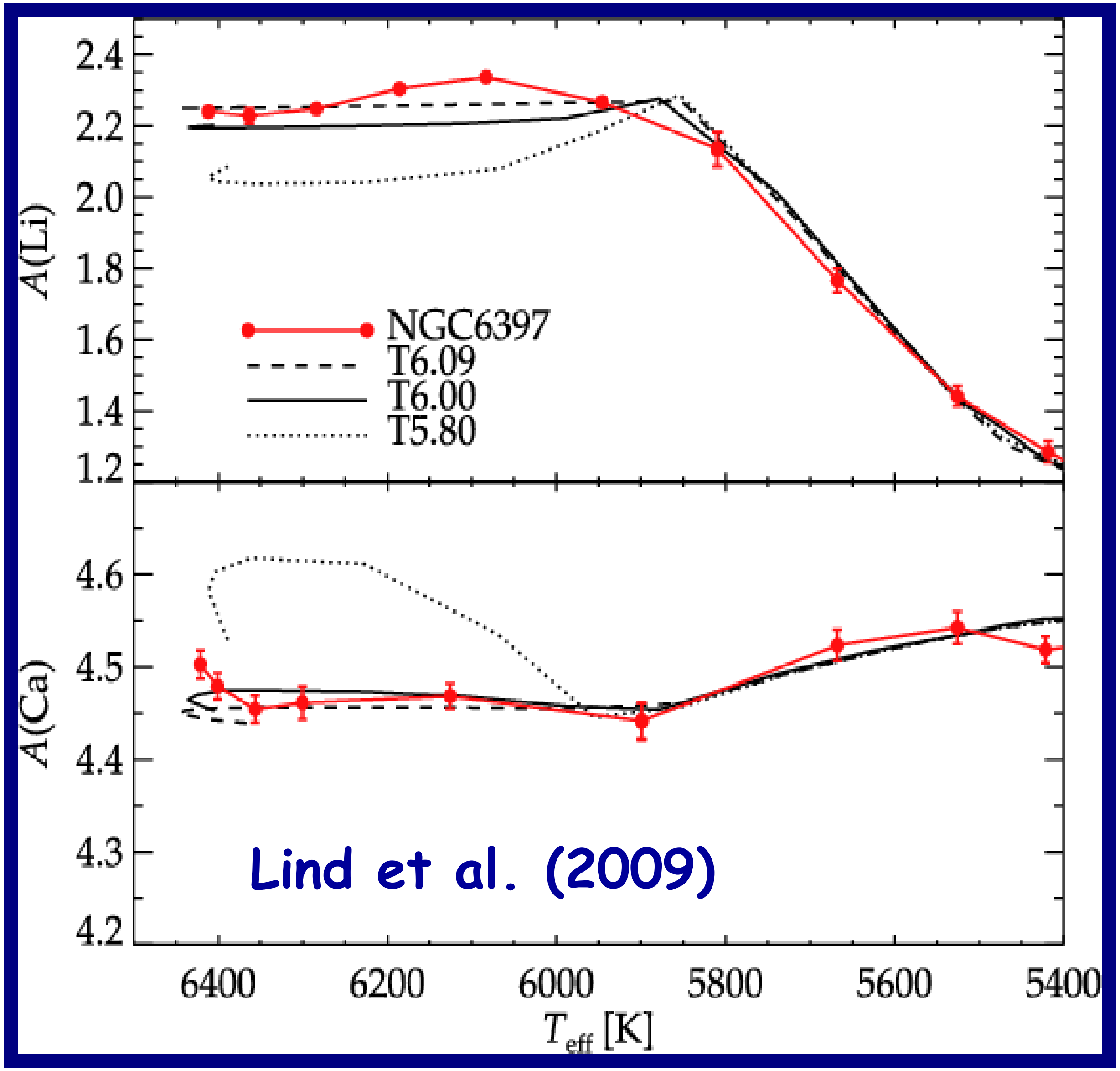
Turbulent diffusion models



From TO stars to RGB stars in NGC 6397

These results are very sensitive to the Teff scale

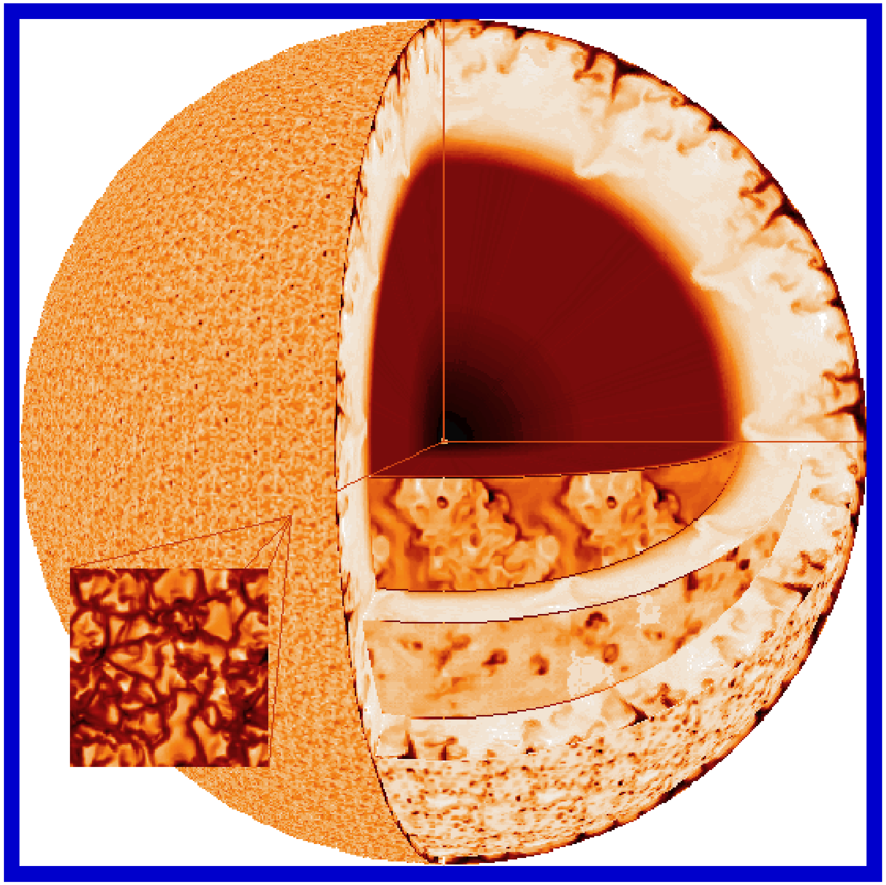
Turbulent diffusion models



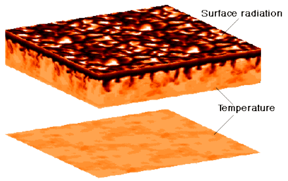
Lind et al. (2009) find also an increase A(Li) towards lower Teff but now this is not consistent with the diffusion-turbulence tracks

They used a different Teff scale

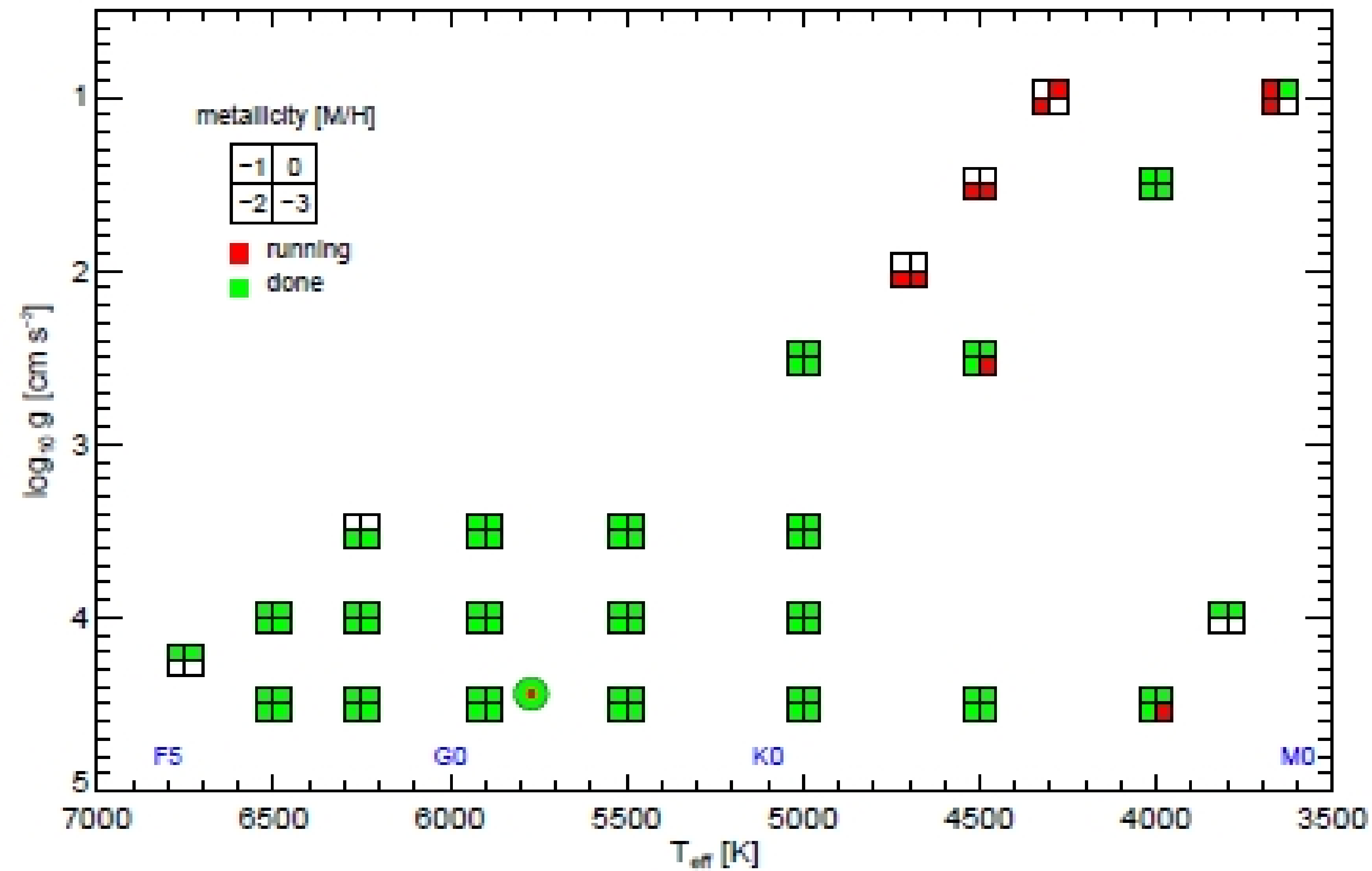
3D Model Atmospheres

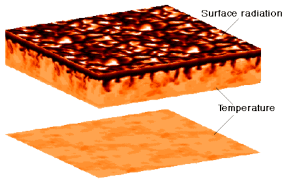


- 3D models computed with CO^5BOLD
- Representative selection of snapshots of the stellar photosphere
- Spectral synthesis code Linfor3D



3D Model Atmospheres





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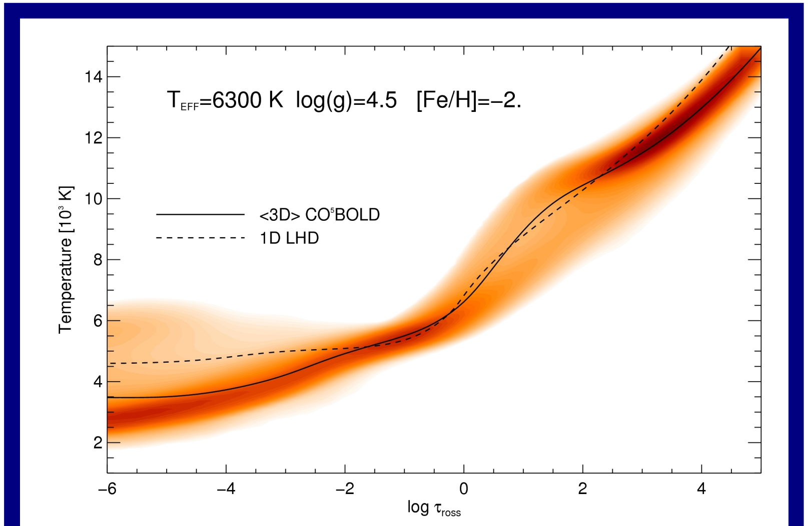
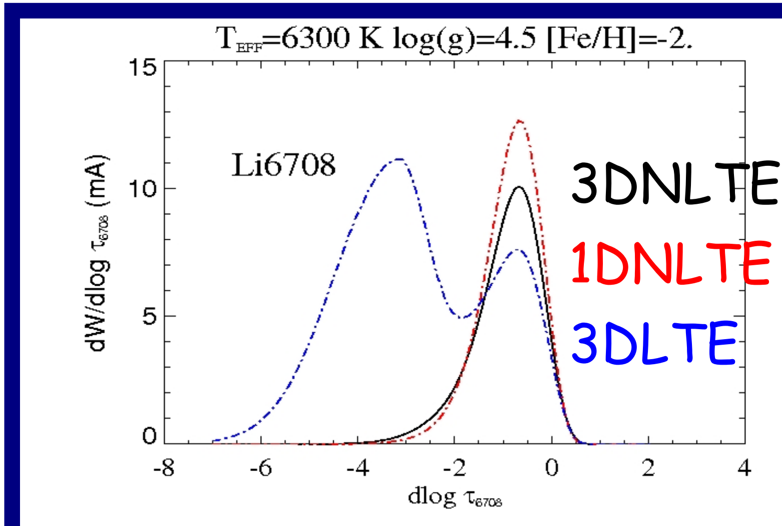
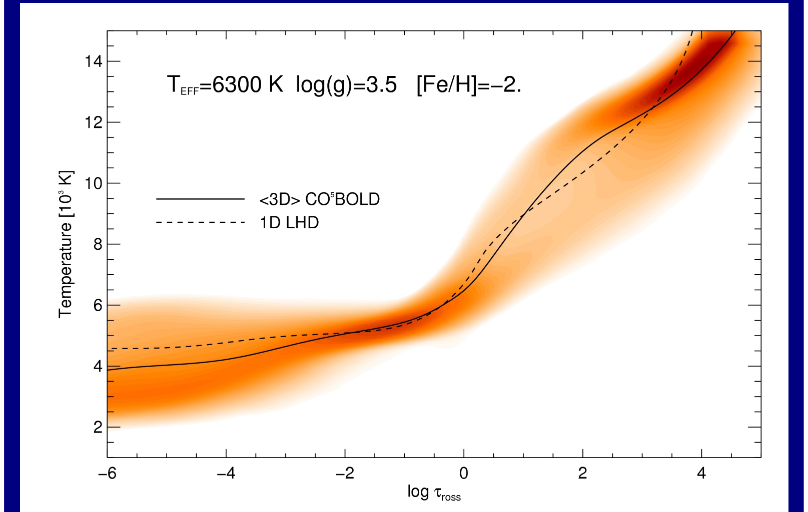
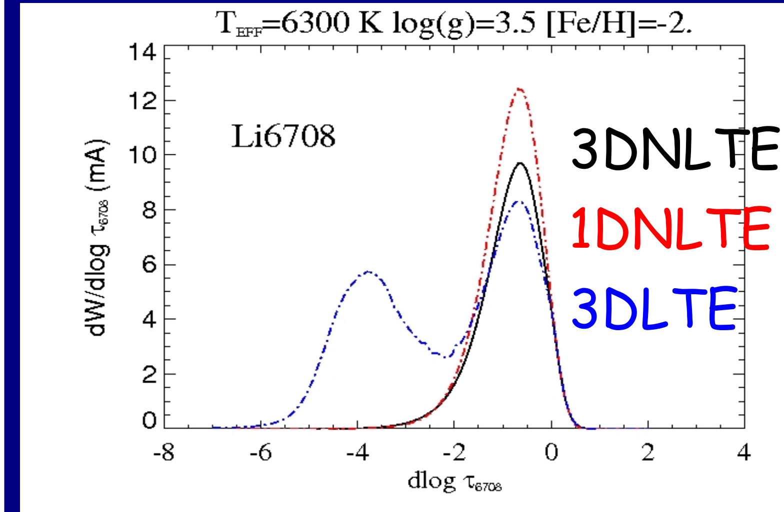


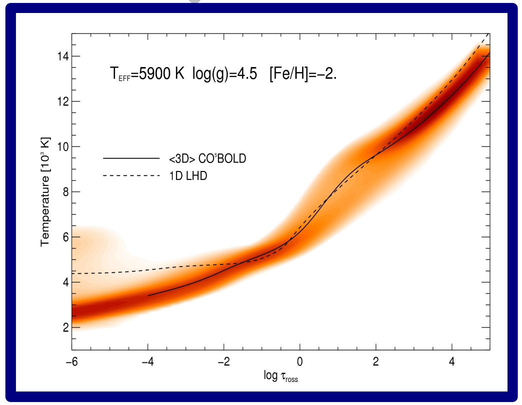


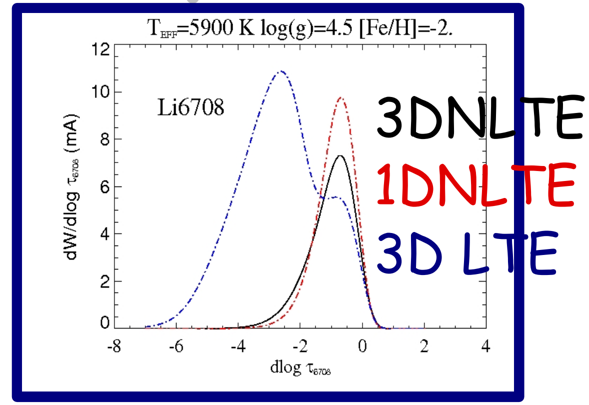




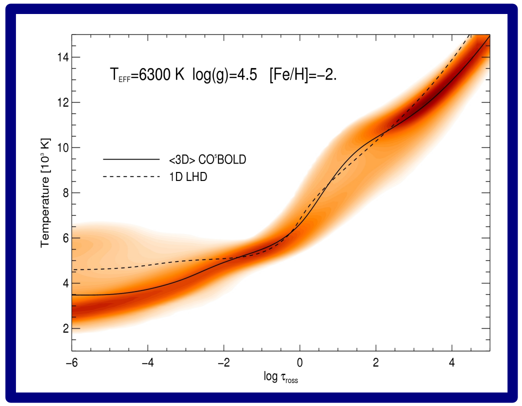
3D Models : temperature dependence

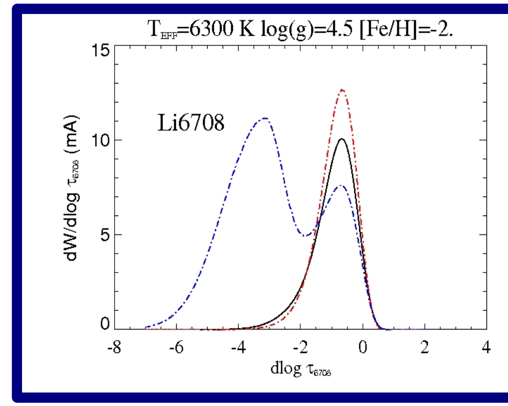
❖ **Teff = 5900K**



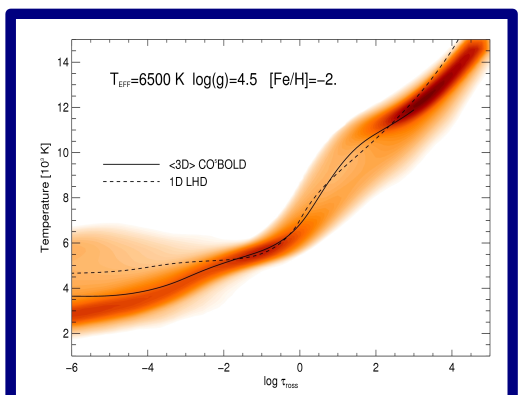


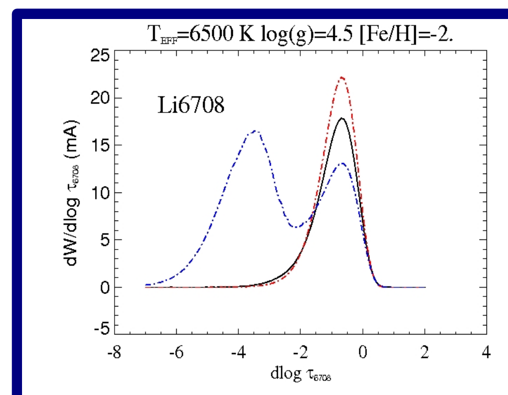
❖ **Teff = 6300 K**





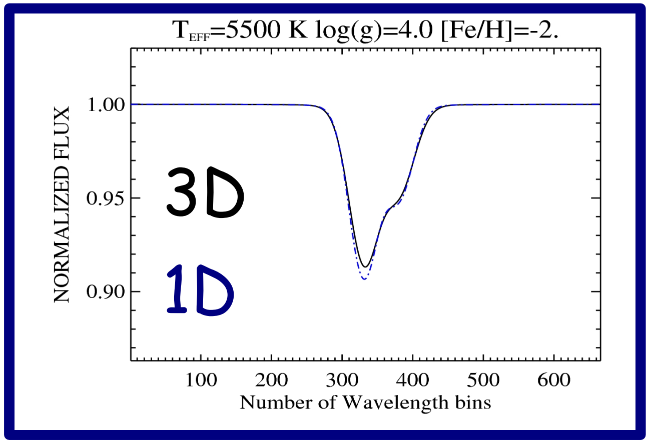
❖ **Teff =6500 K**



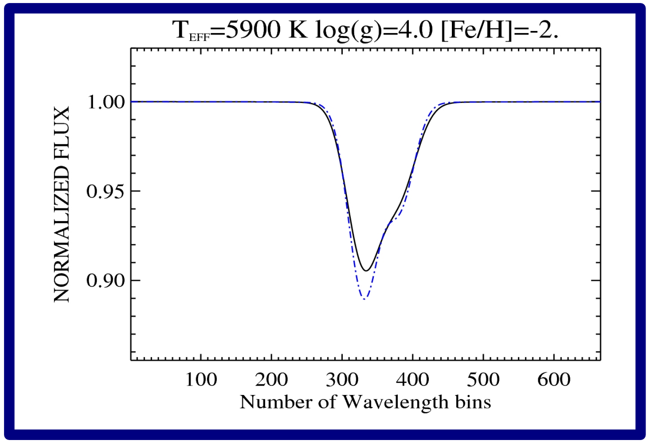


NLTE lithium profiles

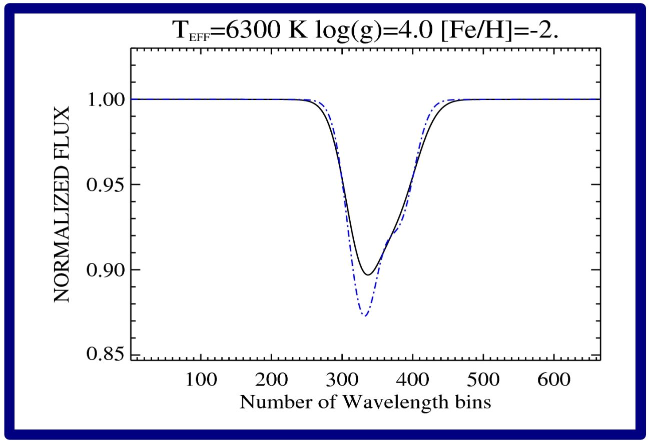
❖ Teff = 5500 K



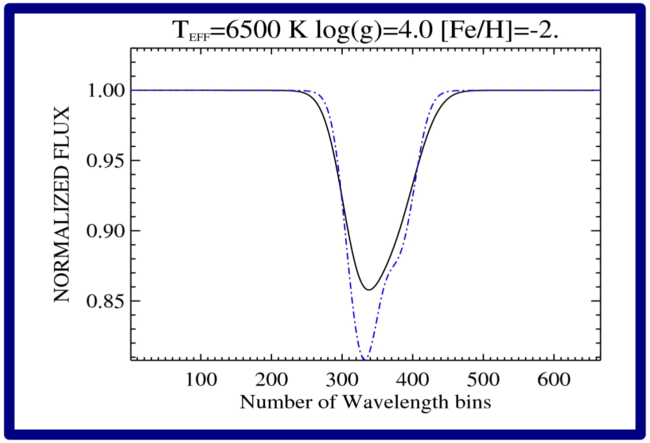
❖ Teff = 5900 K



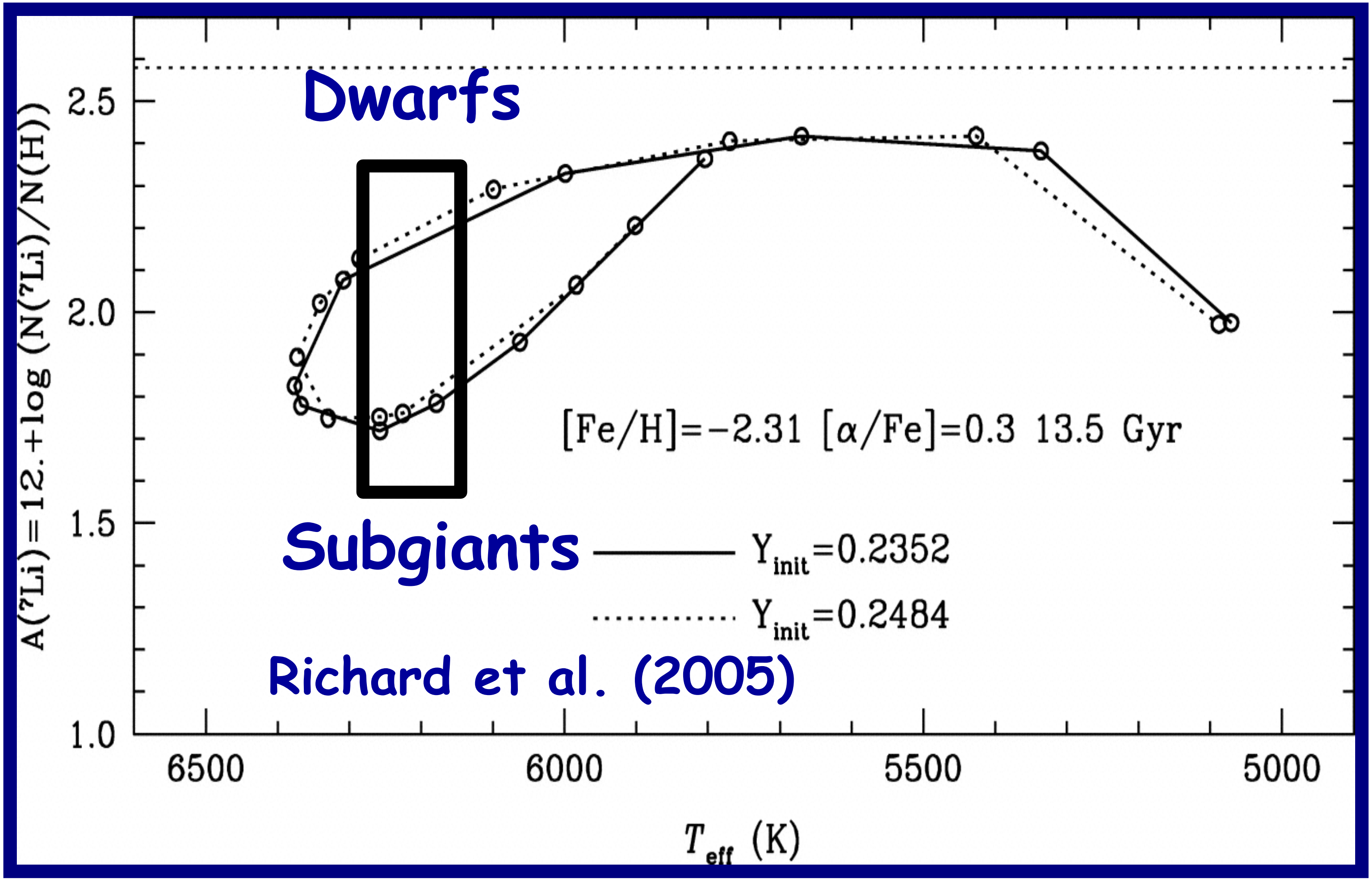
❖ Teff = 6300 K



❖ Teff = 6500 K



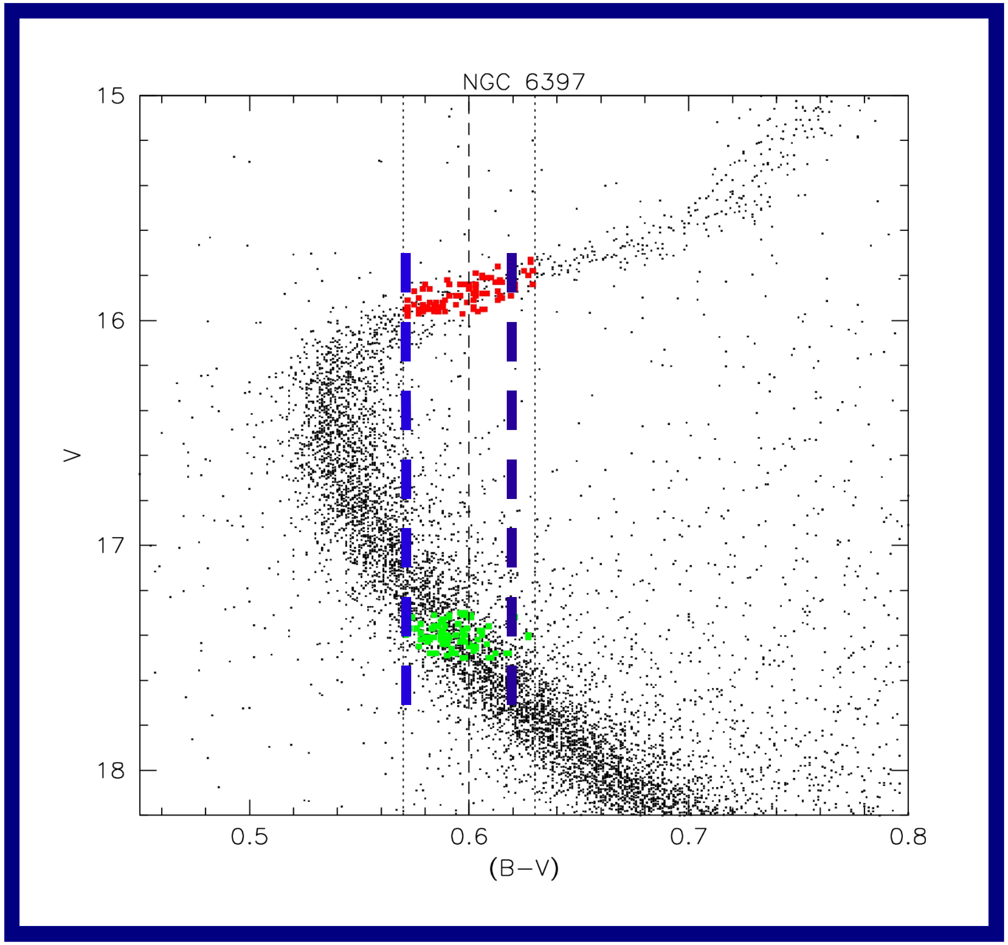
Atomic diffusion models



Observations of NGC 6397

- Subgiant stars (m_V~15.8)
- Dwarf stars (m_V~17.4)

- The same colour B-V ensures that the Teff of the two samples are roughly the same

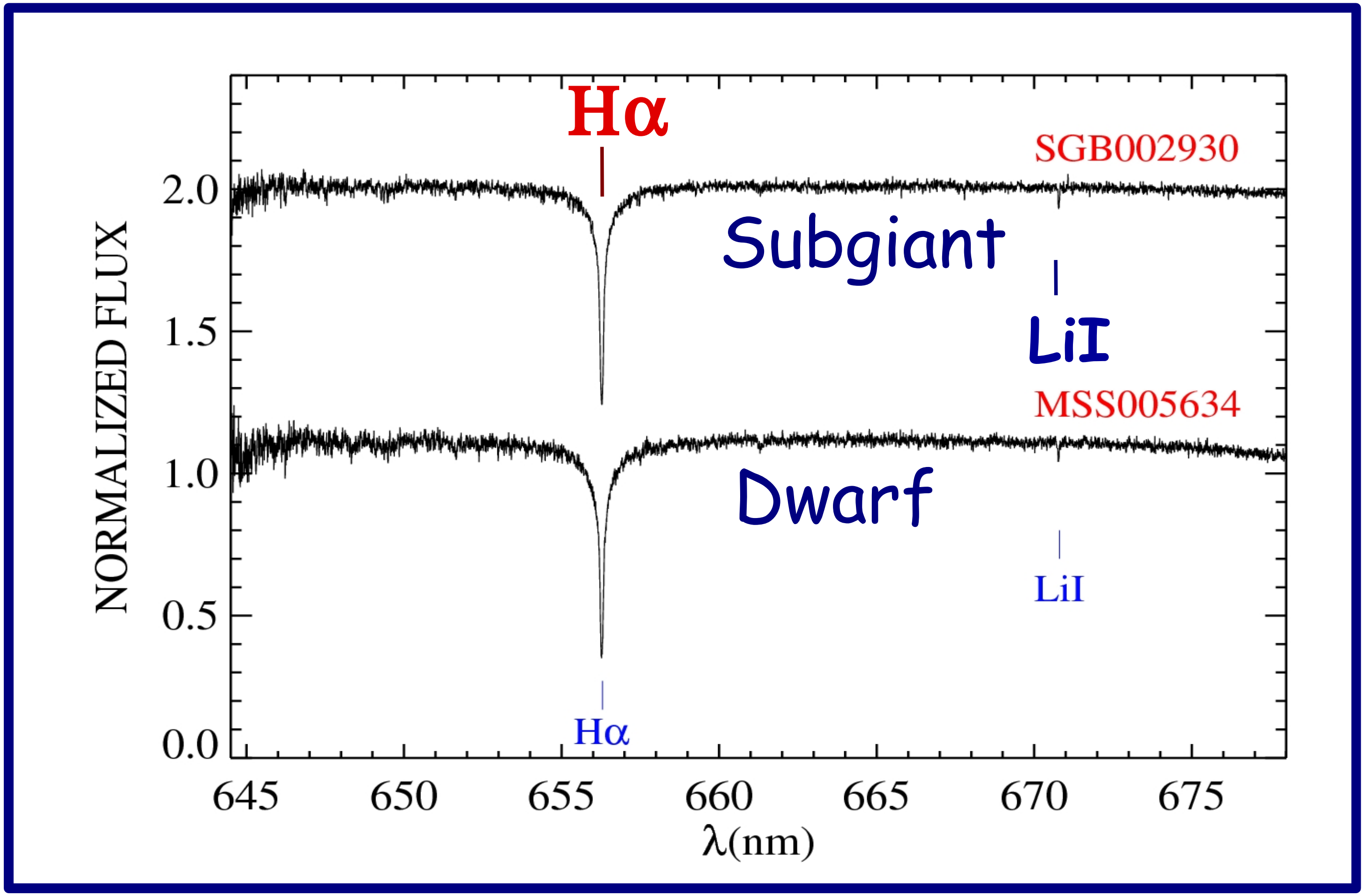


Observations of NGC 6397

- Spectroscopy with FLAMES/GIRAFFE in MEDUSA mode at the VLT
- Spectral range ~6470-6790 angstroms
- Resolving Power: $\lambda/\delta\lambda$ ~17,000 (17.6 km/s)
- S/N~ 80-130

Data Reduction

- We use the GIRAFFE pipeline provided by ESO, within Gasgano and also MIDAS

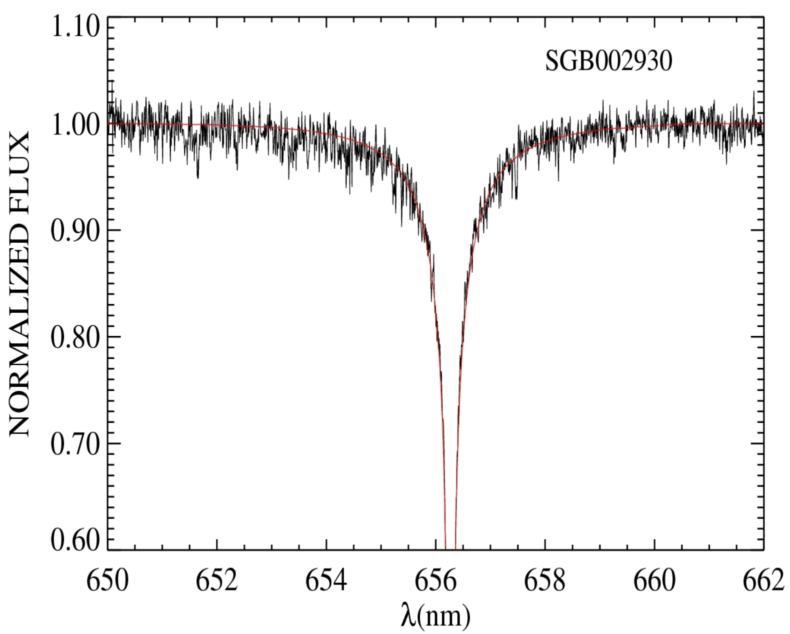


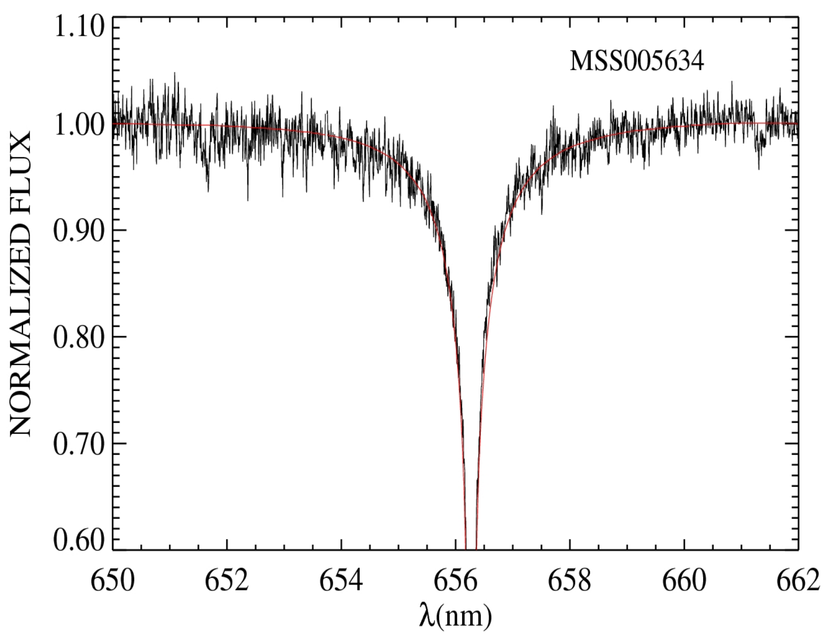
Stellar parameters: 3D Teff

- We fit the observed Hα profiles using theoretical profiles for different effective temperatures and surface gravities
- Surface gravity was fixed according to the position of the stars with respect to an isochrone of 12Gyr and [Fe/H]=-2
- We do this exercise in 1D and 3D using the theory of Barklem et al. (2002) for self-broadening of Hα
- The difference in Teff 3D-1D is typically ~200K

3D effective temperatures:
Behara et al. (2008)
Ludwig et al. (2009)

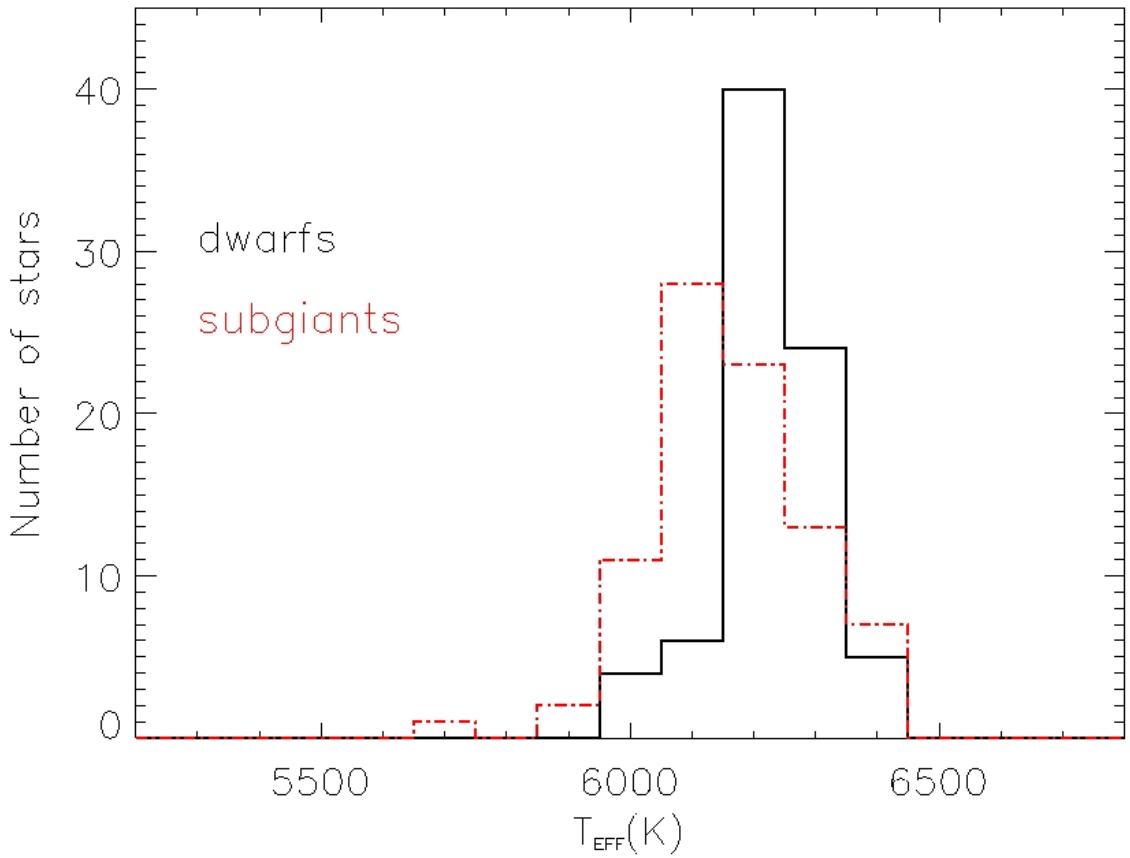
- Subgiant star
- Dwarf star





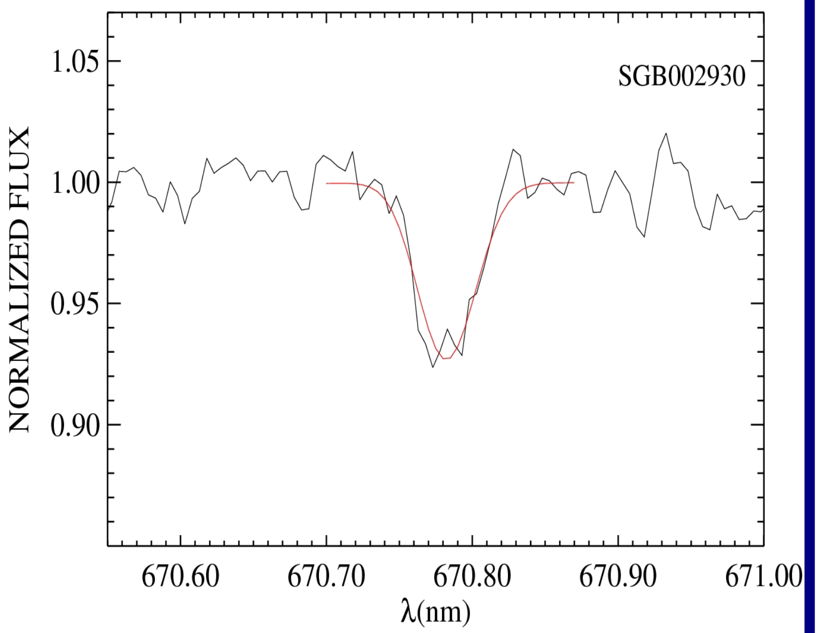
3D Temperatures

- Subgiants & Dwarfs

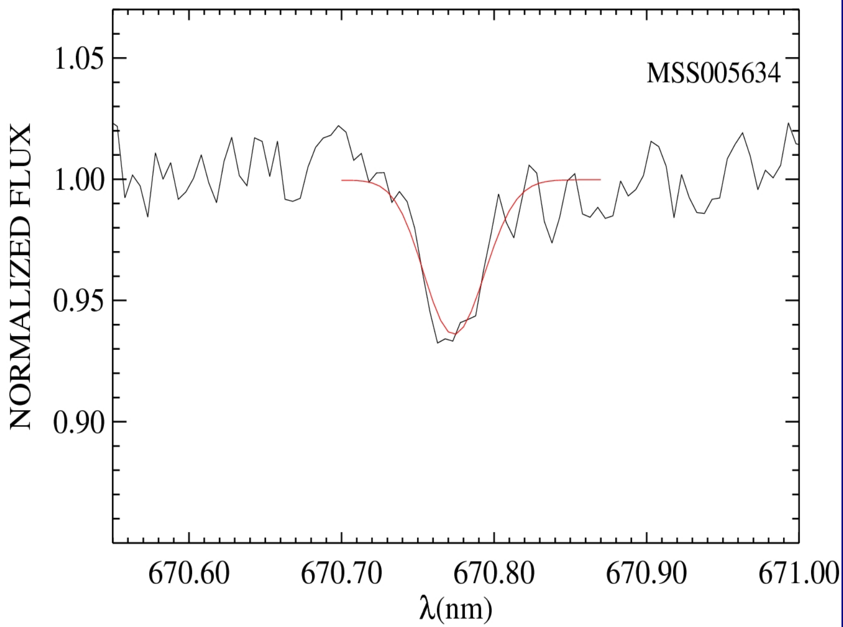


Equivalent Width of Lithium

❖ **Subgiant star**

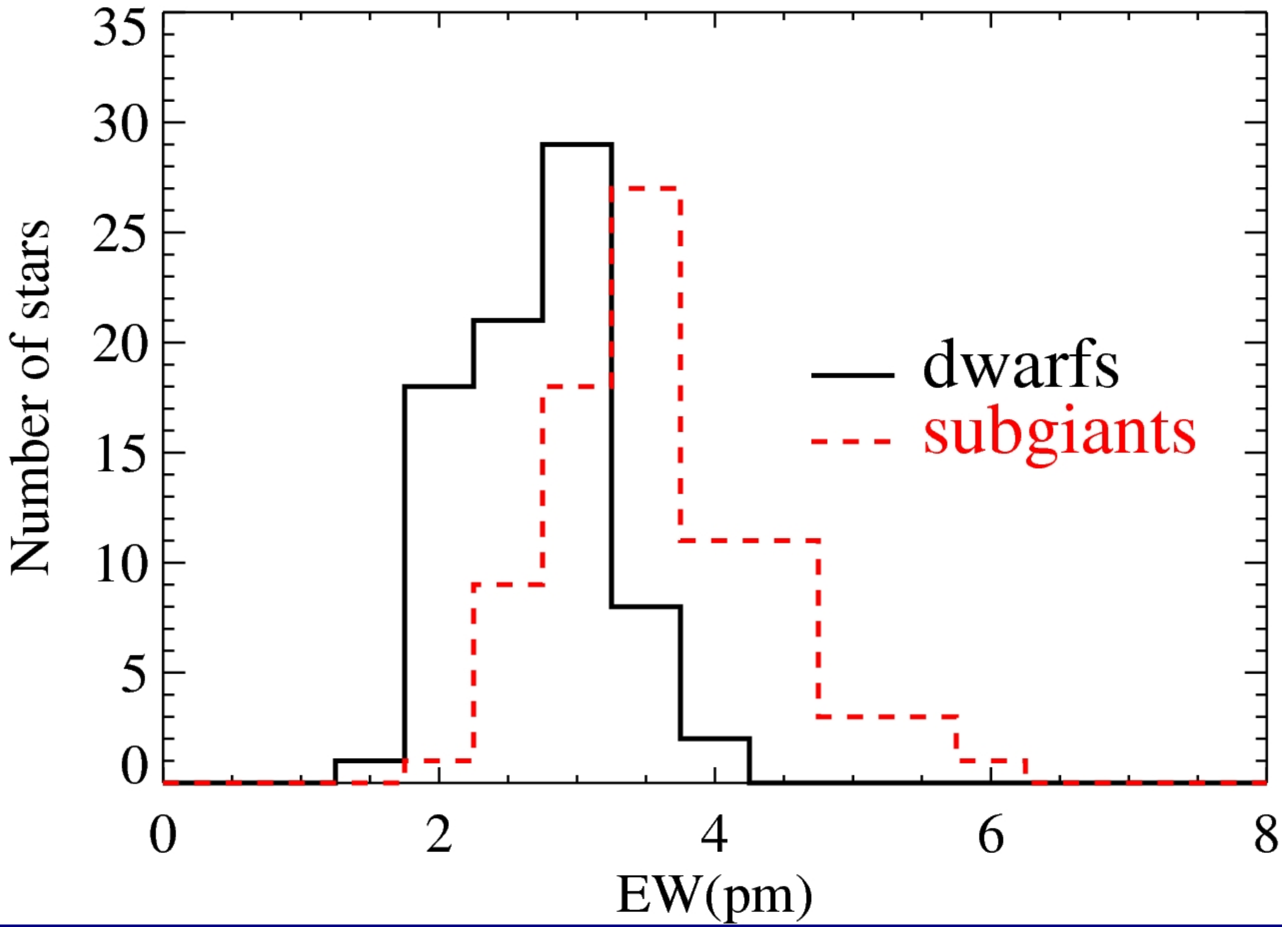


❖ **Dwarf star**



Equivalent Width of Lithium

- Subgiants vs. dwarfs

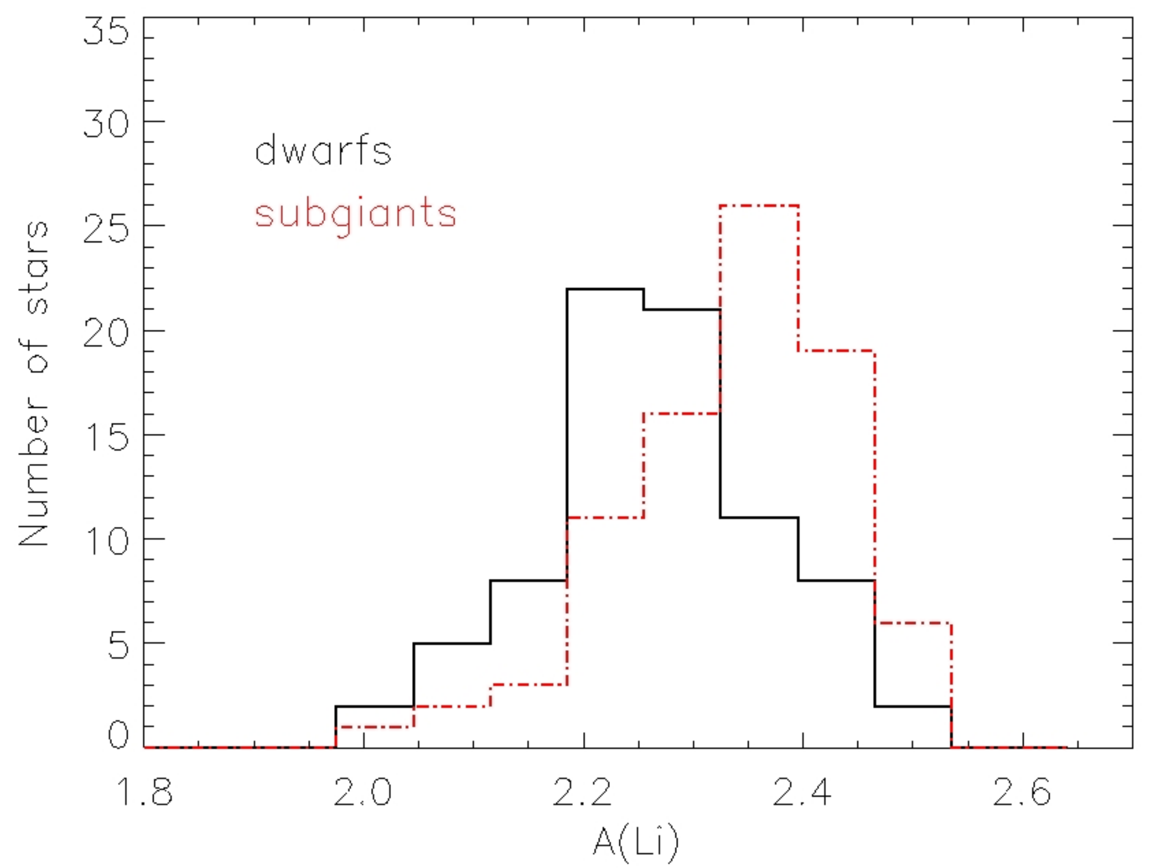


3D NLTE Lithium abundances

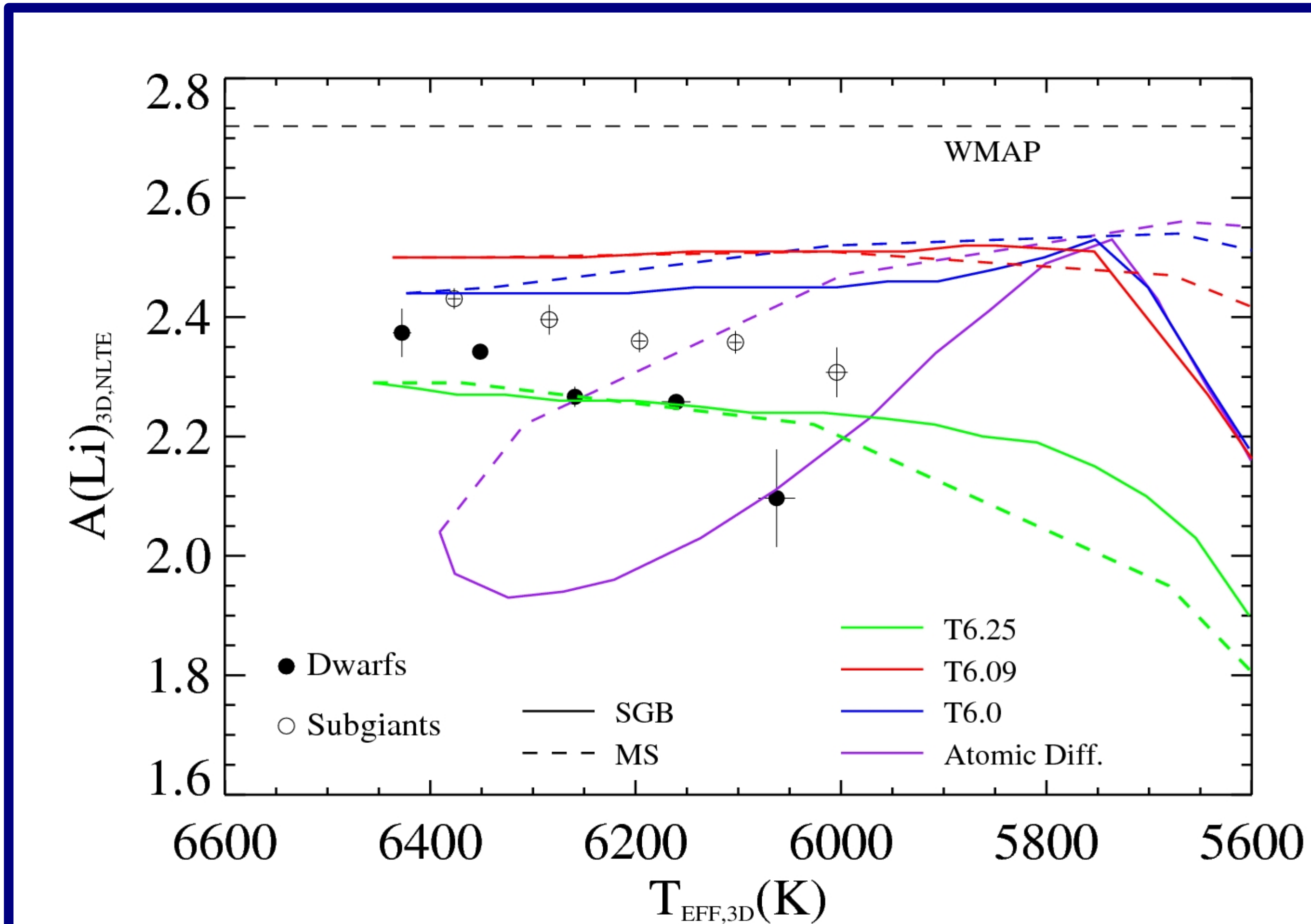
- We determine the curve of growth of Li for each of the 3D models with NLTE performed using the same code and model atom as in Cayrel et al. (2007), more details in Sbordone et al. (2009,submitted, Poster N. 27)
- We determine the Li abundance using a analytical fit as a function of the stellar parameters, metallicity and the observed EW of Li of each star (see Sbordone et al. 2009, submitted, Poster N. 27)

3D NLTE Li abundances

- Subgiants & Dwarfs



3D NLTE Li abundances and 3D Teff of subgiants and dwarfs vs. Turbulent-Diffussion models



González Hernández et al. (2009, A&A, 505, L13-L16)

Conclusions

- Li surface abundance changes with evolutionary status.
- The Li abundance pattern seen in the globular cluster NGC 6397 has not been observed so far in field stars.
- The cosmological lithium problem still awaits a solution.
- Our observations call for new investigations into the stellar physics, including gravity waves, atomic diffusion, winds and turbulent mixing

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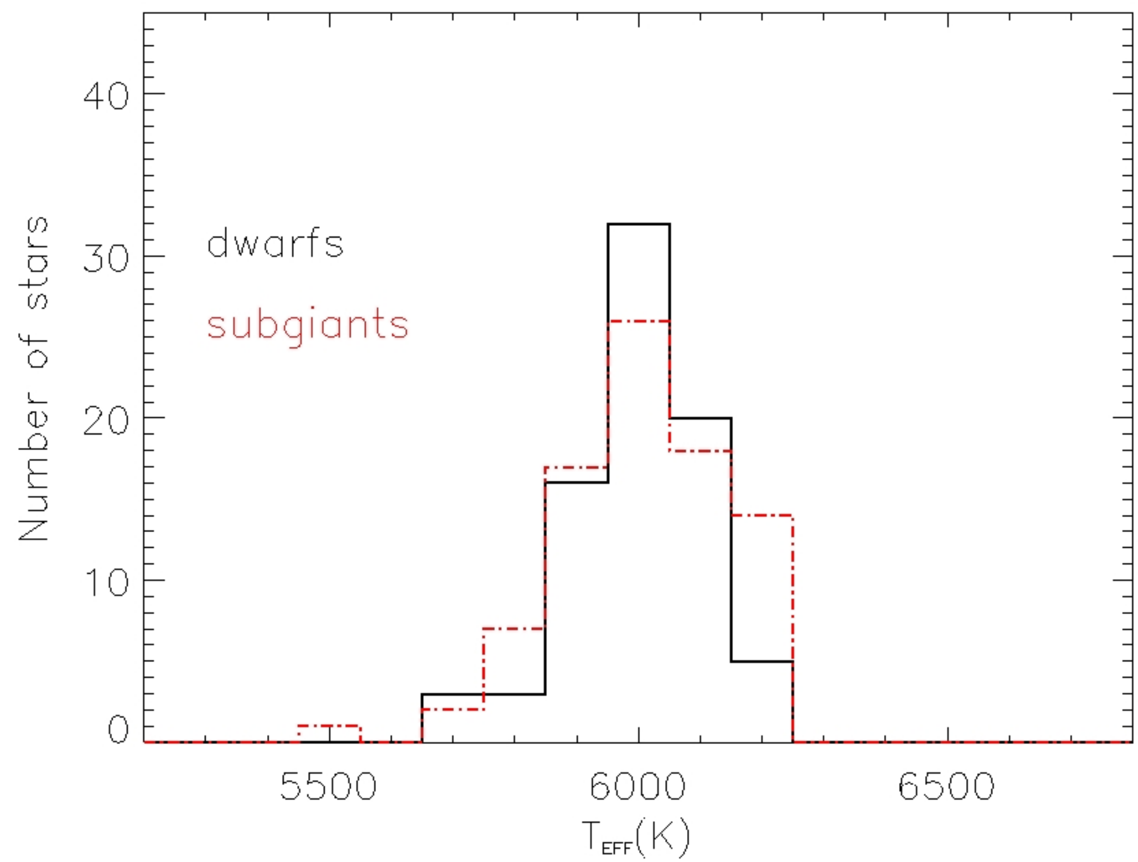
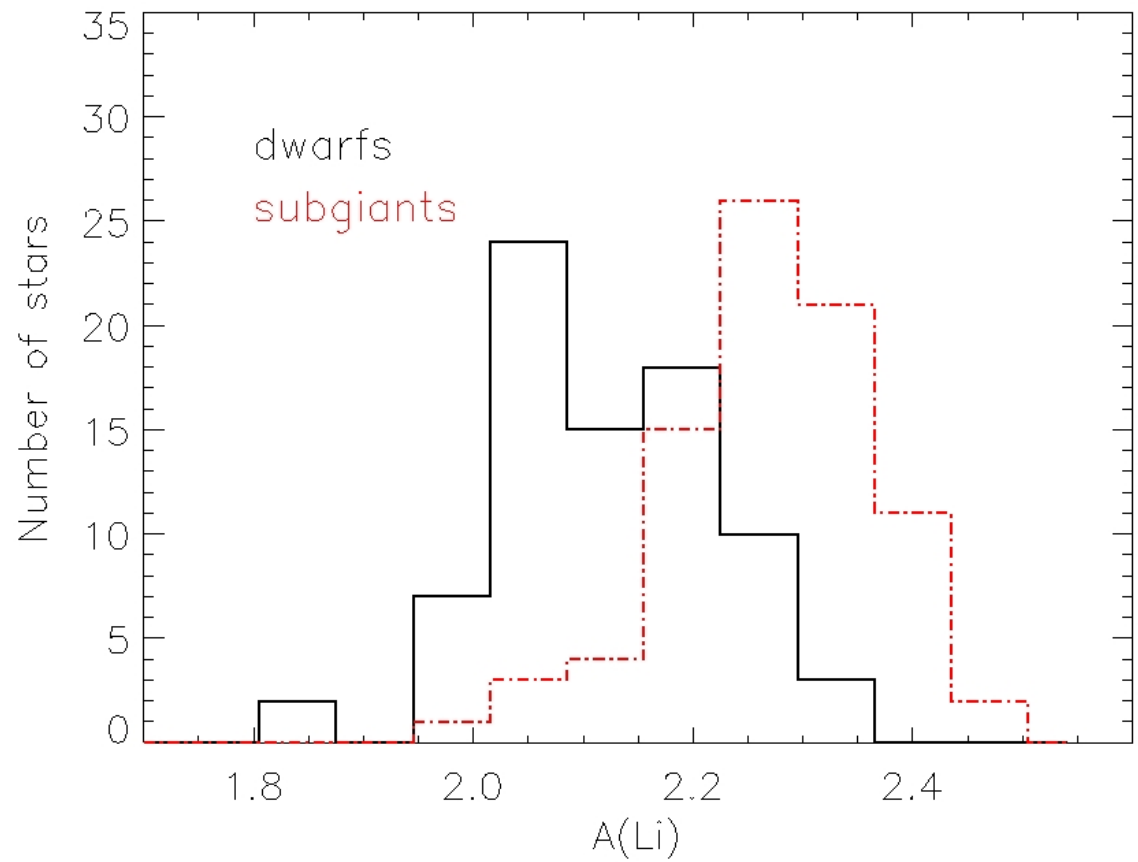
1D Temperatures

- Subgiants & Dwarfs



1D NLTE Li abundances

- Subgiants & Dwarfs



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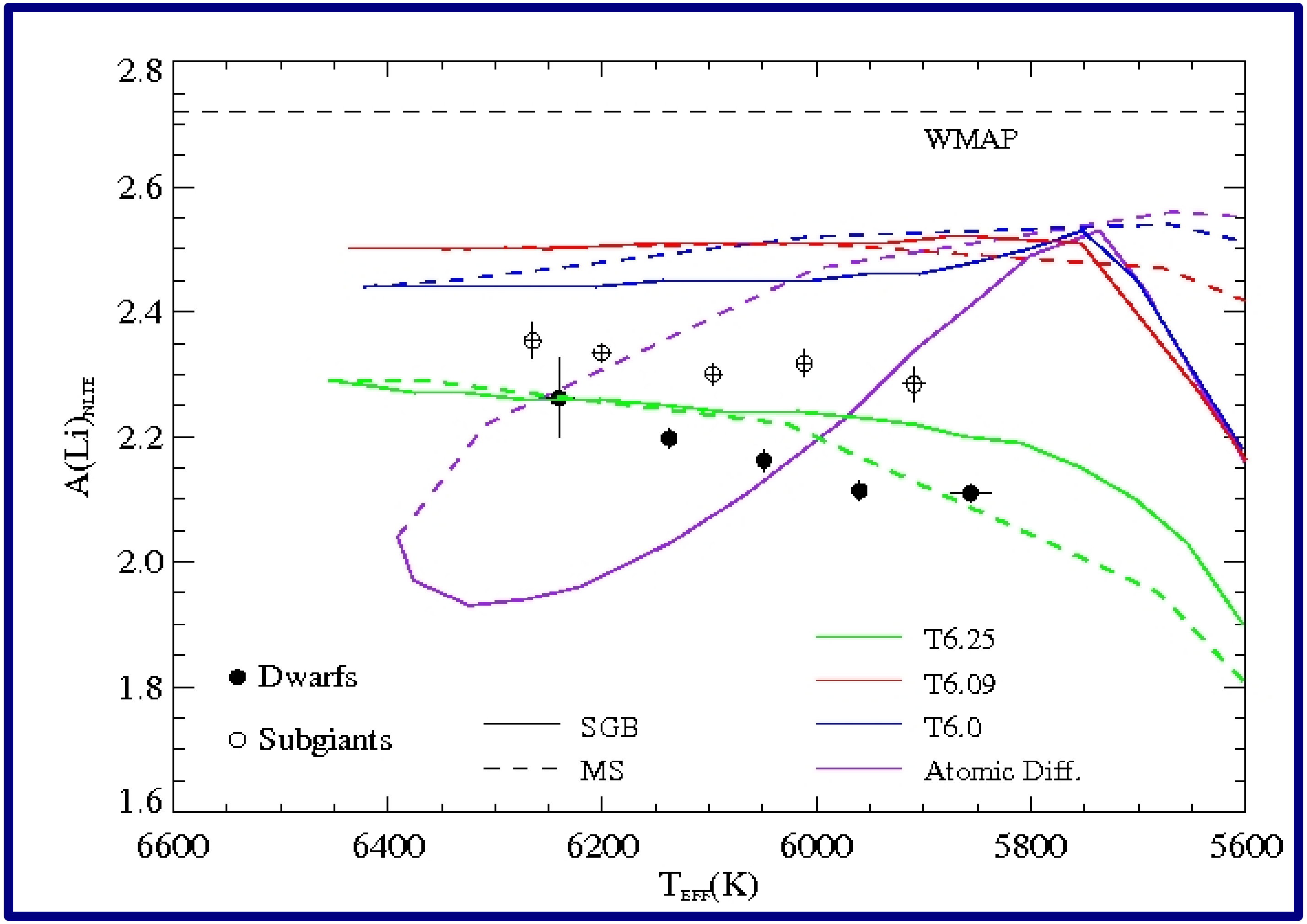
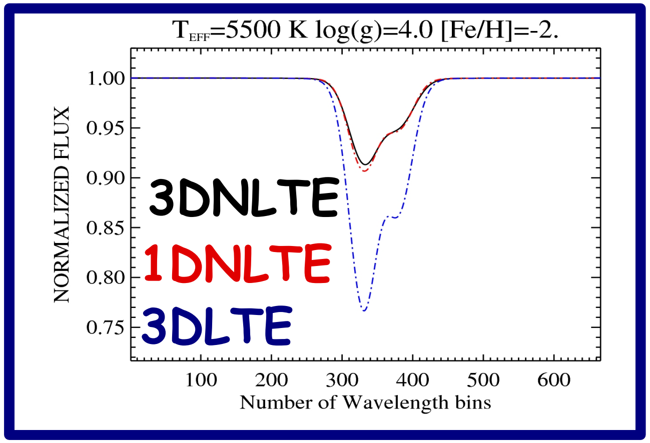


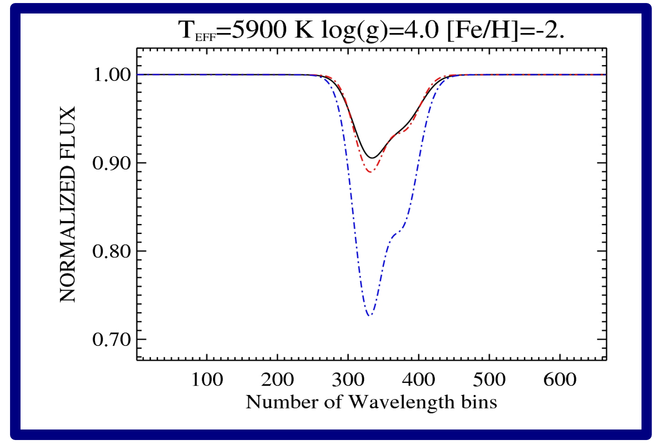
González Hernández et al. (2009, IAU266, arXiv0910.2305)

Lithium profiles:

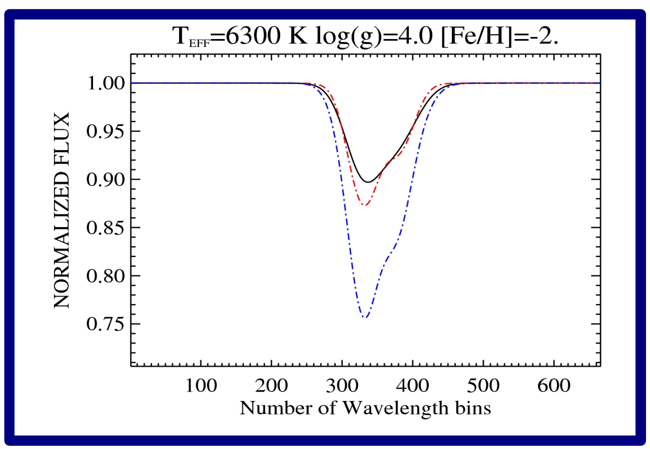
- Teff = 5500 K



- Teff = 5900 K



- Teff = 6300 K



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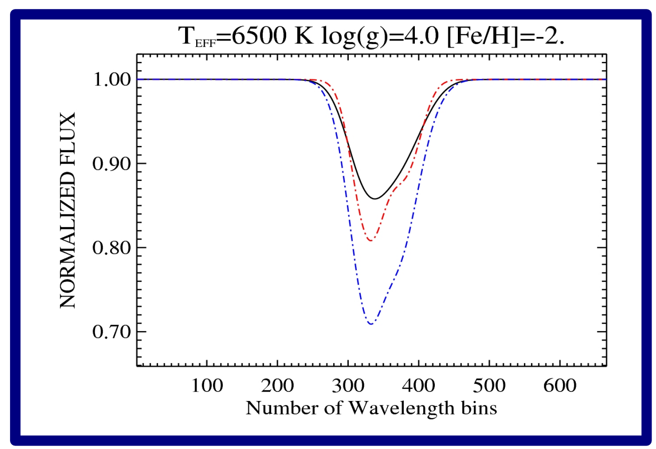
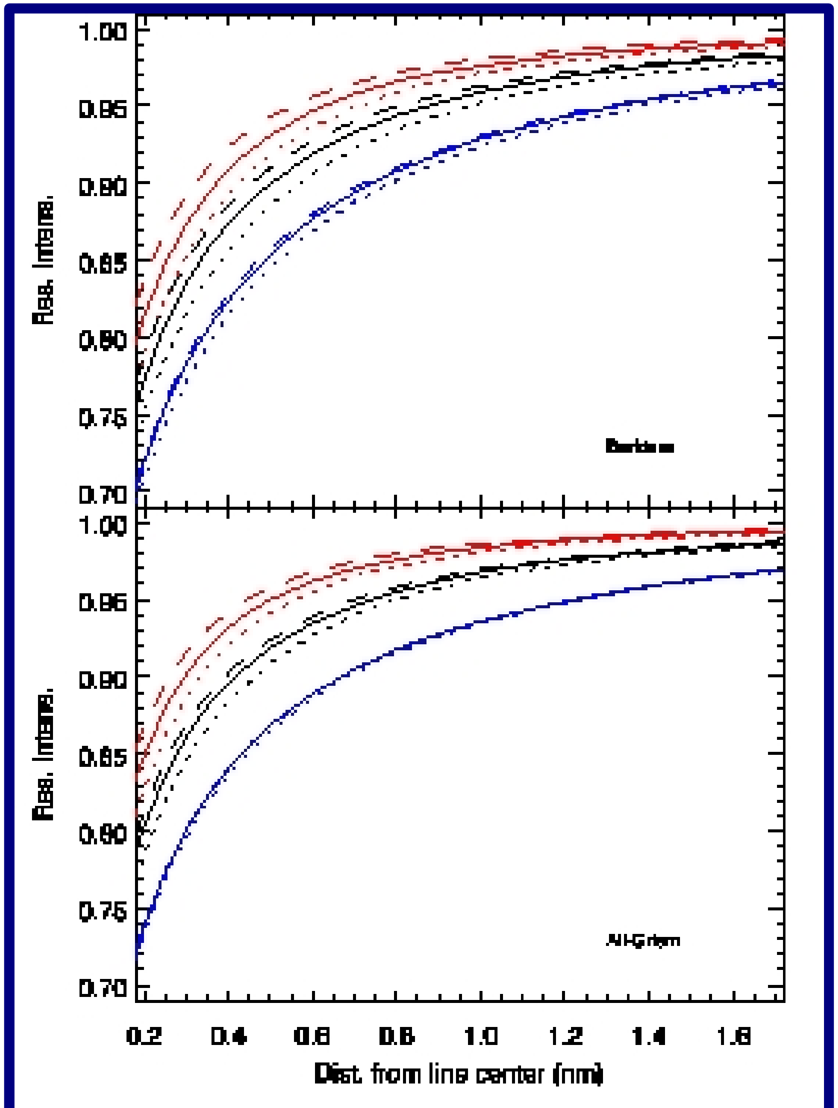
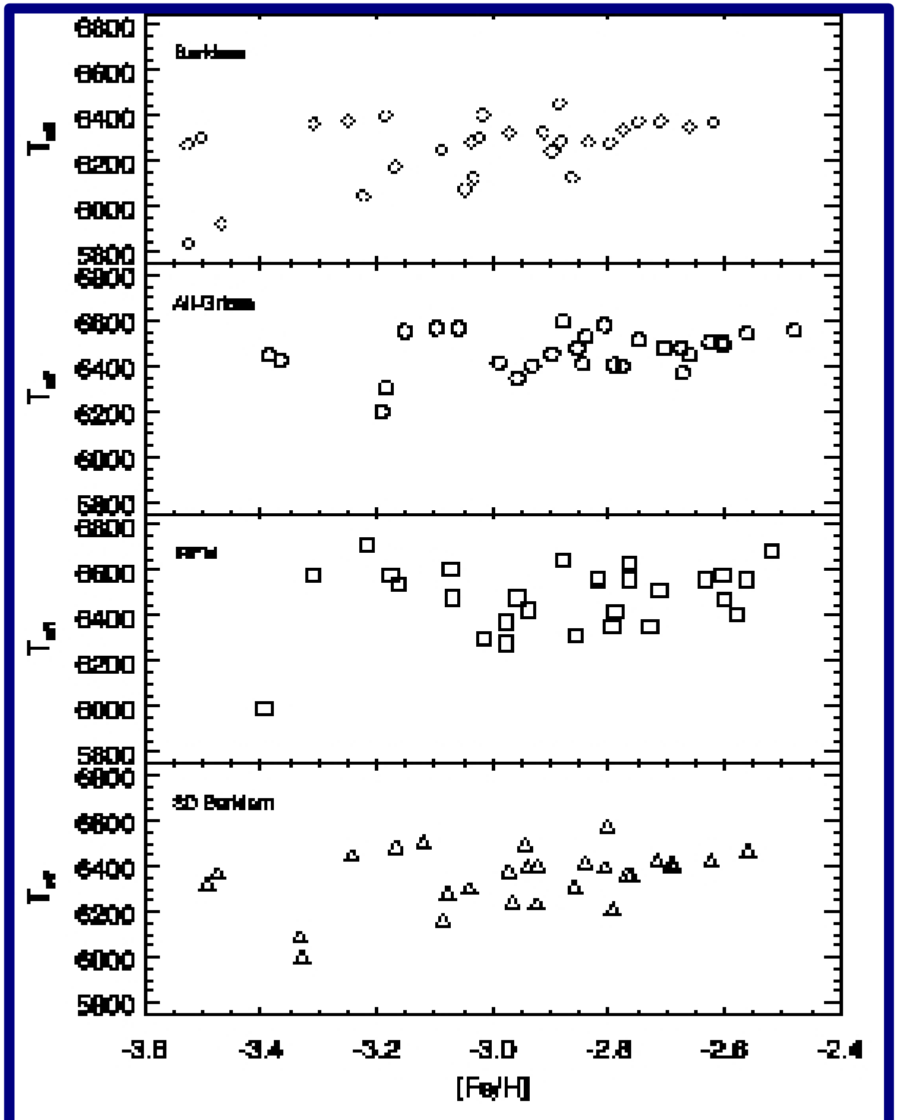


Gravity & Temperature dependence of Hα profiles



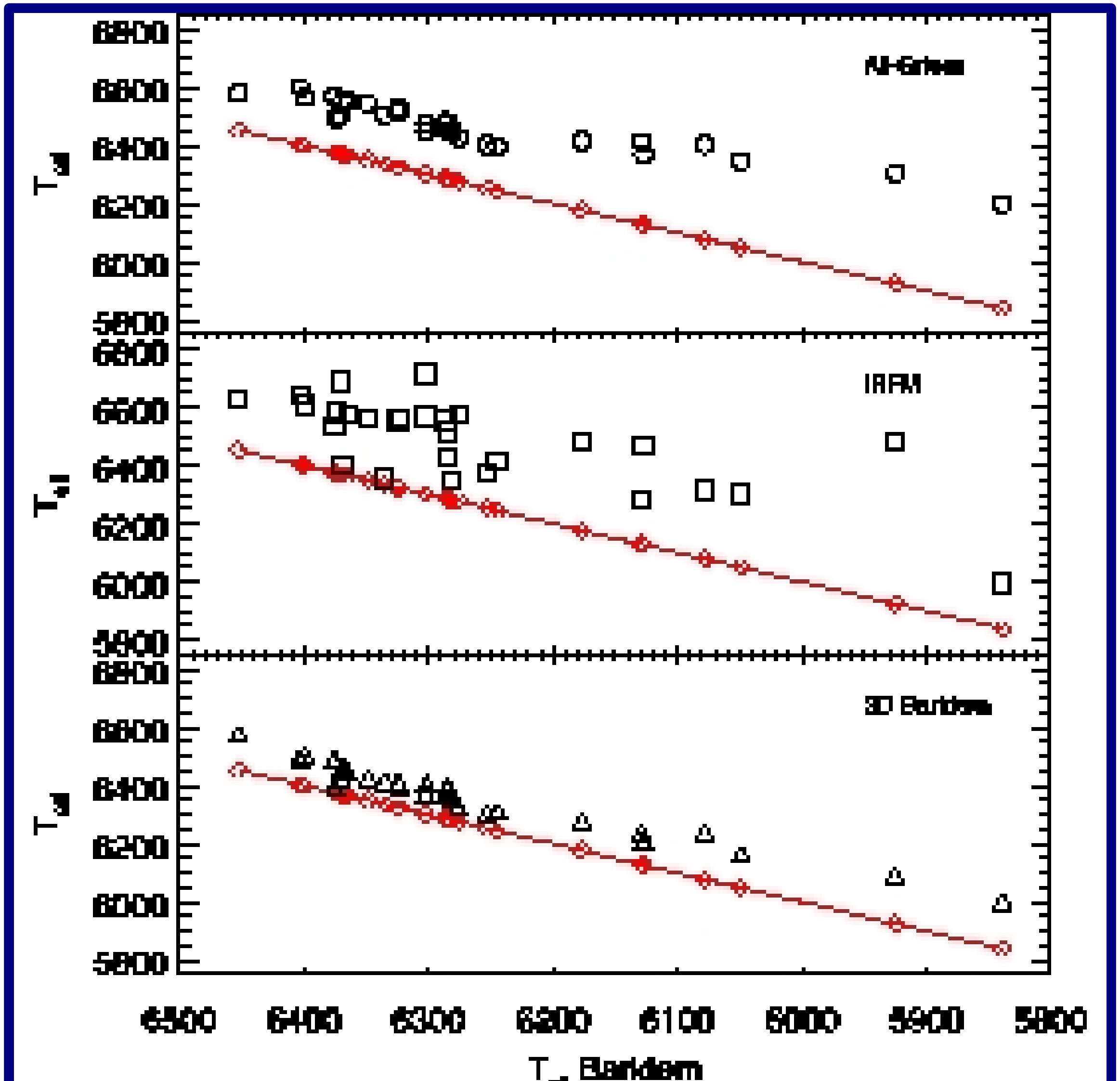
Sbordone et al. (2009, submitted)

Teff vs. [Fe/H]: field metal-poor stars



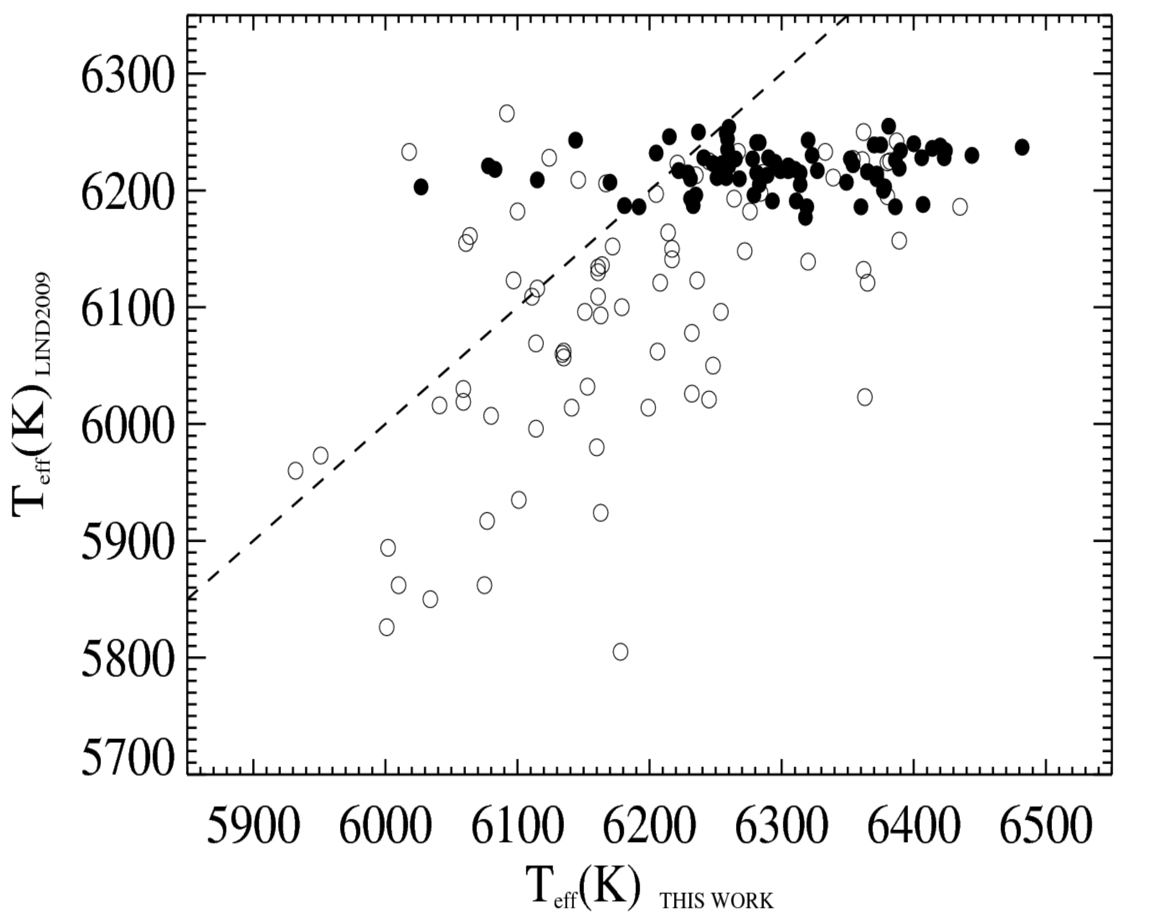
Sbordone et al. (2009, submitted)

1D Barklem Teff vs. IRFM, Ali-Griem and 3D Teff: field metal-poor stars

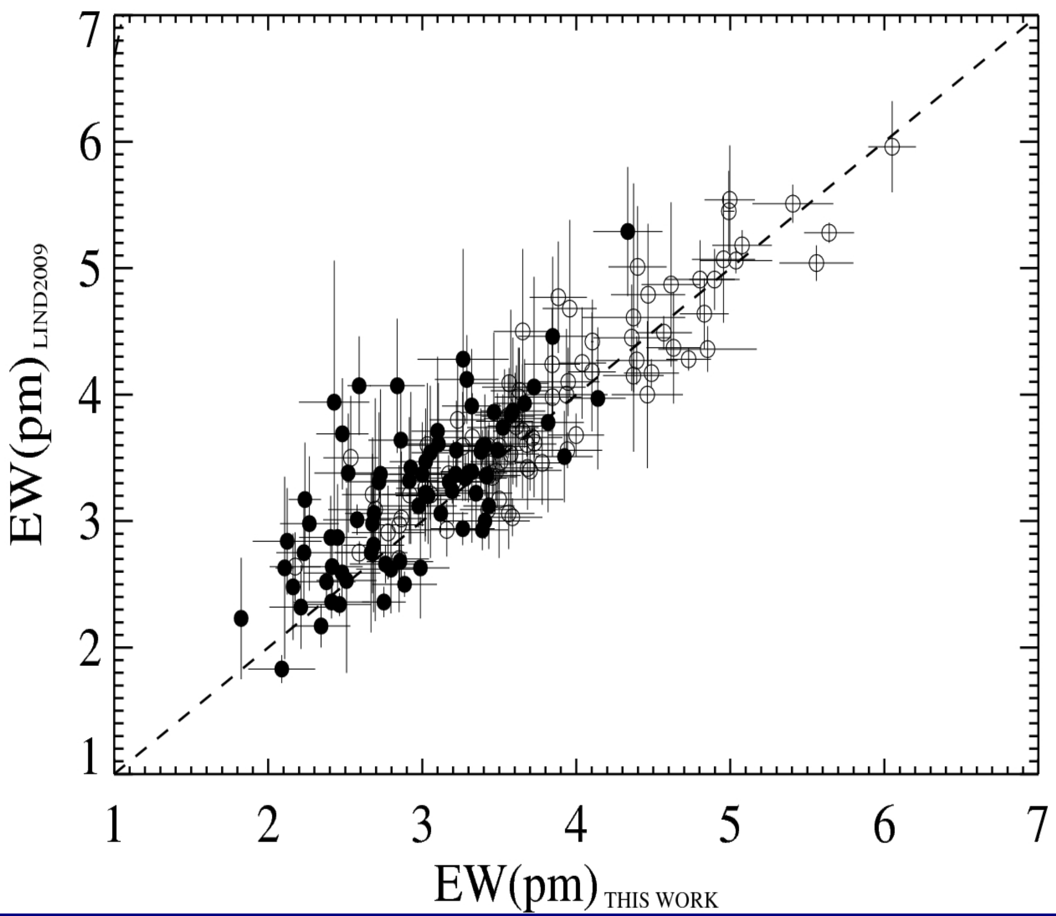


Sbordone et al. (2009, submitted)

Teff: Lind2009's vs. Ours

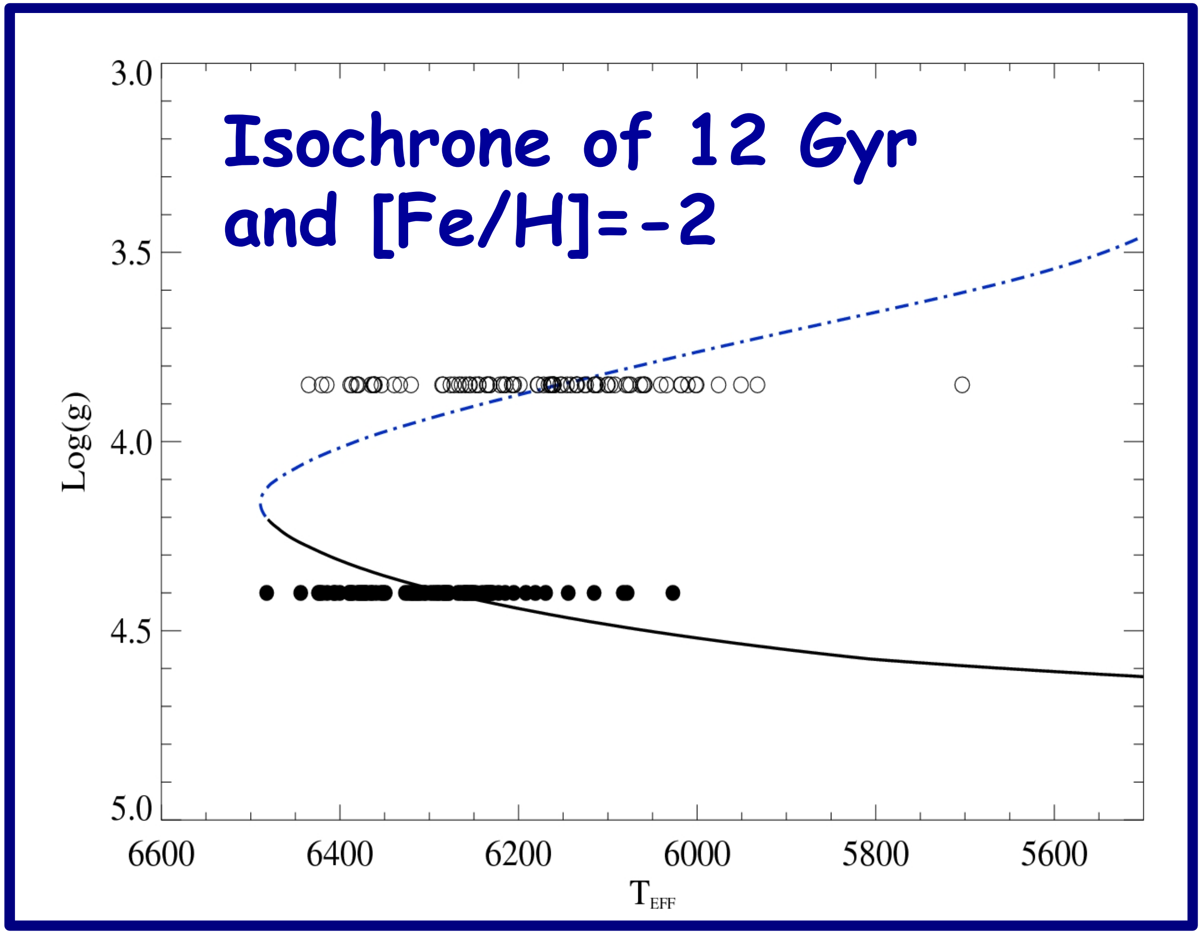


EW: Lind2009's vs. Ours



Surface gravities

- We adopt a logg = 3.85 for subgiants and 4.4 for dwarfs



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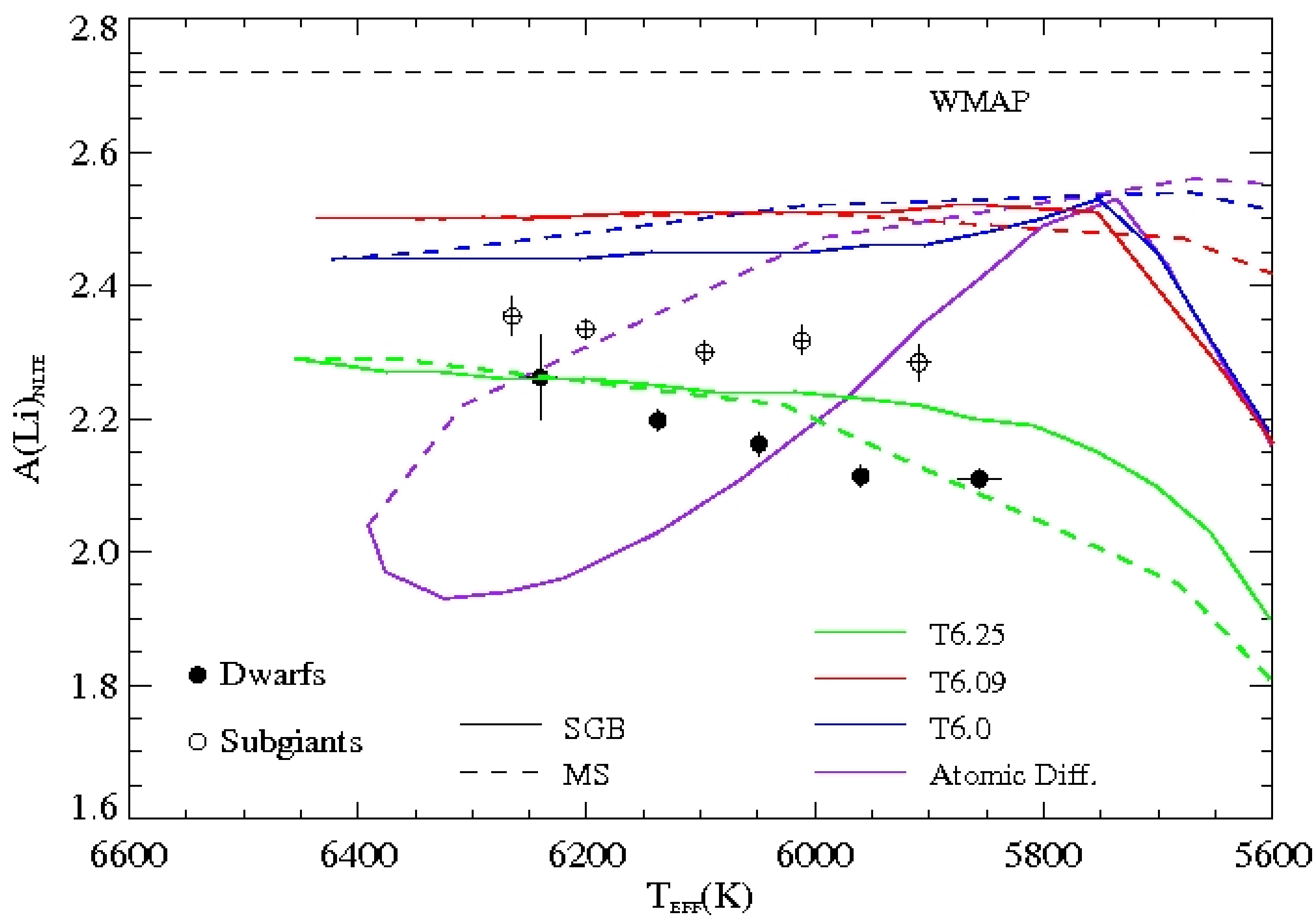
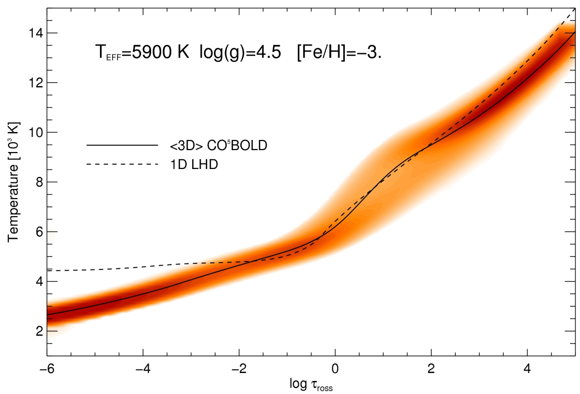
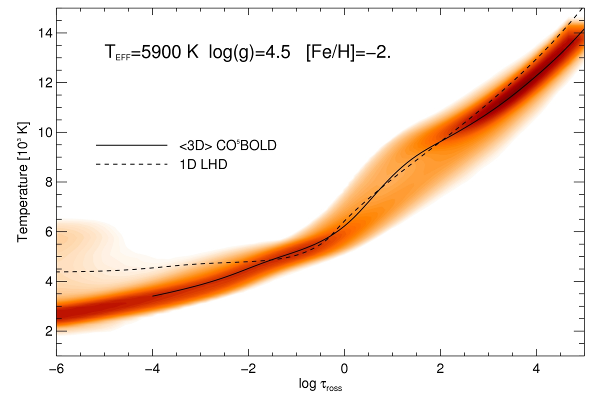


3D Models : metallicity dependence

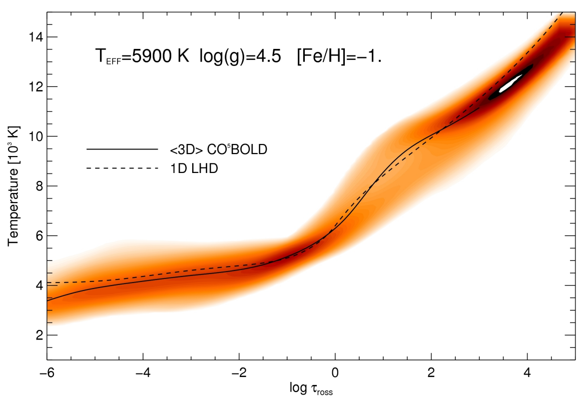
❖ [Fe/H] = -3



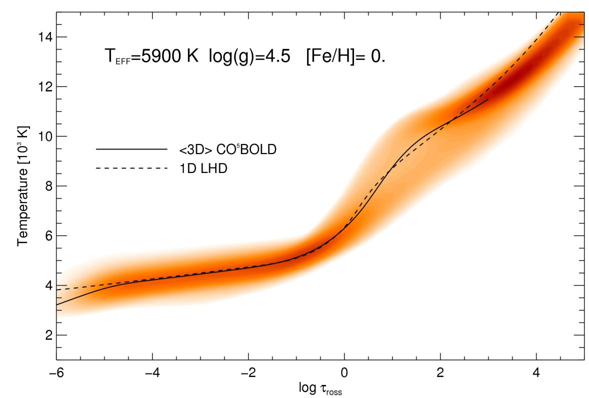
❖ [Fe/H] = -2



❖ [Fe/H] = -1

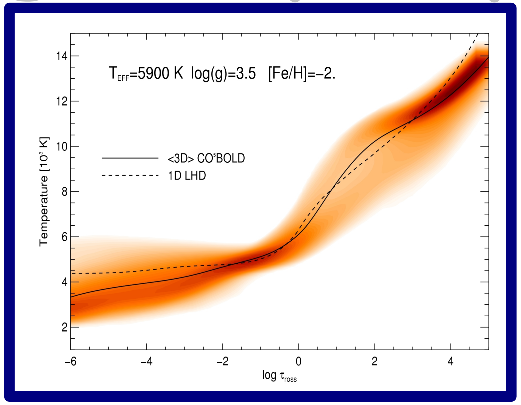


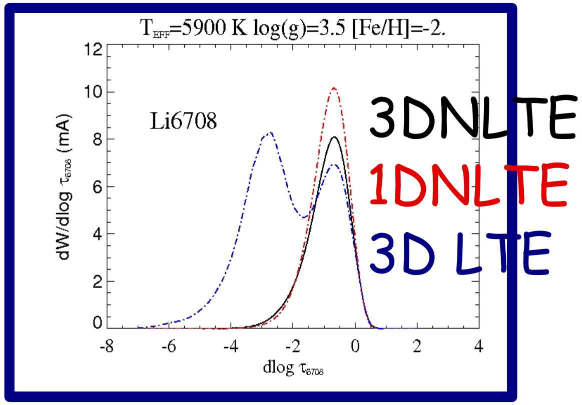
❖ [Fe/H] = 0



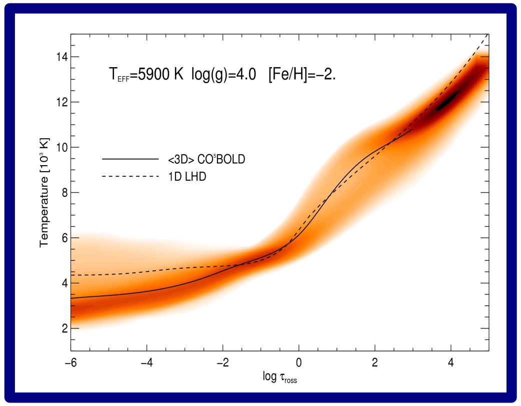
3D Models : gravity dependence

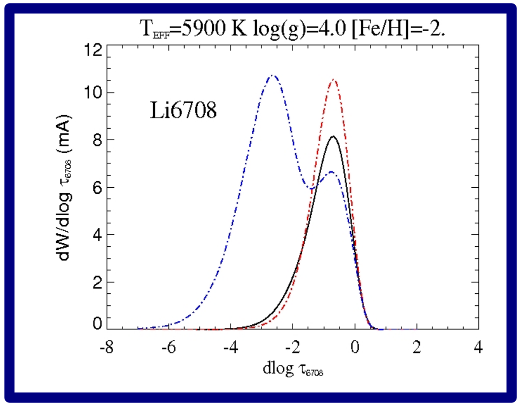
- **Log(g) = 3.5**



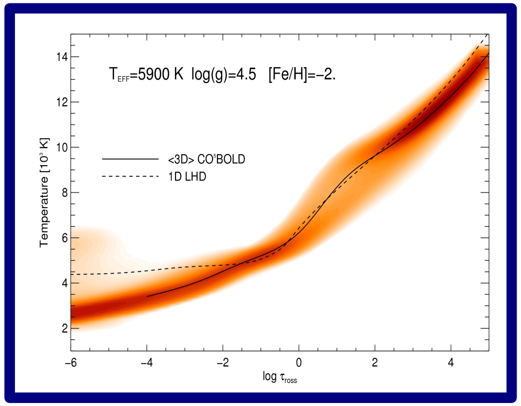


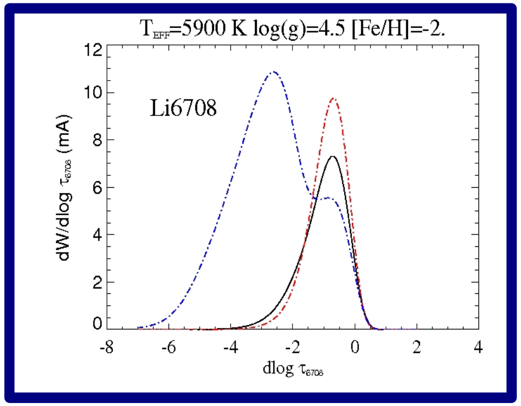
- **Log(g) = 4.0**



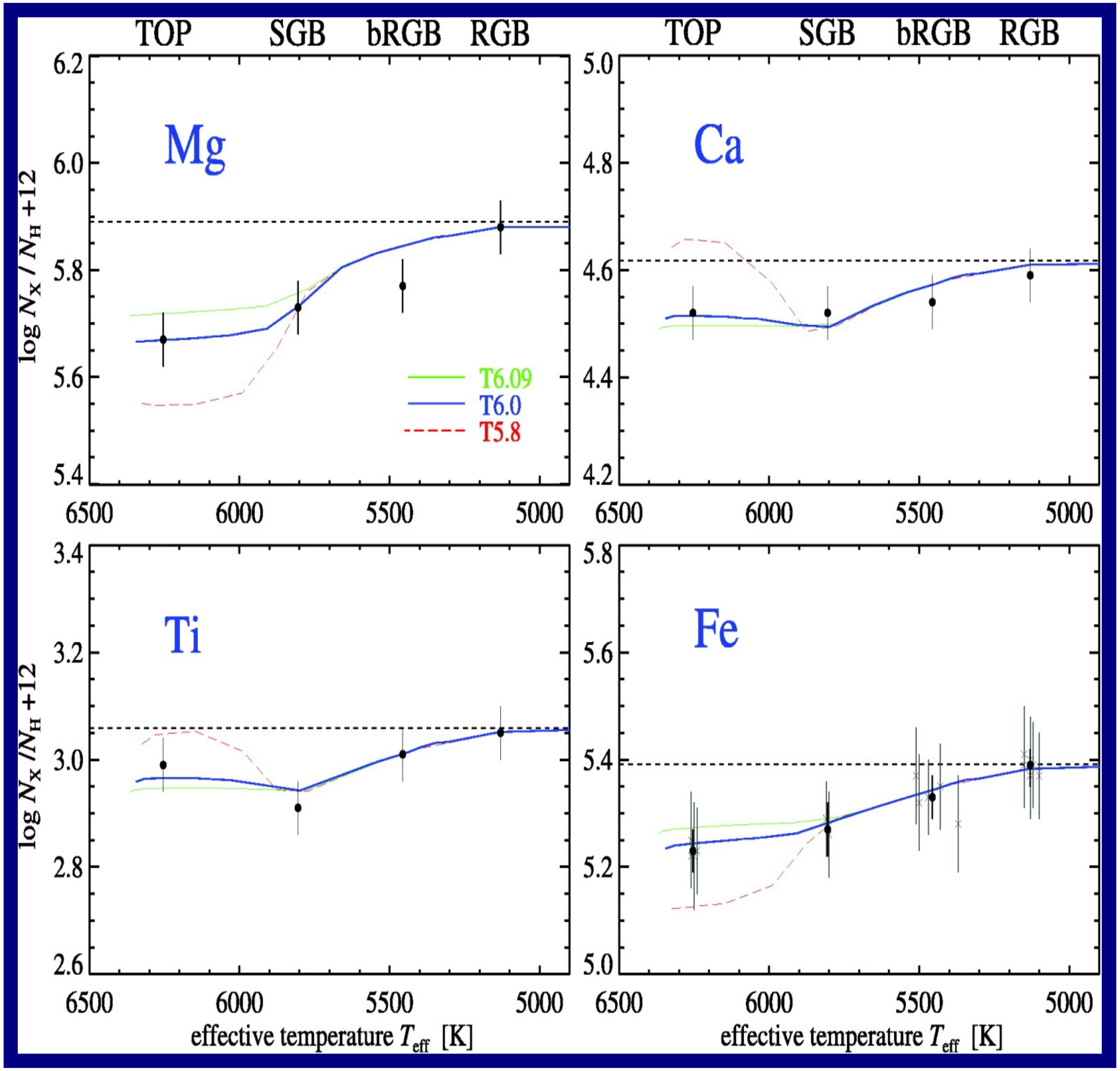


- **Log(g) = 4.5**





Turbulent diffusion models



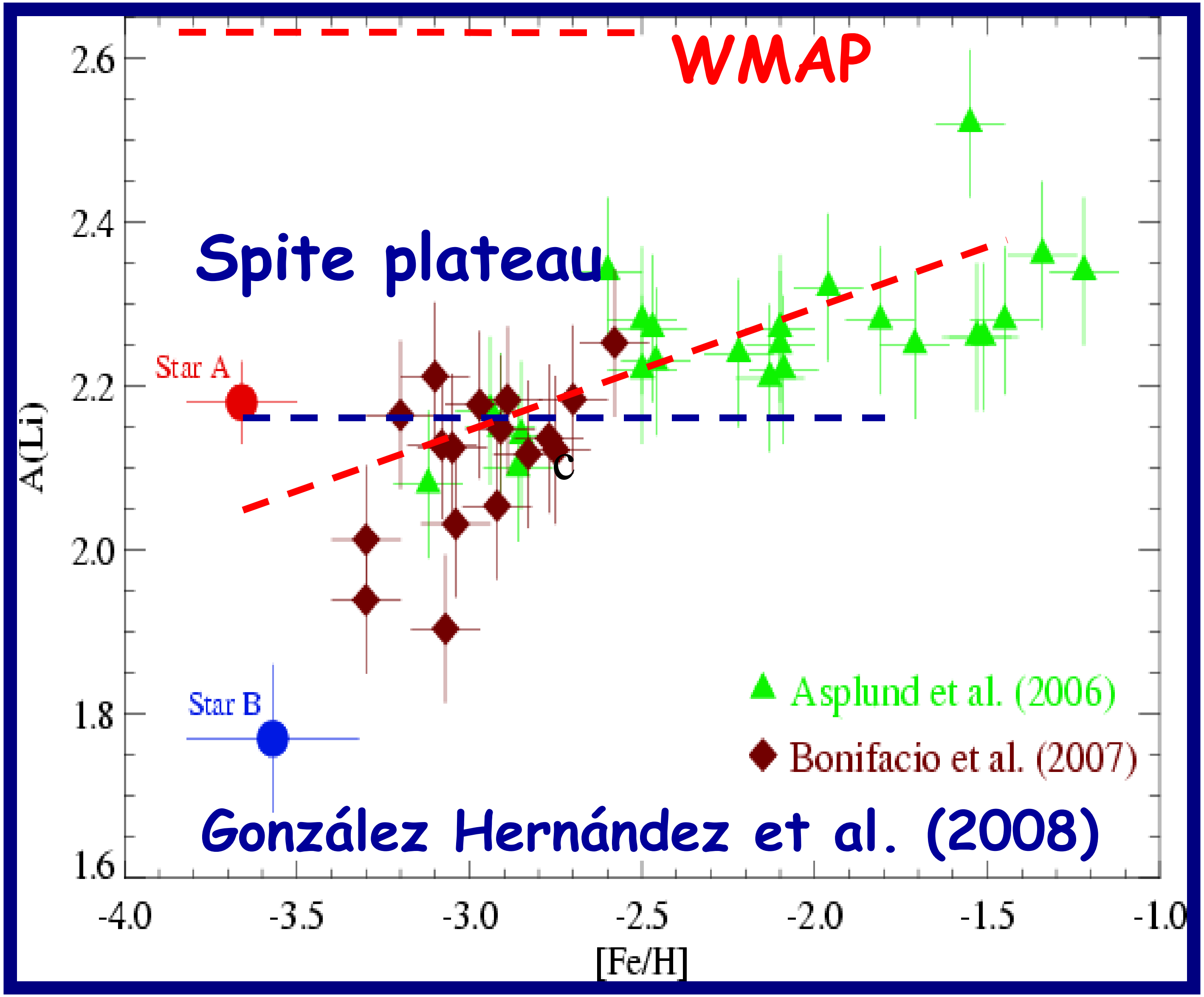
T6.09

T6.0

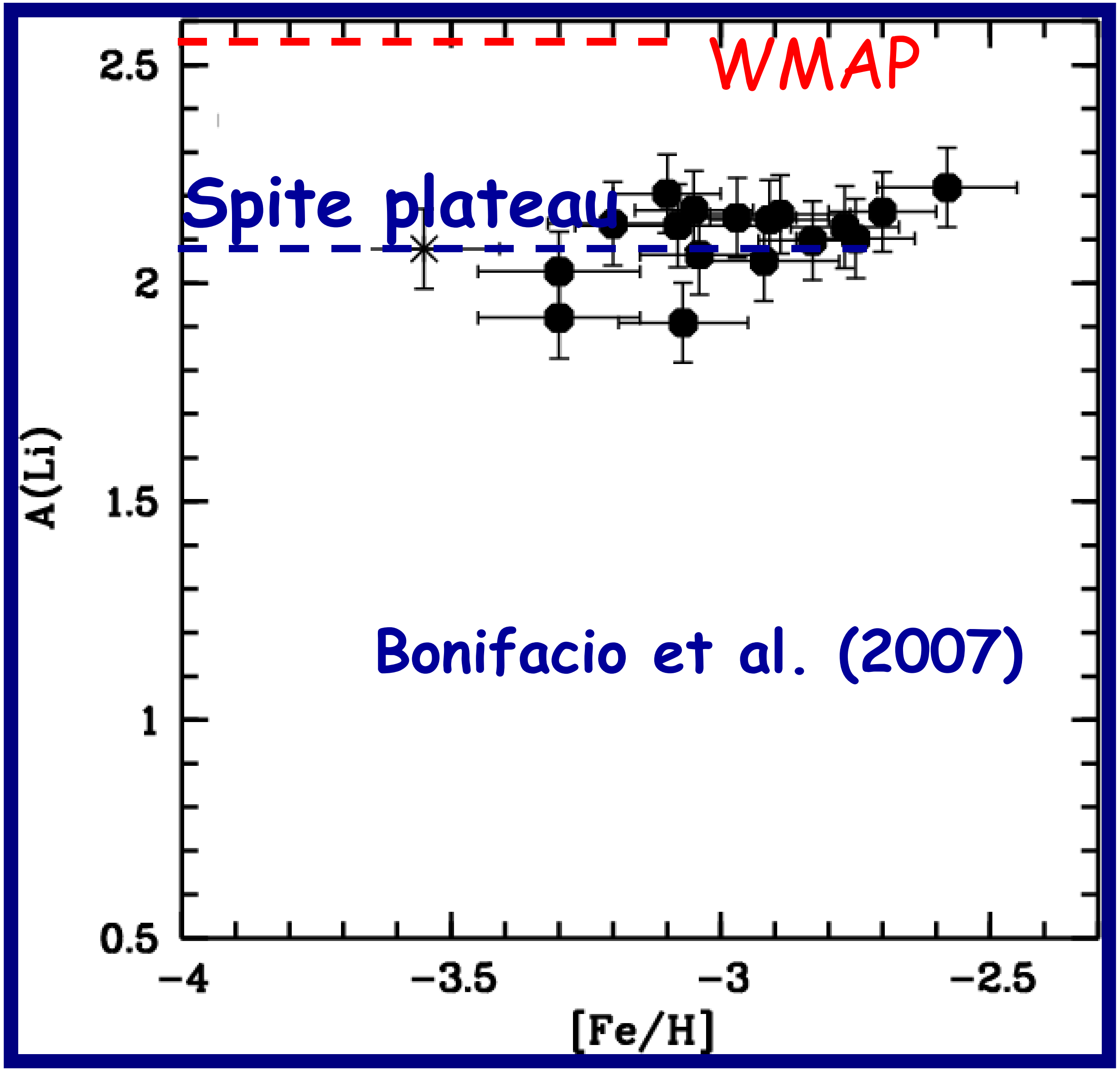
T5.8

Korn et al.
(2006, 2007)

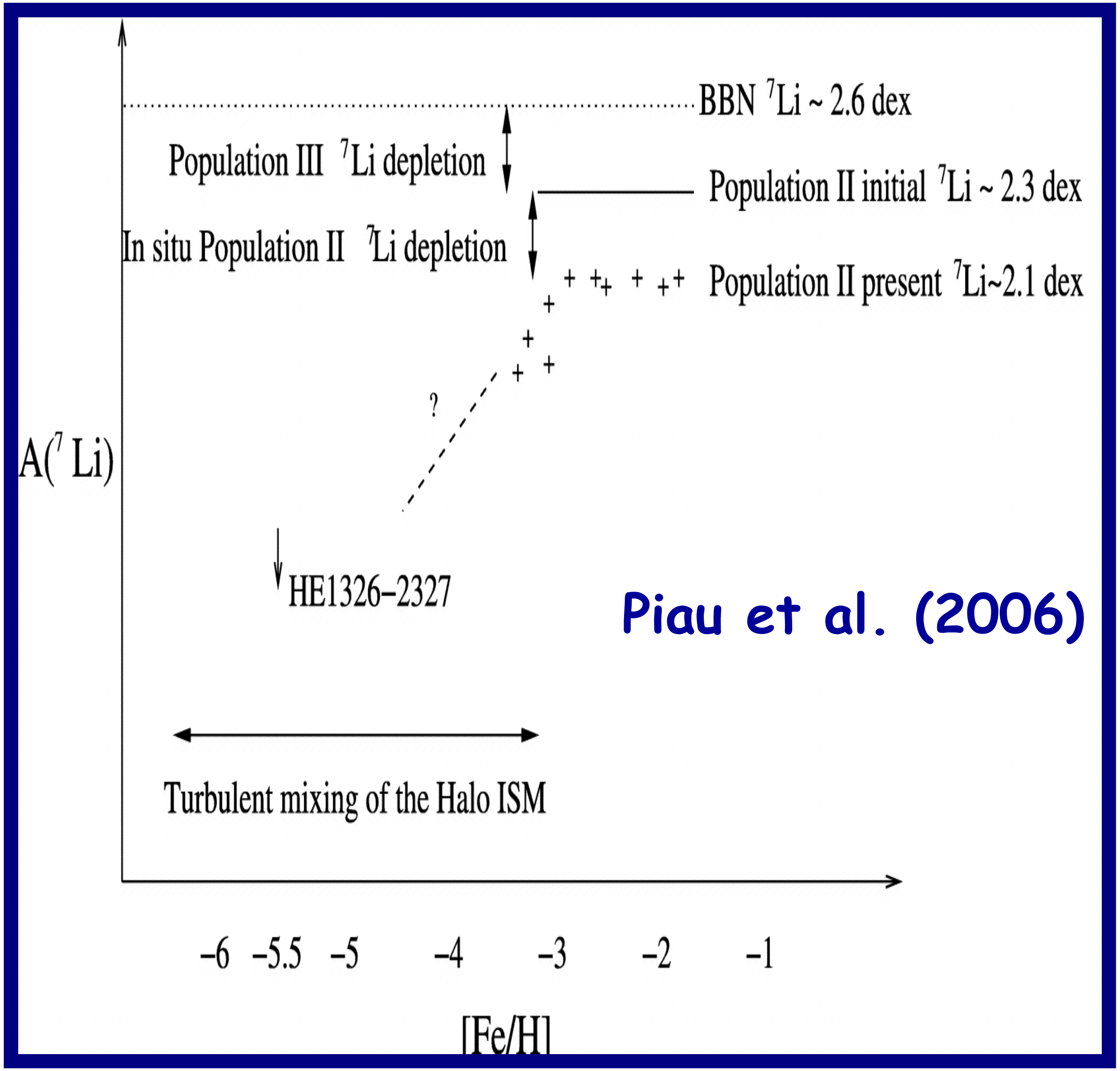
Lithium in metal-poor stars



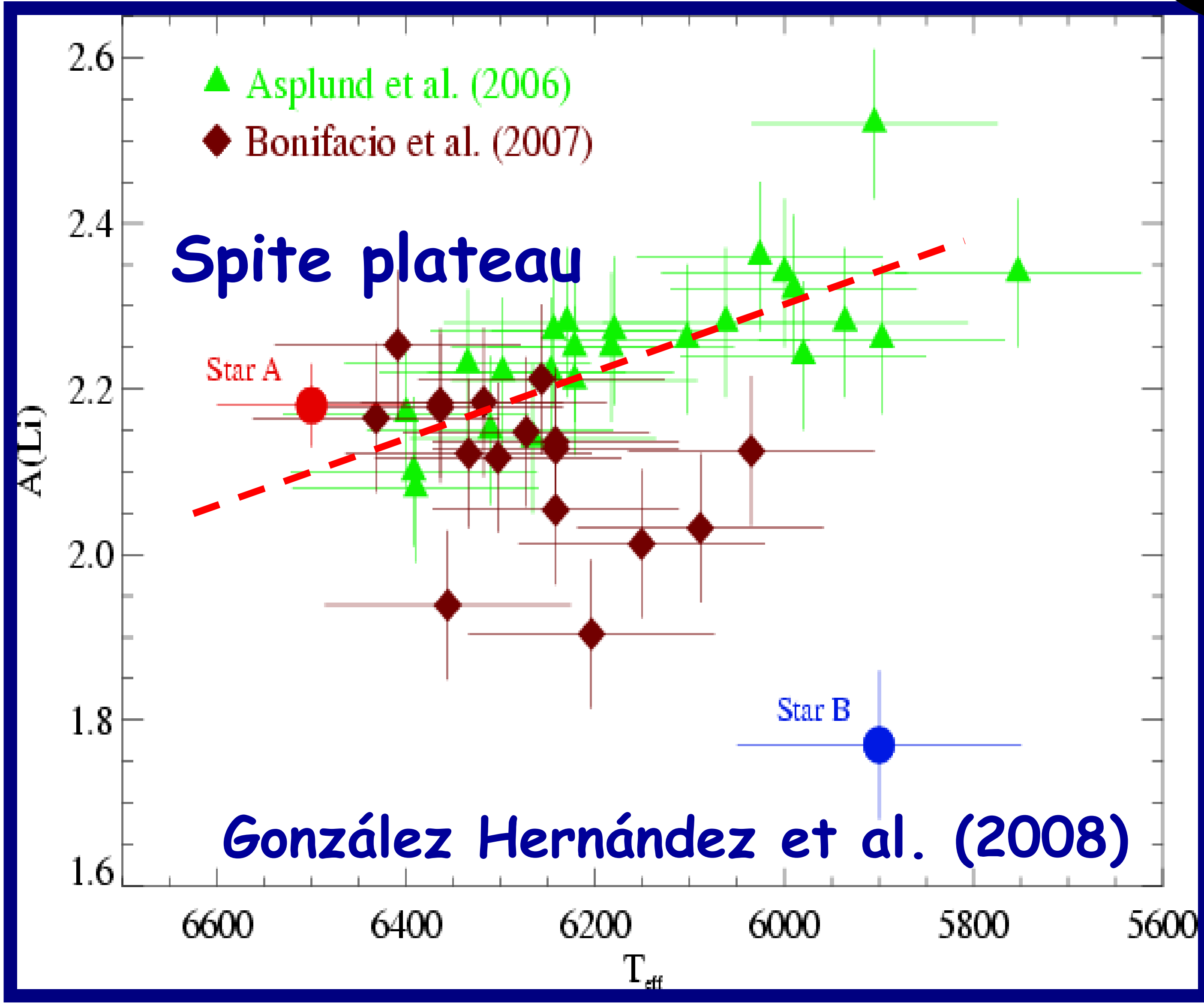
Lithium in metal-poor stars



Pre-Galactic Li depletion



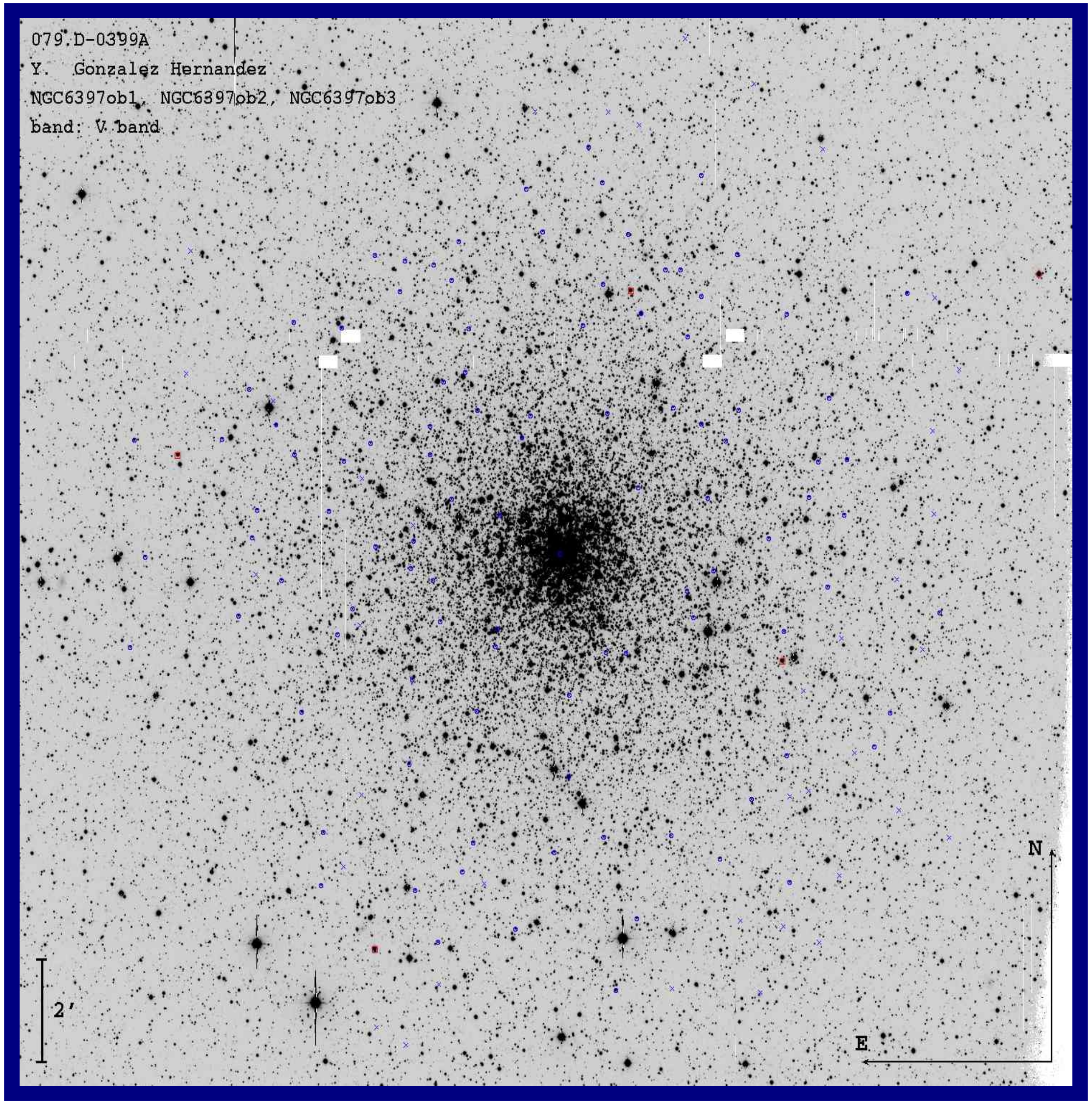
Lithium in metal-poor stars



Non-standard BBN

- In SBBN: possible large errors on the cross-sections of $^{3}He(\alpha,\gamma)^{7}Be$ reaction seems unlikely
- Late-decaying massive particles (Jedamzik 2004): electromagnetic decay implies D abundance too high or $^{3}He/D$ ratio too low (Ellis et al. 2005)
- If the decaying particle = gravitino, then Spite plateau and baryonic density determined by WMAP may be reconciled (Jedamzik 2006).

Fiber positioning



- Globular cluster NGC 6397
- [Fe/H] = -2.

Equivalent width of Lithium

- We use an automatic program that fits the observed Li profile with synthetic spectra and determines the EW
- We fix the instrumental broadening to 17.6 km/s

Conclusions

- The result presented here are preliminary, but they show that the solution to the cosmological lithium problem is not yet solved.

- There exist observational evidence in field stars with subgiants more Li abundant than turn-off stars (Charbonnel & Primas 2005)

Conclusions

- This points towards that internal gravity waves may be the solution to the Li problem (Talon & Charbonnel 2004), although atomic diffusion and rotation should be also important

- We plan to observe the same sample of stars with FLAMES/GIRAFFE at VLT using a blue setup to be able to determine the Fe, Mg, Ti and Ca abundances in order to definitely confirm this result