Abundance analysis of stellar spectra. Metal-poor stars and the Sun.

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Outline

- Why are abundances needed?
- How to calculate abundances?
- Problems in analysis
- Implications

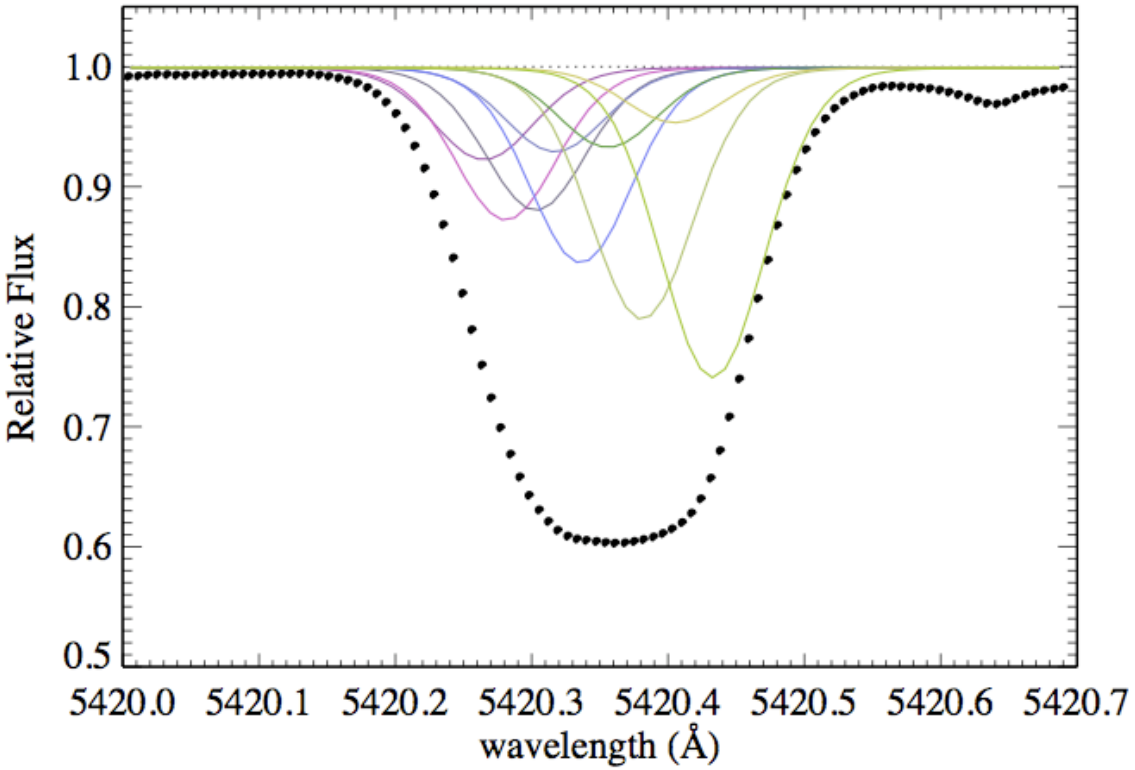
Why chemical composition of Metal-Poor Stars (MPS)?

Low-mass stars are born in different stages of Galactic evolution.

- their surface composition is not affected by nuclear reactions in the interior → reflect composition of the ISM from which the stars formed
- compare the abundances in MPS with Galactic chemical evolution calculations (based on STELLAR YIELDS) → observational constraints on different types of SNe, and nucleosynthesis
- Iron abundance is not sufficient, more information from detailed study of abundance patters of the other elements (α – group, Fe-peak, r-, s-process)
- Do not forget the Sun – the main comparison stone for all other stars: $[El/H] = \log (N_{el}/N_H)_{Star} - \log (N_{el}/N_H)_{Sun}$

How to interpret spectral lines?

Chemical composition (or element abundances) can *only* be extracted from an observed spectrum *by computational modelling* of the atmosphere and the spectrum.



Hyperfine structure, which affects odd-Z elements (Mn, Co)

Minnaert & Moulders (1930)

"*Welche* totale Energie in der Linie verschwunden ist… *Wie* die absorbierte Energie von der Anzahl absorbierender Atome abhängt…"

?

A stellar atmosphere

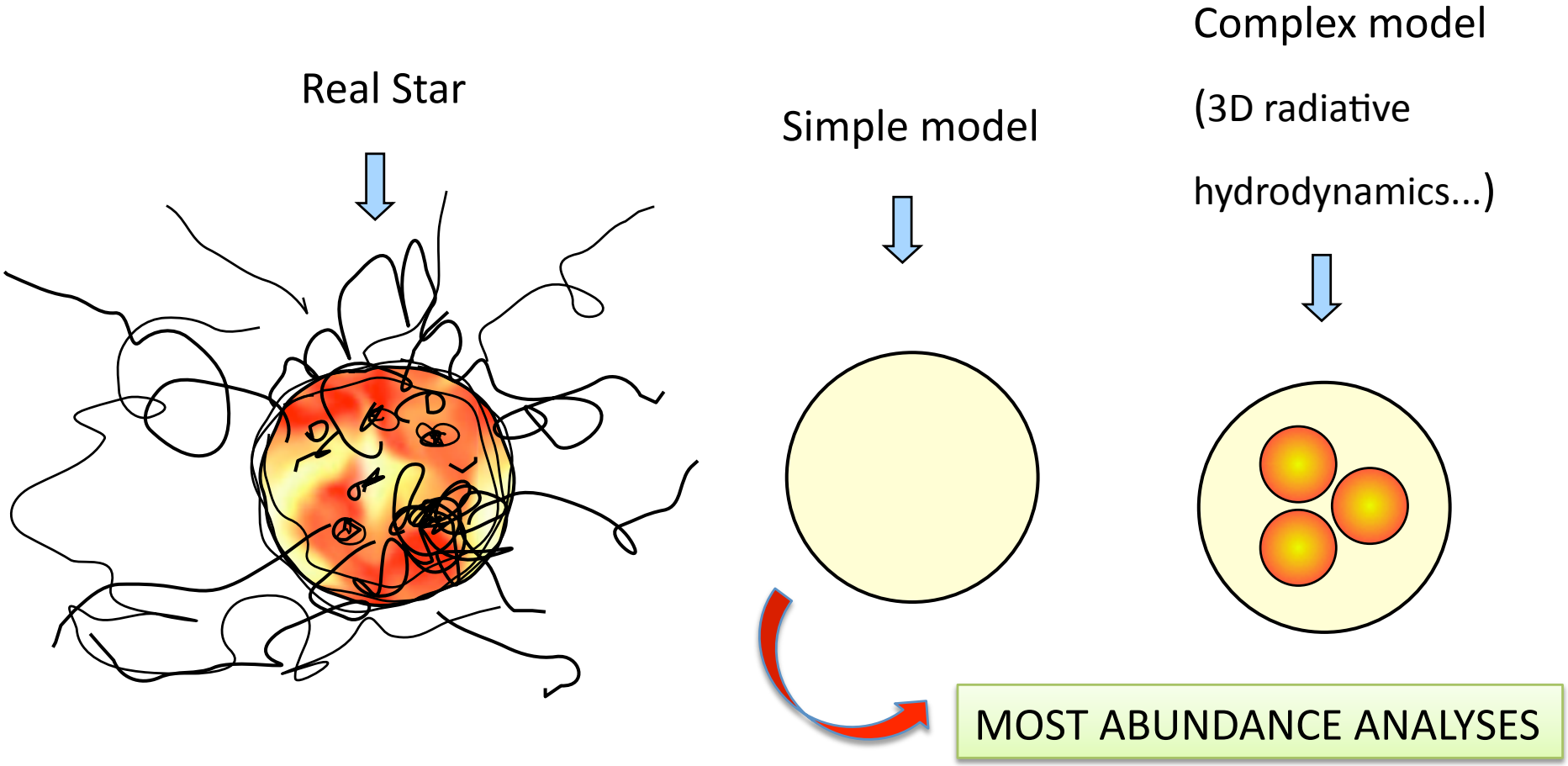
- is a complex system, because both macro- and micro-scopic phenomena determine its *state*
- macro: convection, pulsations, expanding envelopes (3D)
- micro: interactions on (sub)atomic scales: (NLTE)

  photon - electron - ion

It is not possible at present to model all these phenomena simultaneously. Need *simplifications*.

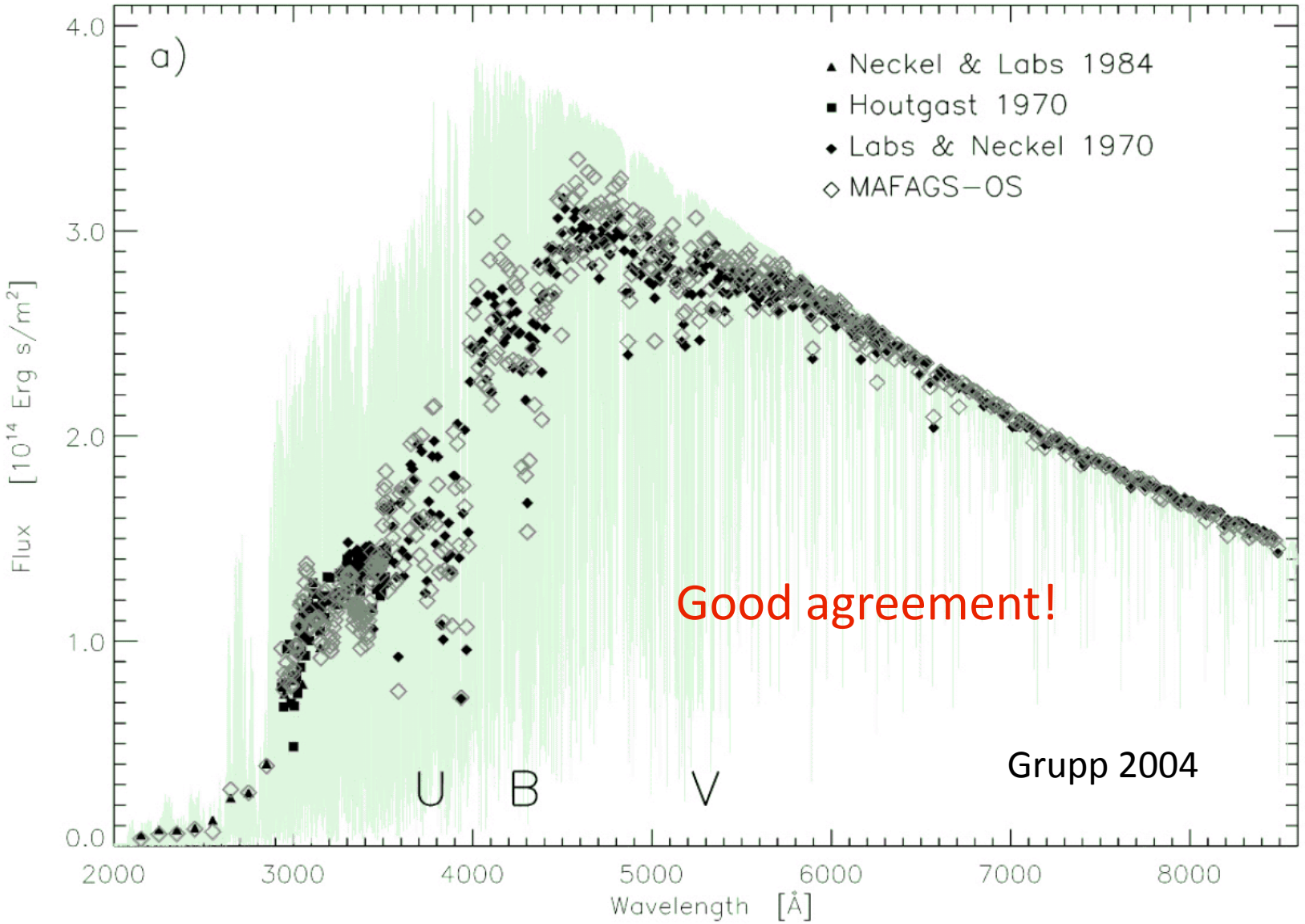
A stellar atmosphere and its models

Most of theoretical models of stellar atmospheres are simple:
1D, static, in LTE, energy transport by radiation & convection

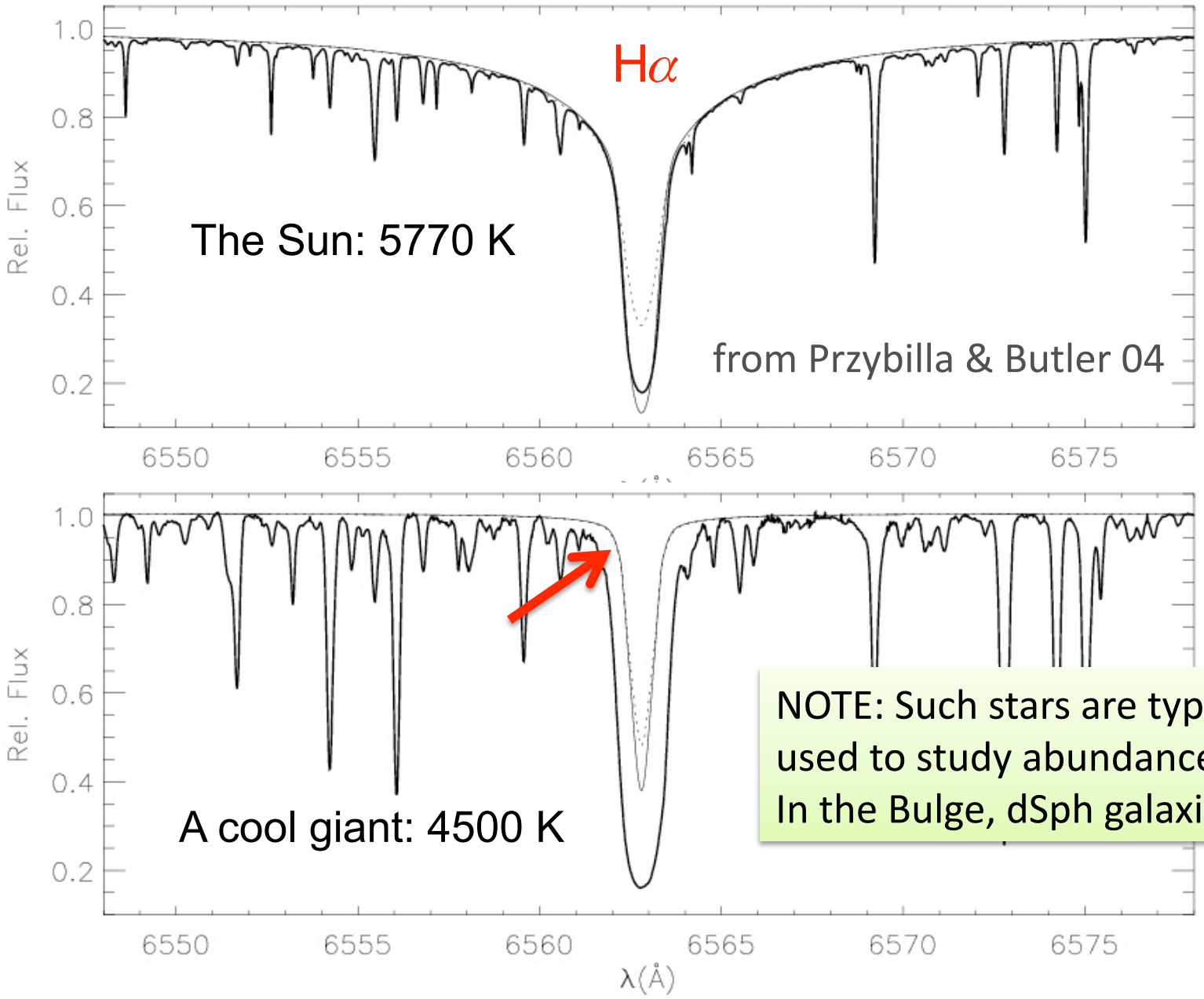


Testing the A models

Sun: theoretical emergent Flux vs. observations

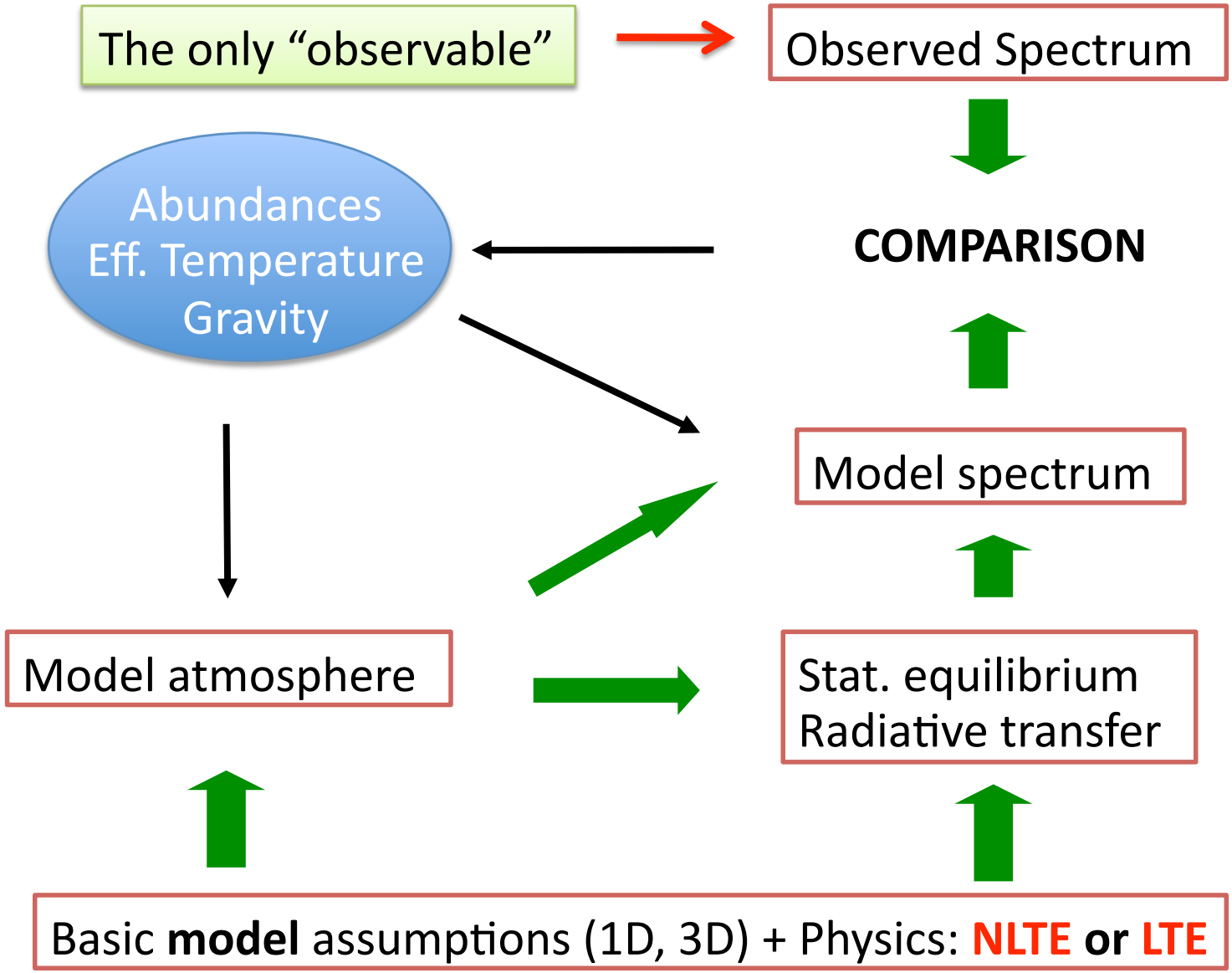


Testing the A models with Hydrogen lines

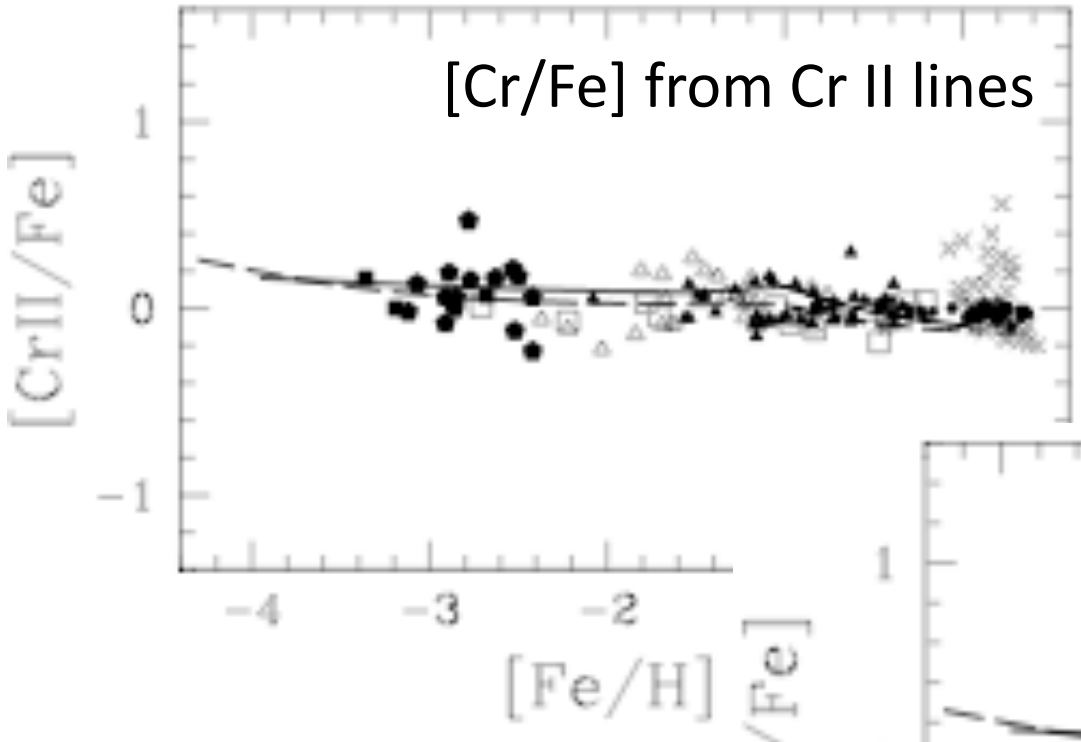


NOTE: Such stars are typically used to study abundance patterns In the Bulge, dSph galaxies

Errors hidden everywhere

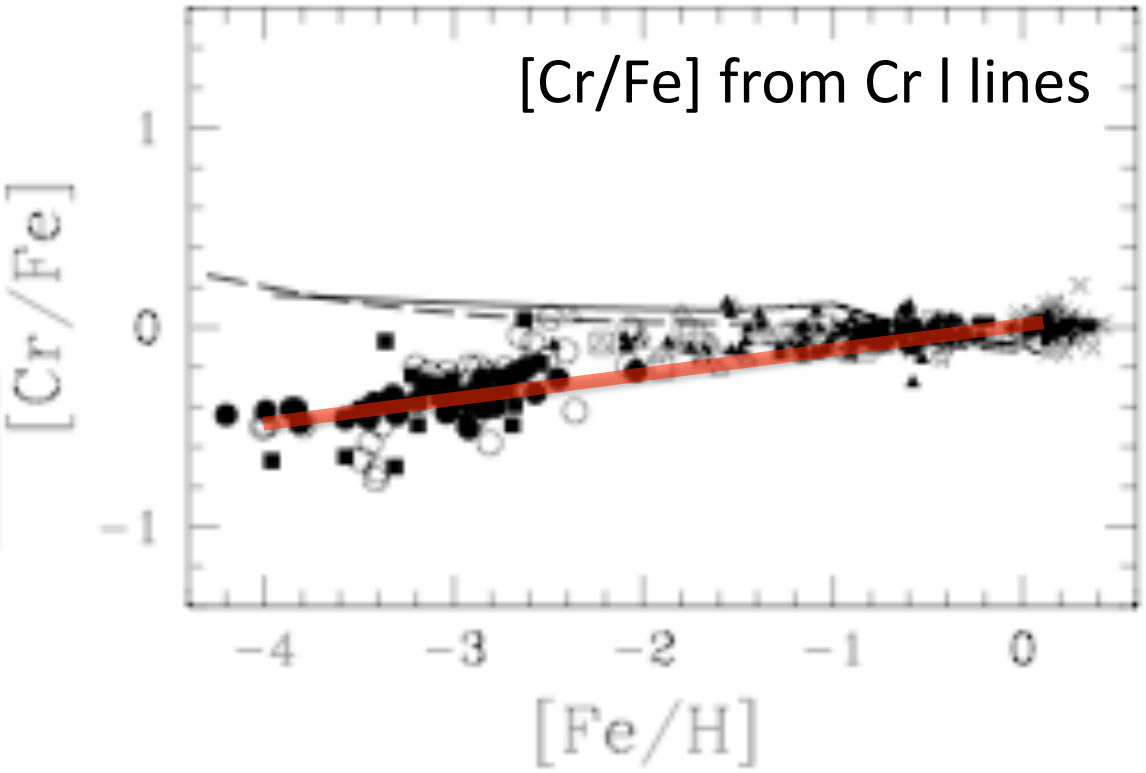


“Observations”



GCE model (curves):
Kobayashi et al. (2006)

Observed stars (symbols):
different sources



Cr I seems to be affected by NLTE!

NLTE

- is crucial for *modelling spectral lines* with the goal to determine *abundances*:

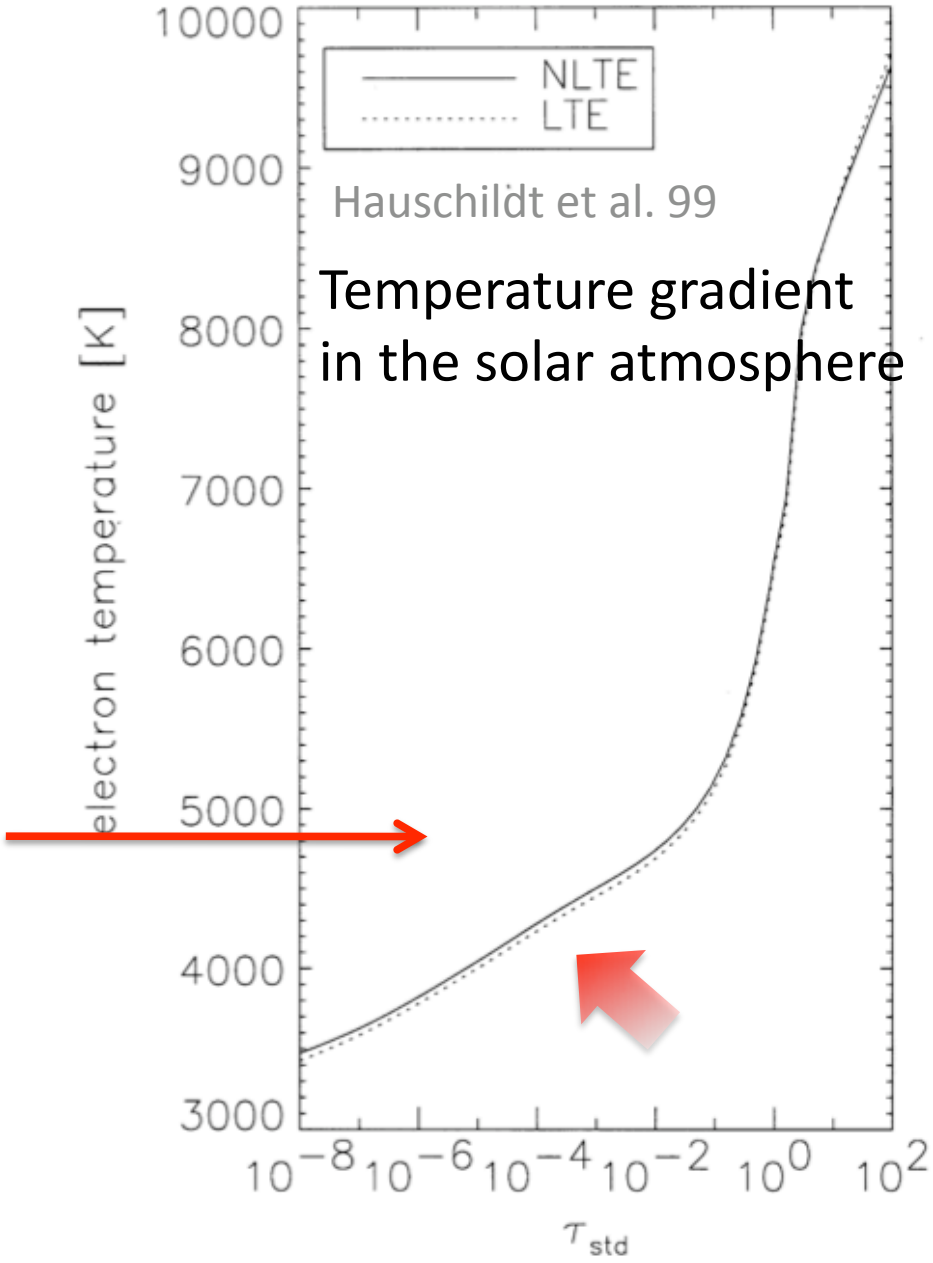
  Li, C, N, O (Asplund et al. 05)

  K, Na, Mg, Al, Si (Gehren et al. 06)

  Mn, Fe, Co, Ni (Korn et al. 03, Bruls et al. 93, Bergemann 08)

  Ba, Eu, Sr, Pr (Mashonkina et al. 08)

- is *not* important for the atmospheric structure of solar-type stars (T_{eff} < 10000)



Fe-peak revised

- LTE underestimates the abundances:

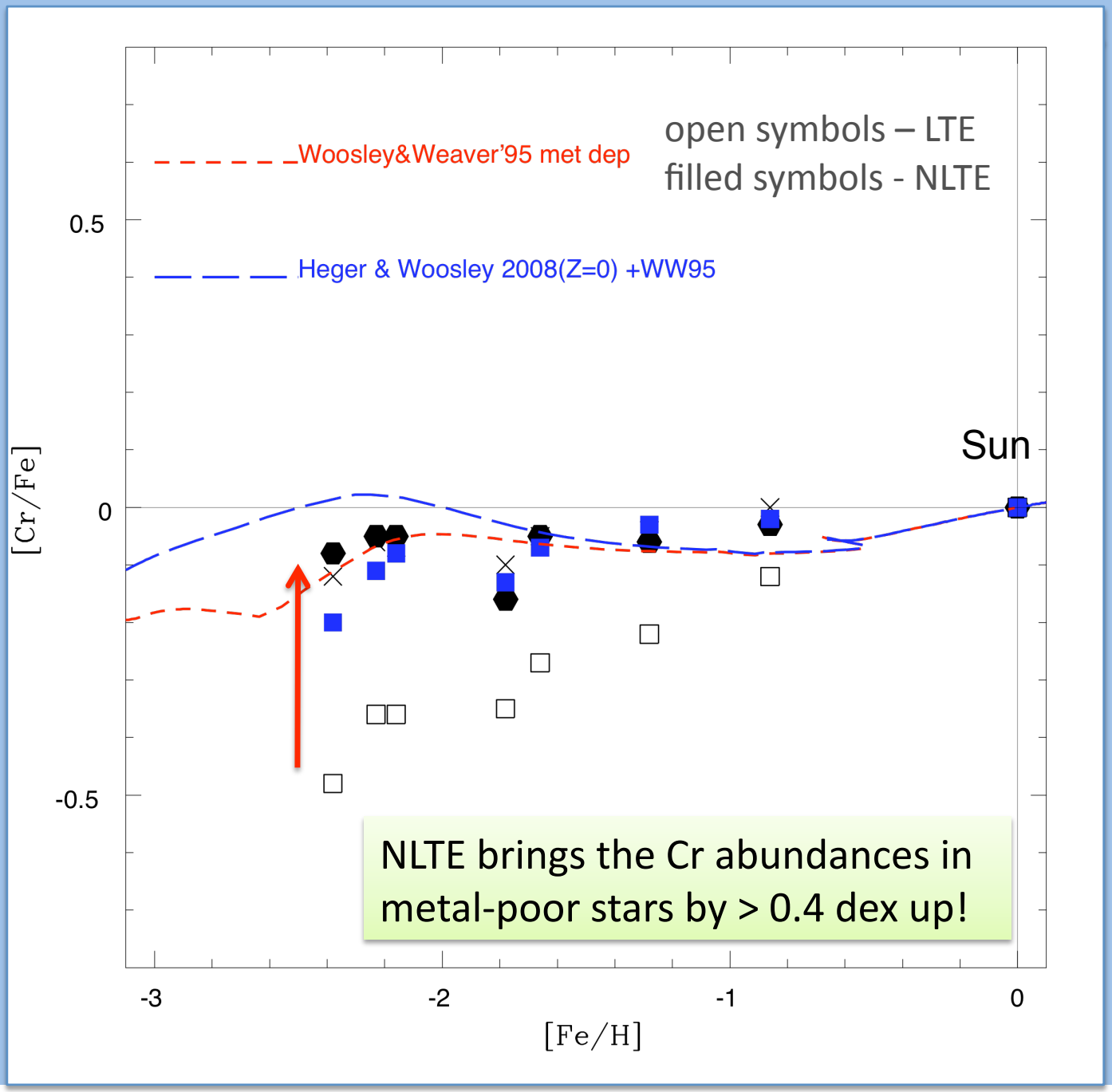
  neutral species by 0.3…0.6 dex (Ti, Cr, Mn, Co)

  ionized species by -0.1 … 0.3 dex (Co)

- Neglect of HFS leads to the errors of 0.1 – 1.0 dex

Radically different trends of [Cr/Fe], [Mn/Fe], [Co/Fe]
in metal-poor stars.

Revised abundances of Cr



Conclusions

- Stellar atmospheres are non-equilibrium systems.

- Many (e.g., Iron-group) elements are affected by NLTE, particularly their abundance variation with metallicity: errors by factor of 2…10!

- The studies of Galactic chemical evolution must follow very careful spectrum analysis methods.

- To minimize systematic errors of theoretical modeling and be sure that elemental surface abundances are not contaminated by thermonuclear reaction products from the stellar interior the sample of stars must be confined to solar-type stars only → differential analysis!

- Many conclusions relevant to the Galactic Chemical Evolution may have to be revised.