Galactic evolution of oxygen:
3D effects on the near-UV OH lines

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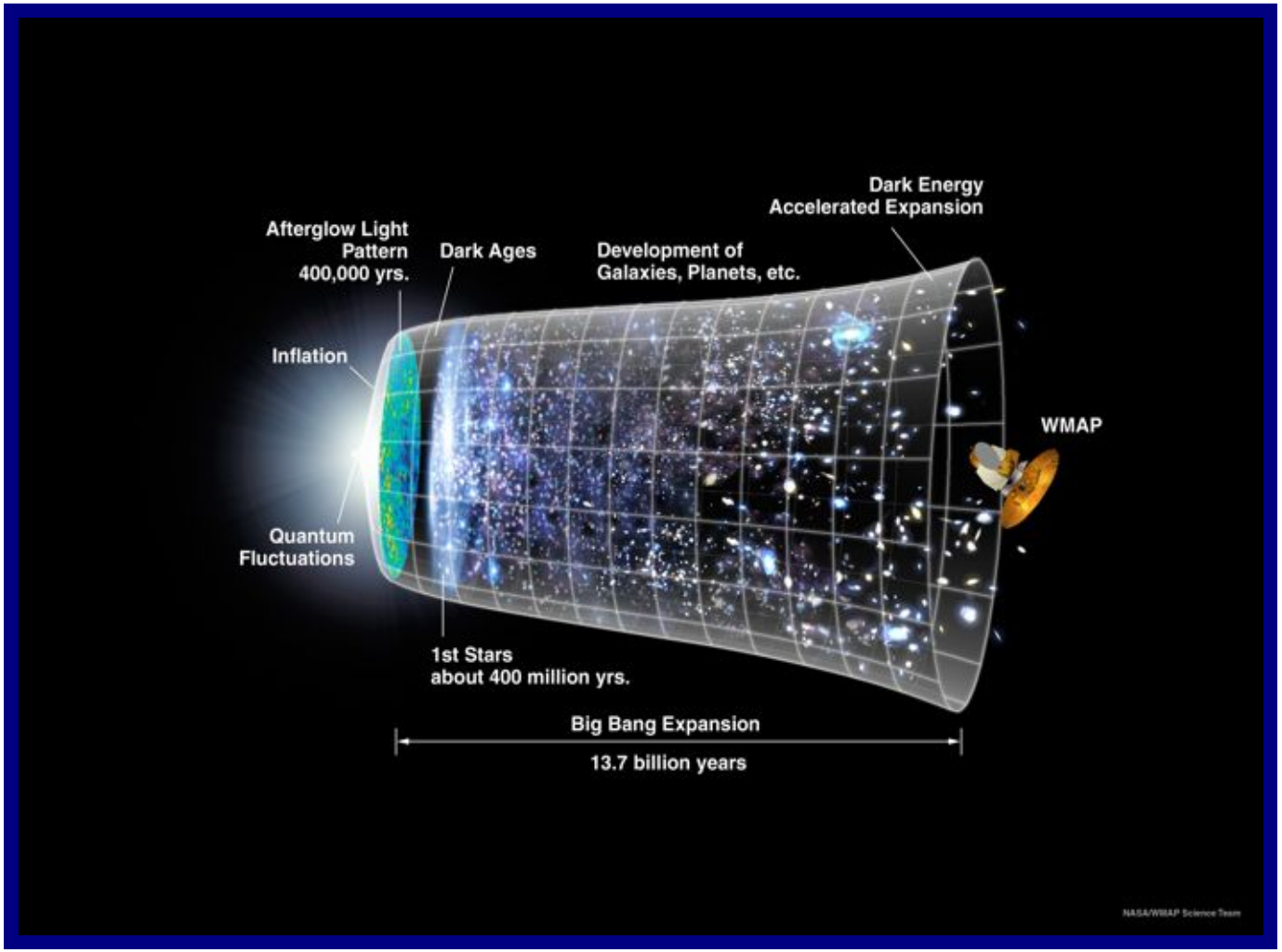
Outline

- Introduction:

the **oxygen problem**: the **Sun** and **metal-poor** stars

- 3D model grid
- 3D effects on OH and Fe lines
- 3D abundance corrections
- Discussion and conclusions

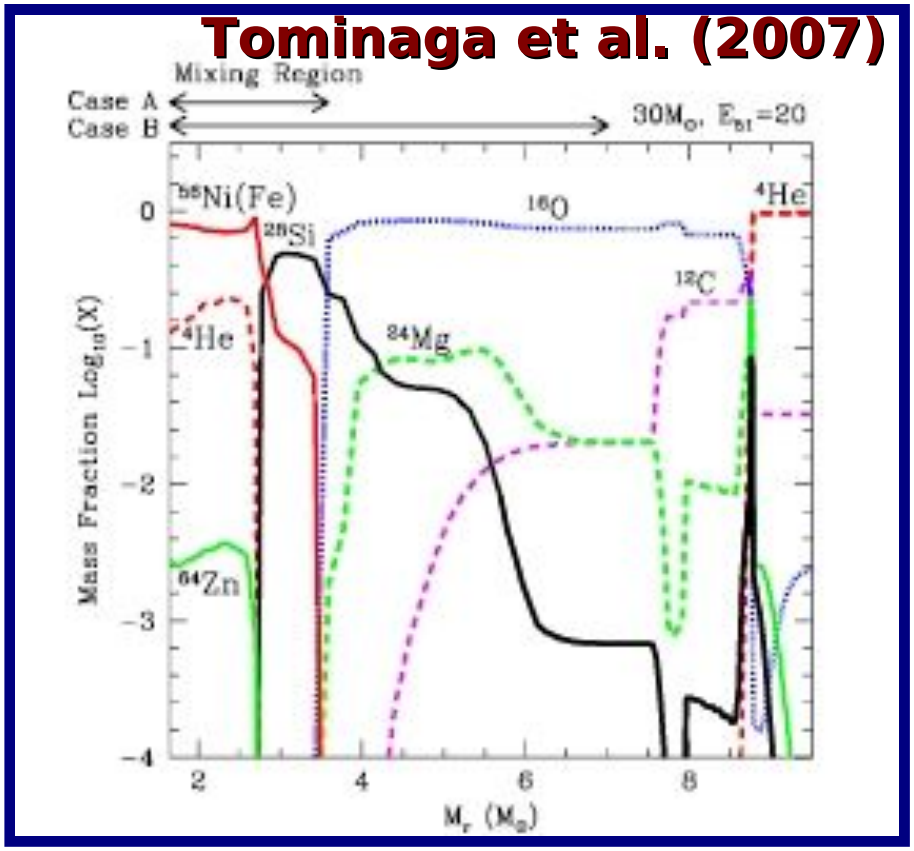
Introduction



Oxygen

- The most abundant element after H and He

- Produced during hydrostatic and explosive nucleosynthesis in massive stars



Oxygen

- Its abundance is determined from:
  - Forbidden lines [OI] 6300 and 6363 Å
  - permitted near-IR triplet OI 7772-5 Å
  - near-IR vibration-rotation bands
  - near-UV electronic transition lines

Oxygen in the Sun: 3D effects

1D analysis:

- Anders & Grevesse (1989); Grevesse & Noels (1996)
  log[N(O)/N(H)]+12= 8.93-8.87 (Z~0.020)

3D analysis

- Asplund et al. (2005)
  log [N(O)/N(H)]+12=8.66 ± 0.05 (Z=0.0122)

- Caffau et al. (2008,2011)
  log [N(O)/N(H)]+12=8.76 ± 0.07 (Z=0.0153)

- Asplund et al. (2009)
  log [N(O)/N(H)]+12=8.69 ± 0.05 (Z=0.0134)

Oxygen: metal-poor stars

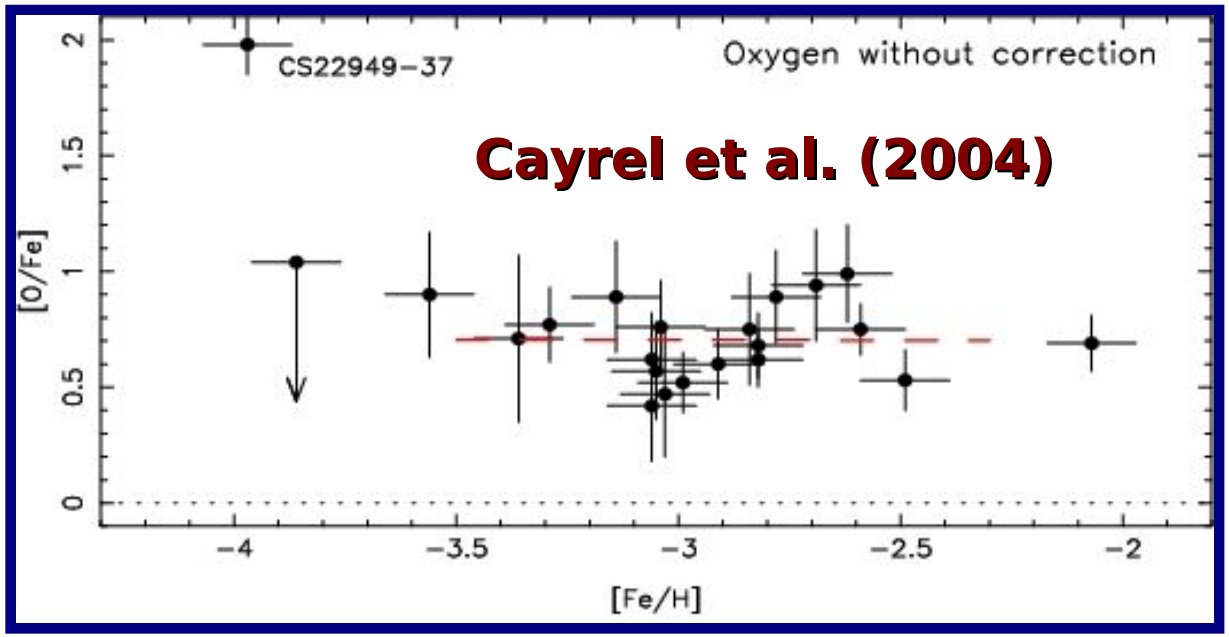
- Each O abundance indicator provides a different abundance trend O vs. Fe

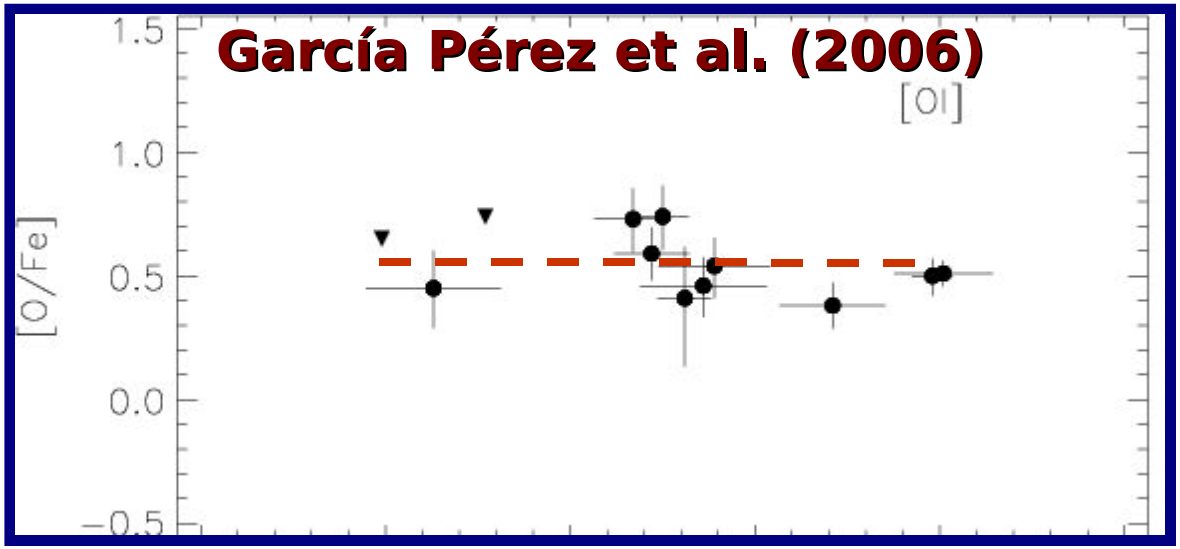
  - [OI] shows a quasi-plateau with [O/Fe]~0.5-0.7 in subgiants and giants (García Pérez et al. 2006; Cayrel et al. 2004) in the metallicity range -3.5 < [Fe/H] < -1.5

  - However, from [OI], Nissen et al. (2002) showed a linear increase [O/Fe] vs [Fe/H] in dwarfs in the range -2.5 < [Fe/H] < -0.5

Oxygen: forbbiden OI line

Subgiants and giants





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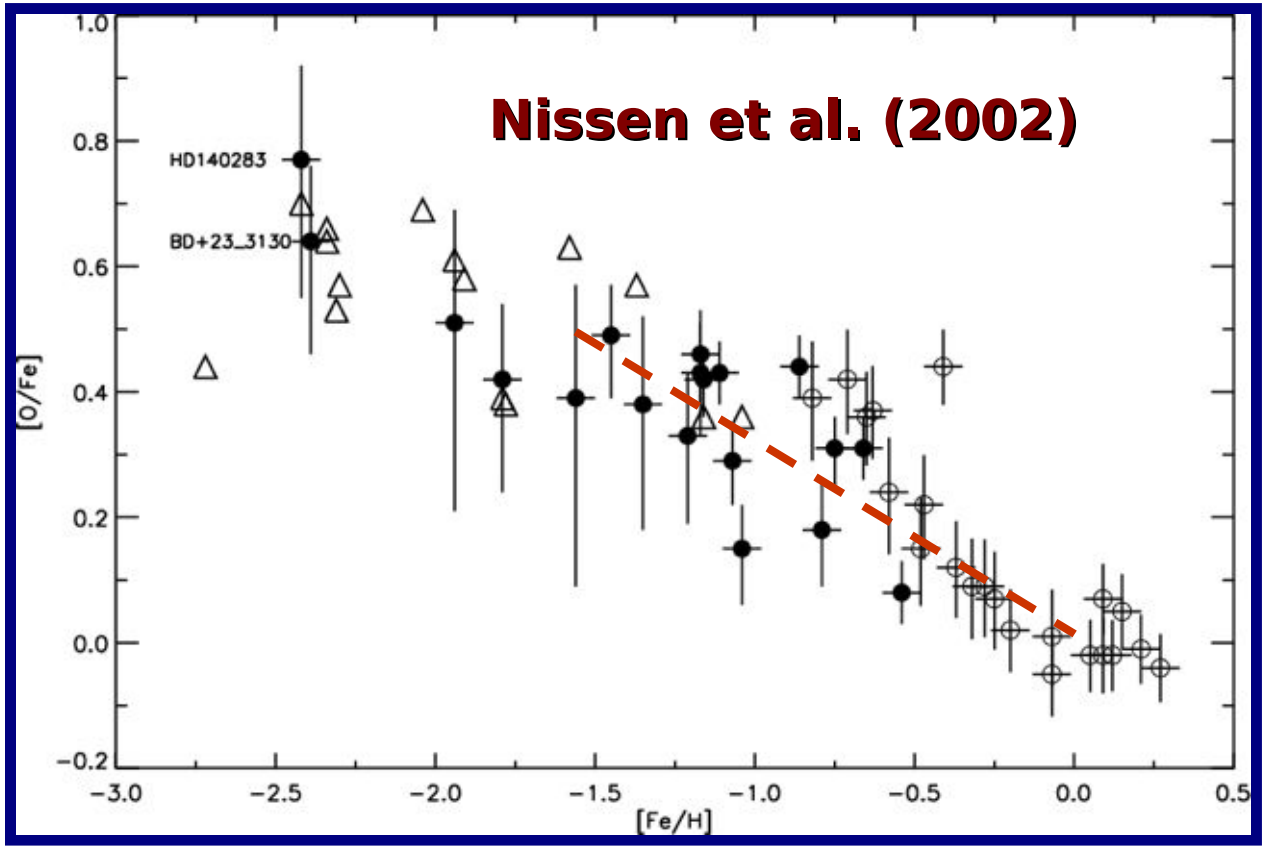
Oxygen: forbbiden OI line

dwarfs



Oxygen: metal-poor stars

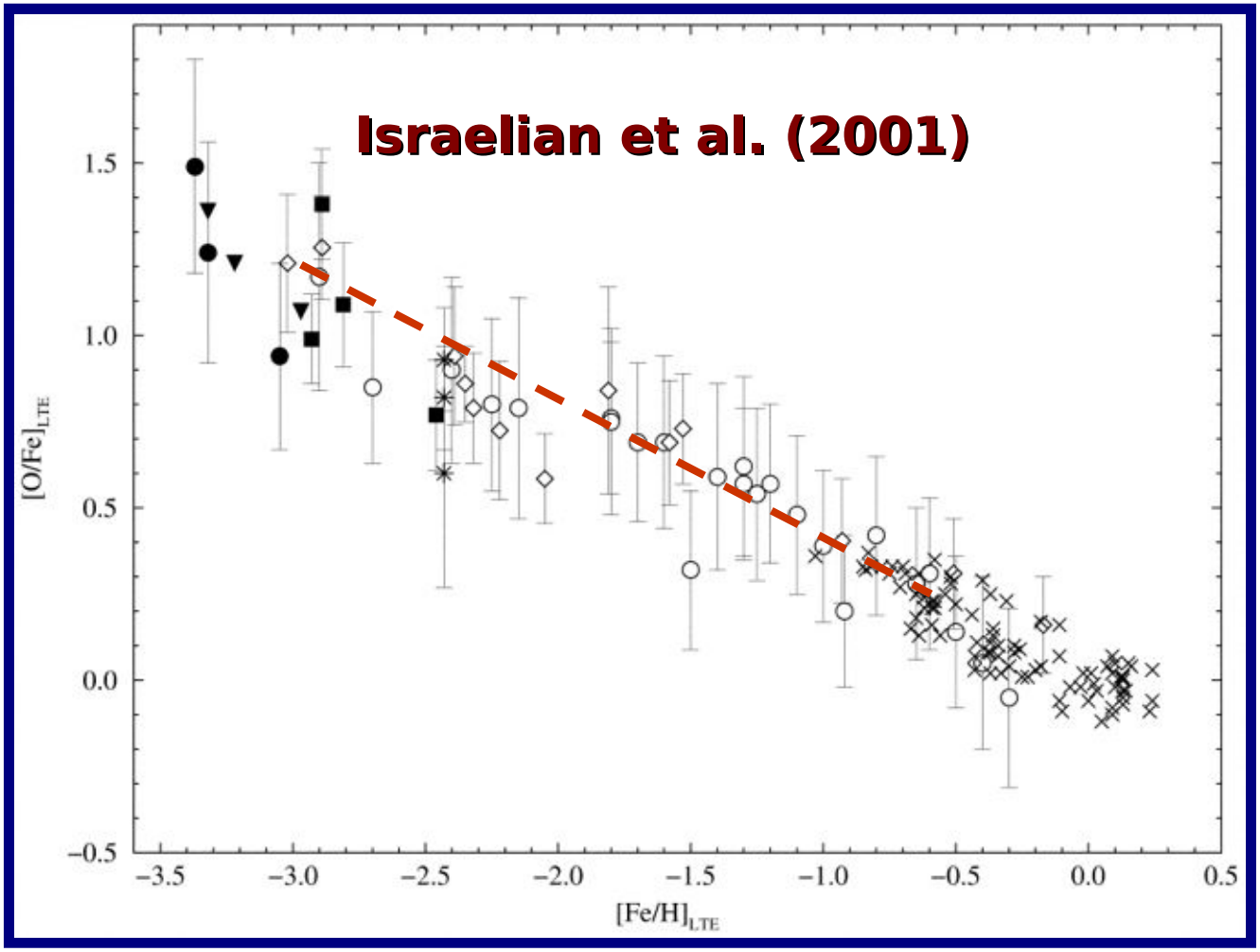
- Near-IR OI triplet shows a linear steep increase [O/Fe] towards lower [Fe/H] (Israelian et al. 2001; Boesgaard et al 1999)

- Nissen et al. 2002; Fulbright & Johnson 2003) for dwarfs, subgiants and giants for $-3.2 < [Fe/H] < -0.8$

- Fulbright & Johnson (2003) found a disagreement of 0.4 dex between OI triplet and [OI]

Oxygen: near-IR OI triplet

dwarfs



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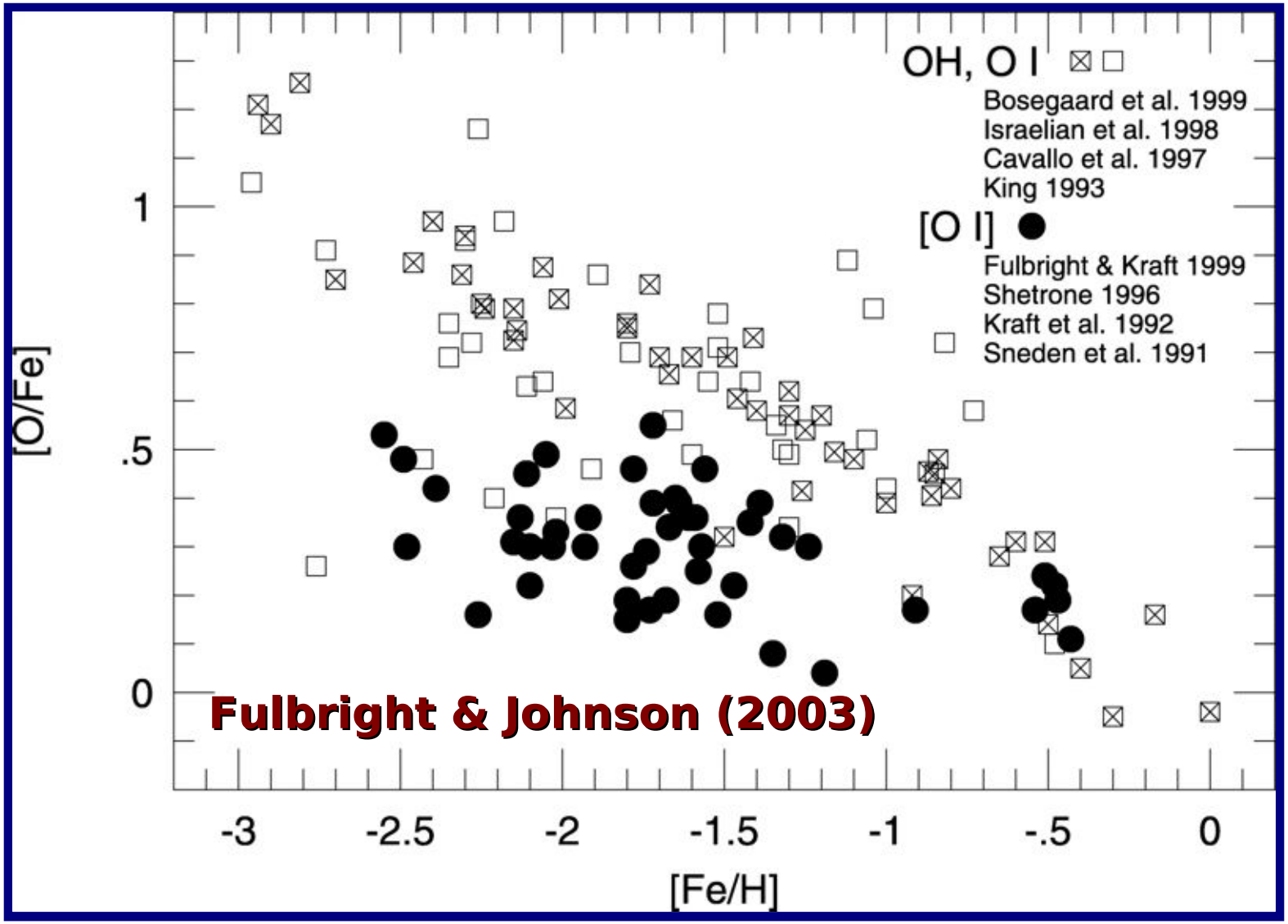
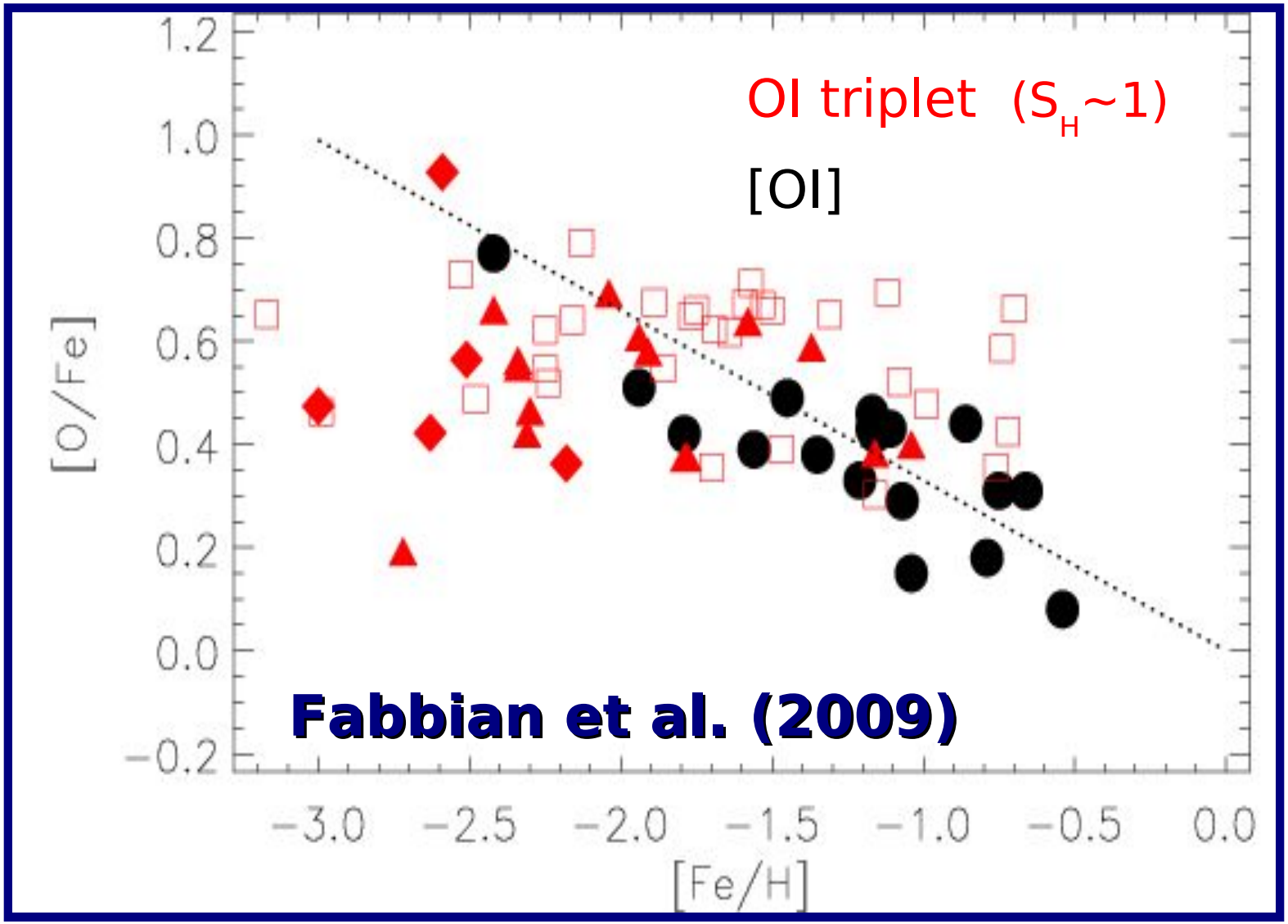
Oxygen: metal-poor dwarf stars



Oxygen: metal-poor stars

- Fabbian et al. (2009) applied NLTE corrections to near-IR OI triplet from Israelian et al. 2001. This allows to reconcile the abundances from the near-IR OI triplet (Israelian et al. 2001) and [OI] (Nissen et al. 2002)

Oxygen: metal-poor stars

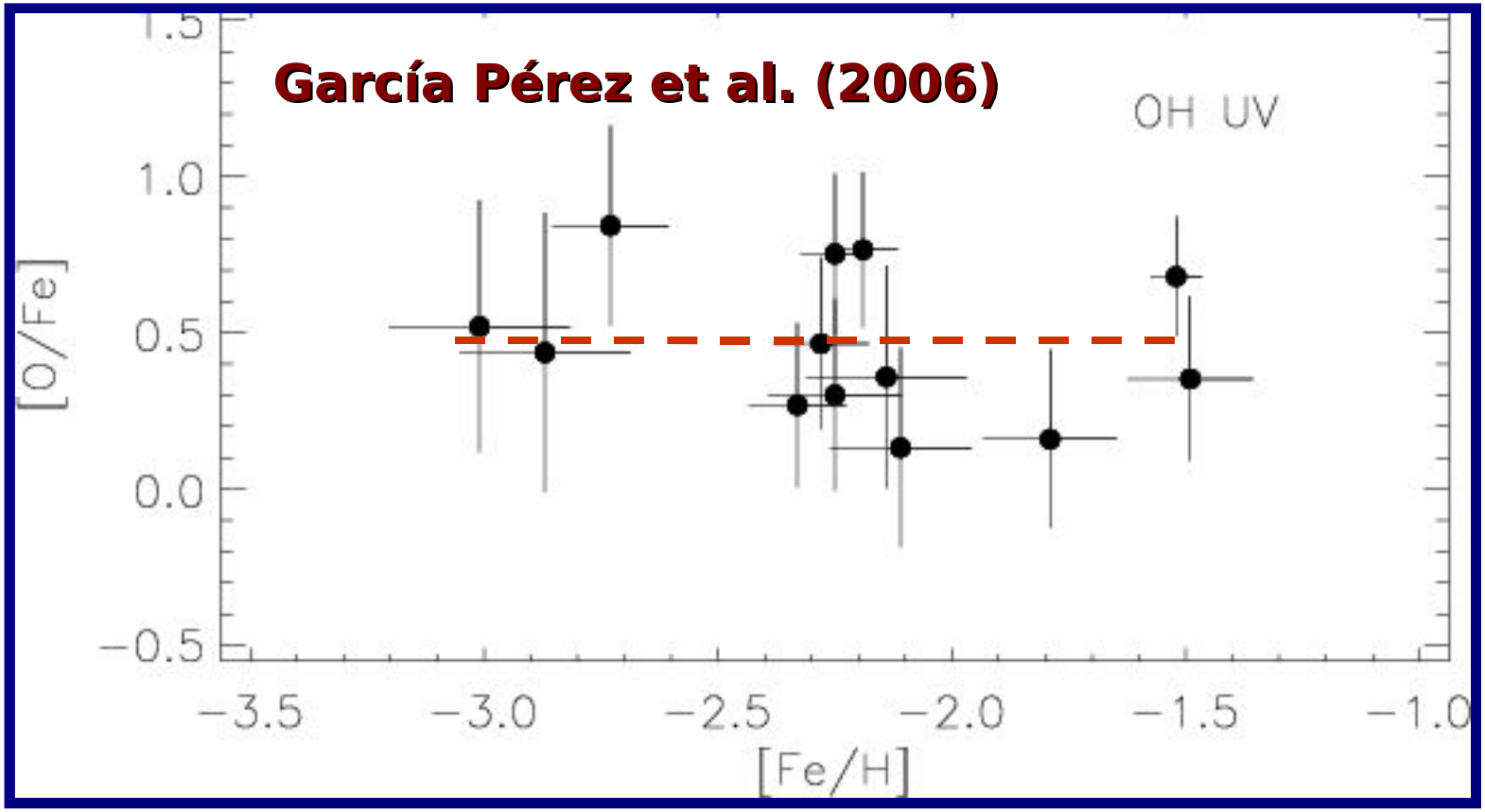


Oxygen: metal-poor stars

- Near-UV OH shows also a linear steep increase of [O/Fe] towards lower [Fe/H] (Israelian et al. 2001; Boesgaard et al 2001) for dwarfs with -3.4 < [Fe/H] < -0.8

- However, García Pérez et al. (2006) claimed a plateau of [O/Fe]~0.5 for subgiants in the range -3.0 < [Fe/H] < -1.5, but they used the FeII abundance to compute the [O/Fe] ratio

Oxygen: near-UV OH lines



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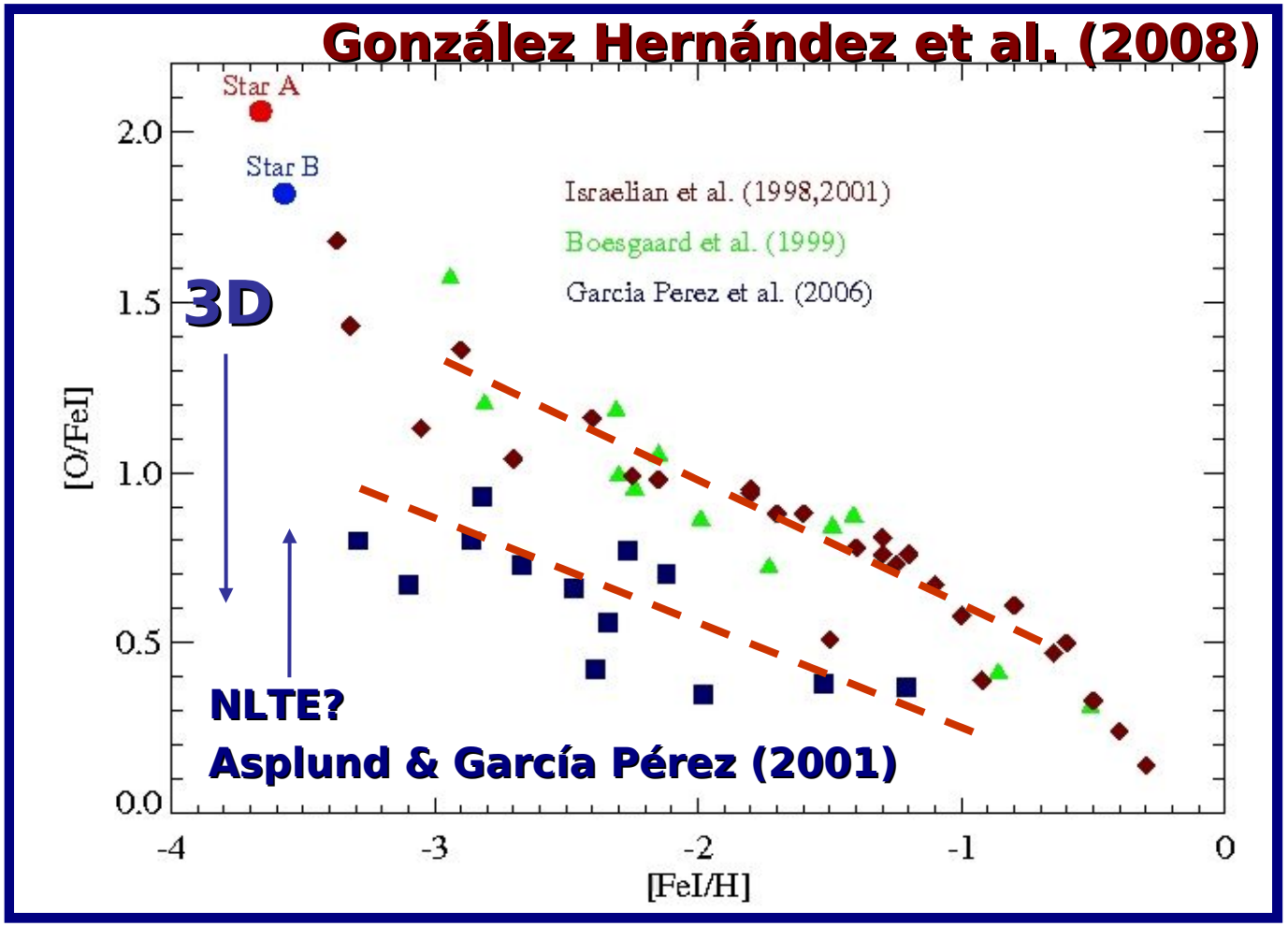
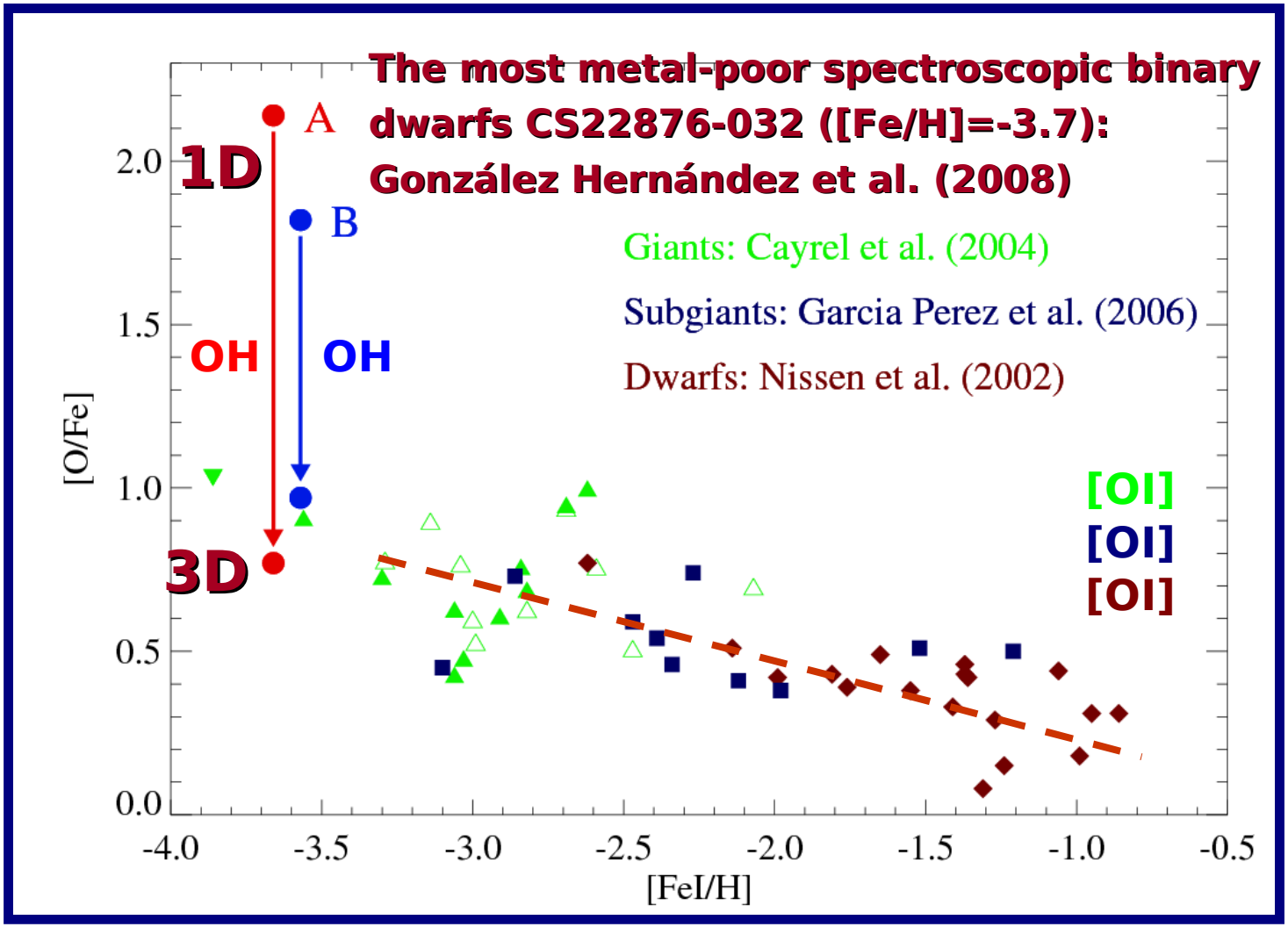
Oxygen: near-UV OH lines

- However, when using the FeI abundance to compute the [O/Fe] ratio



Oxygen: forbidden [OI] line

- Strong 3D effects at the lowest metallicities



Ludwig et al. (2008)

Oxygen: summary

- [OI] is not sensitive to NLTE effects but is affected by 3D inhomogeneities
- Near-IR OI triplet is significantly dependent on NLTE effects
- Near-UV OH are strongly sensitive to 3D effects and slightly dependent on NLTE although in the opposite direction

  - Magnetic fields ...

Oxygen: summary – 1D case

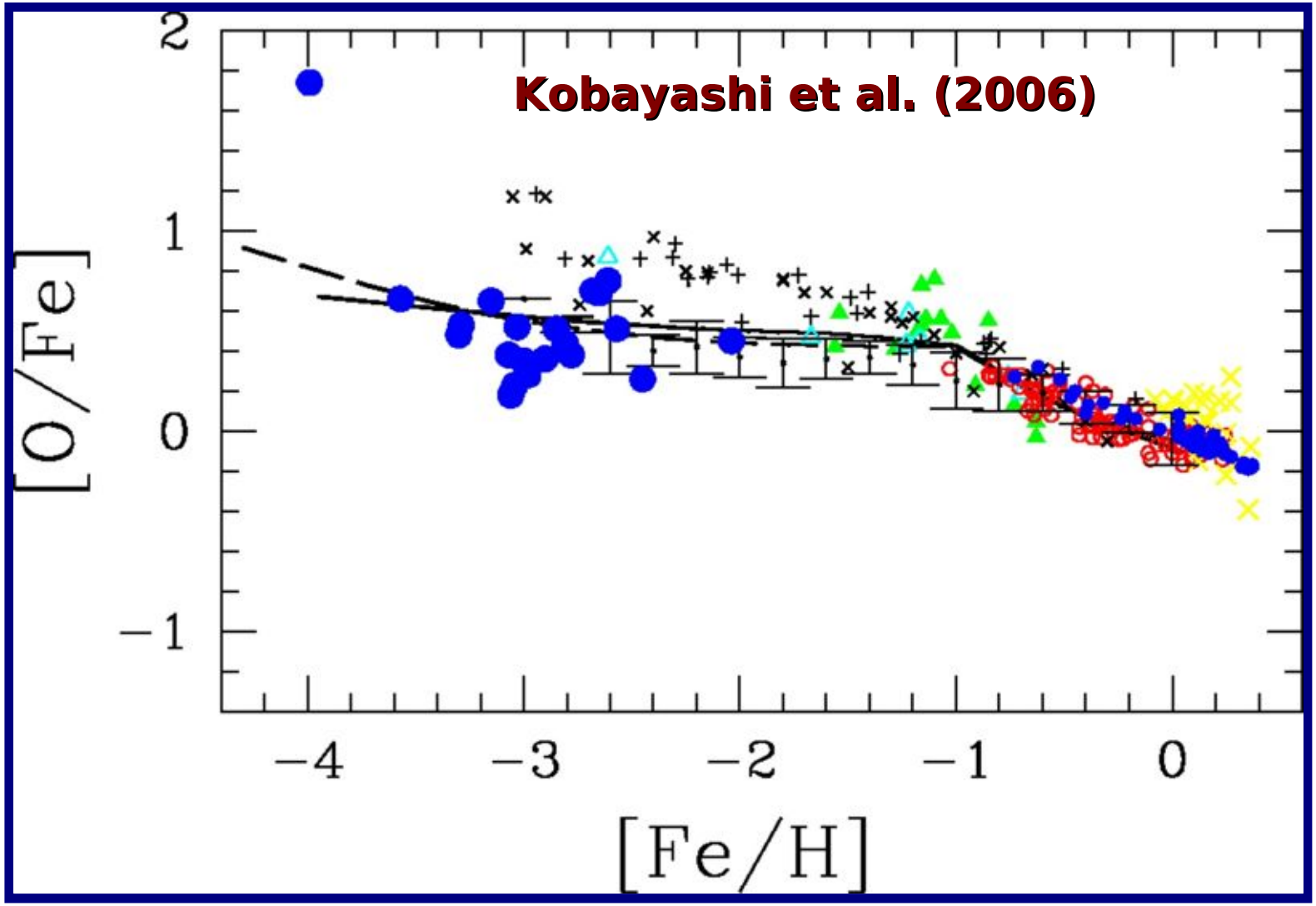
- [OI] line provides an increasing trend [O/Fe] towards lower metallicities at least using 1D models when considering dwarfs, subgiants and giants all together

- Near-IR OI triplet so also shows an increasing trend or a quasi-plateau when applying strong NLTE corrections

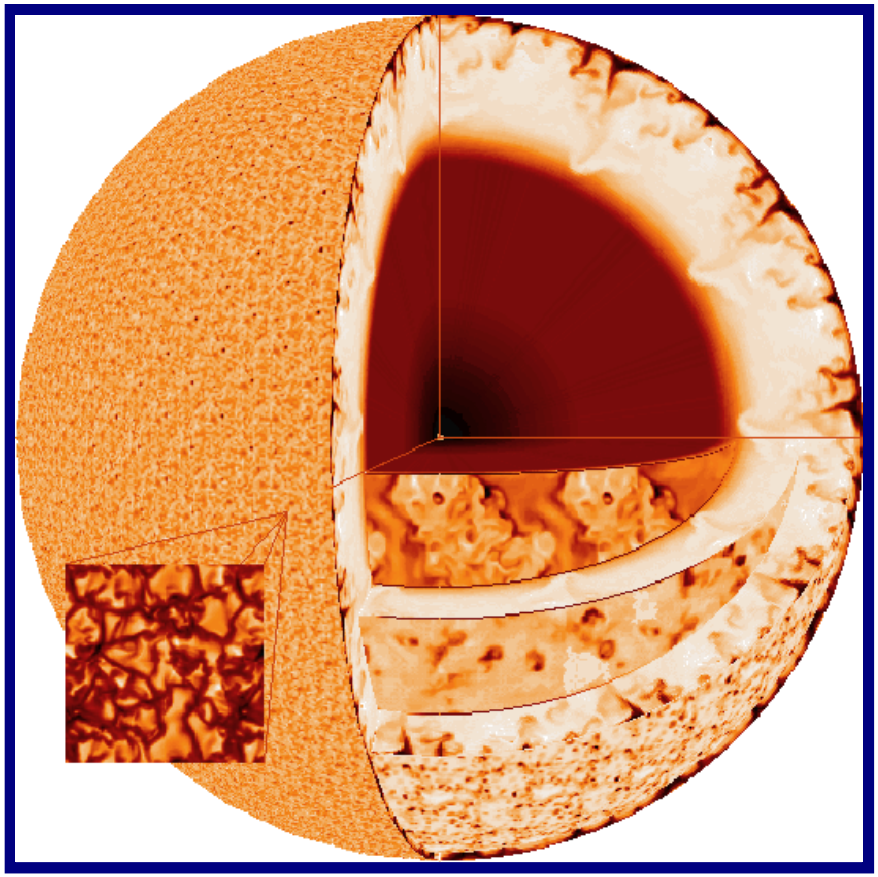
- Near-UV OH lines gives also an increasing trend although at different levels for dwarfs and subgiants

Oxygen: metal-poor stars

- SN-HN explosion models:

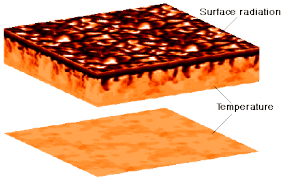


3D Model Atmospheres



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

Freytag et al. (2002); Wedemeyer et al. (2004)



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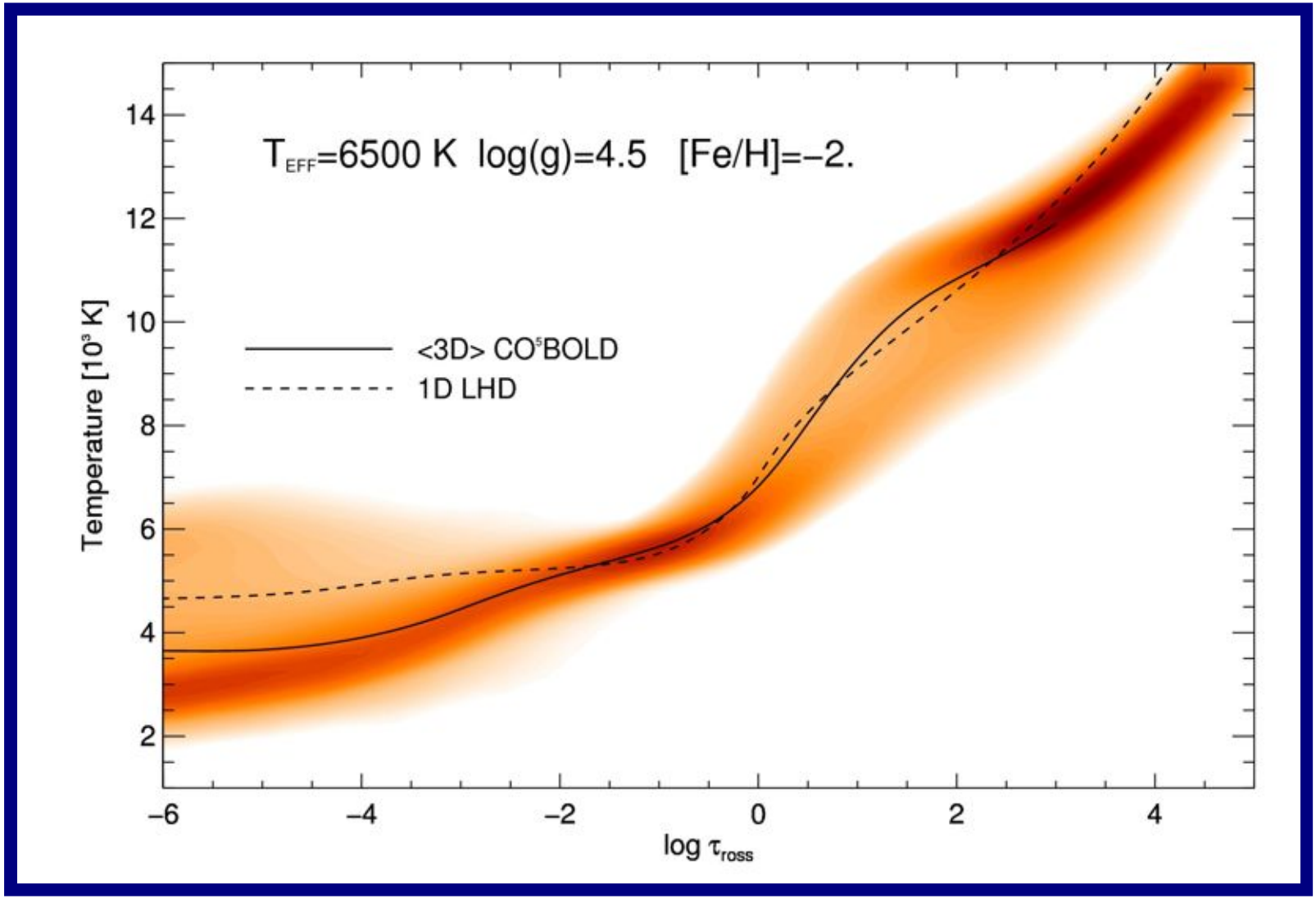
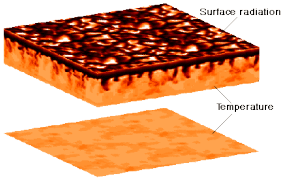


3D abundance corrections

- 3D - <3D> corrections
  - <3D> model: temporal and horizontal average of the 3D model
  - Same micro-physics with v_{TURB} and α_{MLT} fixed
- 3D – 1D corrections
  - Lagrangian hydrostatic 1D model
  - Same micro-physics with v_{TURB} and α_{MLT} fixed



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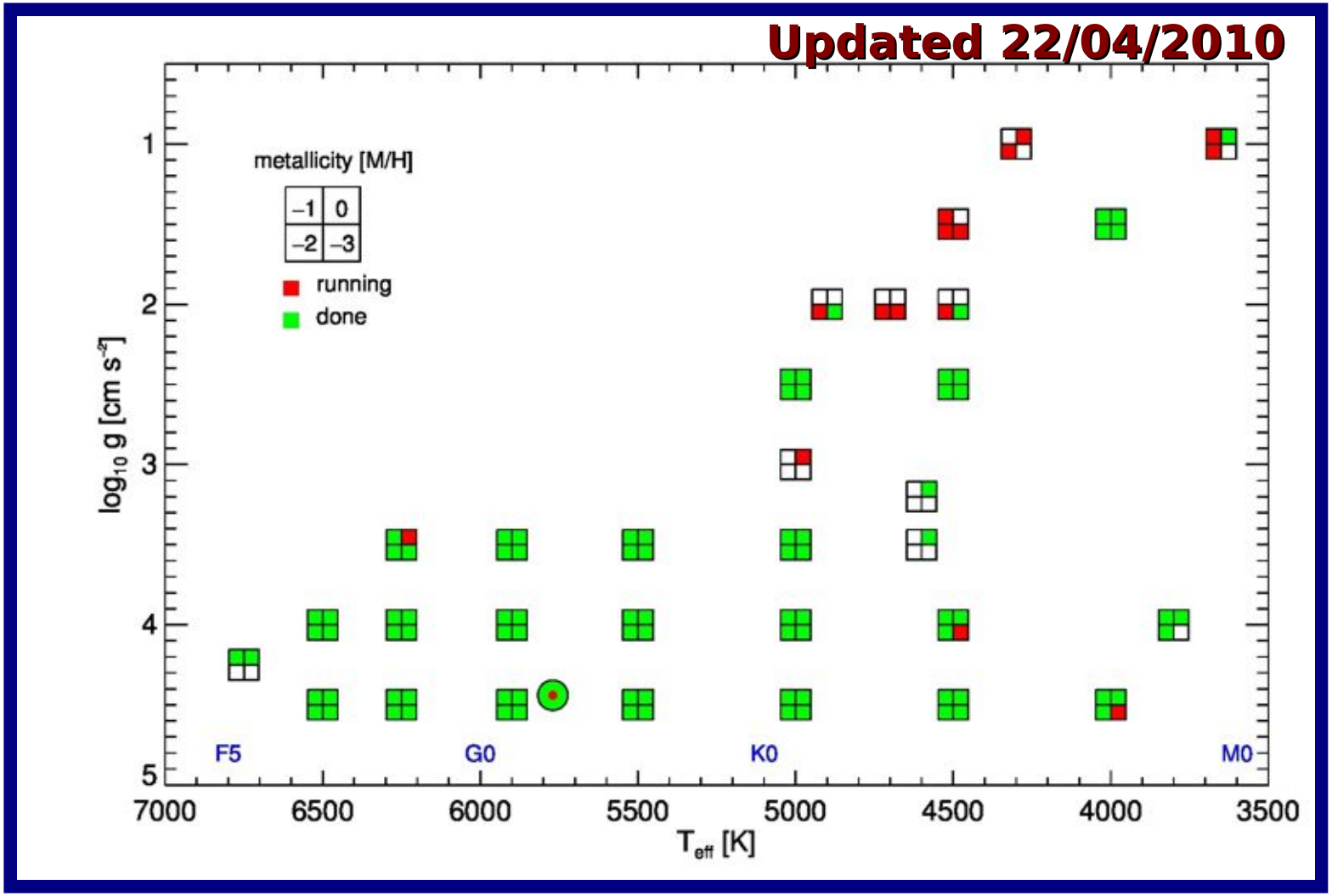
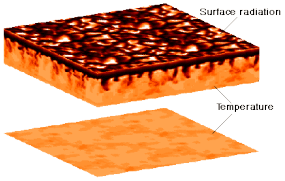


Ludwig et al. (2009)



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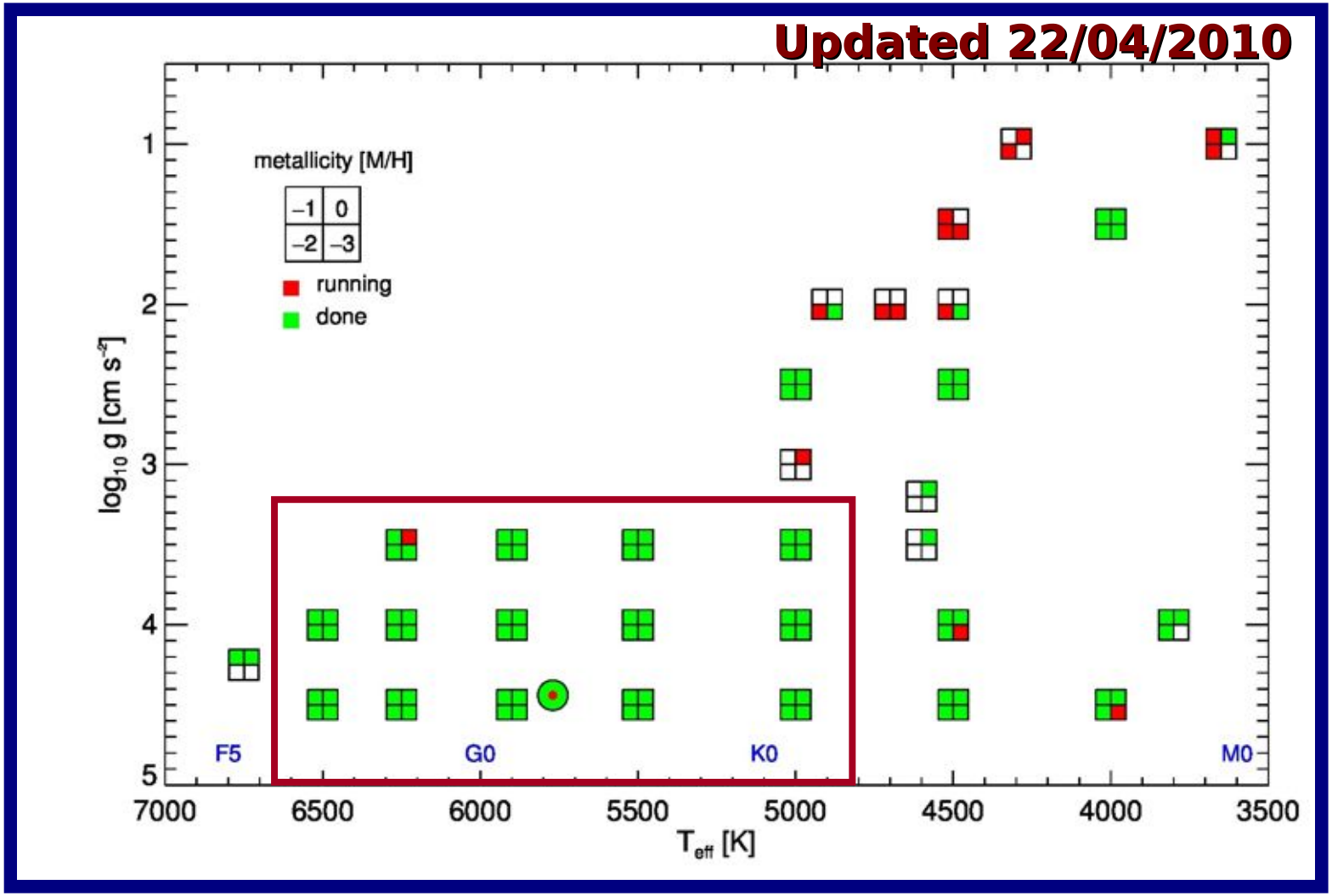

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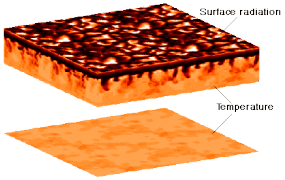

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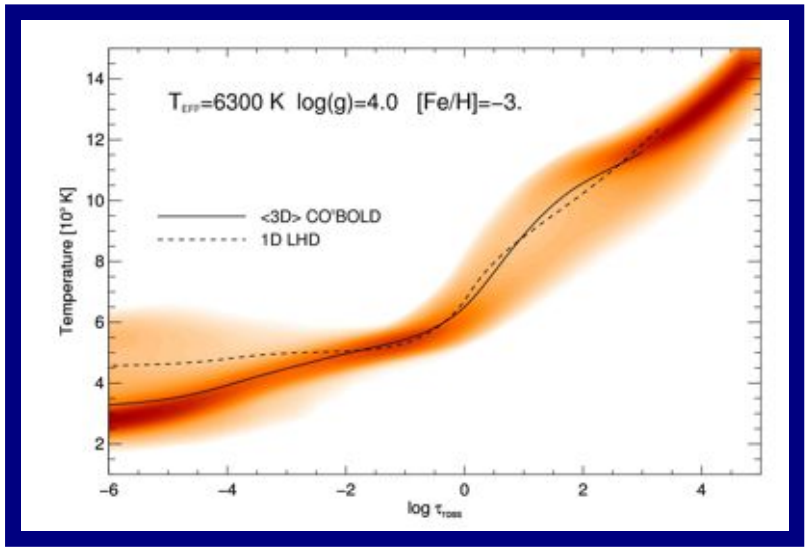
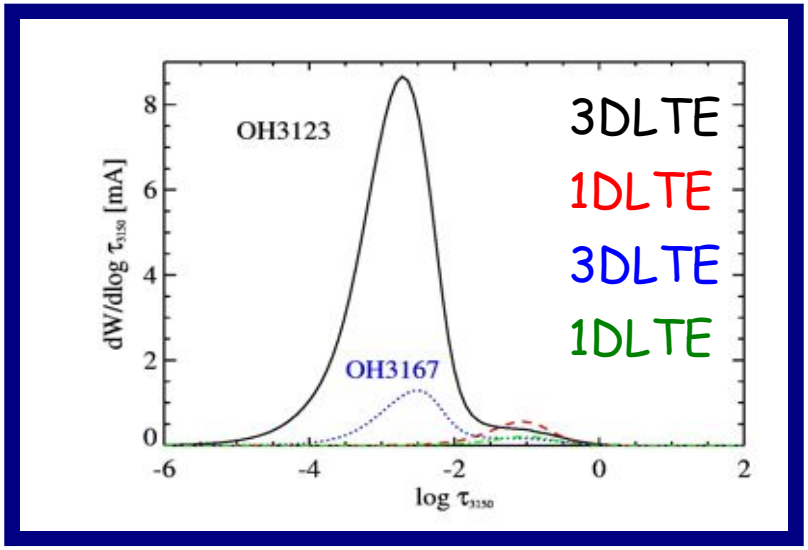
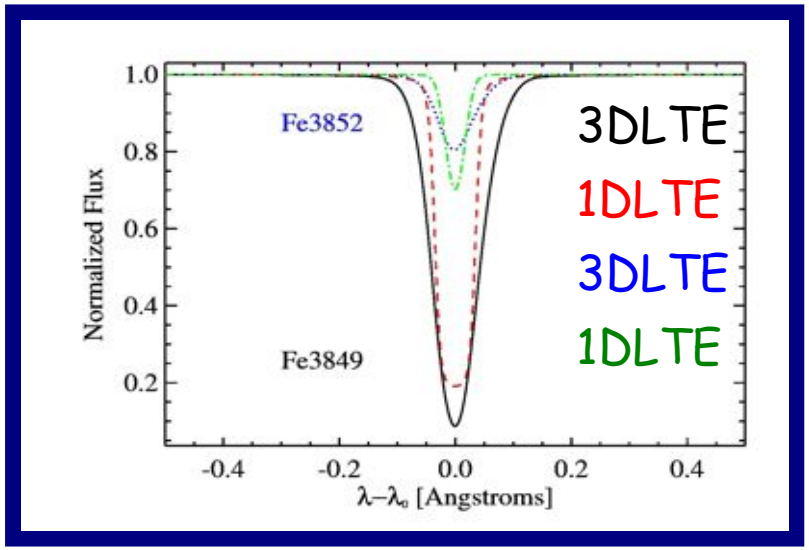
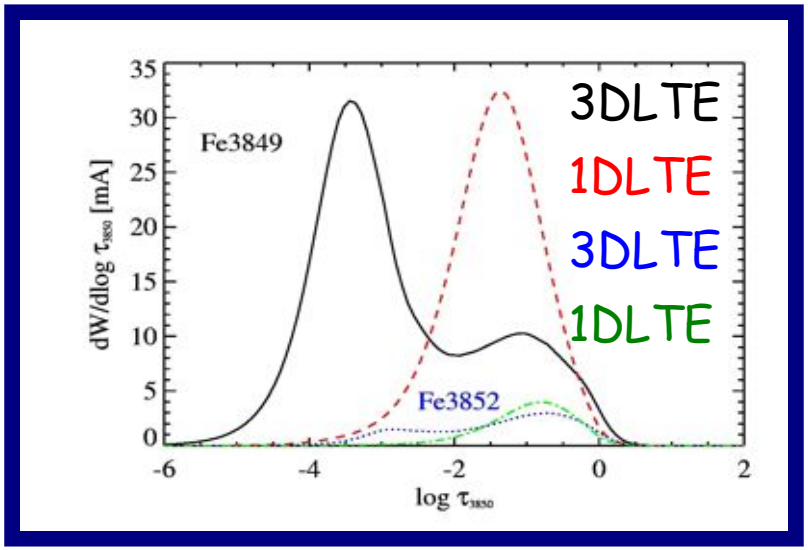






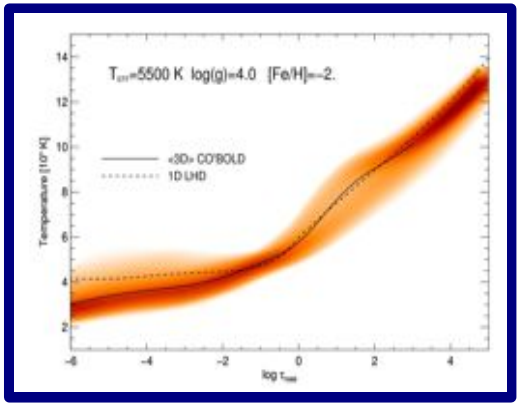


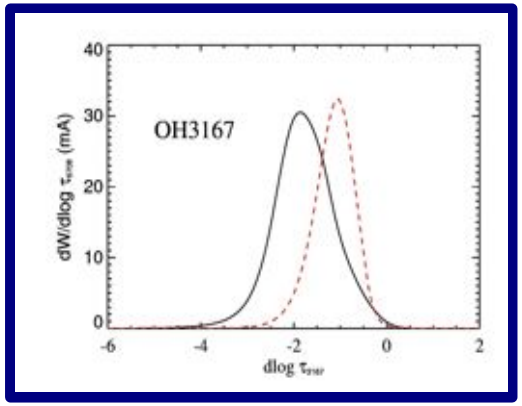
González Hernández et al. (2010)

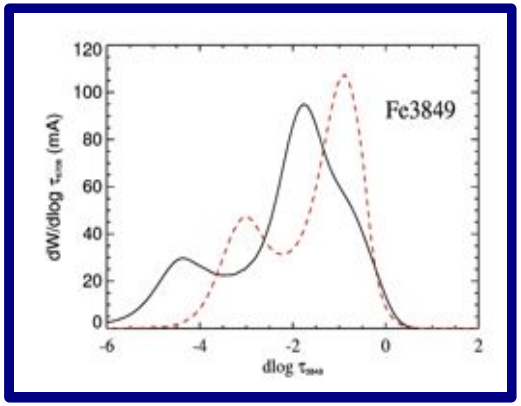
3D Models : temperature dependence

- **5500K**

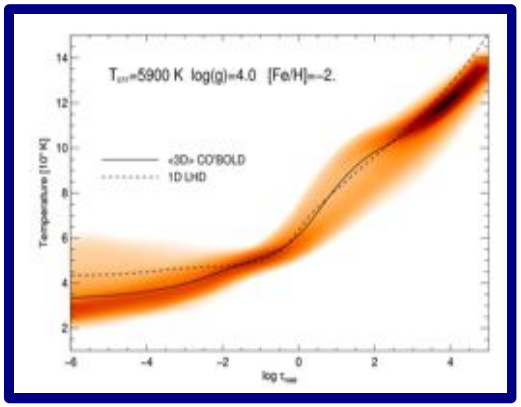
Logg=4.0
[Fe/H]=-2

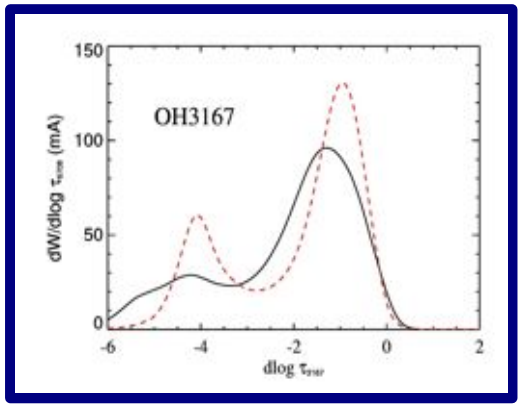


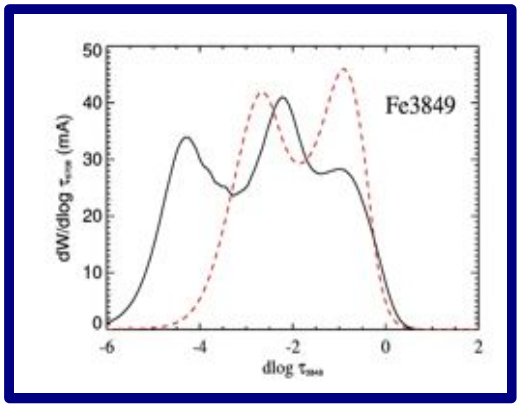




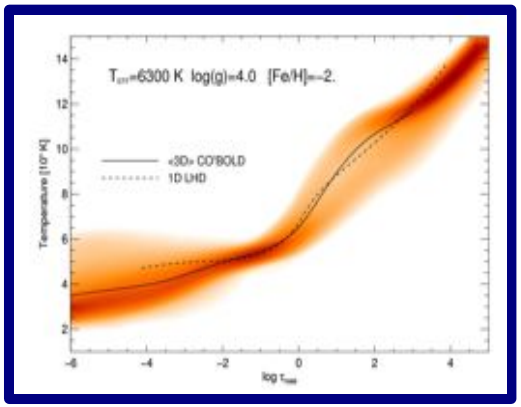
- **5900K**

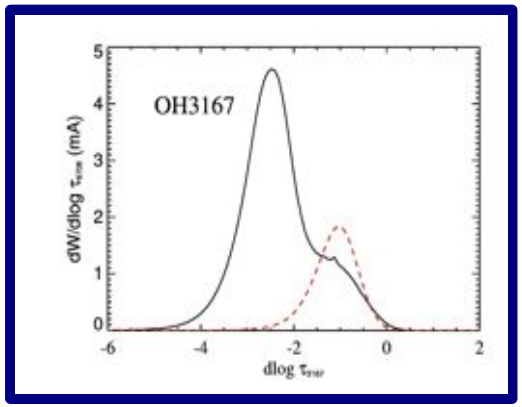


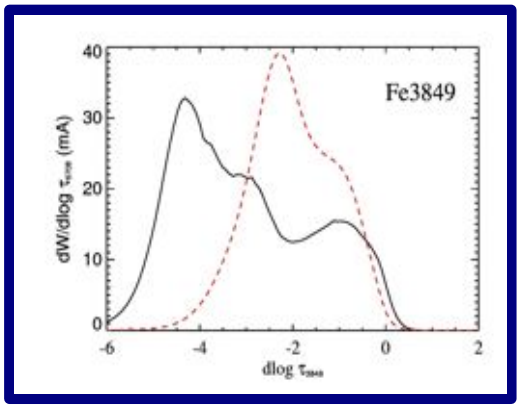




- **6300K**







3D Models : temperature dependence

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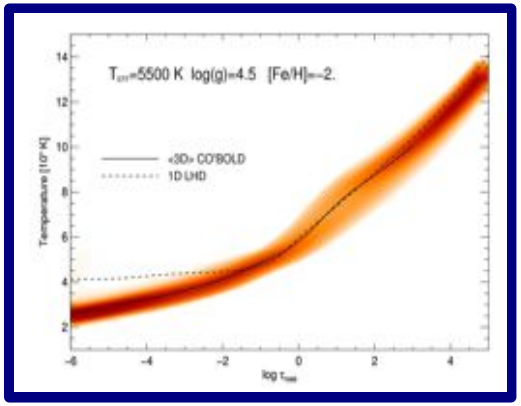
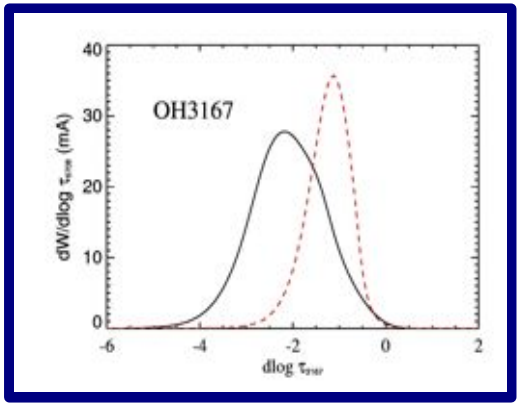
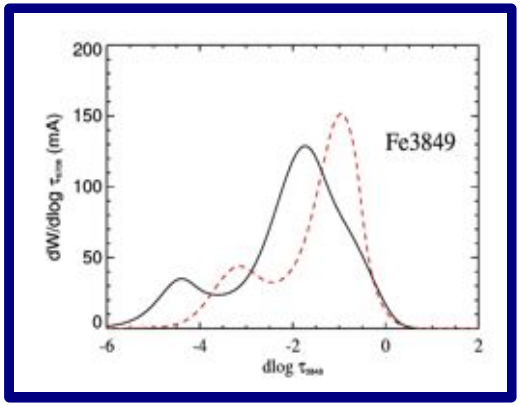
Logg=4.5
[Fe/H]=-2







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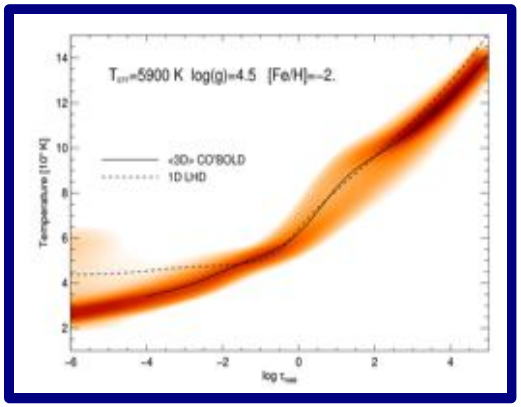

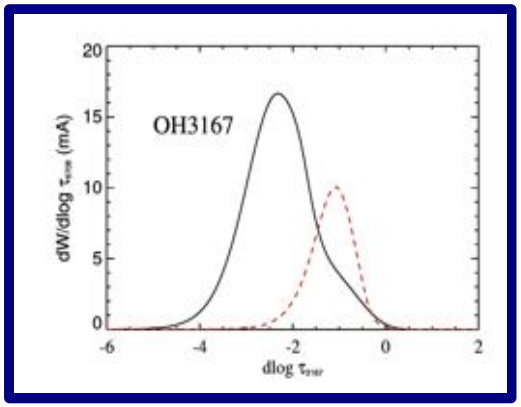

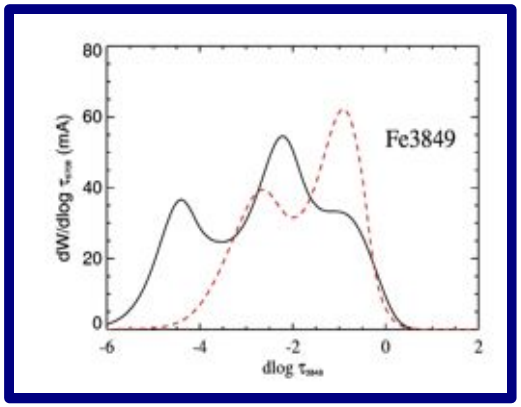

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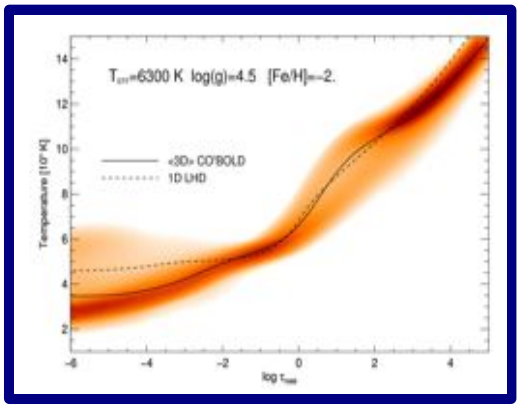
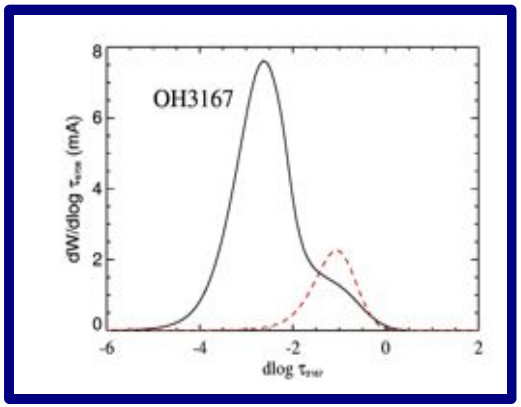
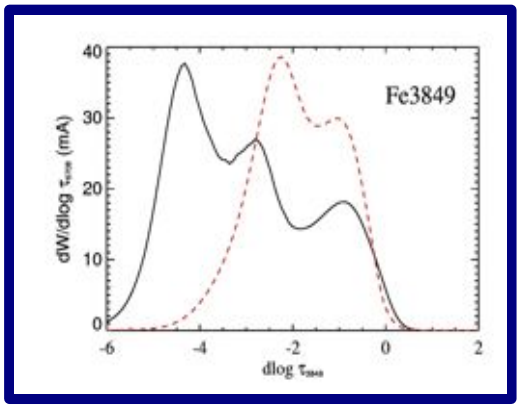


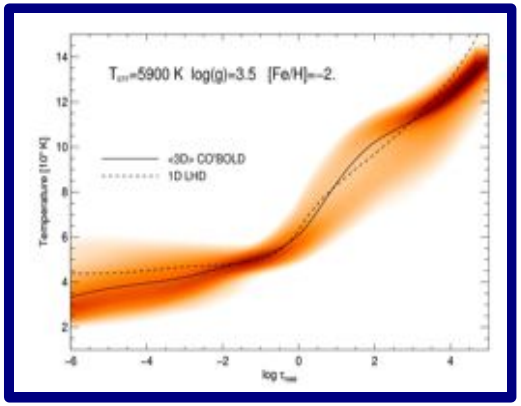


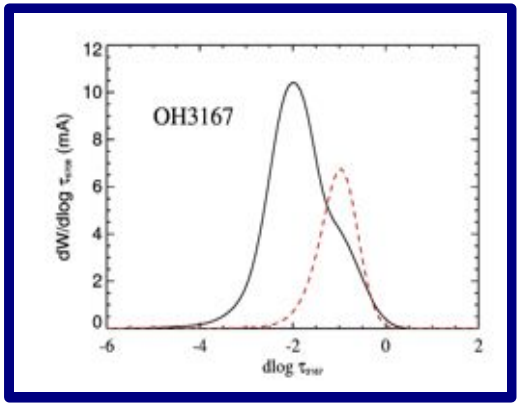


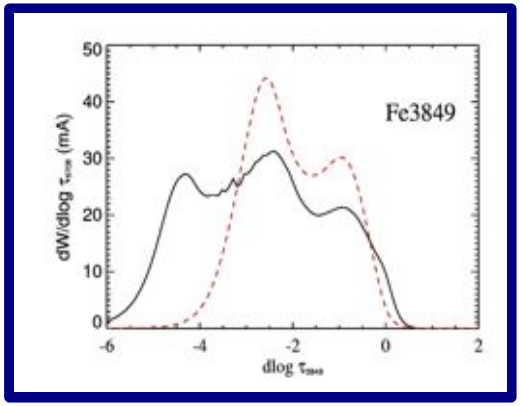
3D Models : gravity dependence

- **3.5dex**

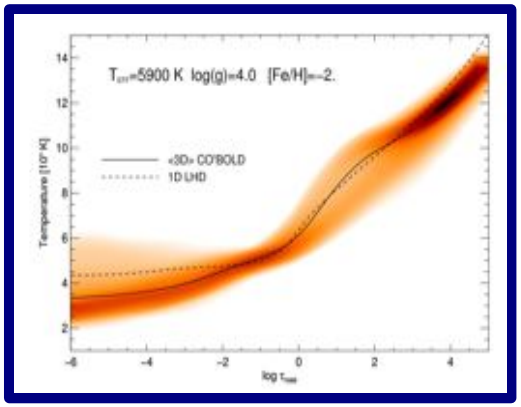
Teff=5900
[Fe/H]=-2

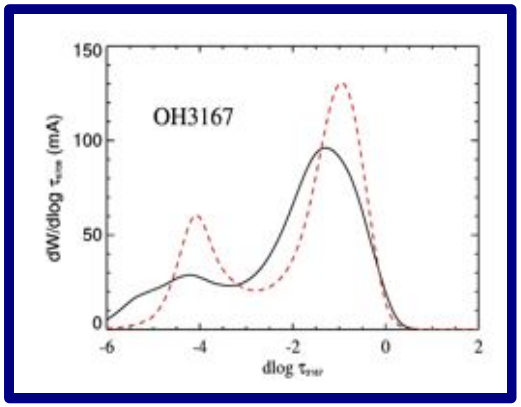


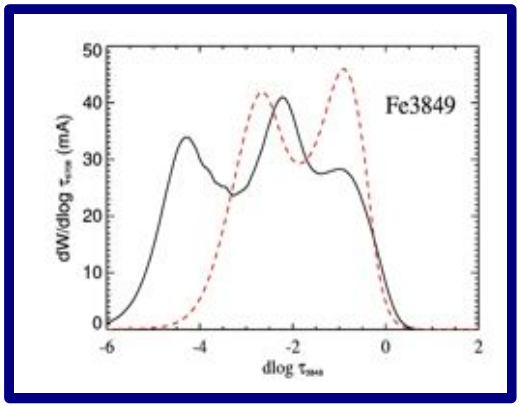




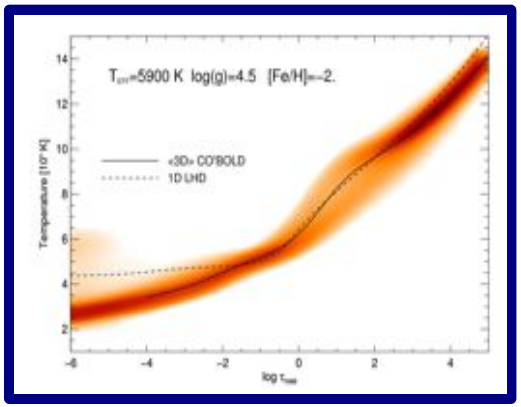
- **4.0dex**

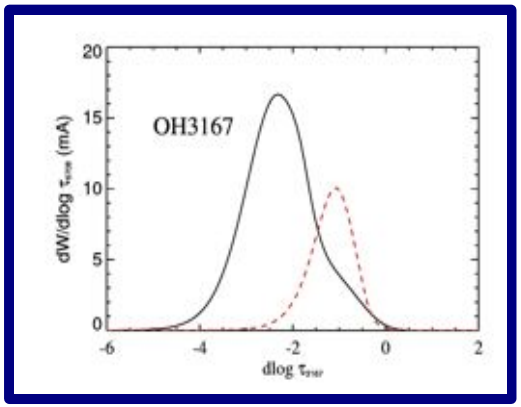


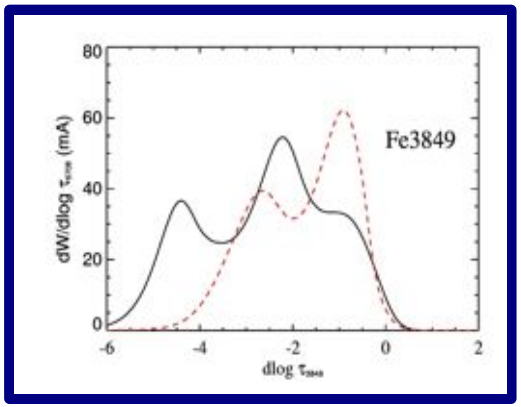




- **4.5dex**

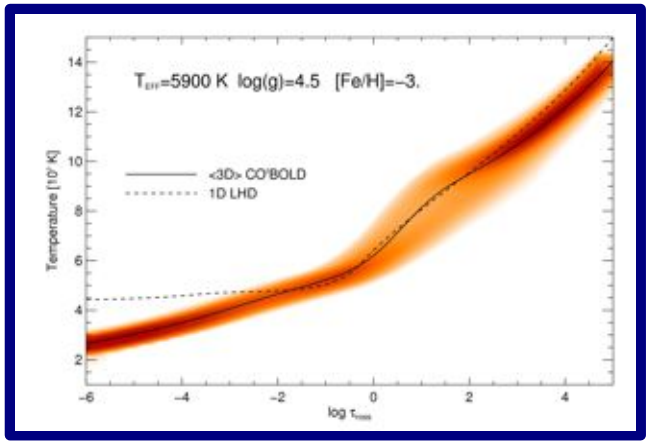




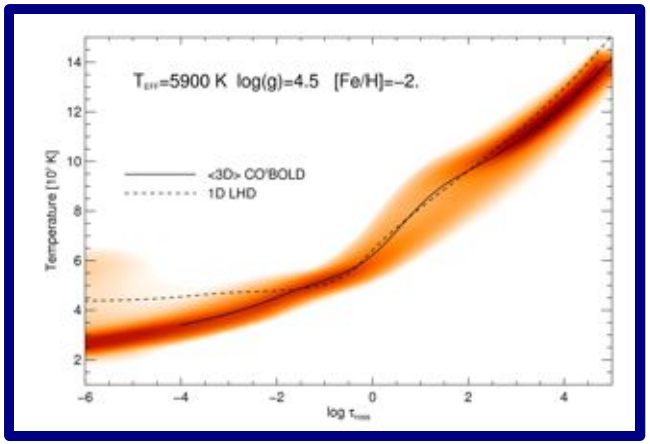


3D Models : metallicity dependence

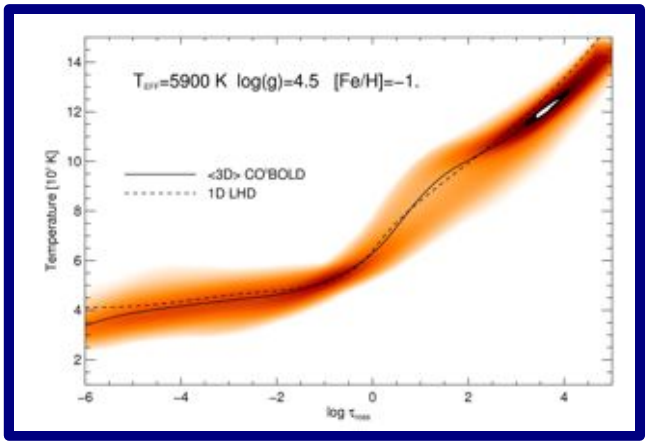
- [Fe/H] = -3



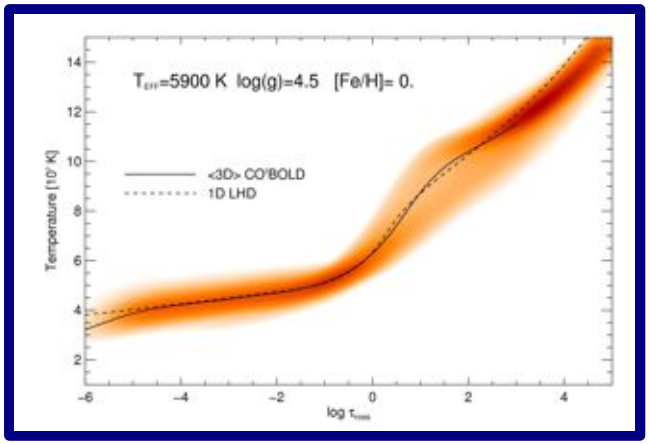
- [Fe/H] = -2



- [Fe/H] = -1

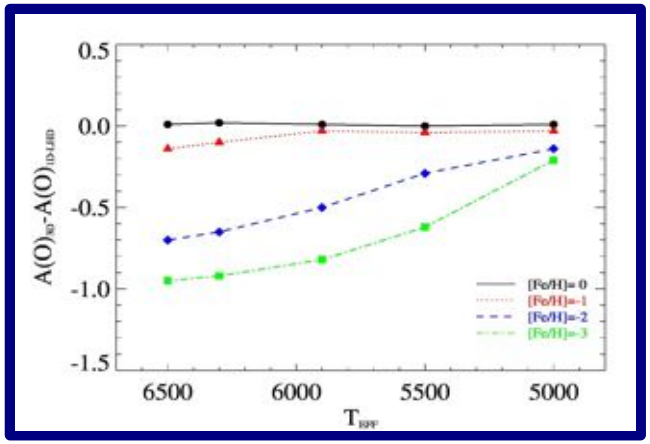


- [Fe/H] = 0

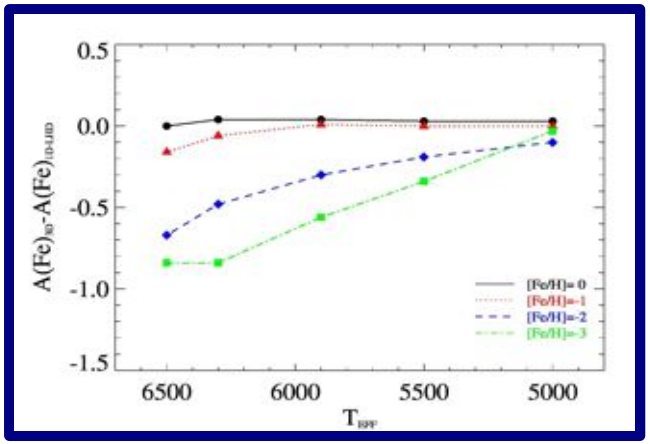


3D corrections: Teff dependence

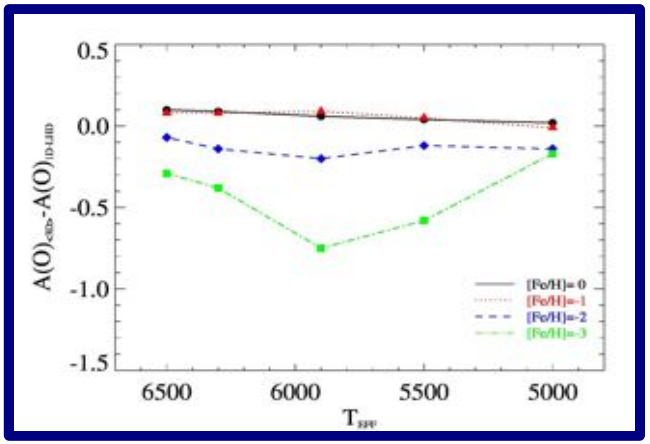
- 3D−1D (OH 3167Å)



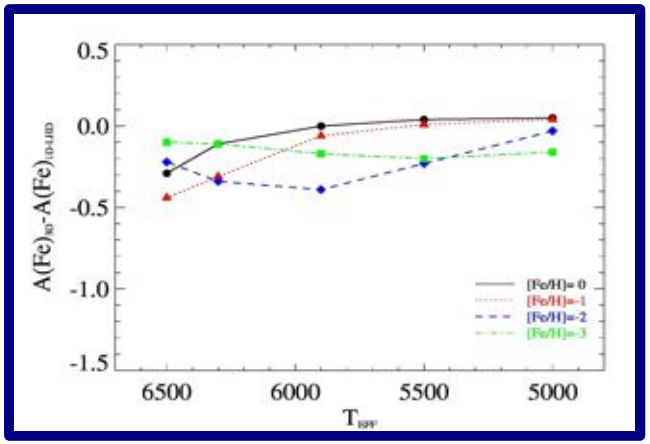
- χ=1.0eV (FeI 3849Å)



- <3D>−1D (OH 3167Å)



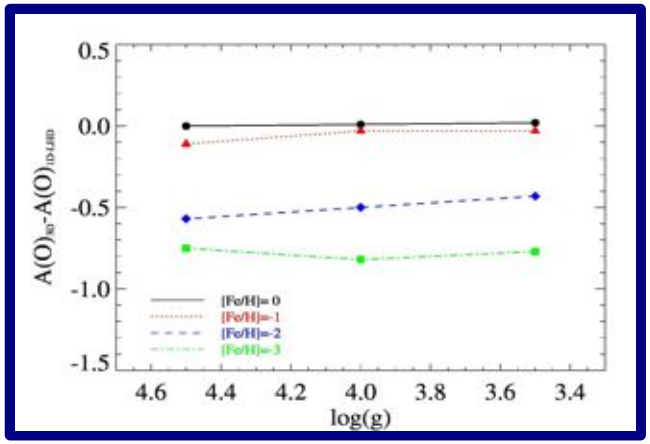
- χ=2.2 eV (FeI 3852Å)



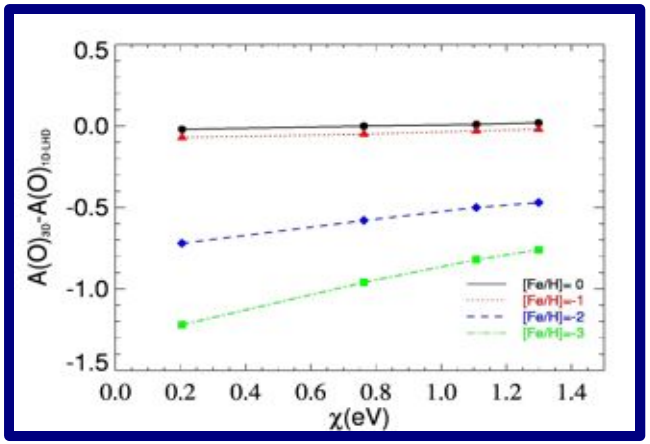
González Hernández et al. (2010)

3D corrections: logg and χ dependence

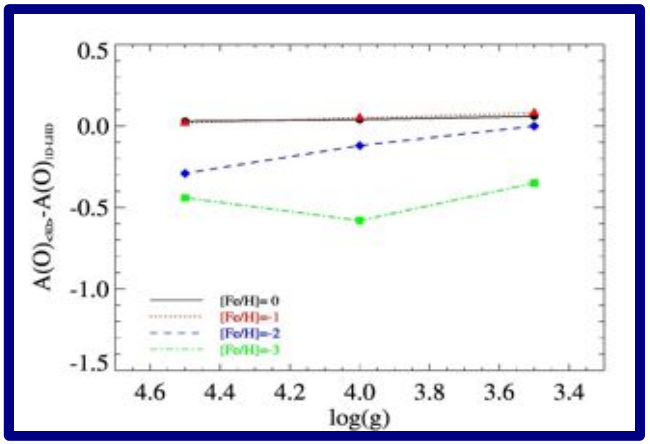
- 3D–1D (OH 3167Å)



- 3D–1D (OH lines)



- <3D>–1D (OH 3167Å)



- Opacity binning:12 vs. 6

- OH lines (χ=0.2-1.1eV)

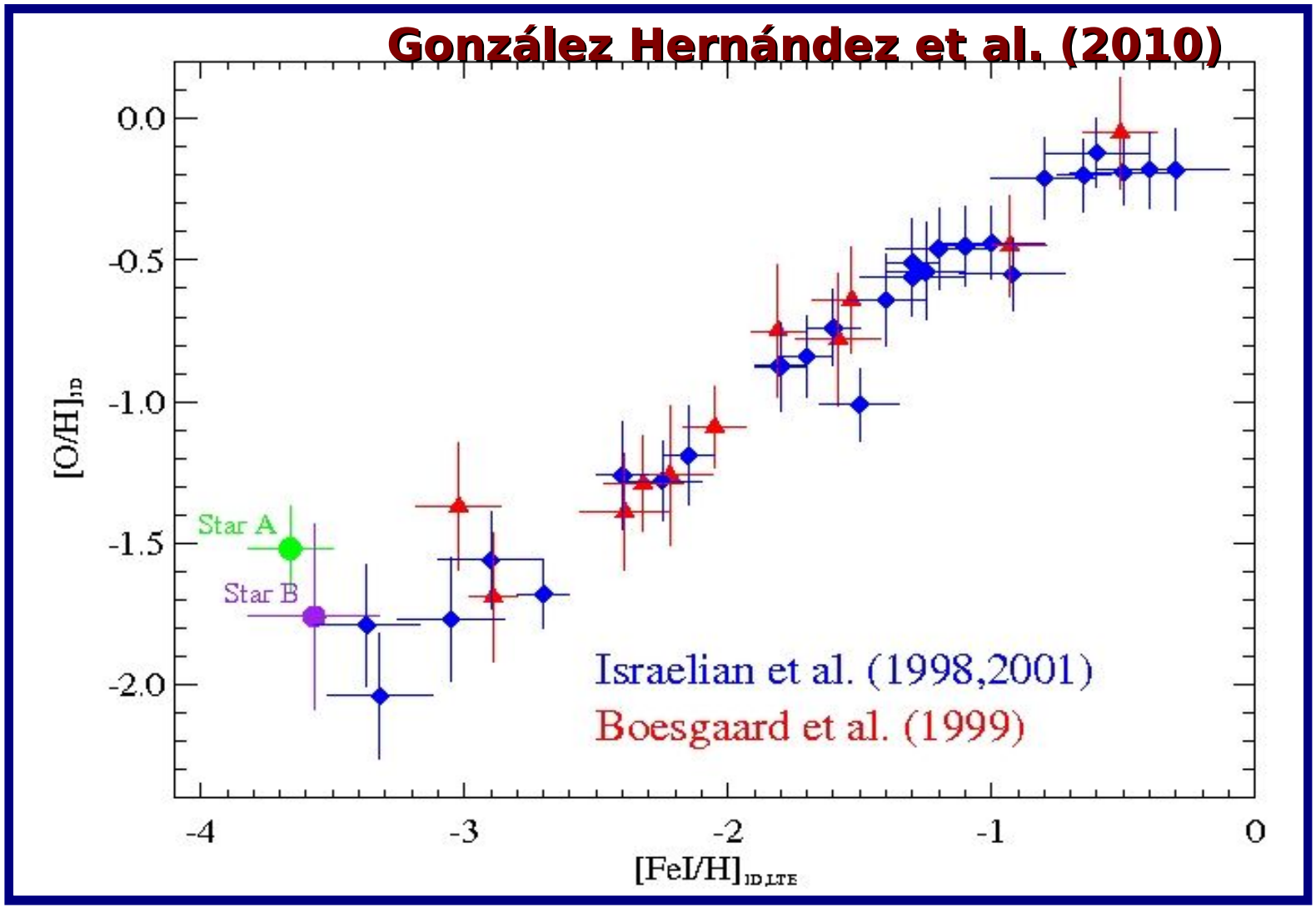
3D–1D ~ -0.36 – -0.23

- [C/O] = -1 and -0.2 implies a 3D –1D difference ~ 0.15 dex

González Hernández et al. (2010)

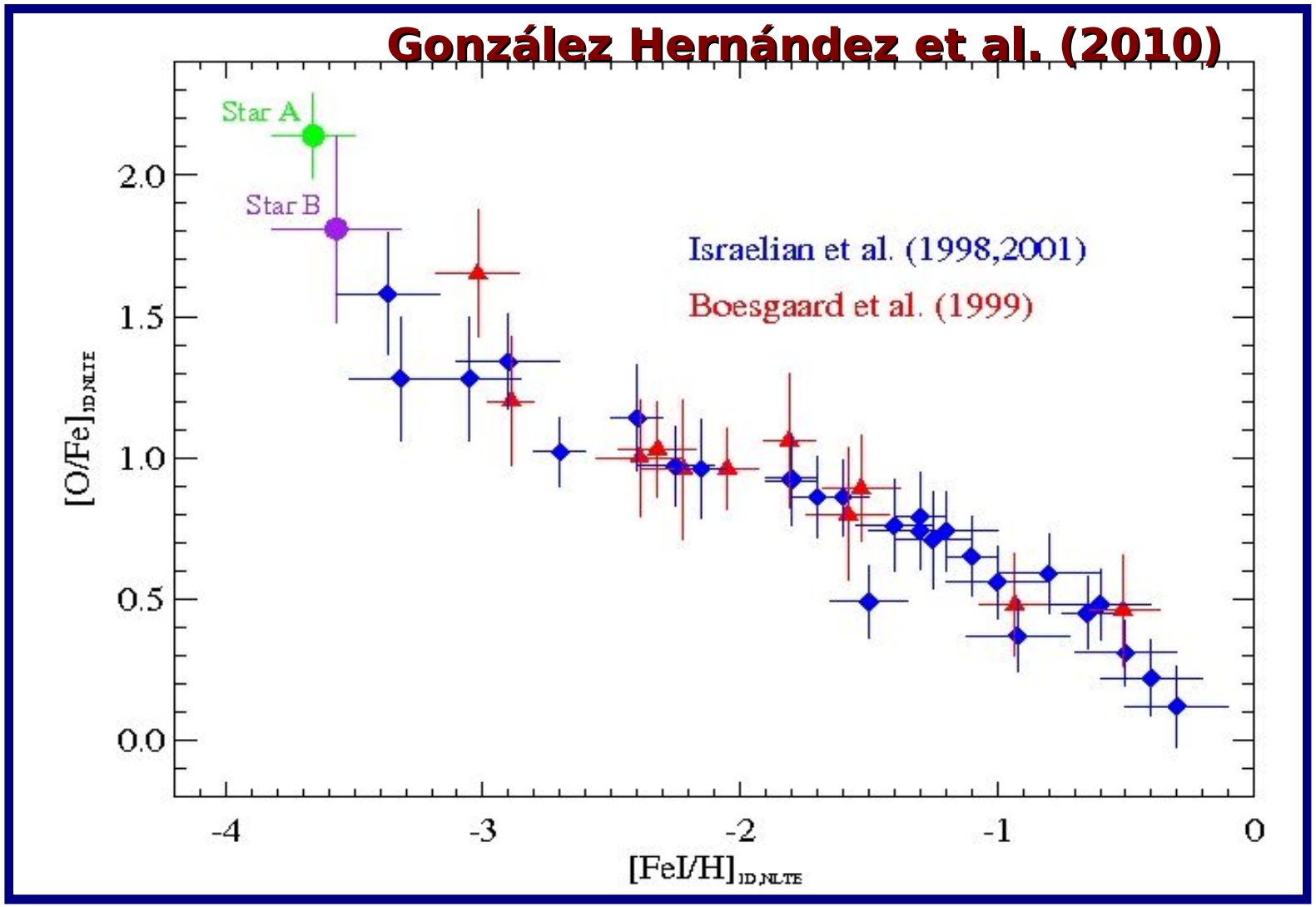
Oxygen: metal-poor stars

- [O/H] in 1D:



Oxygen: metal-poor stars

- [O/Fe] in 1D:



1D Fe NLTE corrections

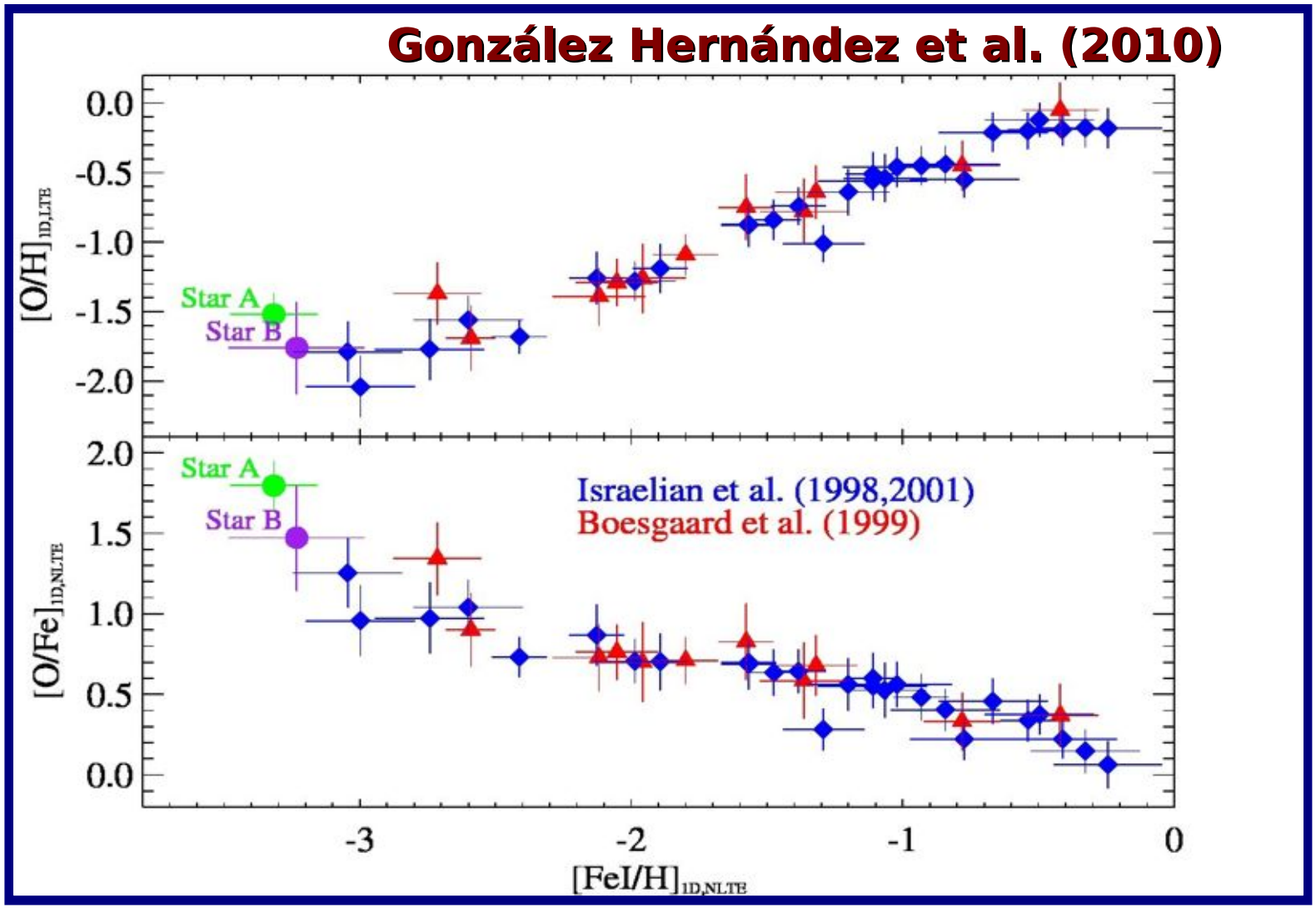
- We used the simple formula in Israelian et al. (2001), based on the 1D-NLTE corrections for Fe:

$$[Fe/H]_{NLTE-LTE} = -0.001 - 0.204\,[Fe/H]_{LTE} - \\ -0.052([Fe/H]_{LTE})^2 - 0.006\,([Fe/H]_{LTE})^3$$

- This has been extracted from the 1D-NLTE corrections provided by Thévenin & Idiart (1999) as a function of metalllicity

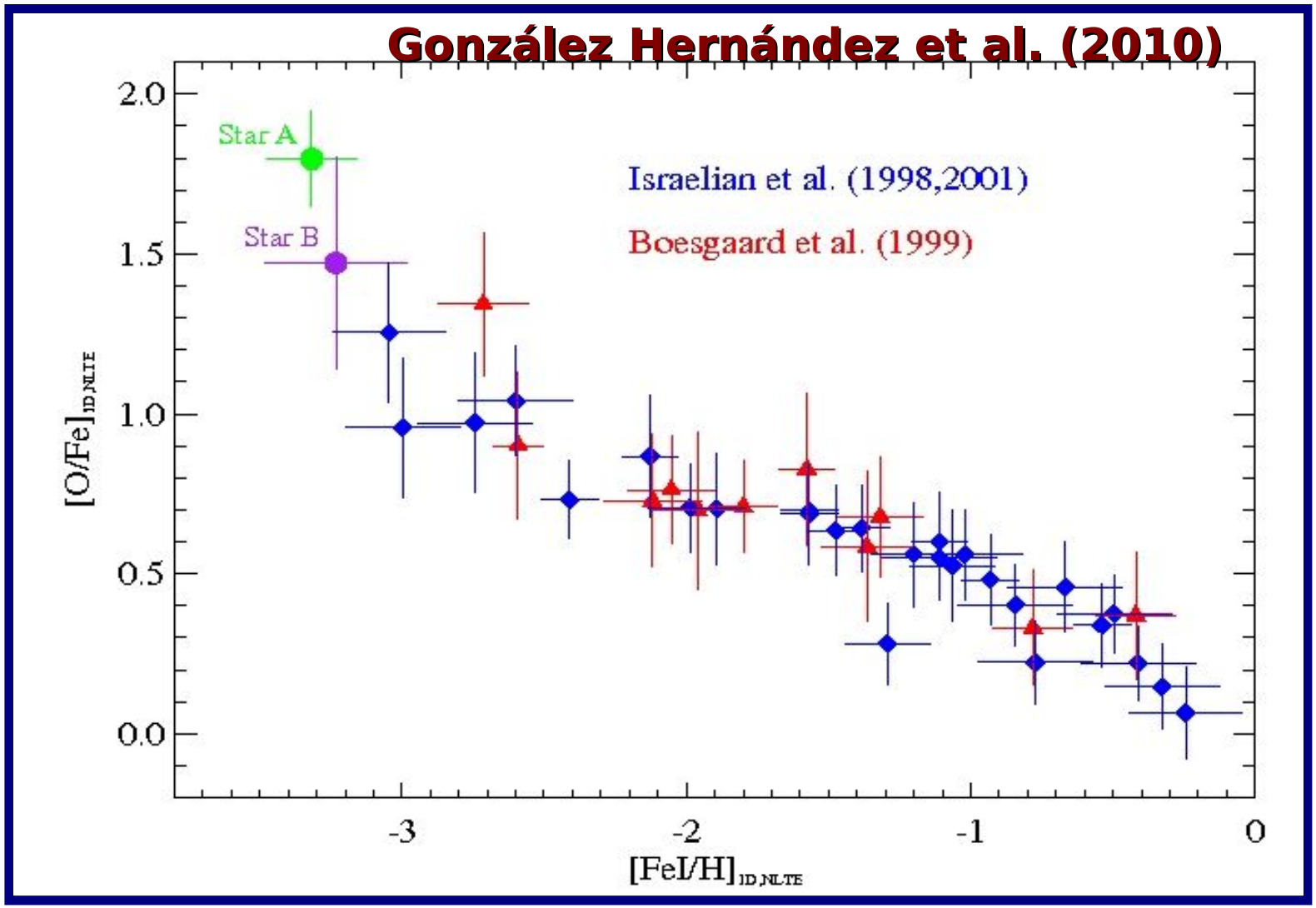
Oxygen: metal-poor stars

- OH in 1D and FeI in 1D-NLTE:



Oxygen: metal-poor stars

- [O/Fe] in 1D-NLTE:



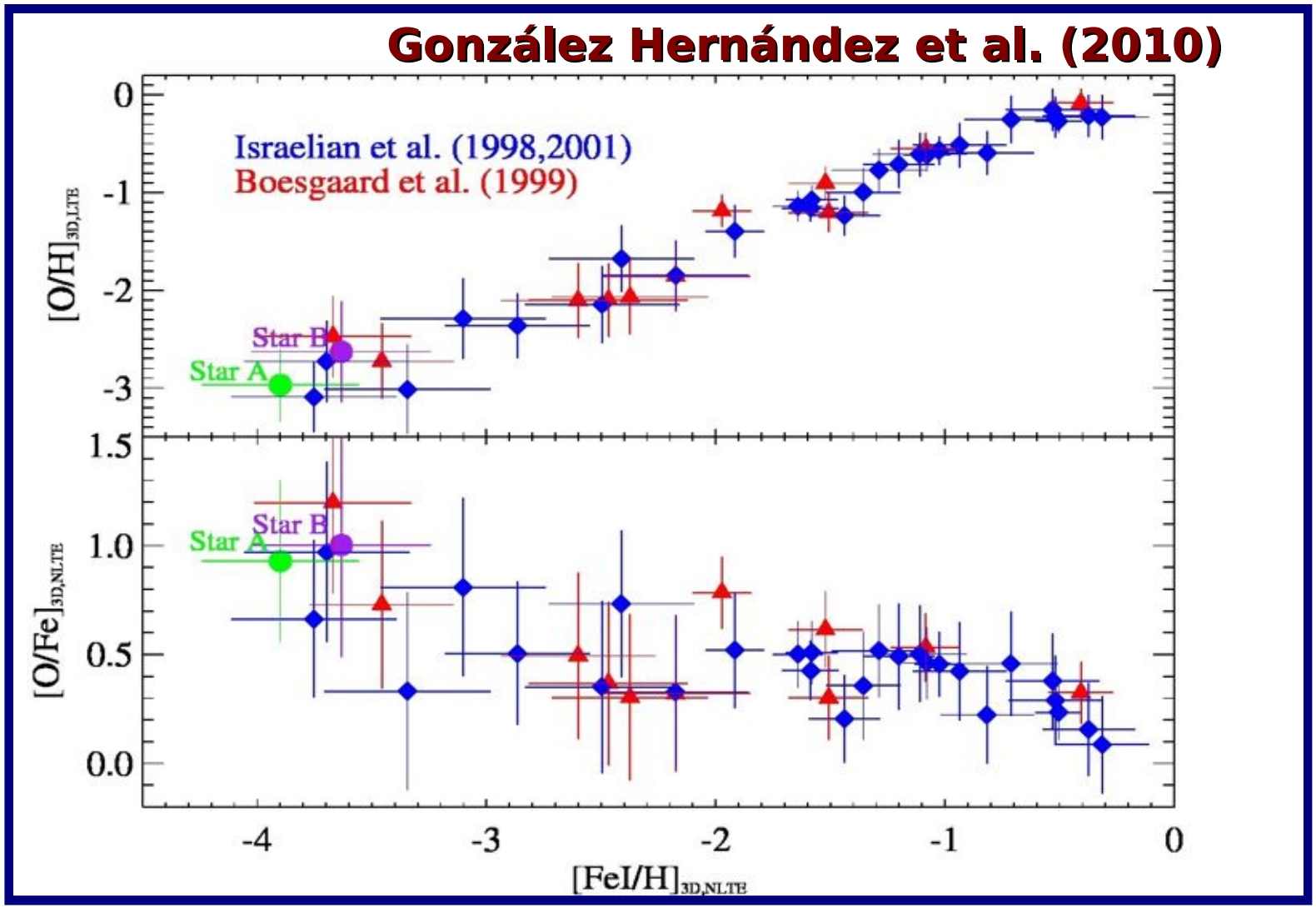
3D corrections

- We used 5 OH lines at 3123-3255 Å with χ in the range 0.2-1.3 eV and compute the abundance correction for each line by interpolating in the grid according to the stellar parameters of each star

- We used 3 FeI lines at 3843-52 Å with χ ~ 1-3eV, Israelian et al. only provides lines with χ ~ 1eV, so we decide to use the following recipe:
  -For stars with [Fe/H] < -2, we use FeI abundance correction of the FeI with χ ~ 1eV
  -For stars with [Fe/H] > -2, we use the average FeI abundance correction of 2 FeI lines with χ ~ 2 and 3 eV.

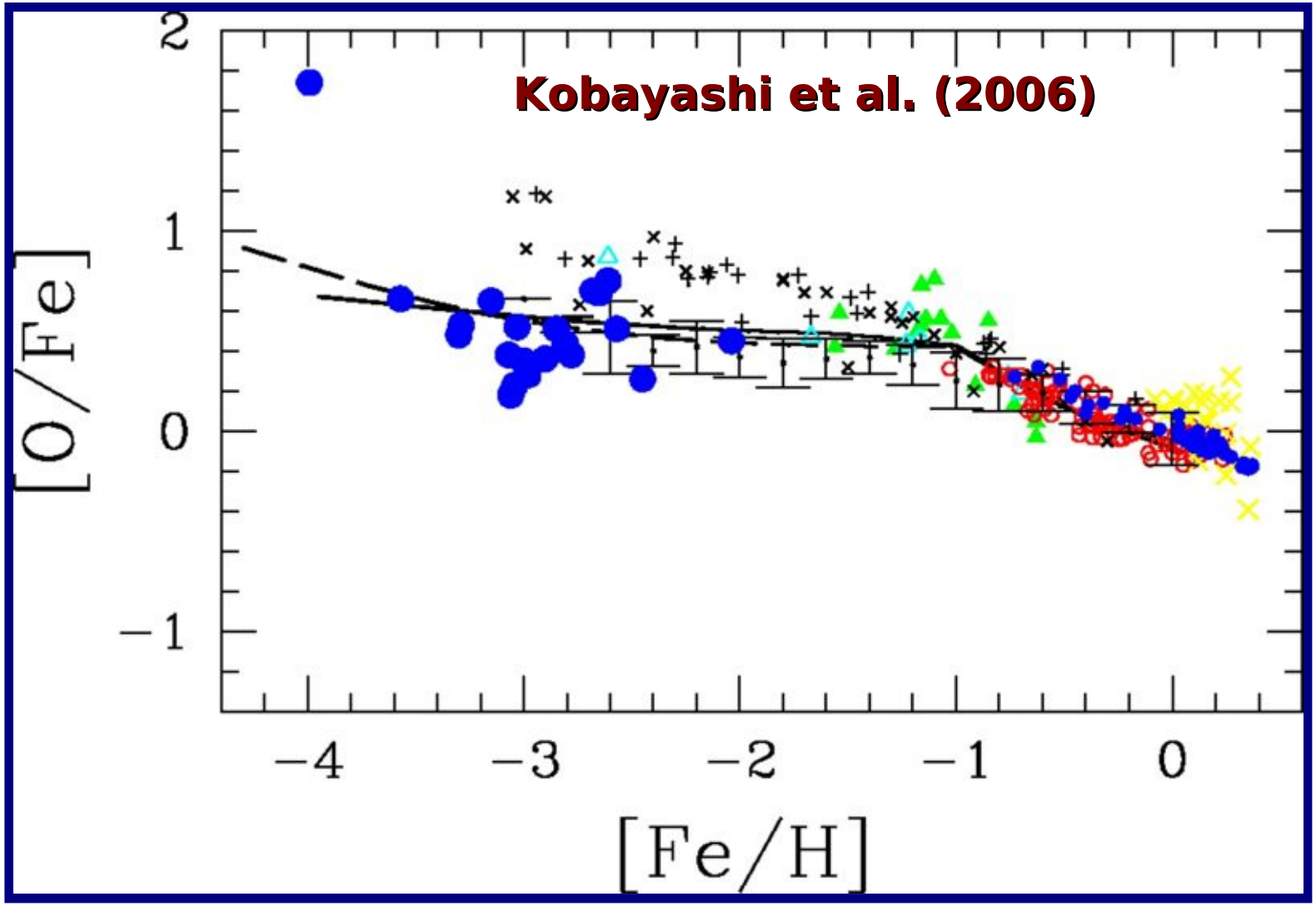
Oxygen: metal-poor stars

- OH and FeI in 3D + FeI in 1D-NLTE:



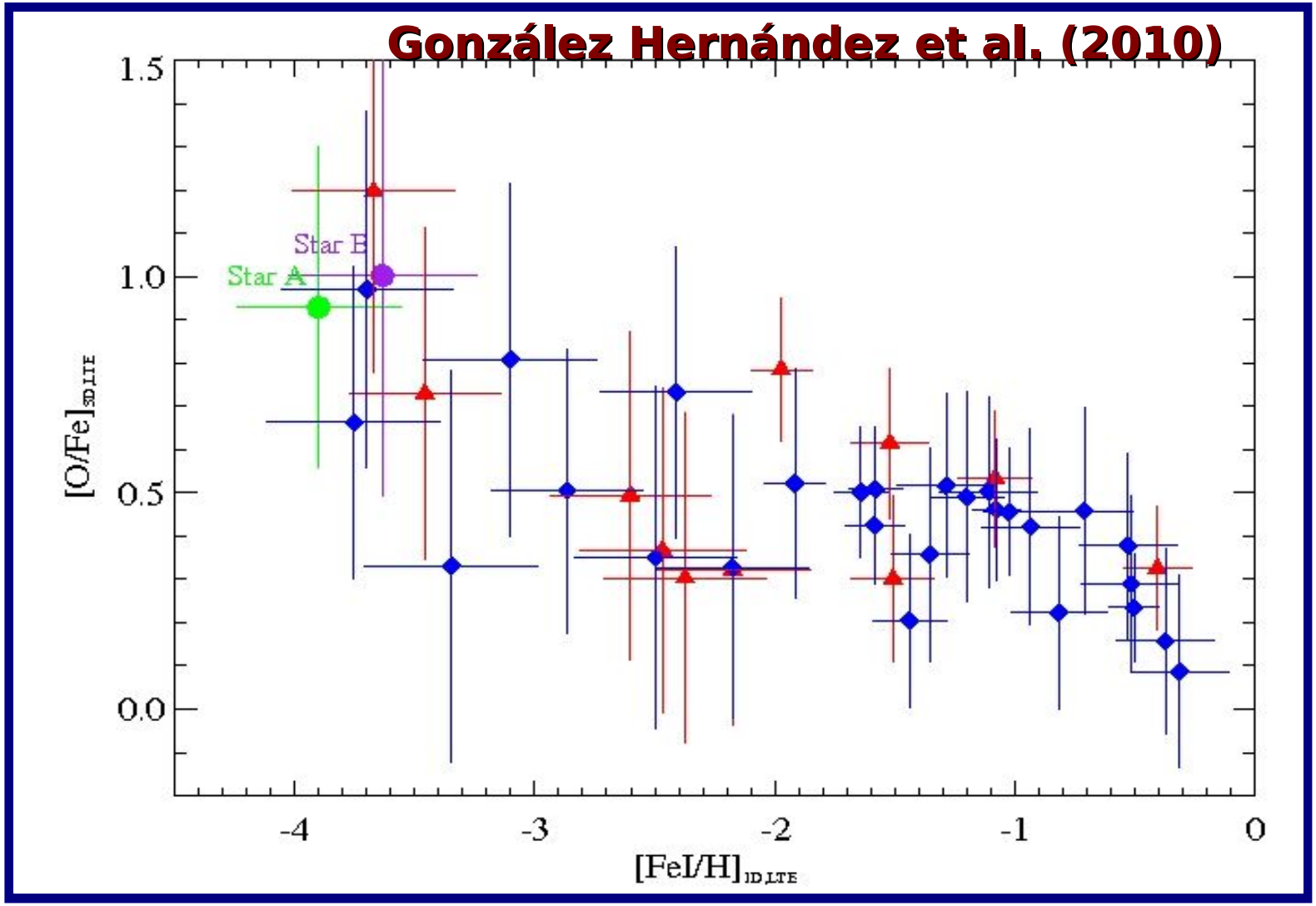
Oxygen: metal-poor stars

- SN-HN explosion models:



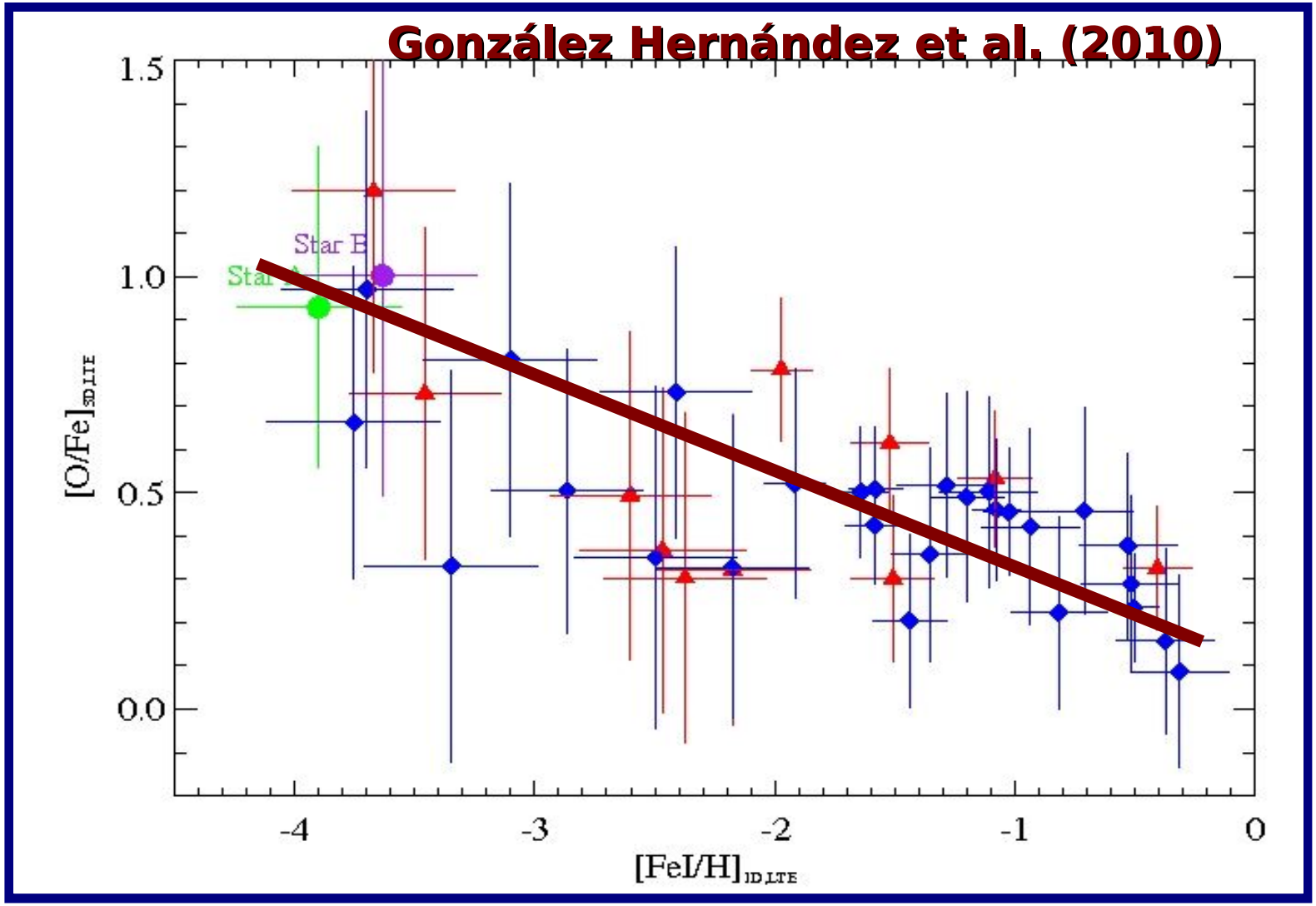
Oxygen: metal-poor stars

- [O/Fe] in 3D-NLTE:



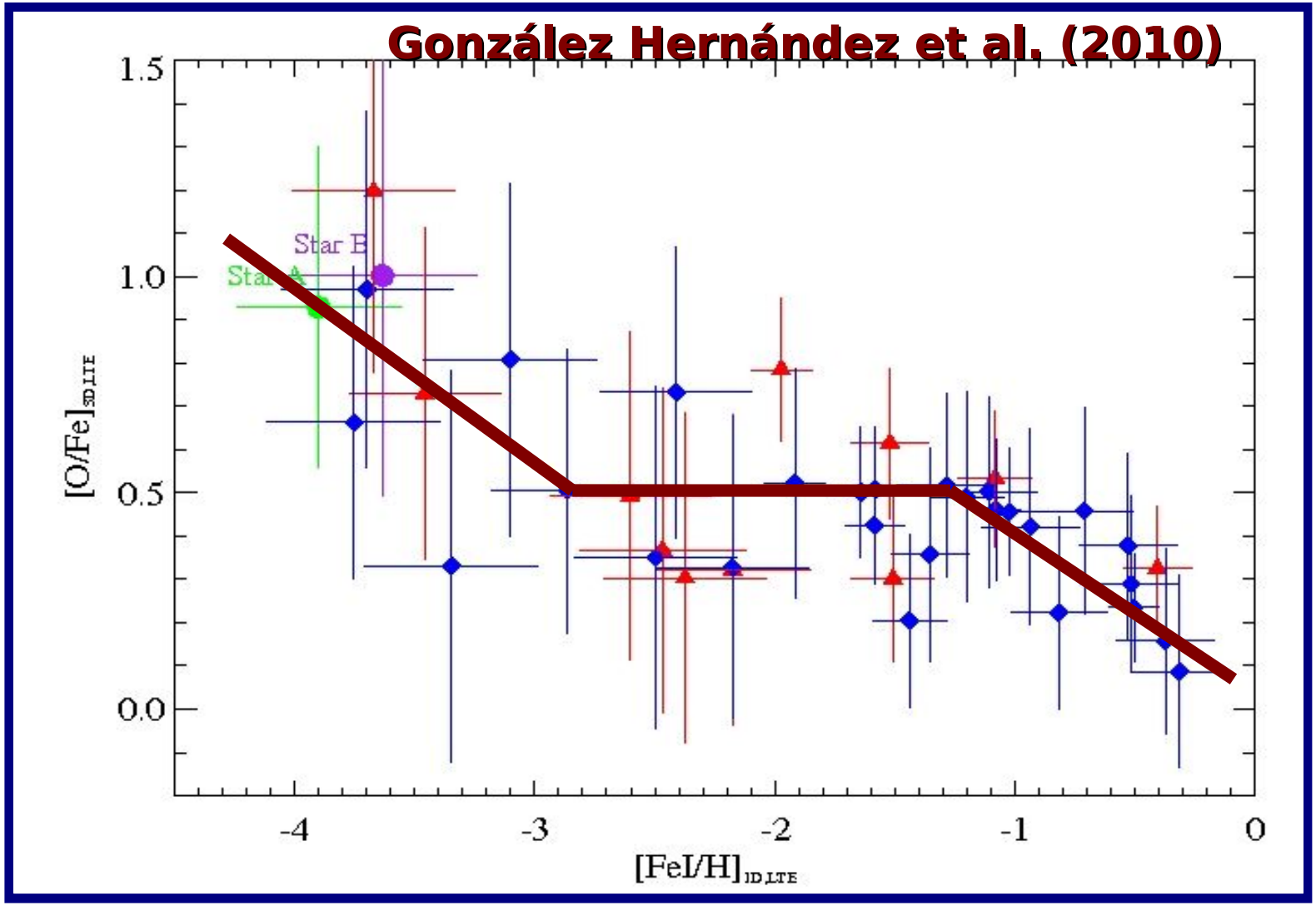
Oxygen: metal-poor stars

- [O/Fe] in 3D-NLTE:



Oxygen: metal-poor stars

- OH lines in 3D-NLTE:



Conclusions

- 3D models appear necessary in order to determine O abundances from near-UV OH bands, mainly due to cooling effects that metal-poor 3D models show

- The abudance trend of [O/Fe] in 3D-LTE seems to show a linear increase towards lower metallicity, and this trend still remains when applying 1D-NLTE corrections to the FeI abundances

- However, this might be considered with caution until 3D corrections and NLTE effects are applied to O and Fe for different abundance indicators in dwarfs, subgiants and giants

Galactic evolution of oxygen:
3D effects on the near-UV OH lines

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(1) Instituto de Astrofísica de Canarias (IAC)
(2) Cosmological Impact of the FIrst STars (CIFIST Marie Curie Excellence team)

Oxygen: metal-poor stars

- OH lines in 3D and 1D LTE abundances: