Convection and ^{6}Li in the atmospheres of metal-poor halo stars

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Outline

- **Introduction:**
  ^{6}Li and convective line asymmetry
- **Method:**
  3D NLTE line formation calculations for lithium
- **Results:**
  - **Correction of the Asplund et al. (2006) ^{6}Li abundances**
  - **Examples: HD74000, G271-162, HD 84937**
- **Conclusions**

A radical solution of the 2nd lithium problem

Line shift, line asymmetry, and the ^{6}Li/^{7}Li isotopic ratio determination ⋆

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Instead of invoking new physics ...
we considered the possibility that

Astronomy & Astrophysics Highlight

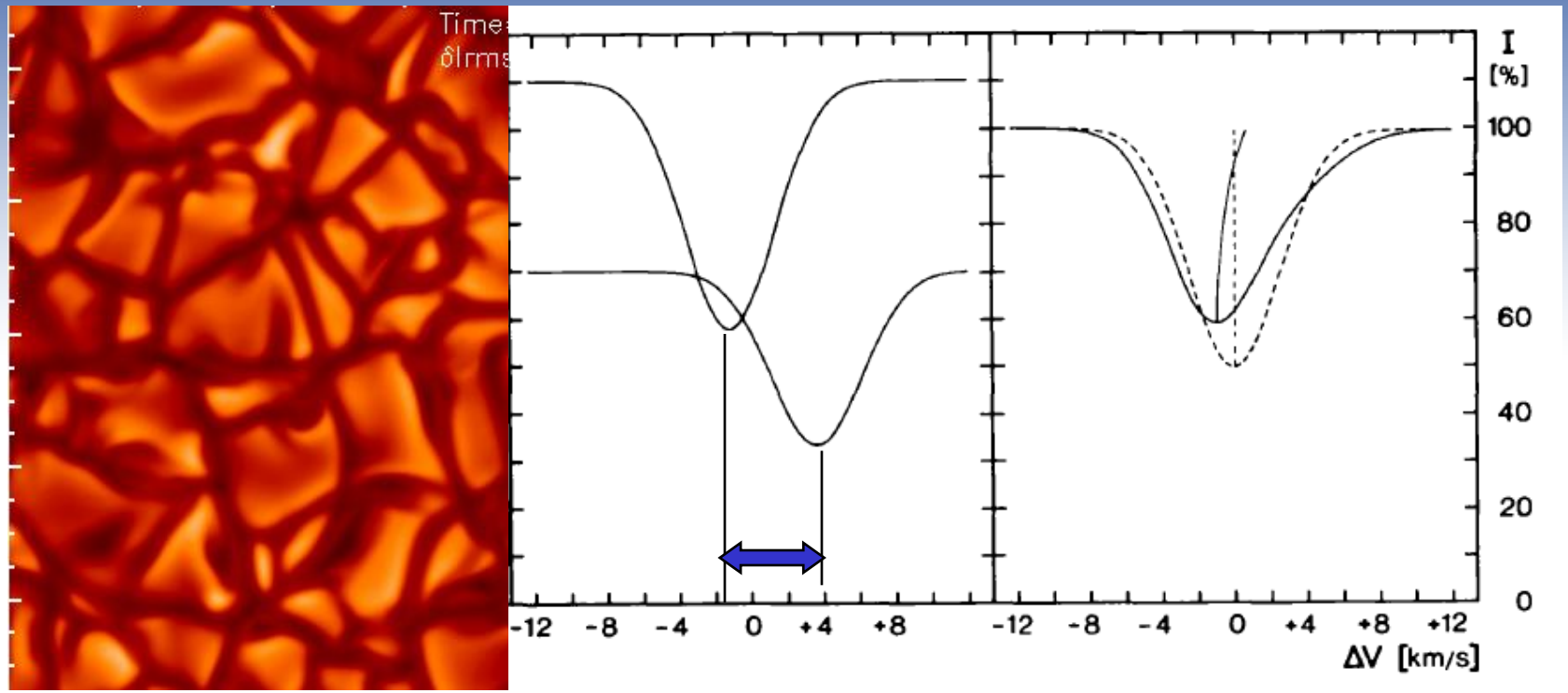
- **Previous ^{6}Li detections are only upper limits**

  ignoring the intrinsic, convection-induced line asymmetry results in a systematic overestimation of the ^{6}Li abundance

- **A systematic reappraisal of former determinations of ^{6}Li abundances in halo stars is needed**

  ultra-high spectra resolution, highest possible S/N

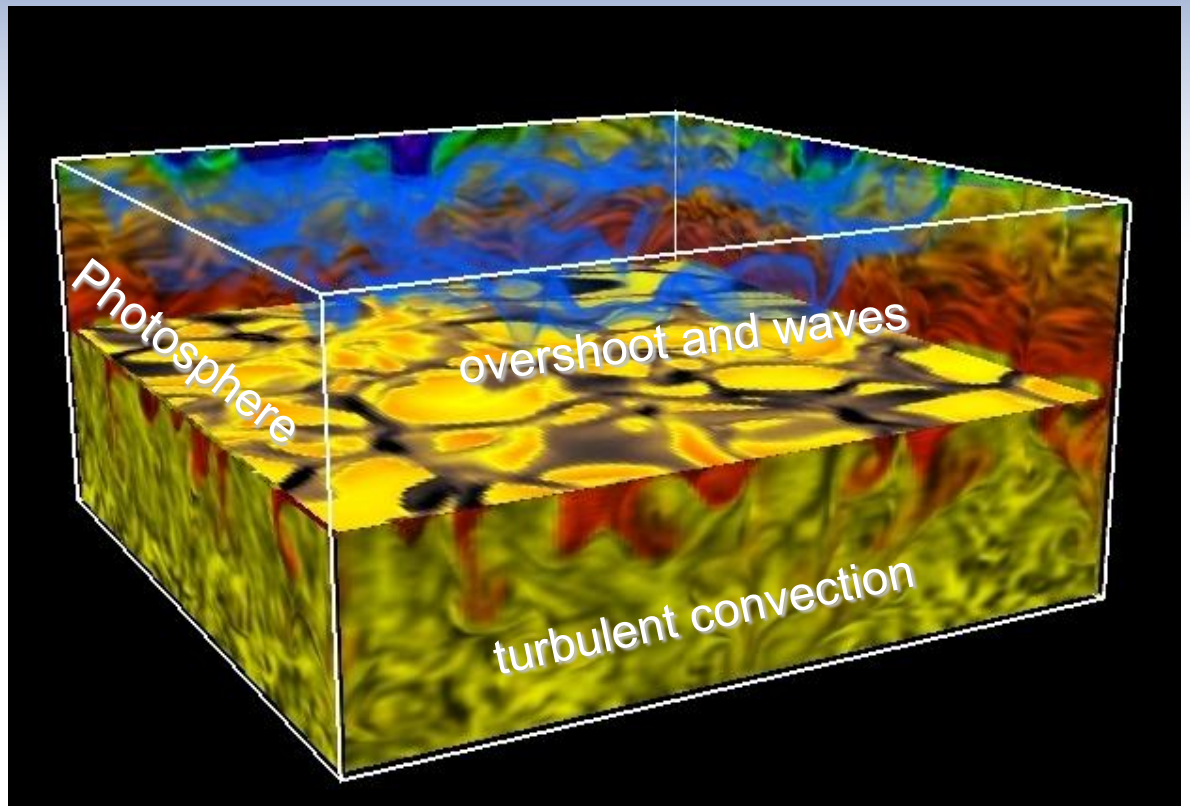
Origin of convective line asymmetry



Strong blue-shifted + weak red-shifted profile ➔ asymmetry

After Dravins et al. (1981)

CO5BOLD 3D hydrodynamical simulations of surface convection in metal-poor stars



← log $\tau_{Ross} \approx -8$

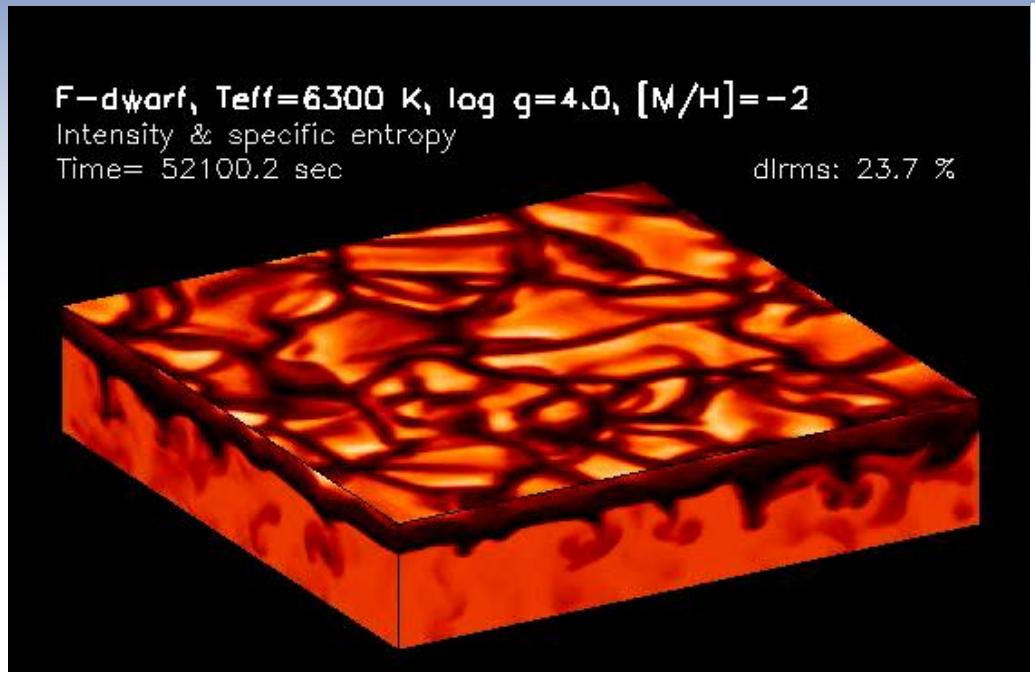
← log $\tau_{Ross} \approx 0$

← log $\tau_{Ross} \approx +7.5$

Teff = 6300 K, log g = 4.0, [M/H] = –2

- **typically 140x140x150 cells**
- **realistic MARCS opacities**
- **RT in 6 frequency bands**

3D-NLTE line formation in metal-poor stars

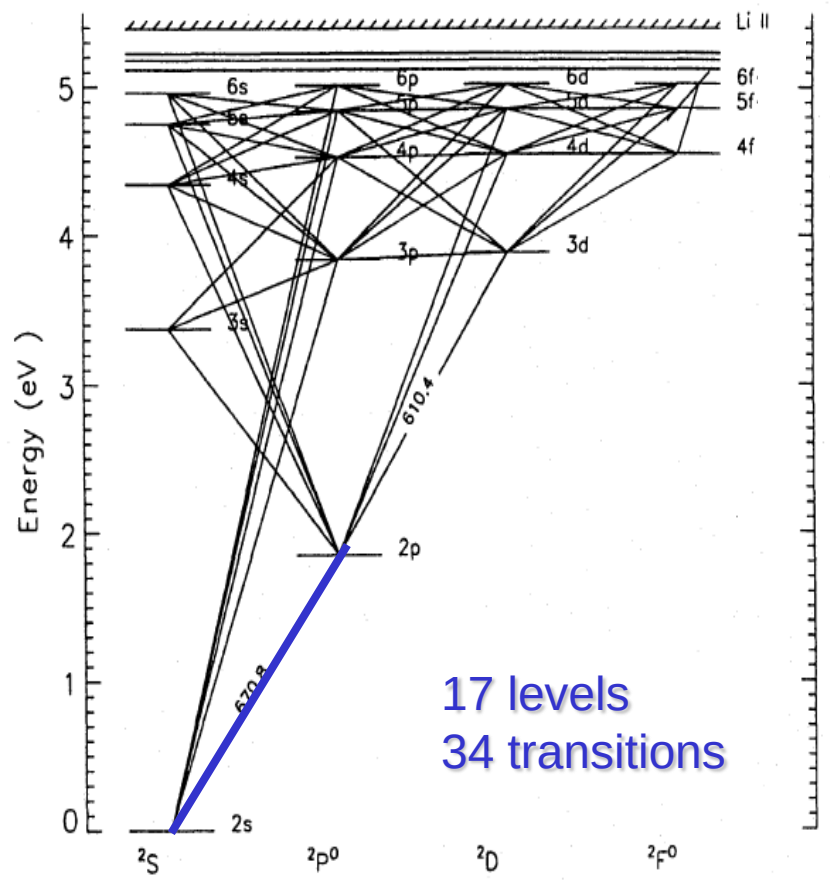


1. Radiation field $J\nu(x,y,z)$, ν : UV .. IR
2. Photo-ionization rates for all levels *i*
3. Statistical equilibrium equations

➔ departure coefficients *bi*(x,y,z)

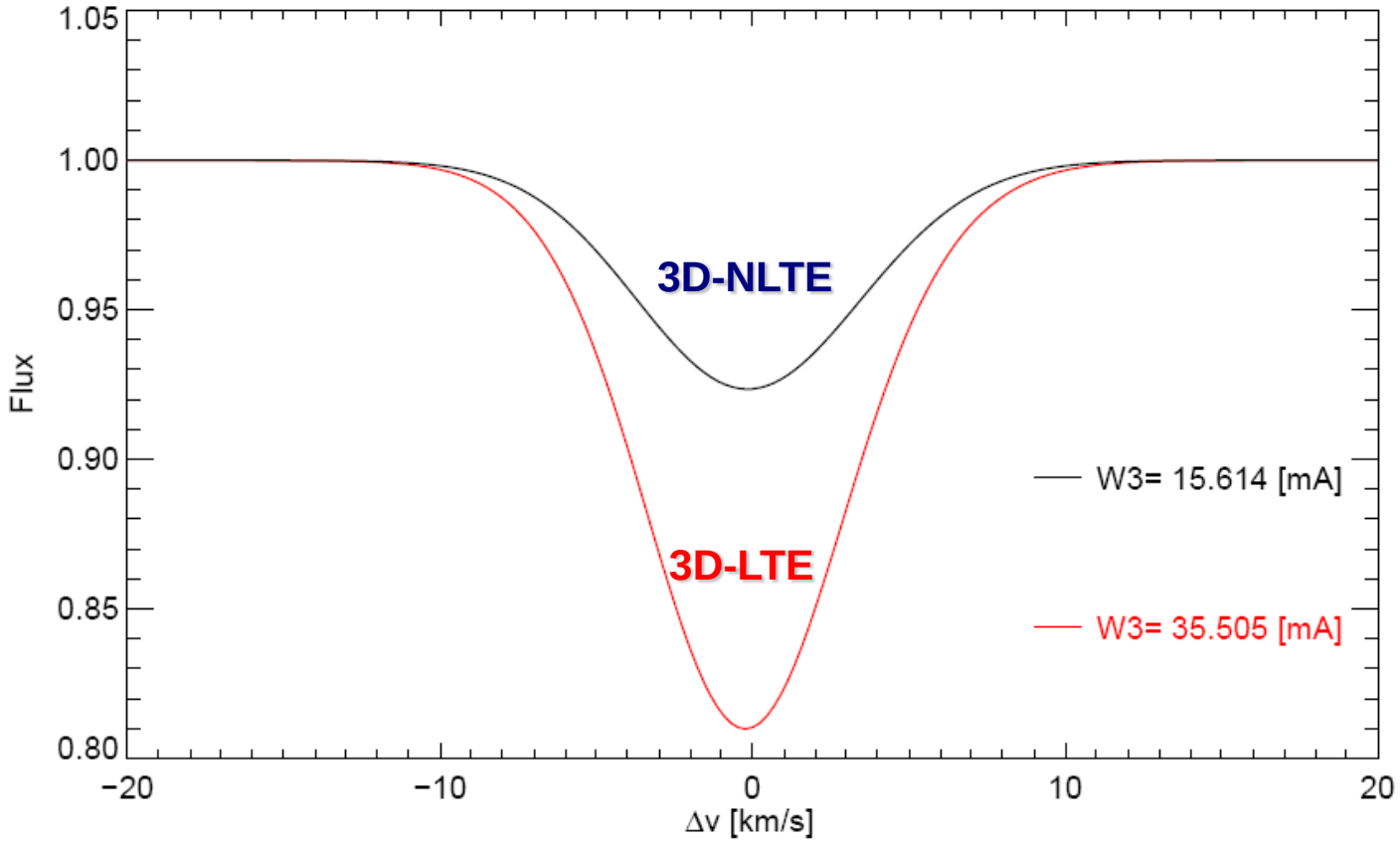
Cayrel, Steffen, et al. (2009)

Lithium model atom



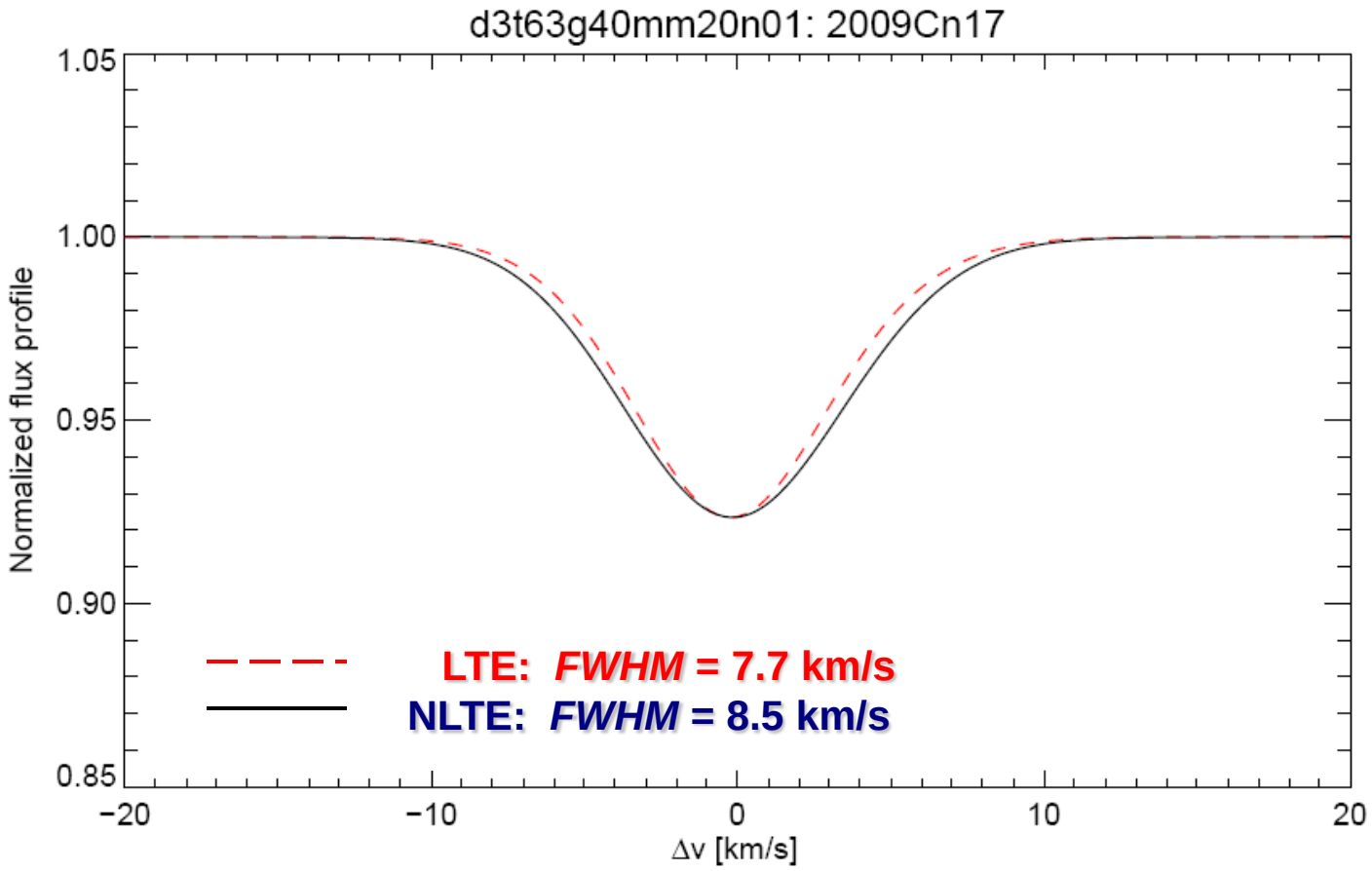
H + Li ⇔ H$^-$ + Li$^+$: Barklem et al. 2003

Li 6707: line formation in LTE / NLTE

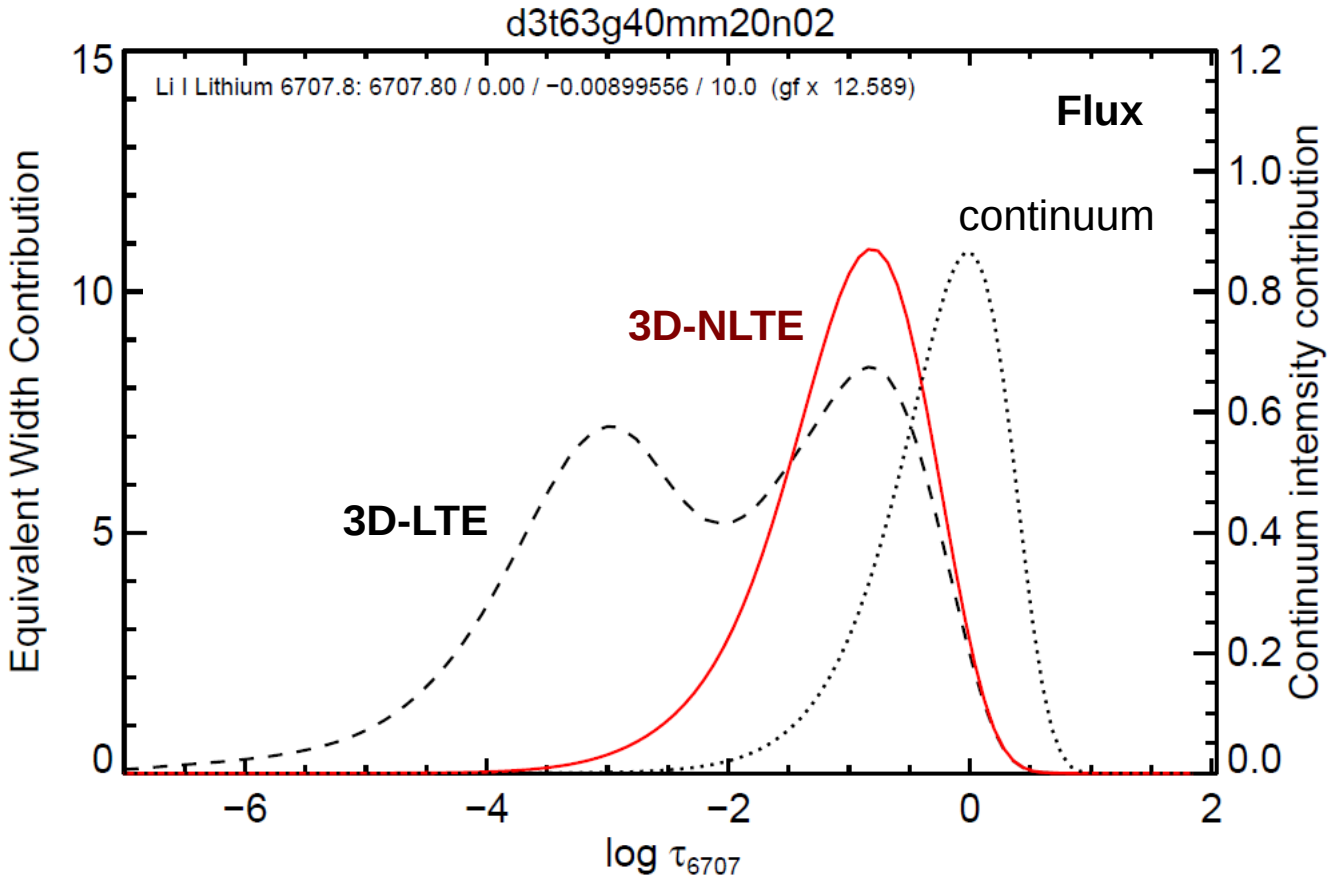


Li line strength smaller by factor ≈ 2 in NLTE

Li 6707: line formation in LTE / NLTE

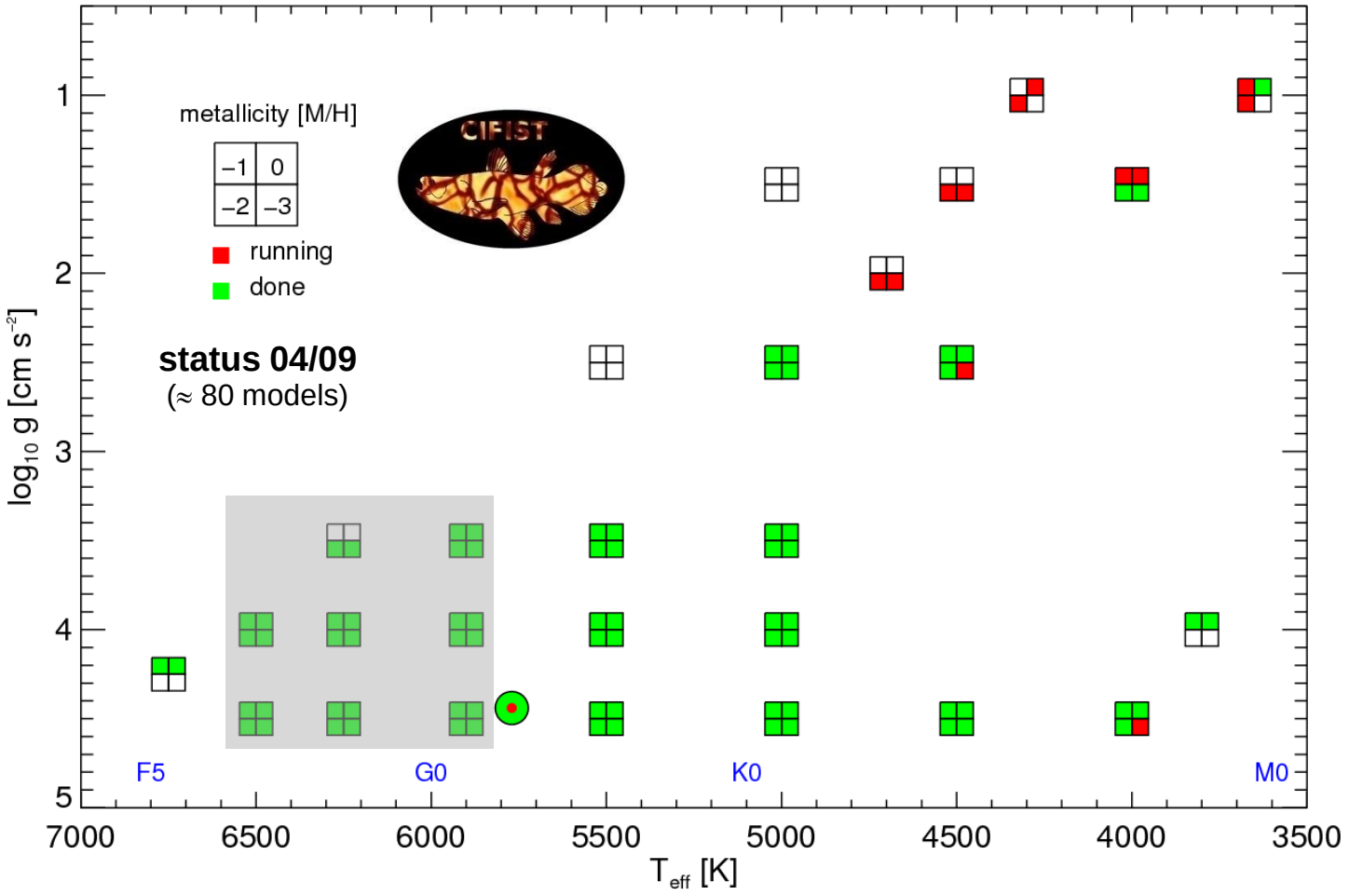


3D-LTE / NLTE Li 6707 line contribution function



Cayrel, Steffen, et al. (2009)

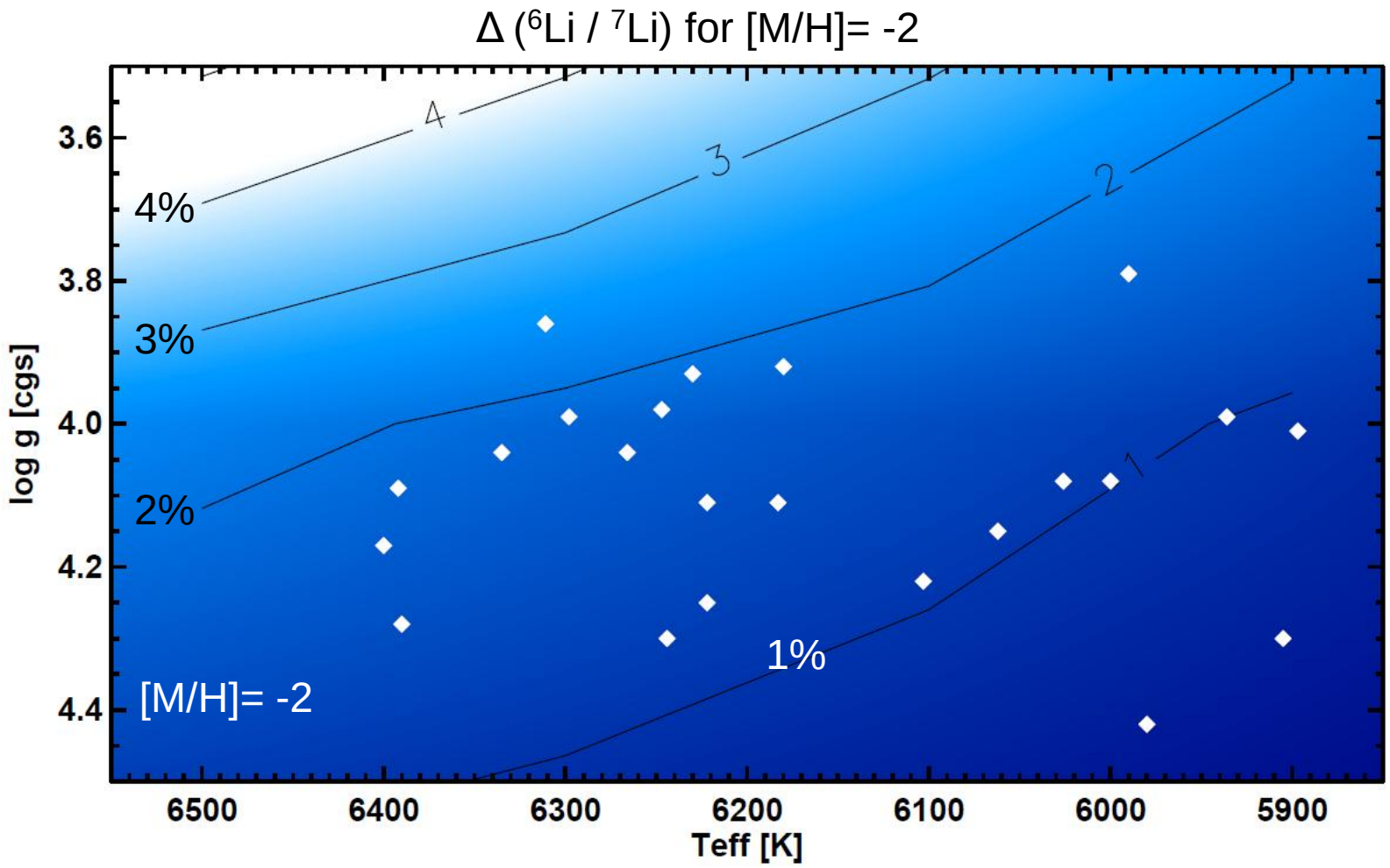
The CIFIST 3D model atmosphere grid



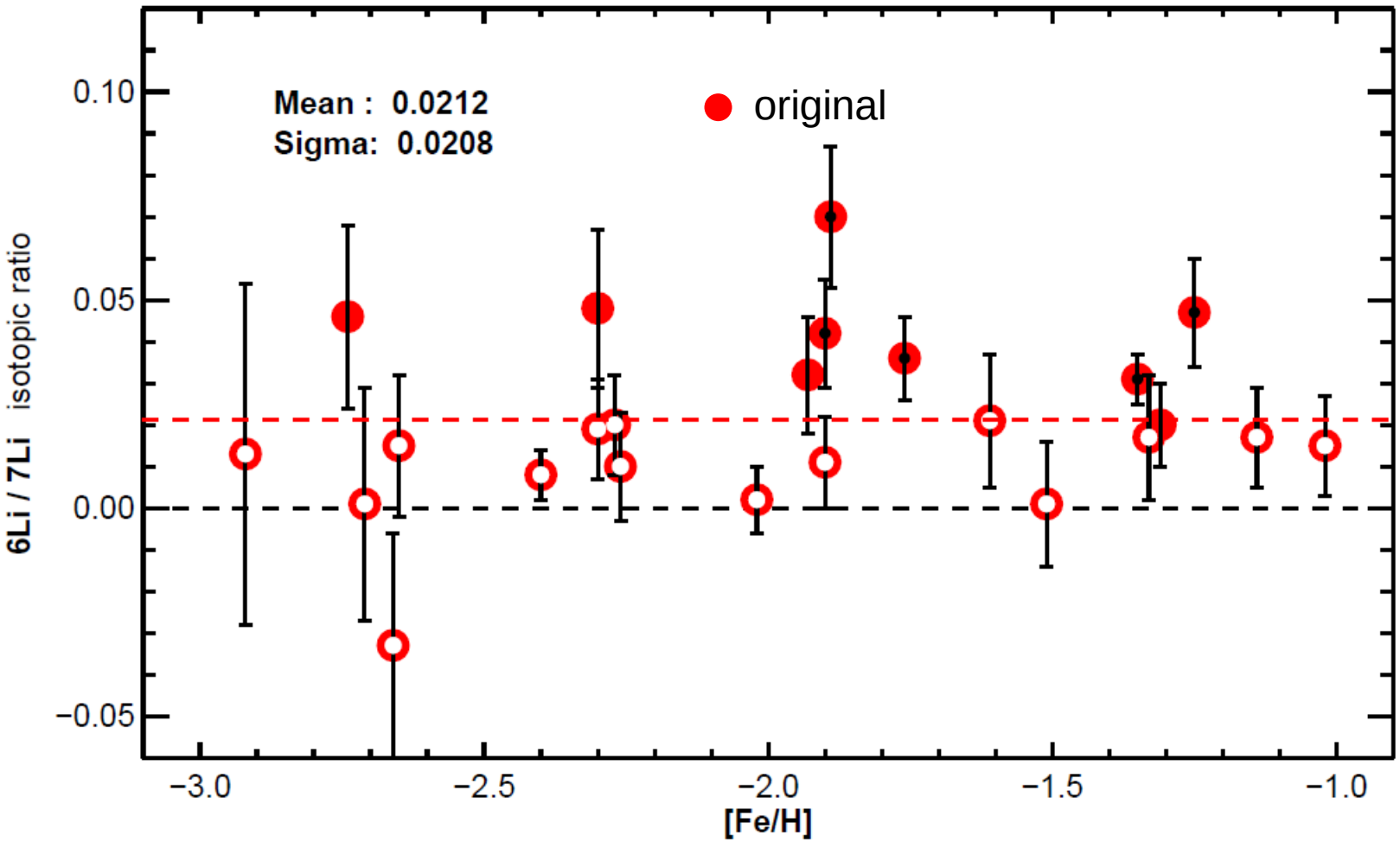
Fitting 3D-NLTE with 1D LTE

- 3D NLTE ^{7}Li λ6707 full blend (no ^{6}Li)
- Fitting with 1D LTE ^{6}Li / ^{7}Li full blend
- 4 free fitting parameters:
  - ➔ A(Li)
  - ➔ ^{6}Li / ^{7}Li
  - ➔ ξ_{mac} (macro + instrumental broadening)
  - ➔ Δv (global line shift)
- Fixed: ξ_{mic}, v sin i
- Saturation effects included
- Result: Δ (^{6}Li / ^{7}Li) = correction for intrinsic line asymmetry

Spurious ^{6}Li signal due to intrinsic line asymmetry



^{6}Li detection by Asplund et al. (2006)



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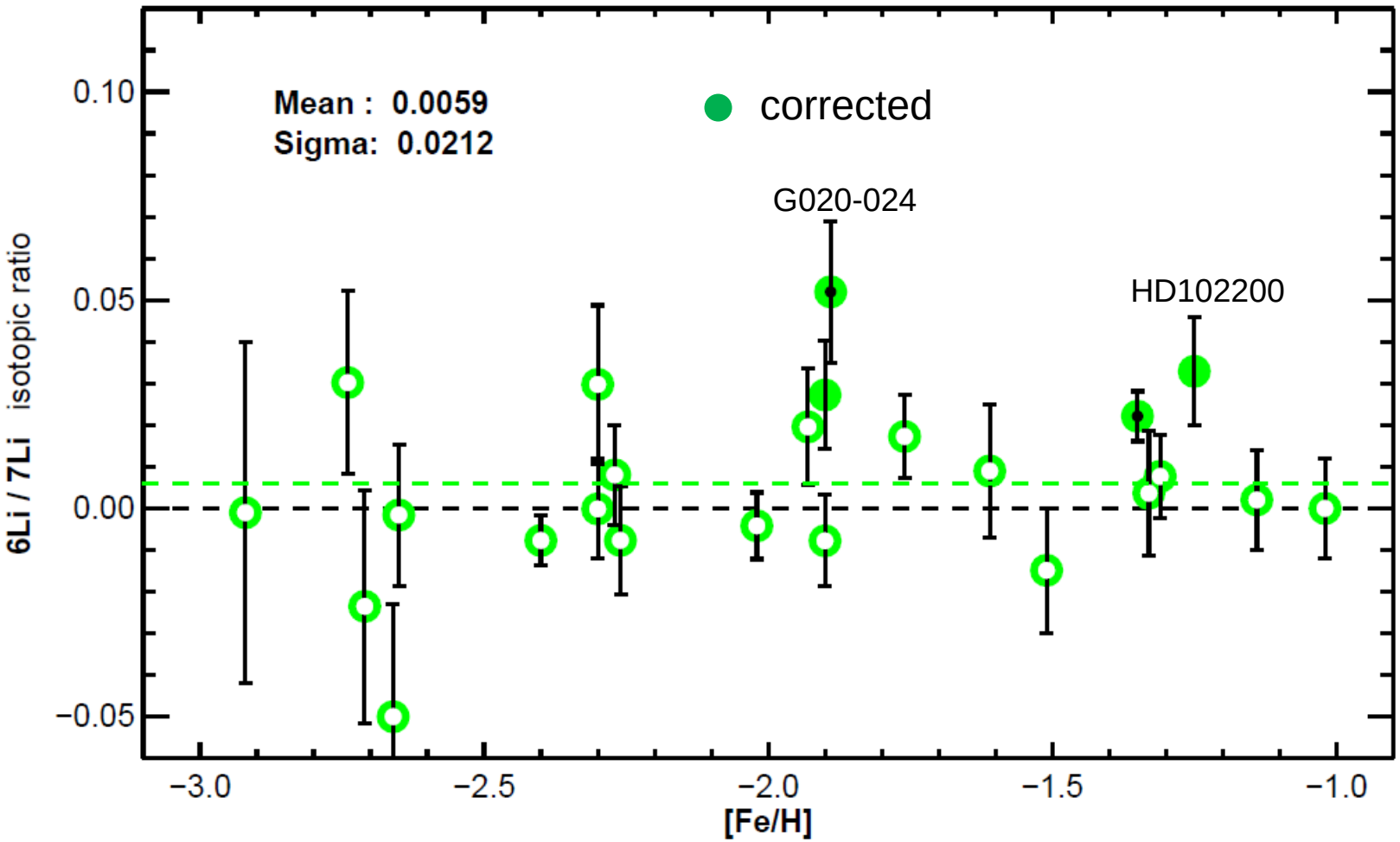
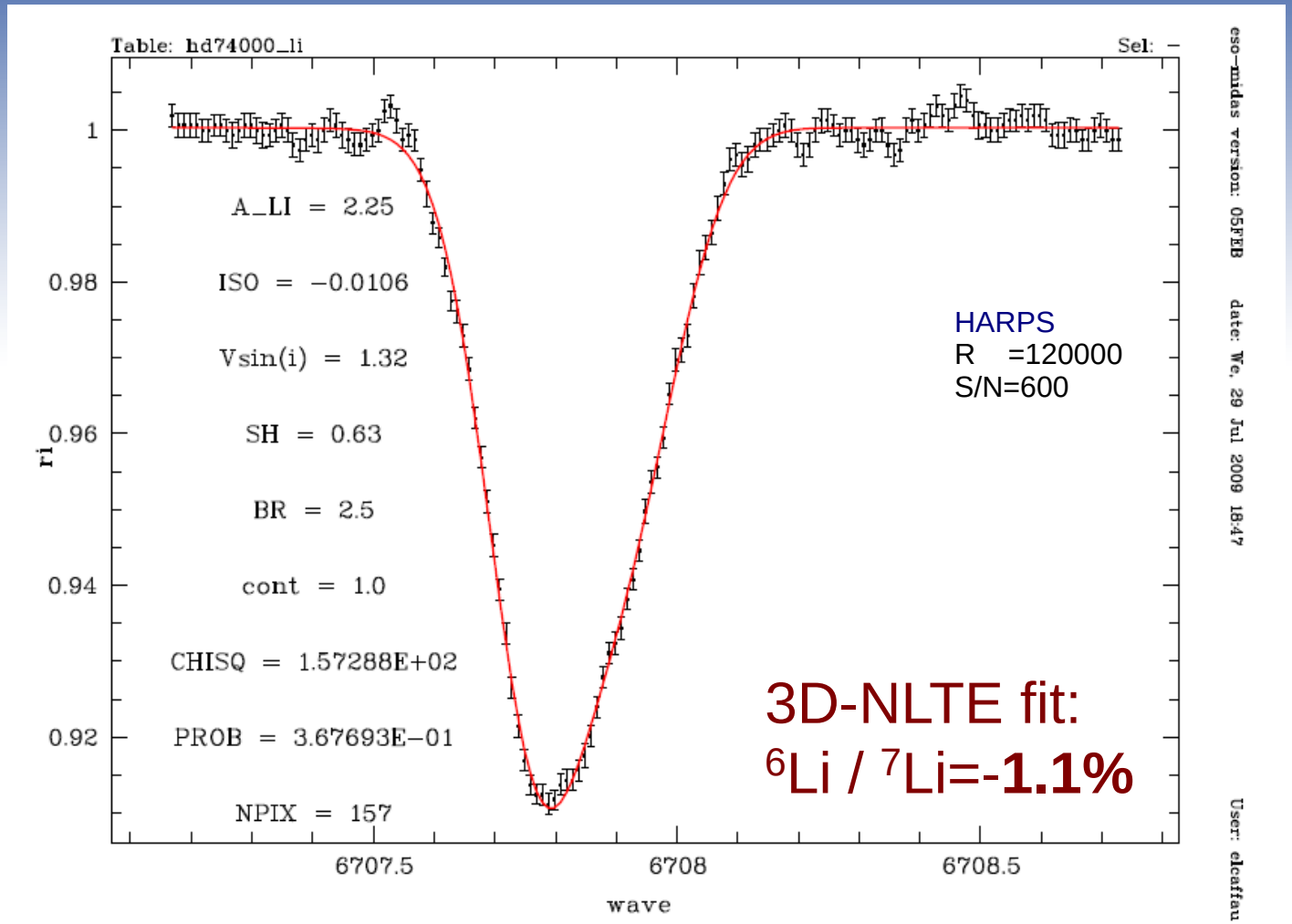
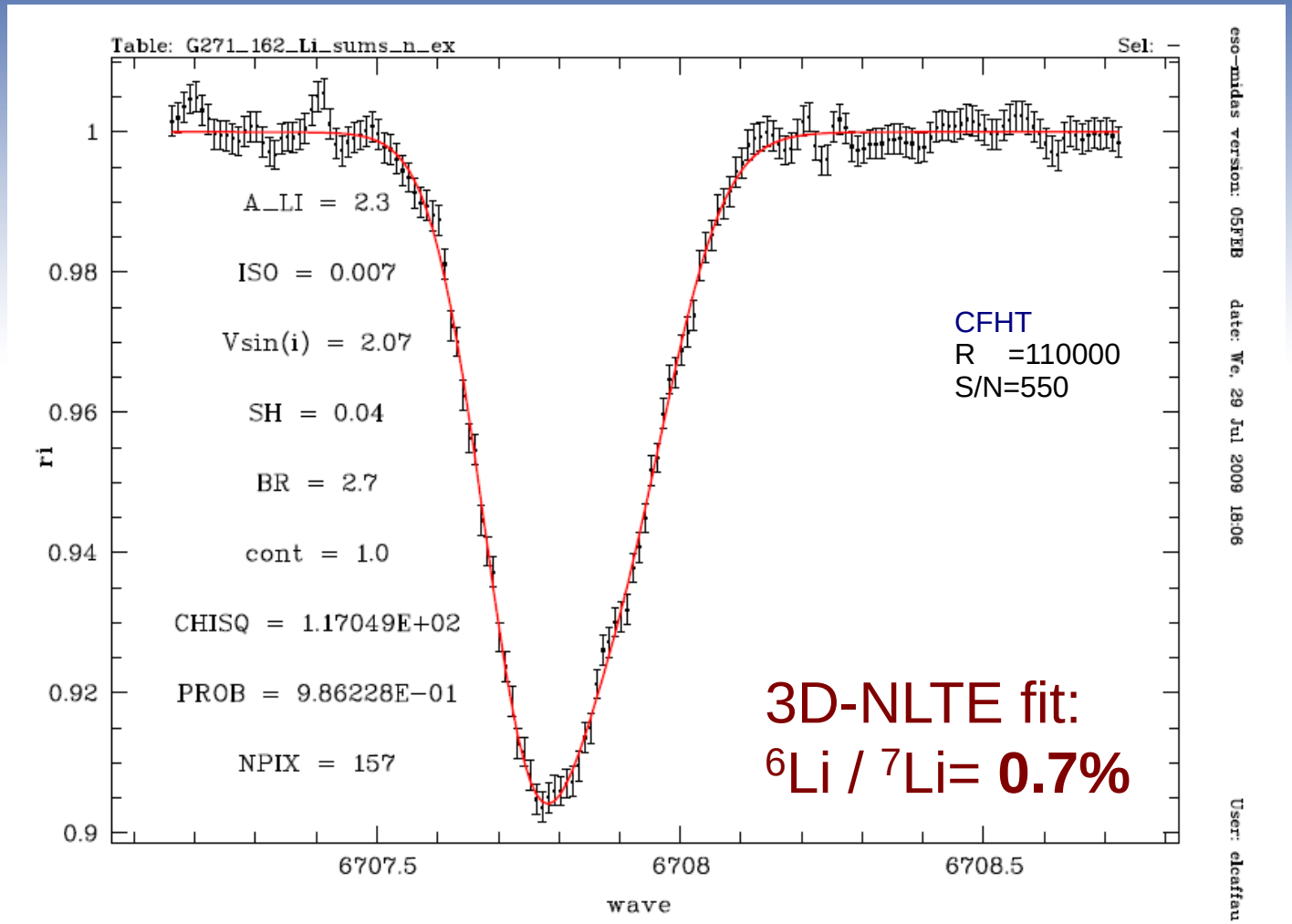


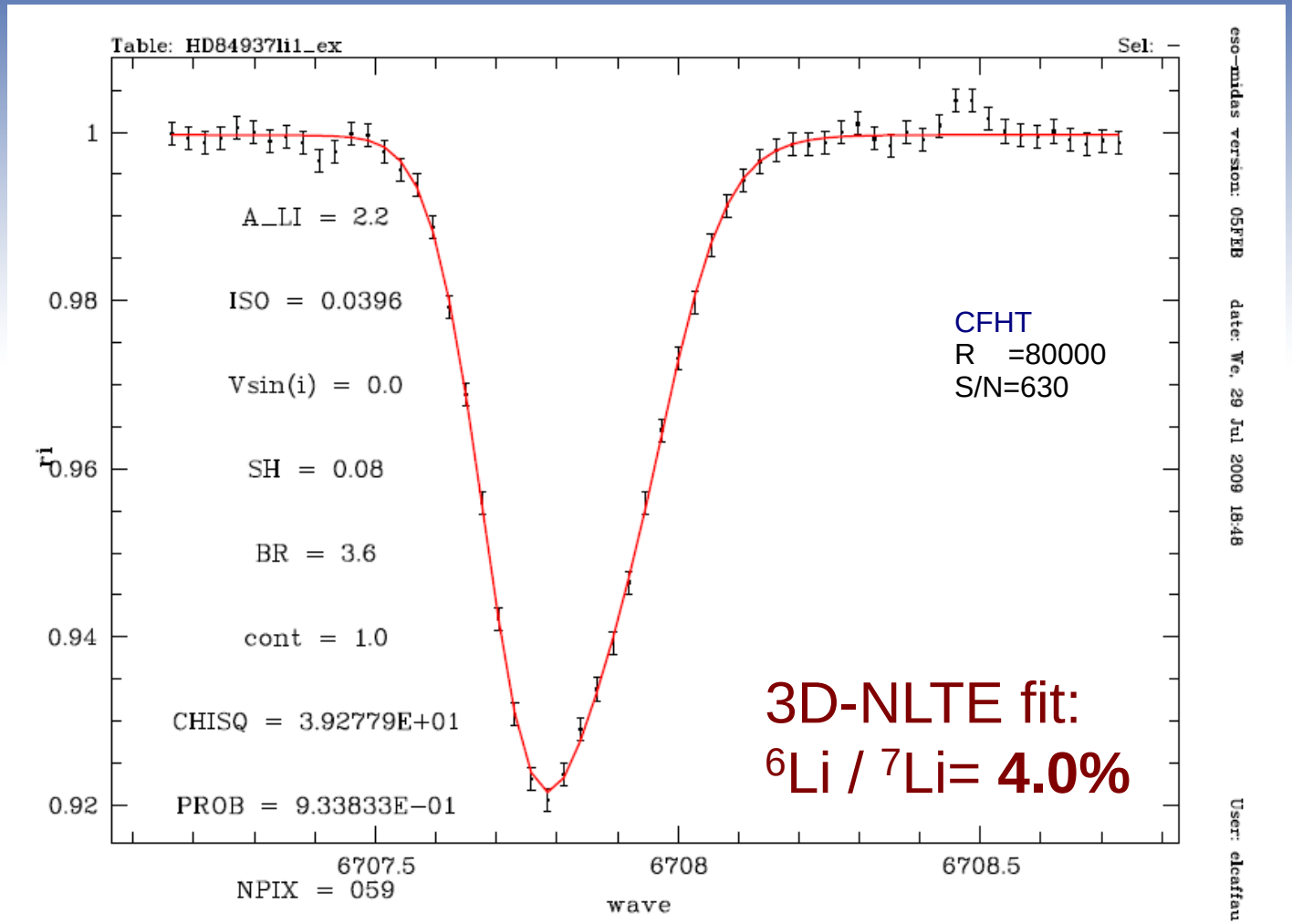
no ^{6}Li detection in HD 74000



no ^{6}Li detection in G271-162



^{6}Li detection in HD 84937



Fitting results for three real stars

$^6Li/^7Li$ [%]	1D LTE	3D NLTE
v sin *i*	0.0 / 2.0 km/s	0.0 / 2.0 km/s
HD 74000	0.6 / 0.6	-1.1 / -1.1
G271-162	2.2 / 2.2	0.6 / 0.5
HD 84937	6.3 / 6.0	4.0 / 4.2

Fits by EC

^6Li / ^7Li insensitive to assumed *v* sin *i*

Fitting results for HD 74000 using additional lines (CaI, FeI)

	1D LTE	3D LTE
Residual line broadening	Macro + Rot. + Instr.	Rot. + Instr.
FWHM (from Li only)	5.9 km/s	3.8 km/s
FWHM (from Ca, Fe)	5.6 km/s	3.0 km/s
$^6Li/^7Li$ free ➔ fixed	0.6% ➔ 1.1%	-0.9% ➔ 1.3%

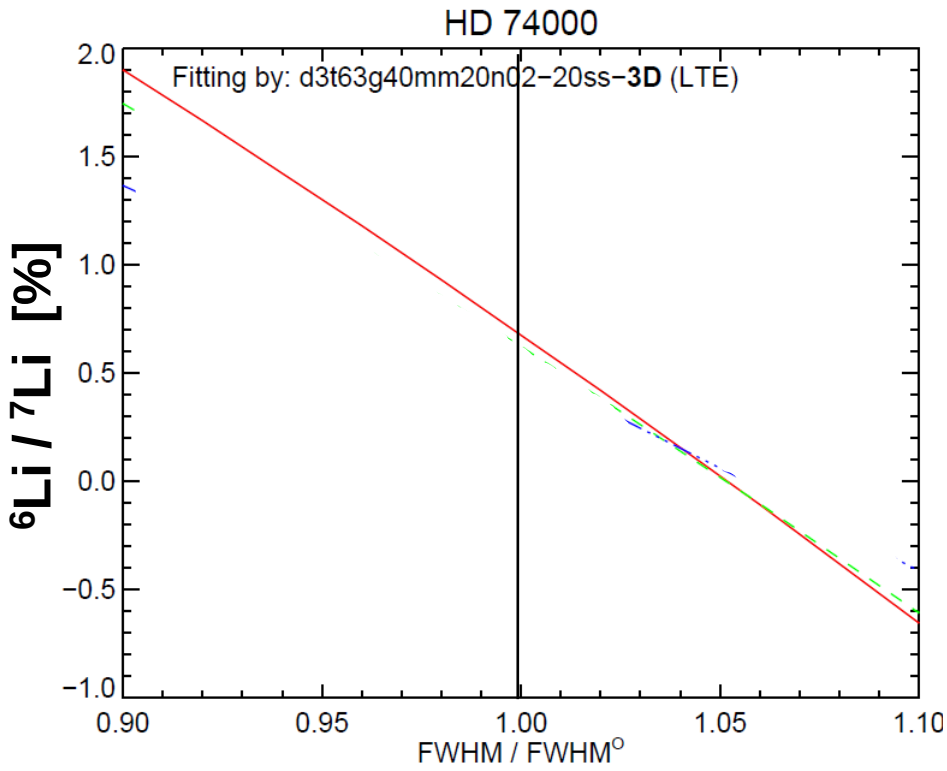
Fits by EC

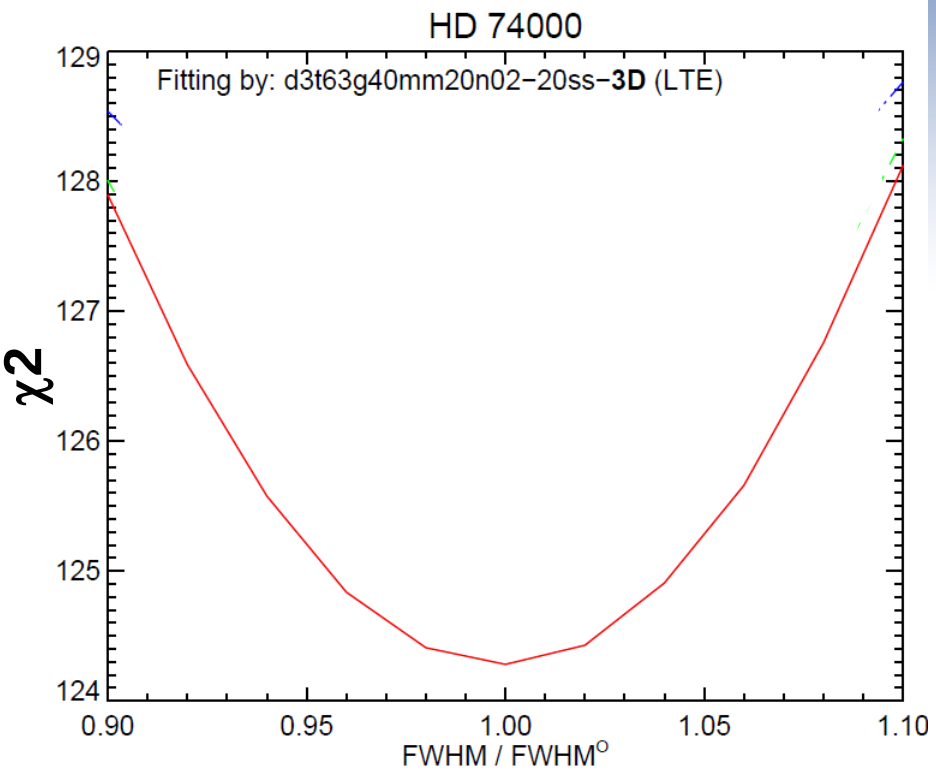
Li only: $^6Li/^7Li$ (3D) < $^6Li/^7Li$ (1D)

Li + Ca, Fe: $^6Li/^7Li$ (3D) > $^6Li/^7Li$ (1D)

3D LTE fitting of HD 74000:

Anti-correlation between line broadening and ^{6}Li abundance





ΔFWHM=-20% ➔ ^{6}Li / ^{7}Li ≈ +0.022

Conclusions

- **Taking intrinsic line asymmetry into account in 3D NLTE reduces the ^{6}Li / ^{7}Li ratio by ≈ 2%**
- **Correcting the Asplund et al. (2006) sample reduces the number of 2σ detections from 9 to 2**
  (no ^{6}Li plateau, no cosmological ^{6}Li problem)
- **HD 84937: ^{6}Li / ^{7}Li ≈ 4% (2σ detection)**
  (peculiar case?)
- **Fixing the broadening of Li from other lines is potentially dangerous**
- **Further investigations necessary**
  Theory: 3D non-LTE line formation of K, Ca, Fe, …
  Observation: spectra of even higher quality