

Massive Stars as Tracers for Galactochemical Evolution

Norbert Przybilla

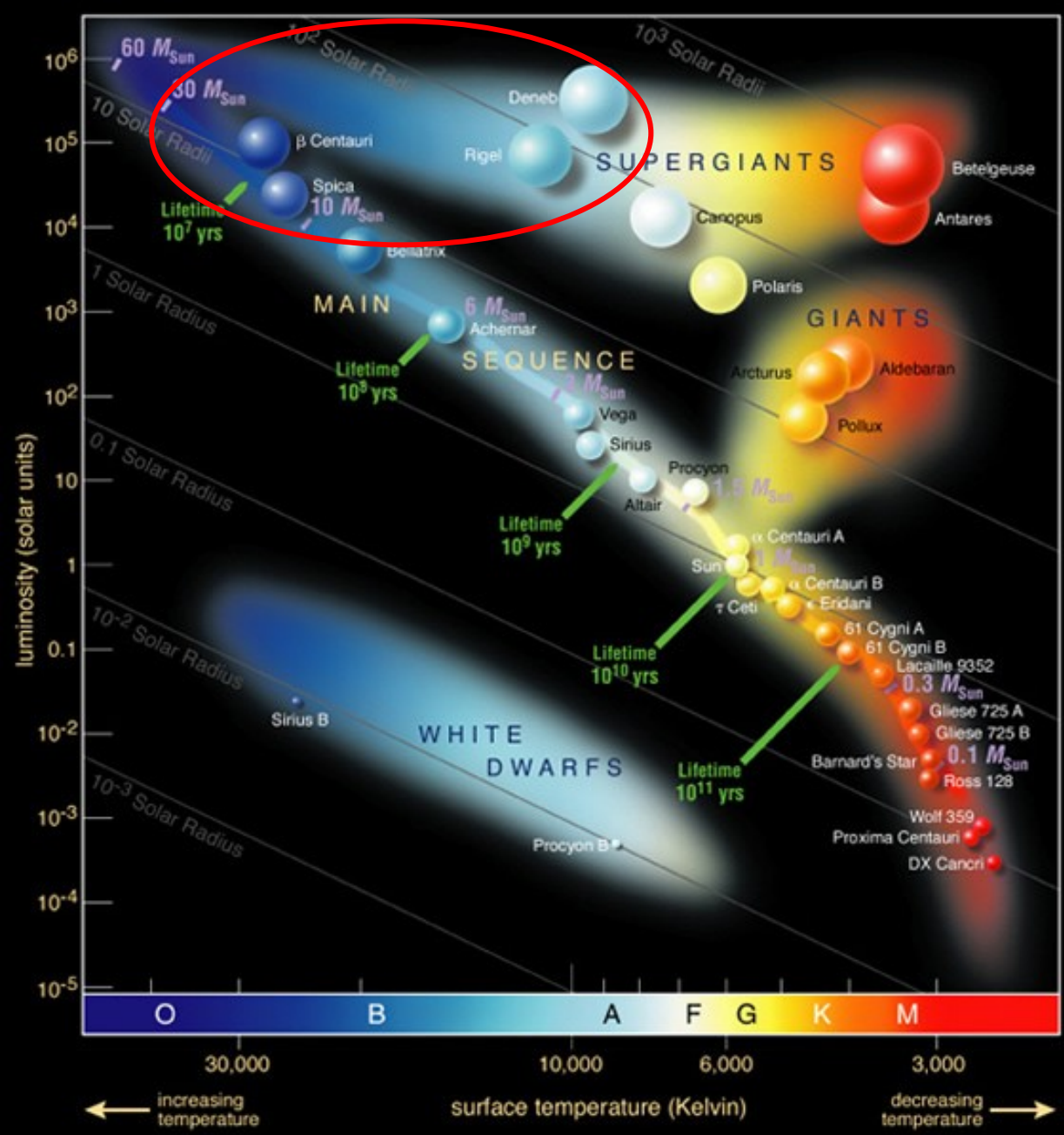
Maria Fernanda Nieva & Markus Firnstein

Outline

- Motivation
- Diagnostic Challenges
- Spectral Analyses of Massive Stars:
Implications for Galactochemical Evolution
- Outlook: Extragalactic Stellar Astronomy

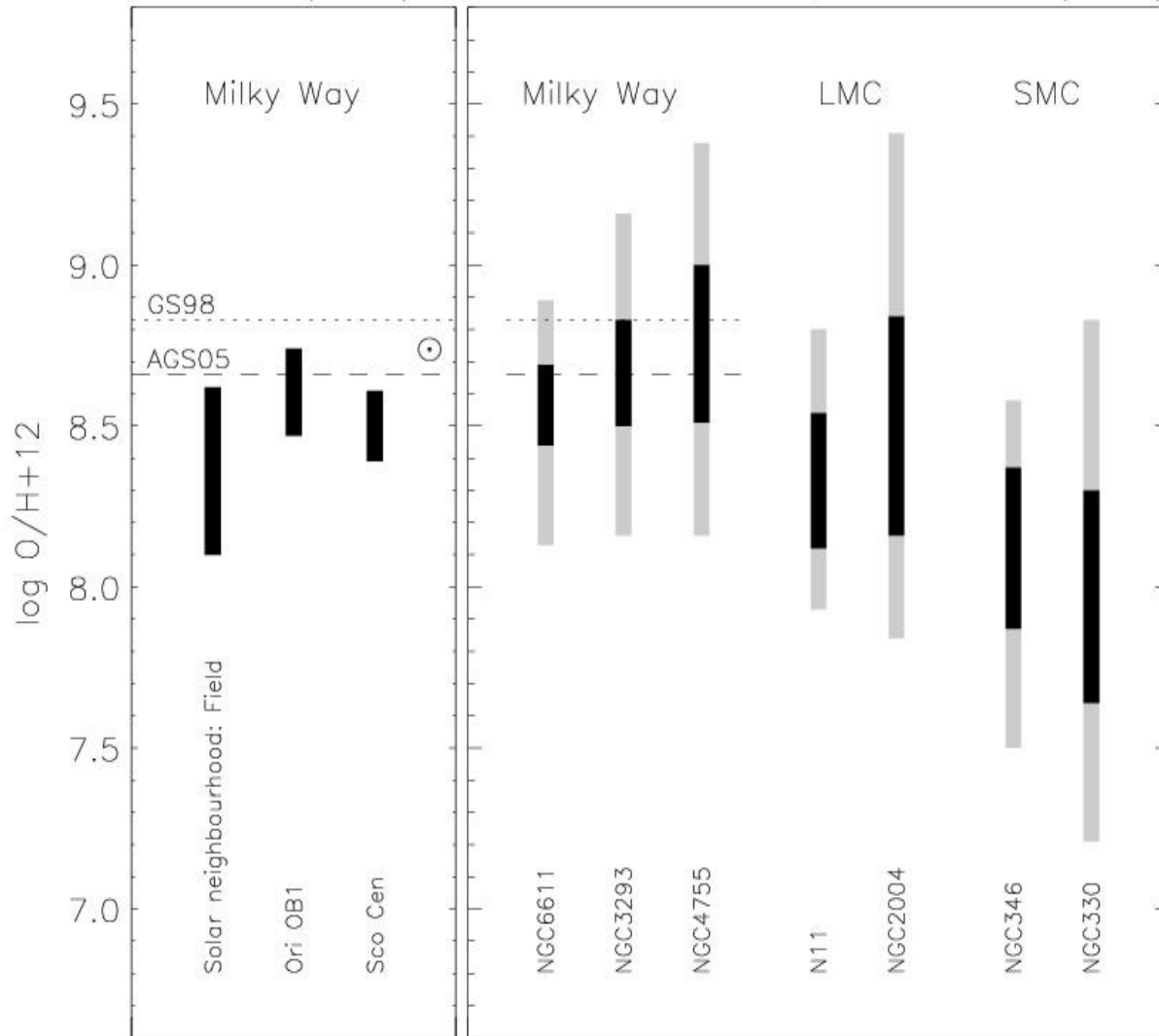
OB Stars

- dominate **energy** and **momentum budget** of ISM in galaxies
 - SN II, winds, UV photons
- key drivers for **cosmic cycle of matter**
 - star formation, nucleosynth.
- highly luminous
 - **abundance indicators** over large distances: Local Group & beyond
 - **spectroscopic distance determination:** FGLR & WLR



Metals in Solar Neighbourhood/Star Clusters

Kilian (1992) FLAMES: Hunter et al., Trundle et al. (2007)



- early-type stars:
inferred from observation
→ **chemical inhomogeneity**

BUT

- gas-phase of ISM in
solar neighbourhood
homogeneous
(Sofia & Meyer 2001)

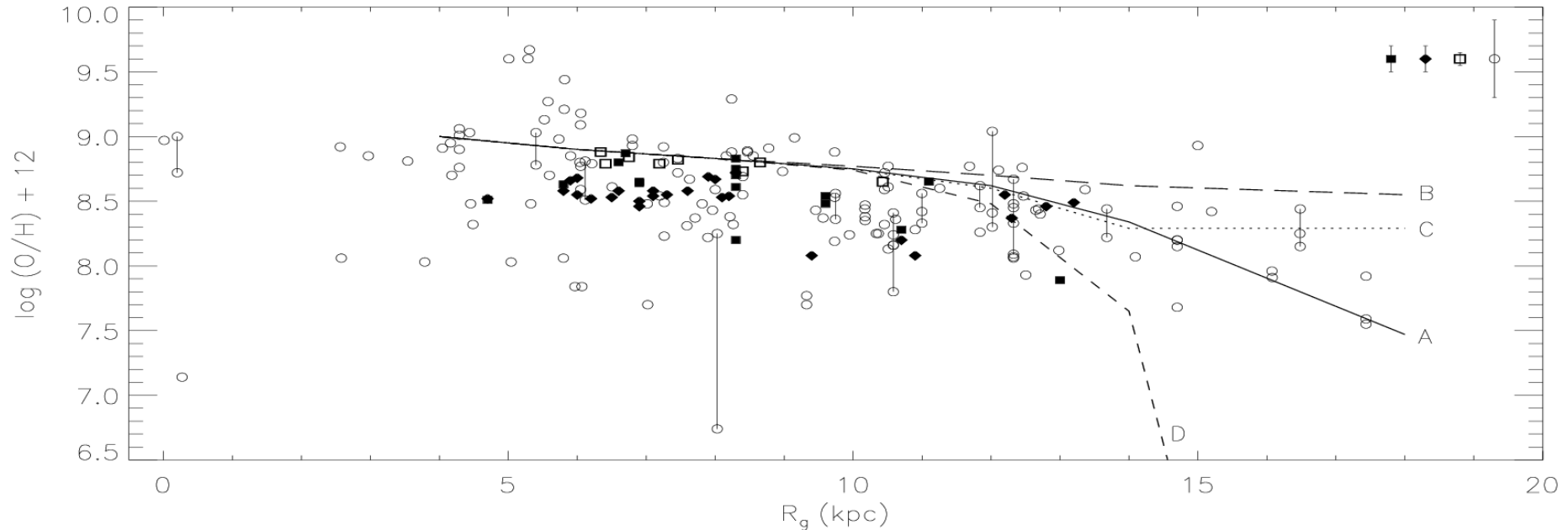
- efficient mixing
mechanisms
→ **homogeneity**
(e.g. Edmunds 1975,
Roy & Kunth 1995)

■ range in abundance
■ uncertainty

Galactochemical Evolution

present-day abundance gradients

B-stars: Gummersbach+ (1998),
Daflon & Cunha (2004)
HII: Esteban+ (2005), Rudolph+ (2006)
models: Chiappini+ (2001)



- large scatter @ every R (early-type stars & nebulae)
- difficult to explain physically
- test of Galactochemical evolution models?
 → improving abundance determination !

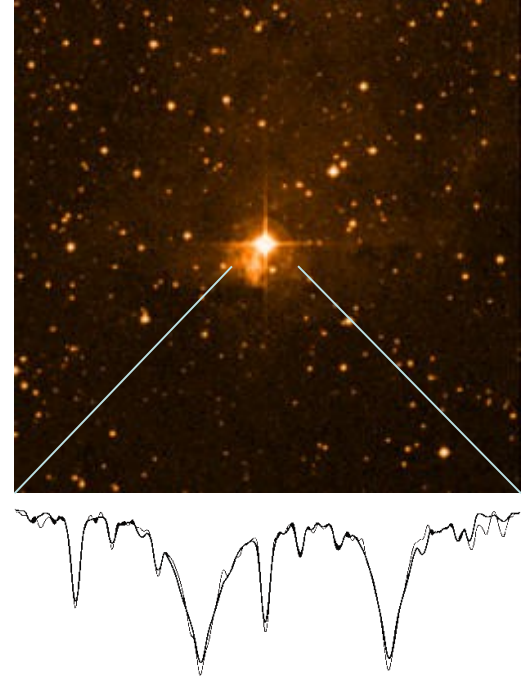
Diagnostic Problem

stellar analyses from
interpretation of observation

➔ photometry, **spectroscopy**

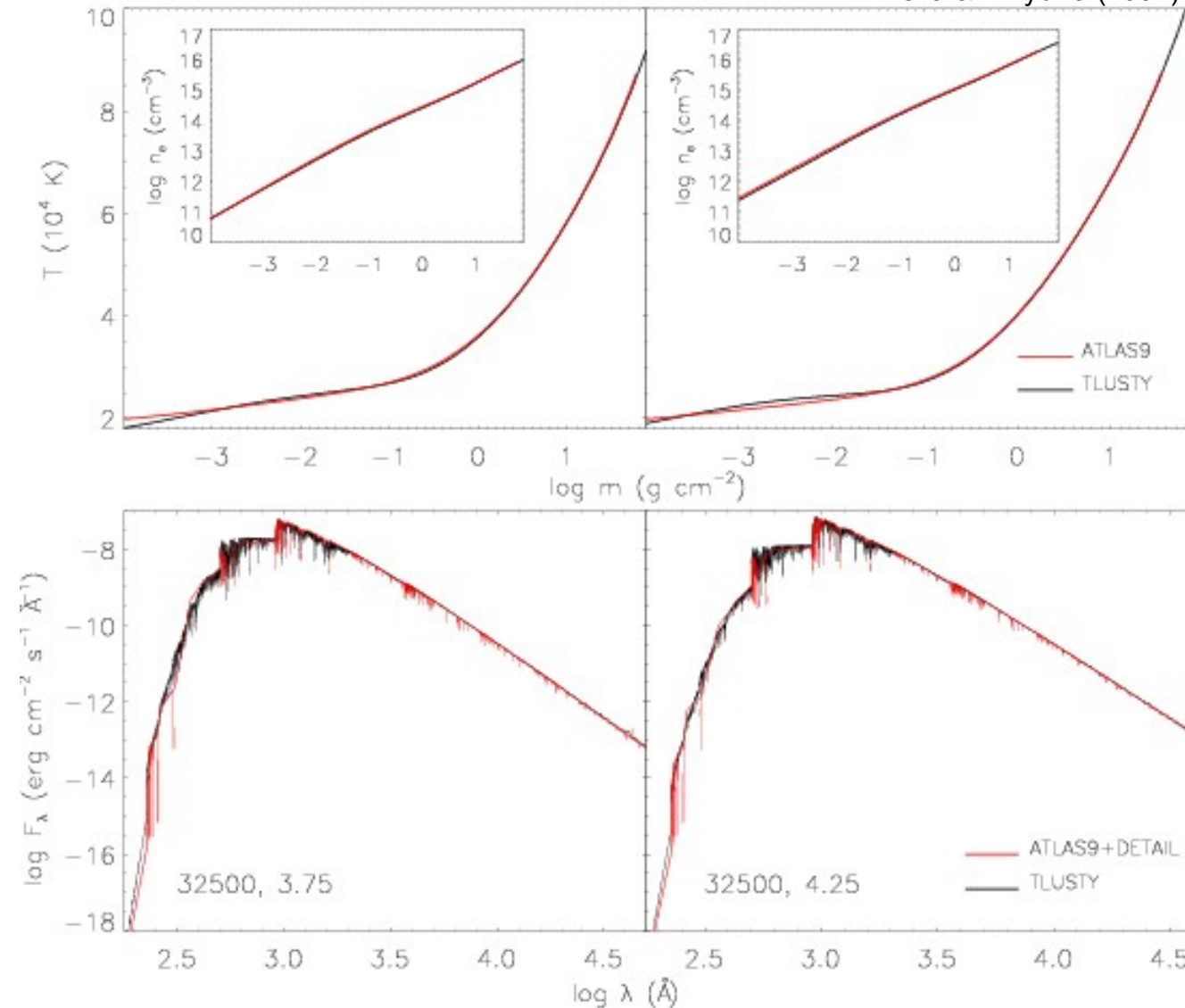
- fundamental stellar parameter: **L, M, R**
- atmospheric parameters: **T_{eff} , $\log g$, ξ , Y, Z, etc.**
- **elemental abundances**

➔ **quantitative spectroscopy**
via model atmospheres



Hybrid non-LTE approach

Nieva & Przybilla (2007)



- LTE atmospheres + NLTE line-formation
- equivalent full NLTE calculations
- advantages:
 - comprehensive model atoms possible
 - much faster

➔ tailored modelling

(Restricted) NLTE Problem

- transfer equation

$$\mu \frac{dI_\nu}{d\tau_\nu} = I_\nu - S_\nu$$

- statistical equilibrium (SE):

$$n_i \sum_{j \neq i} (R_{ij} + C_{ij}) = \sum_{j \neq i} n_j (R_{ji} + C_{ji})$$

- radiative rates:

$$R_{ij} = 4\pi \int \sigma_{ij} \frac{J_\nu}{h\nu} d\nu$$

non-local

- collisional rates:

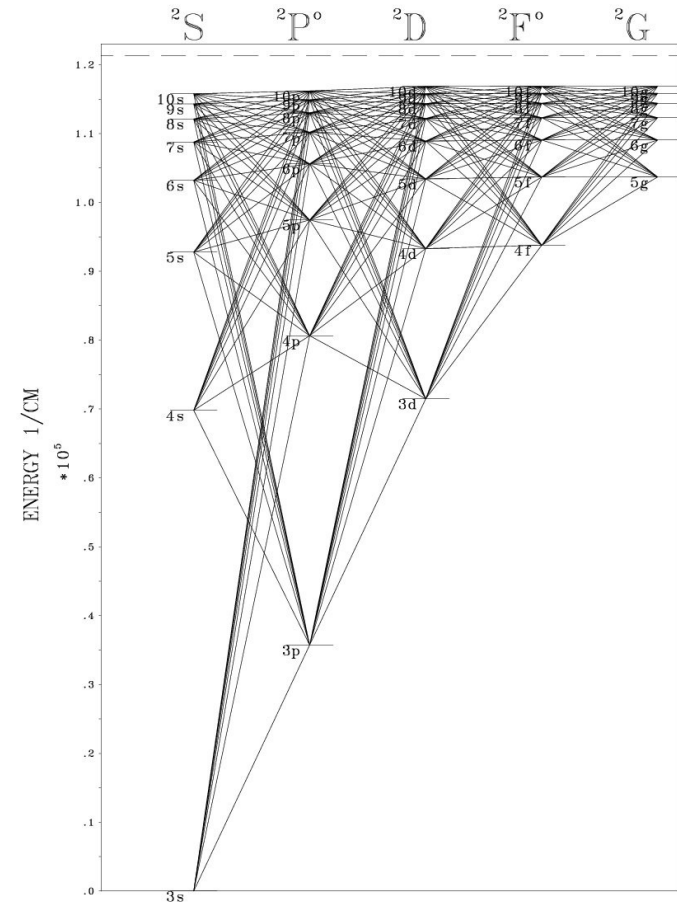
$$C_{ij} = n_e \int \sigma_{ij}(v) f(v) v dv$$

local

- excitation, ionization, charge exchange, dielectronic recombination, etc.



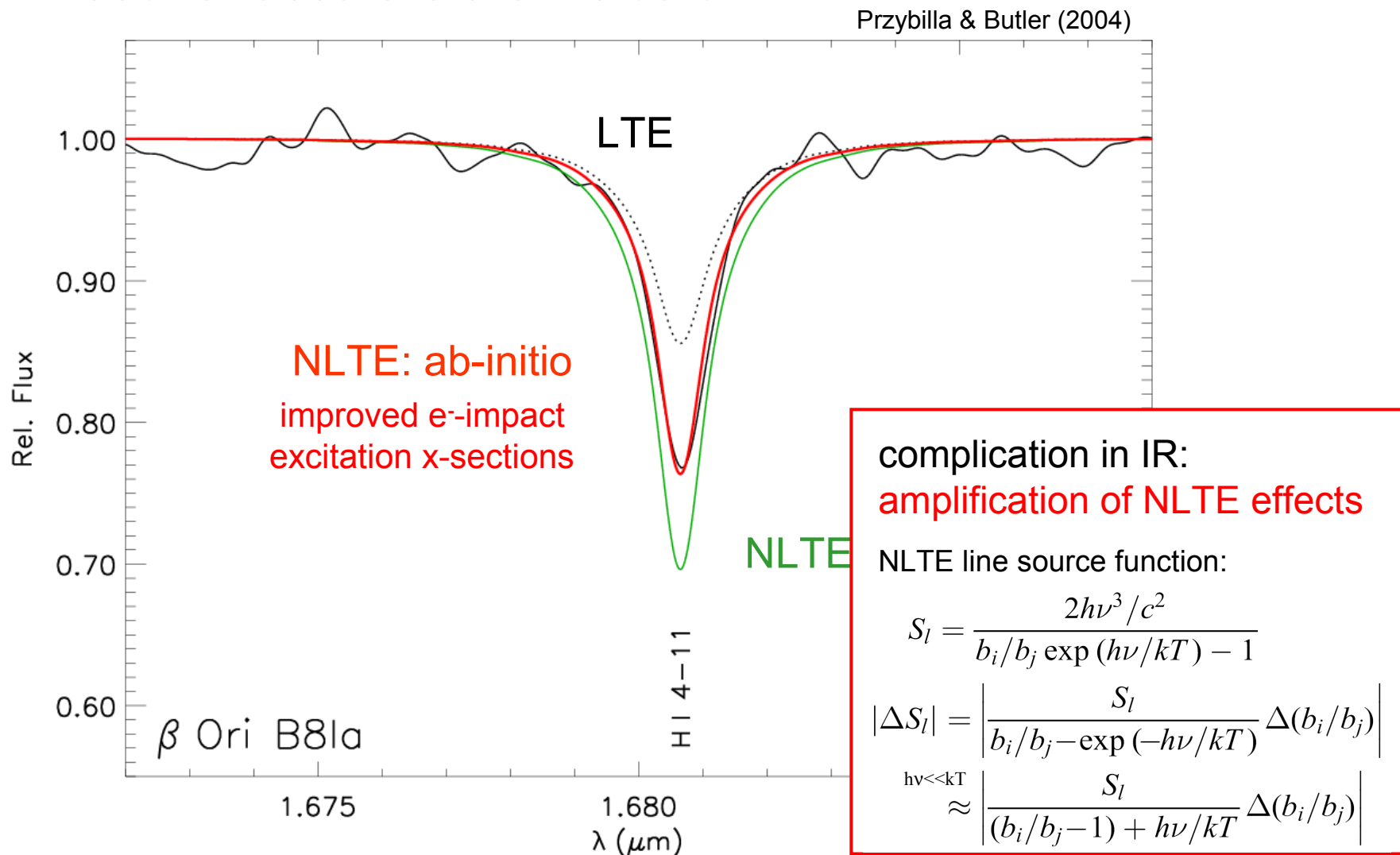
model atoms



MgII: Przybilla et al. (2001)

huge amounts of
atomic data:
OP/IRON Project

Need for accurate atomic data



- IR-lines equiv. to Balmer lines as gravity indicators

NLTE Diagnostics: Stellar Parameters

- ionization equilibria $\rightarrow T_{\text{eff}}$

elements: e.g. He, C, N, O, Ne, Mg, Si, S, Fe

$$\Delta T_{\text{eff}} / T_{\text{eff}} \sim 1\%$$

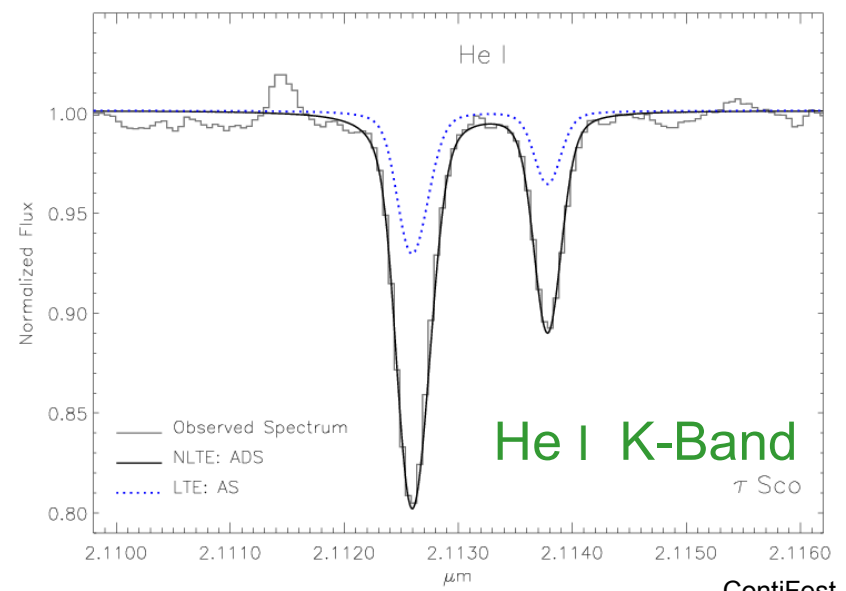
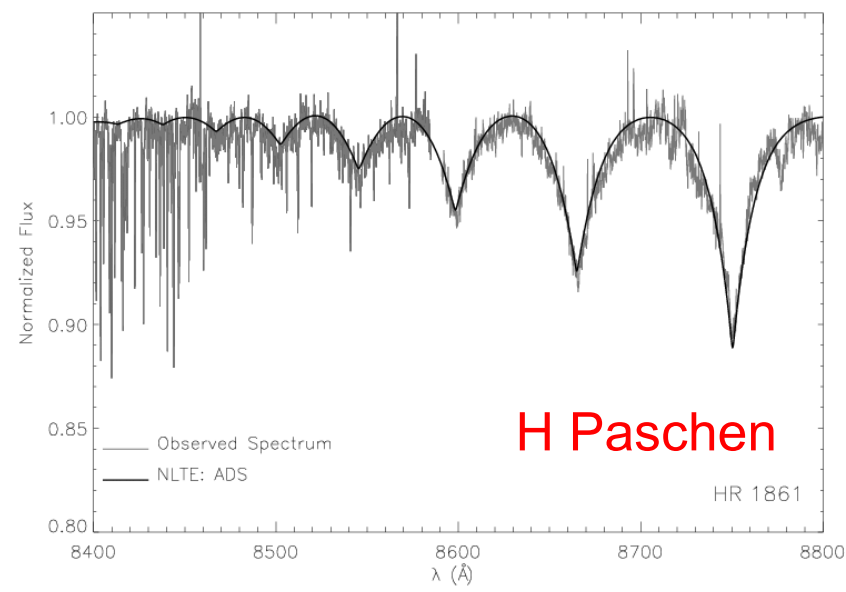
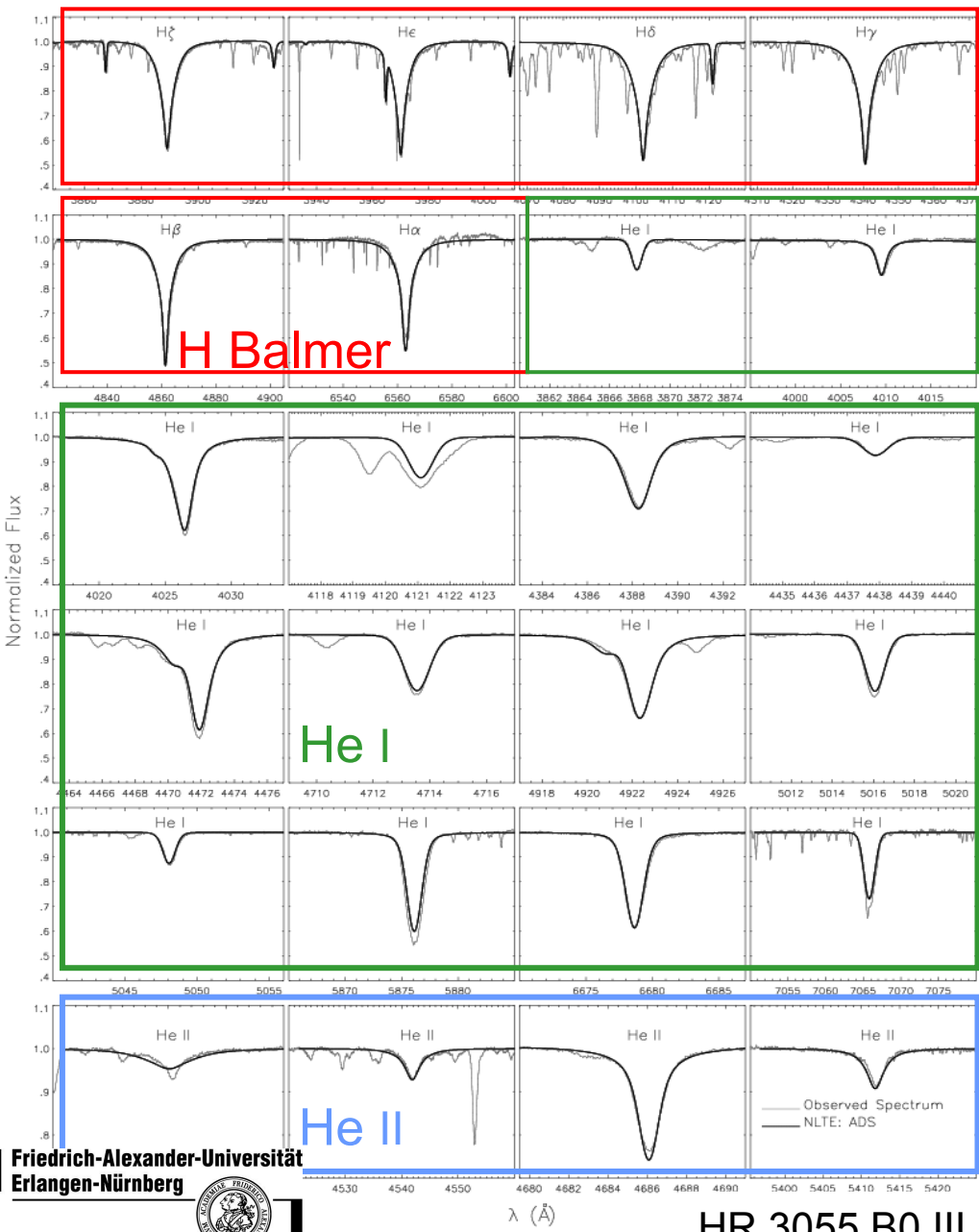
- Stark broadened hydrogen lines $\rightarrow \log g$

$$\Delta \log g \sim 0.05 \dots 0.10 \text{ (cgs)}$$

- microturbulence
- helium abundance
- metallicity

+ other constraints, where available: SED's, near-IR, ...

Stellar parameter determination: spectrum synthesis



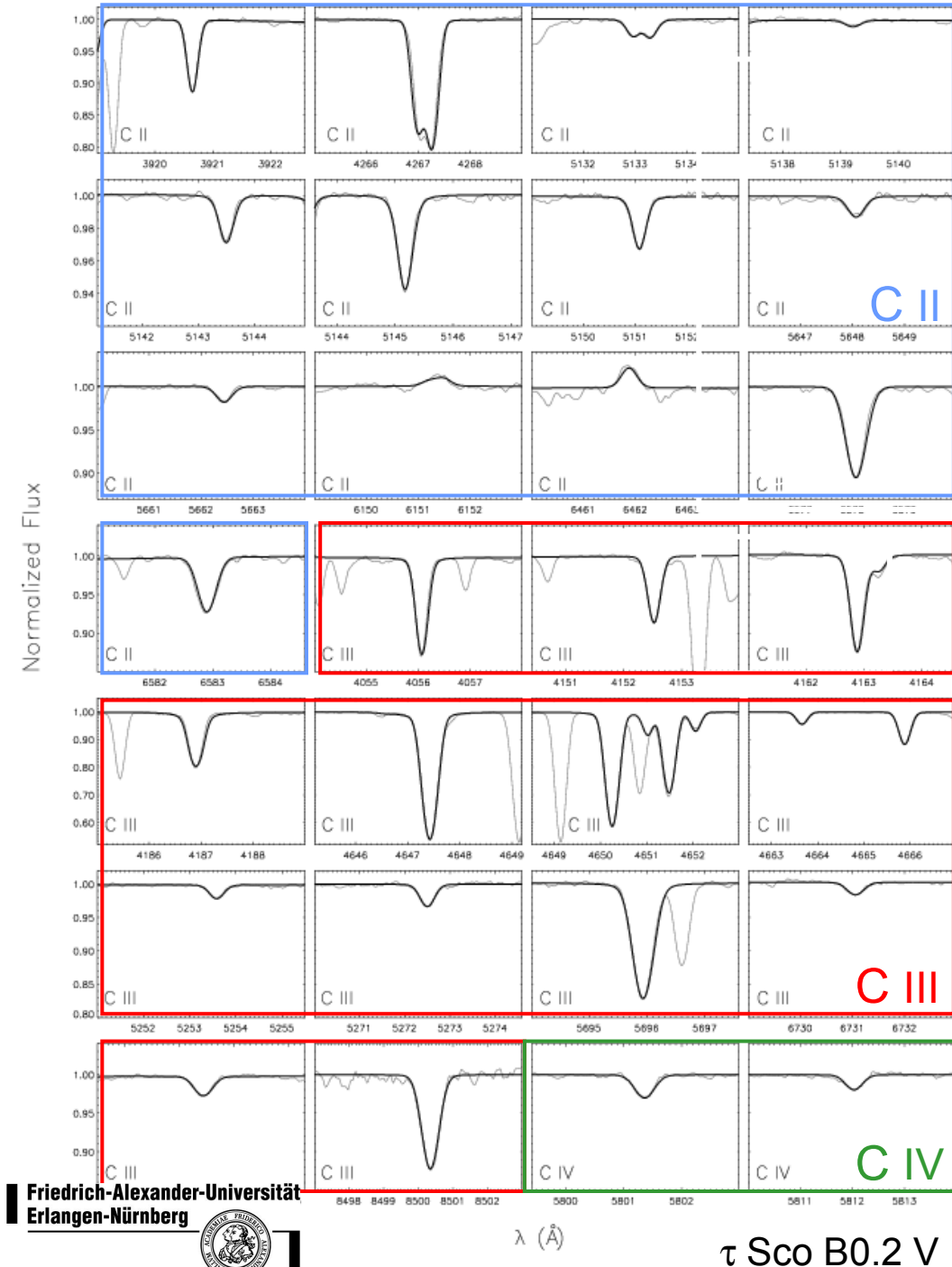
Nieva & Przybilla (2007)

ContiFest
Lowell Observatory – 15.10.2008



Stellar parameter determination: metal ionization equilibria

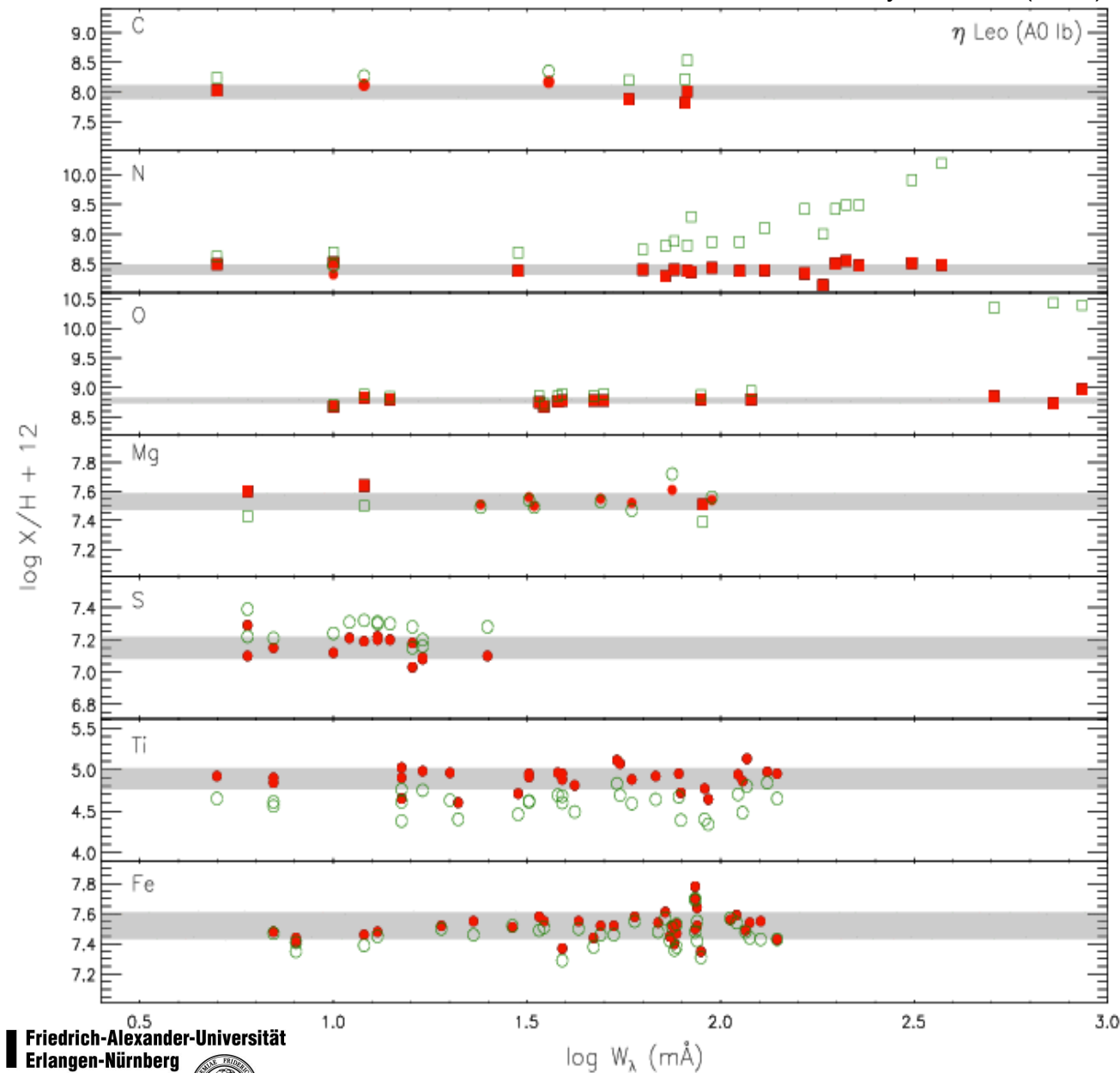
- constraint:
same abundance
for all ionization stages
of an element
- most sensitive T_{eff} -indicators
- modelling:
low abundance scatter for all
spectral lines in multiple
ionization equilibria



Nieva & Przybilla (2008)

Elemental Abundances 1

Przybilla et al. (2006)



- **NLTE:**
absolute abundances
reduced uncertainties
 $\Delta \log \varepsilon$:
~ 0.05 - 0.10 dex (1σ -stat.)
~ 0.07 - 0.12 dex (1σ -syst.)

reduced systematics

- typical uncertainties
in literature:
factor ~2-3 (1σ -stat.)
+ unknown syst. errors

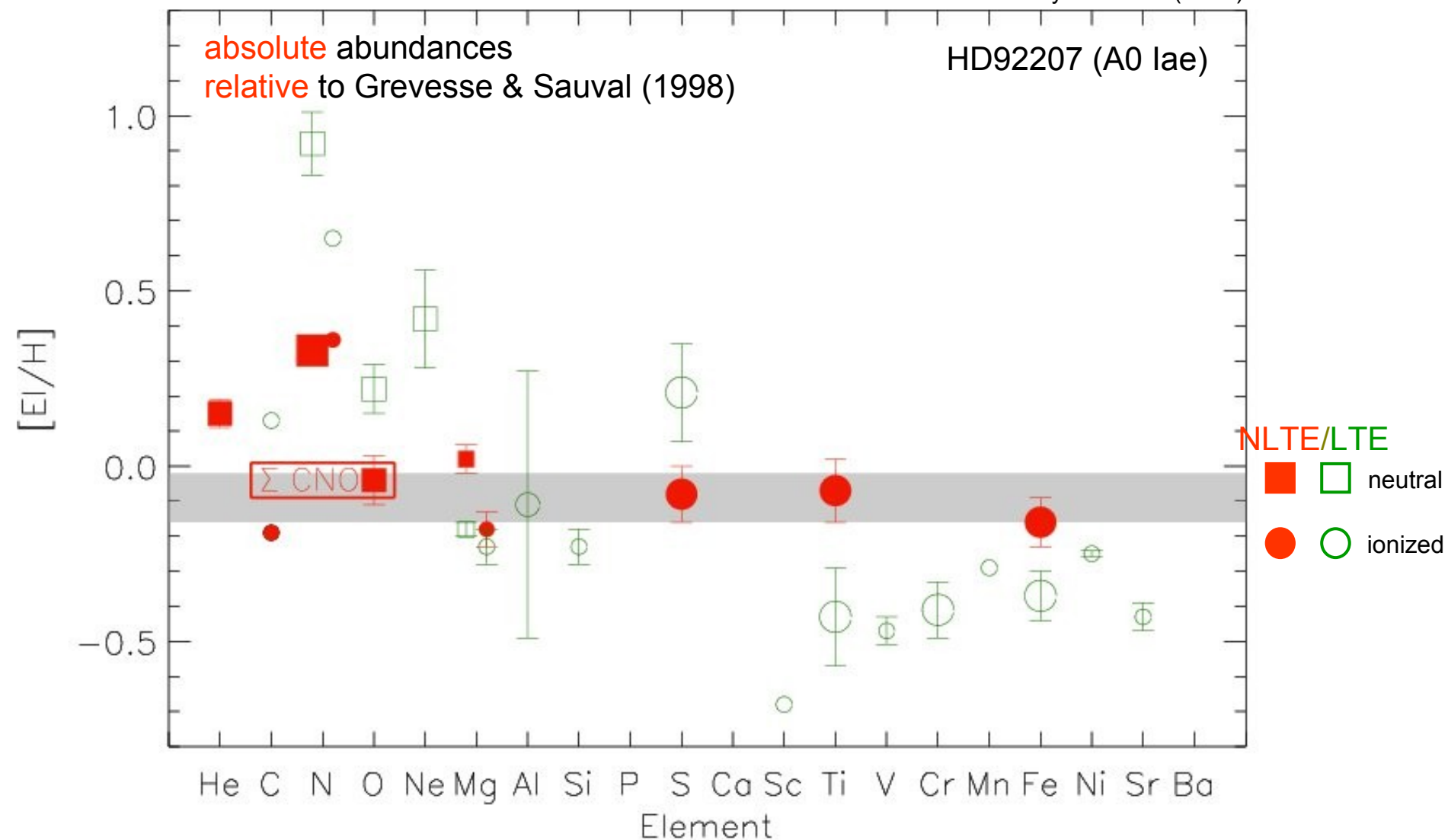
NLTE/LTE

■ □ neutral

● ○ ionized

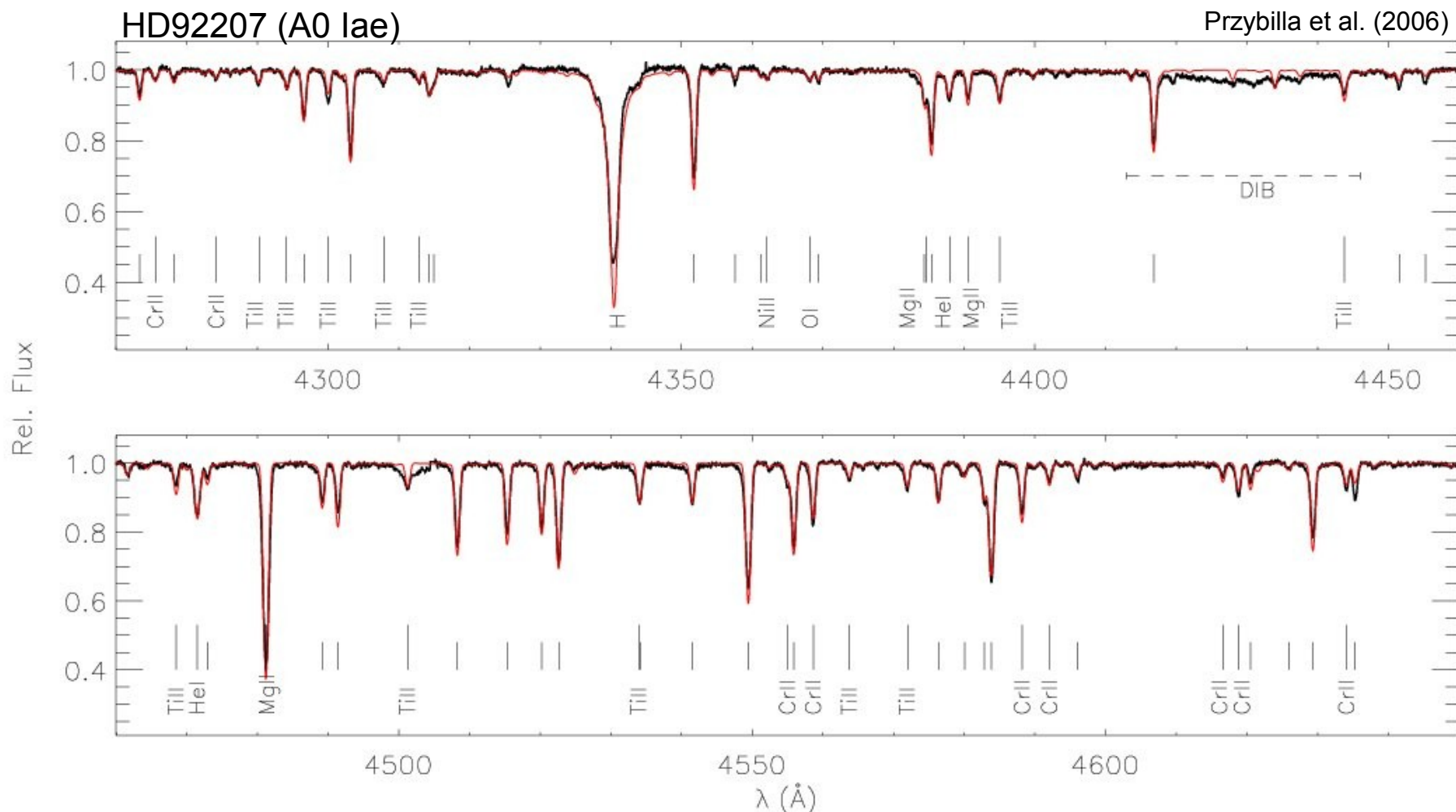
Elemental Abundances 2

Przybilla et al. (2006)



- NLTE: consistency & reduced uncertainties

Spectrum Synthesis 1

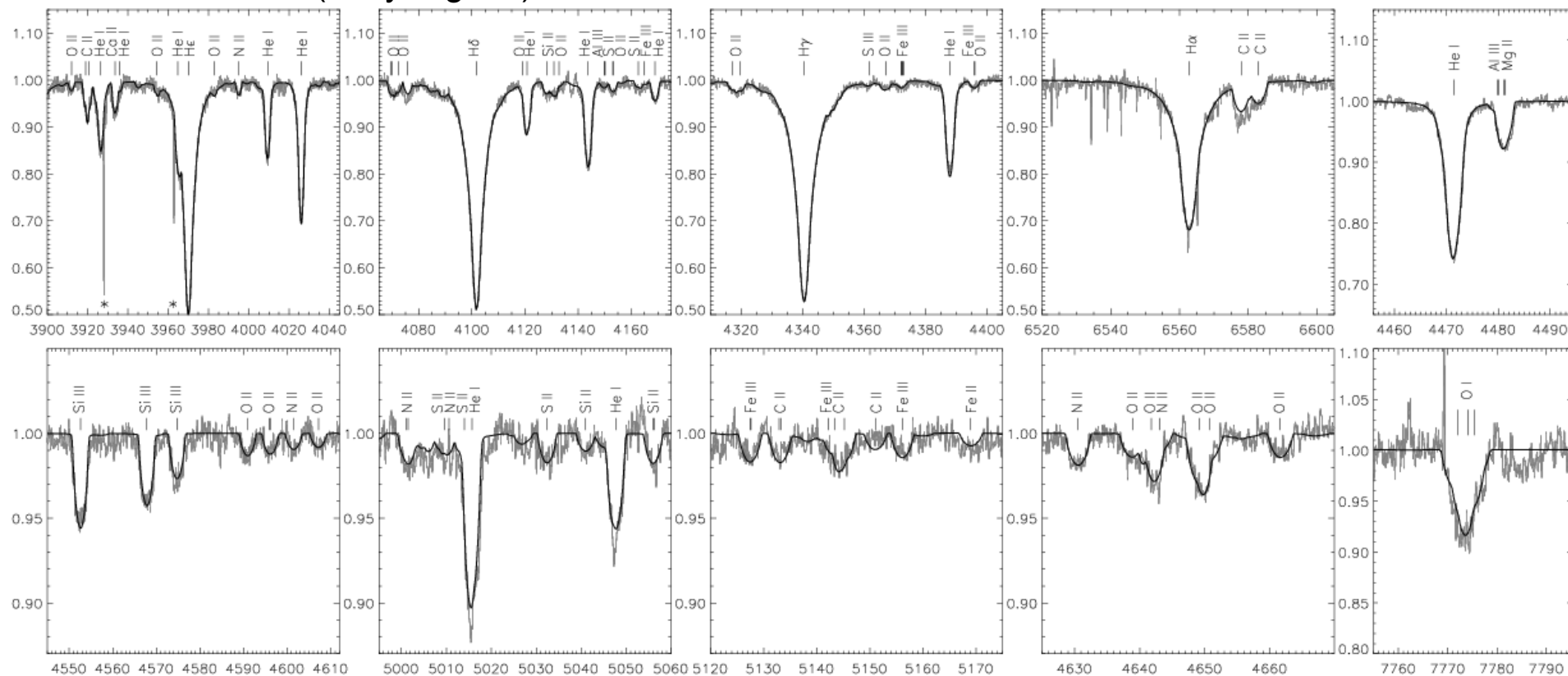


- several 10^4 lines: ~ 30 elements, 60+ ionization stages
- complete spectrum synthesis in visual (& near-IR) **$\sim 70-90\%$ in NLTE**

Spectrum Synthesis 2

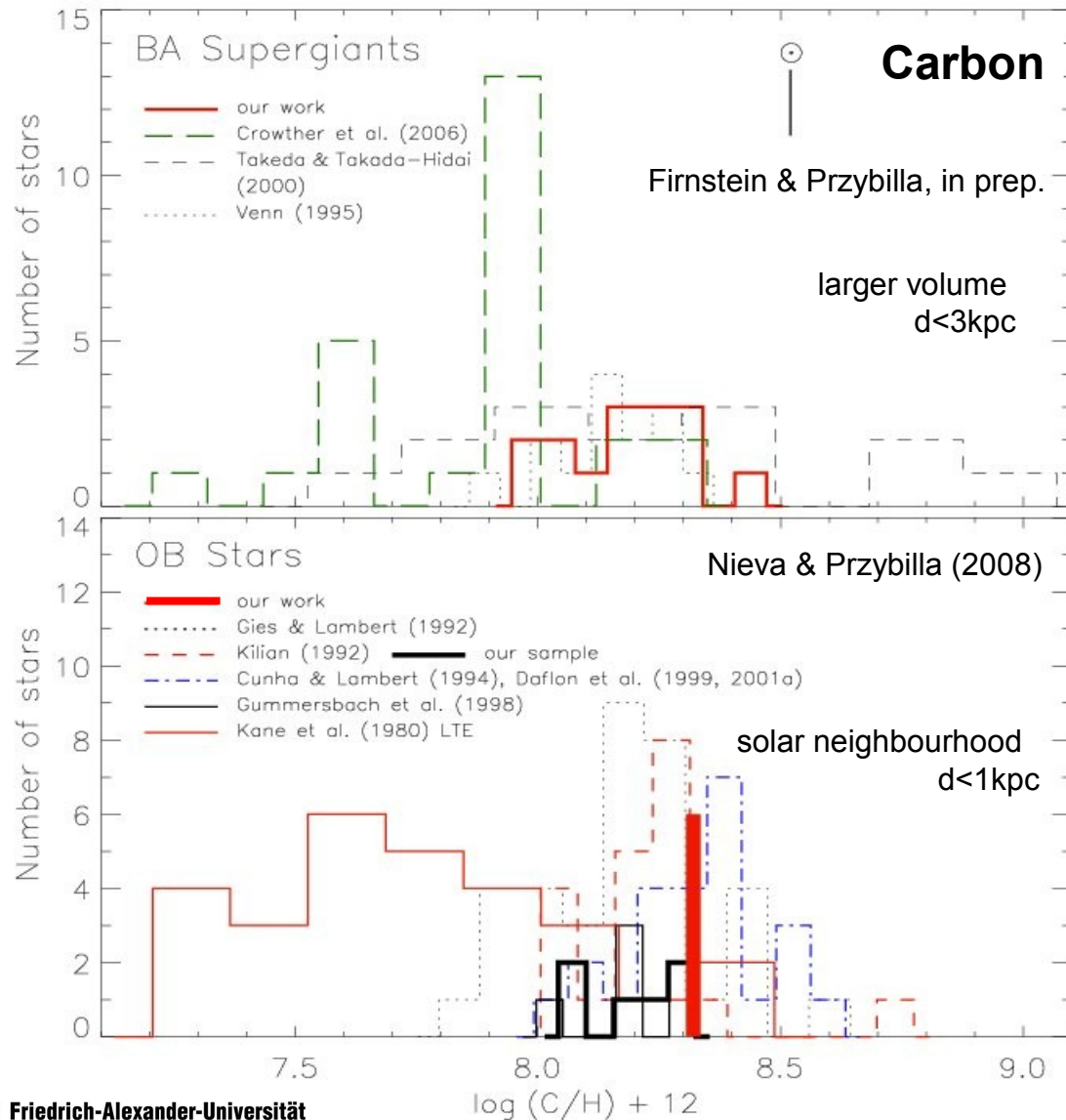
HVS HD271791 (early B giant)

Przybilla, Nieva, et al. (2008)



- several 10^4 lines: ~ 30 elements, 60+ ionization stages
- complete spectrum synthesis in visual (& near-IR) $\sim 70-90\%$ in NLTE

Present-Day Abundances/Solar Neighbourhood

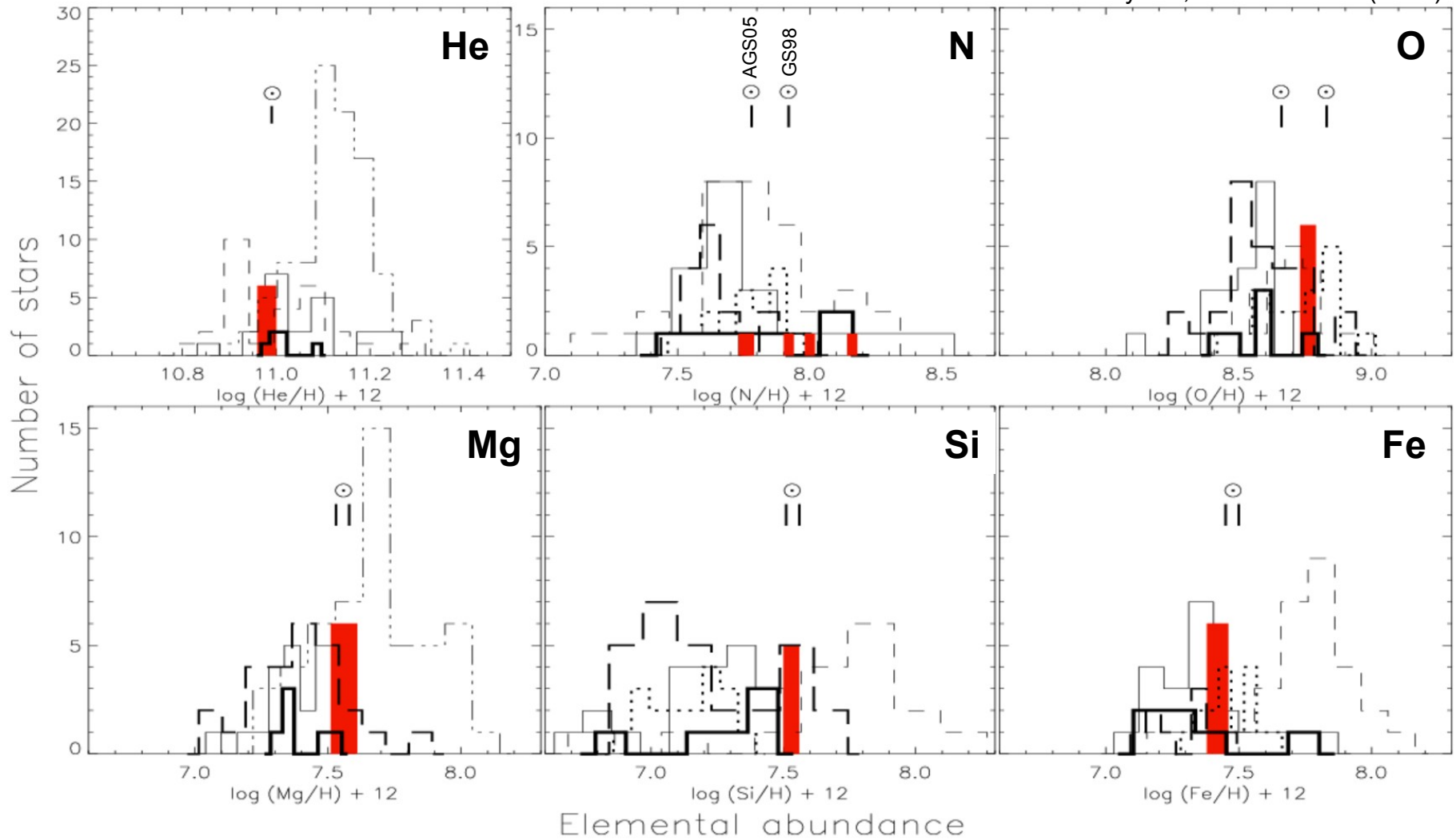


- much smaller scatter than in previous work
- small numbers – but: identical stars in previous work
- qualitative agreement with stellar evolution models
- present-day abundances in solar neighbourhood homogeneous?

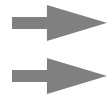
⊙: Grevesse & Sauval (1998)

Present-Day Abundances/Solar Neighbourhood

Przybilla, Nieva & Butler (2008)



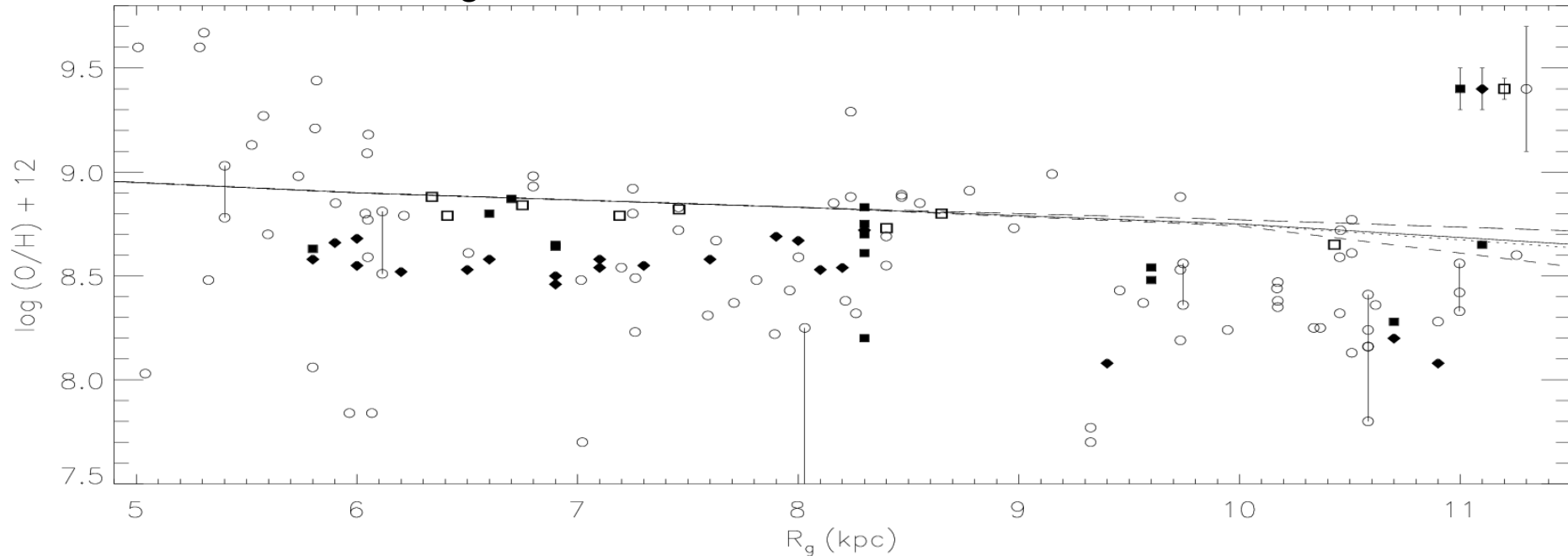
- improved analysis: chemical homogeneity of the solar neighbourhood



cosmic abundance standard
ISM dust-phase composition

Galactic Abundance Gradients

Literature: HII regions & B-stars



HII Regions:

- Rudolph et al. (2006)
- Esteban et al. (2005)

Models:

- Chiappini et al. (2001)

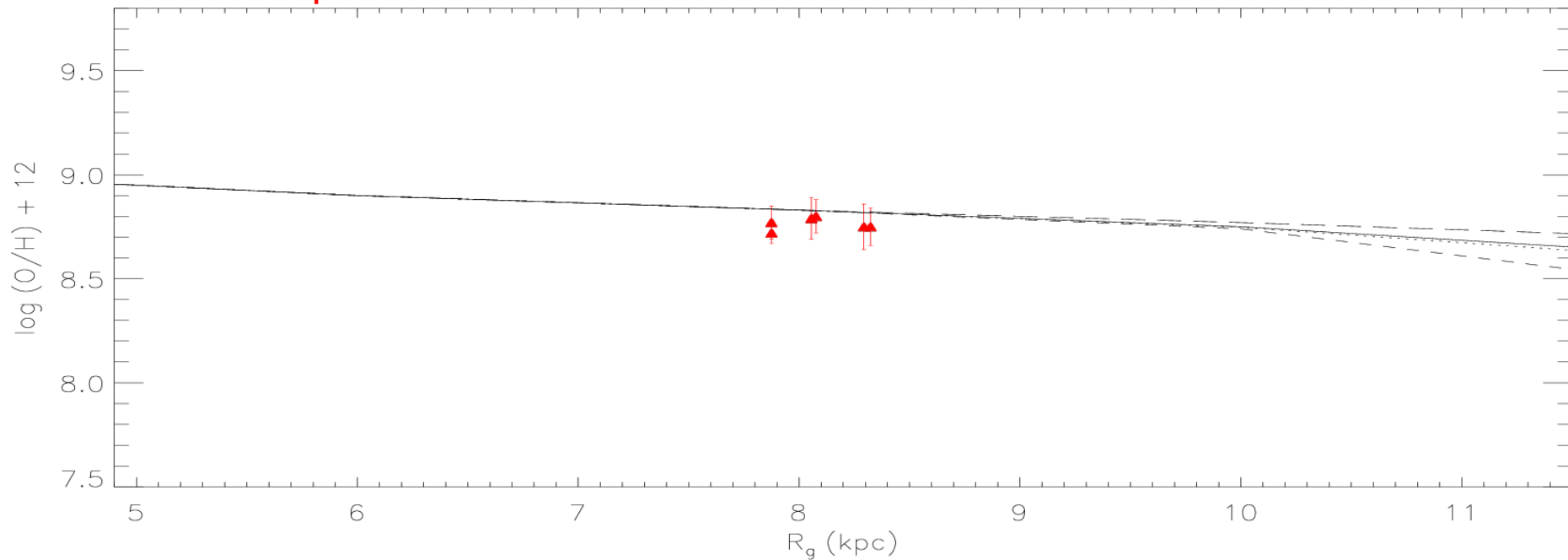
B-Stars (NLTE):

- Gummersbach et al. (1998)
- ◆ Daflon & Cunha (2004)

- large scatter @ every R

Galactic Abundance Gradients

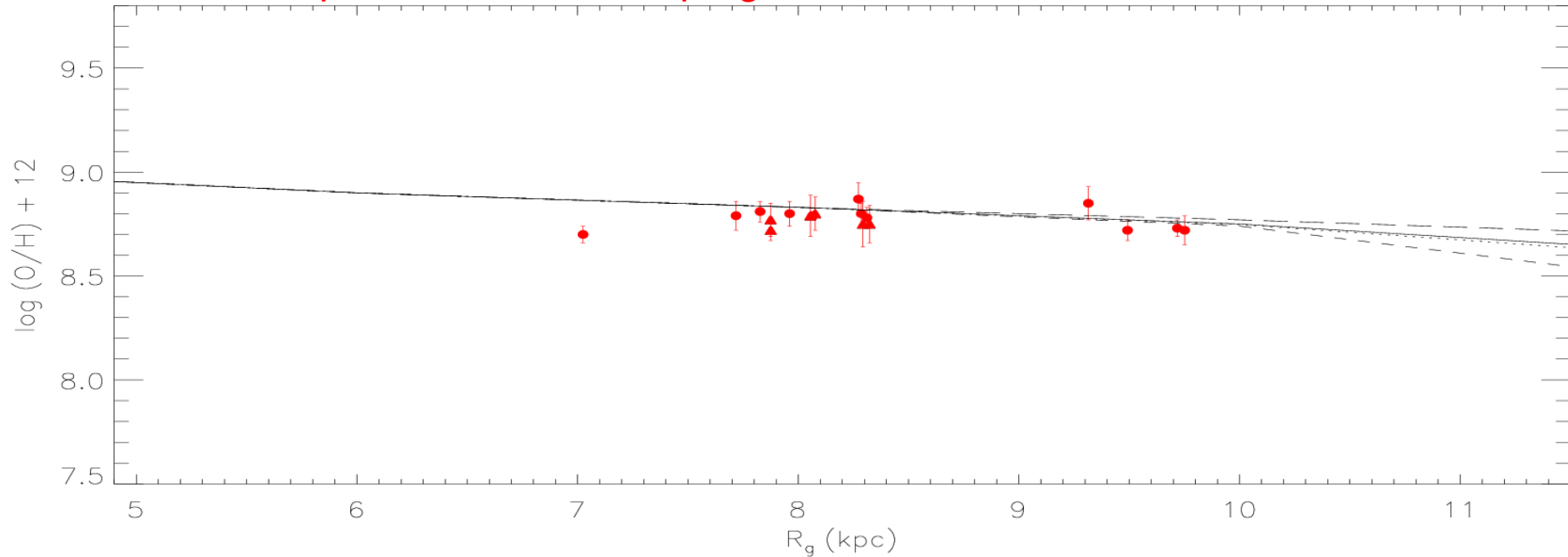
our sample: B-stars



- chemical homogeneity of solar neighbourhood
- near-solar abundances

Galactic Abundance Gradients

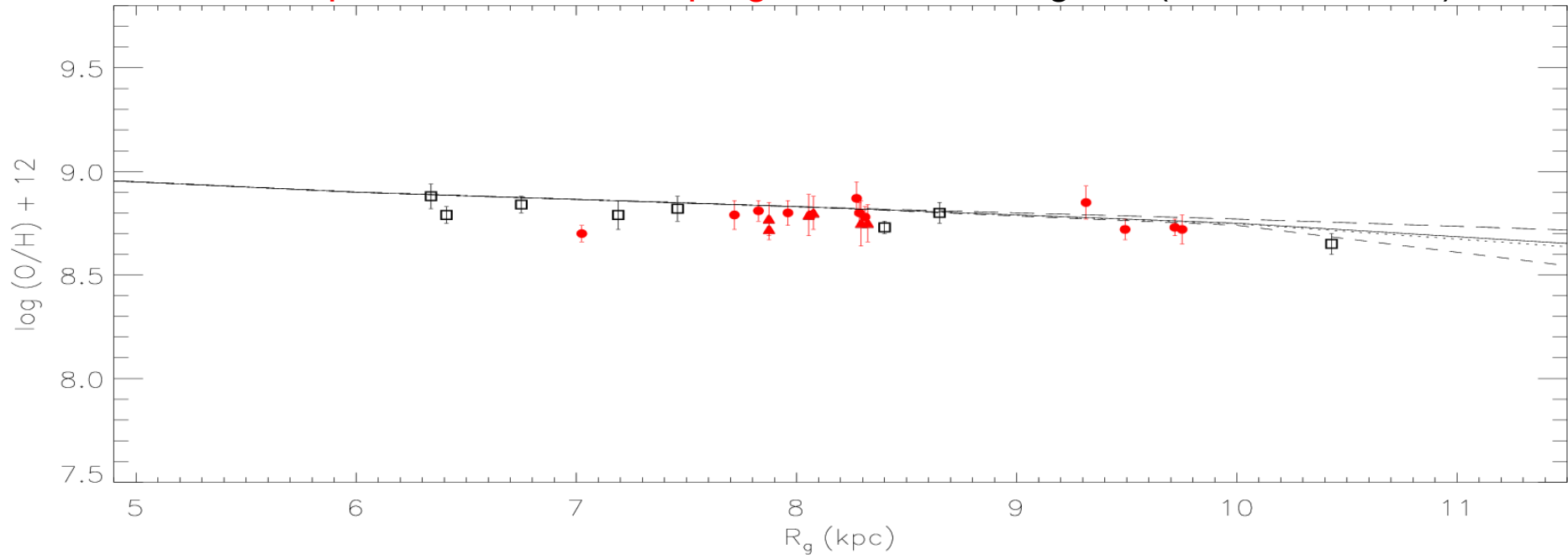
our sample: B-stars + BA-supergiants



- chemical homogeneity of solar neighbourhood:
2nd independent indicator (BA-supergiants)
- near-solar abundances over ~ 3 kpc

Galactic Abundance Gradients

our sample: B-stars + BA-supergiants & HII-regions (Esteban+ 2005)

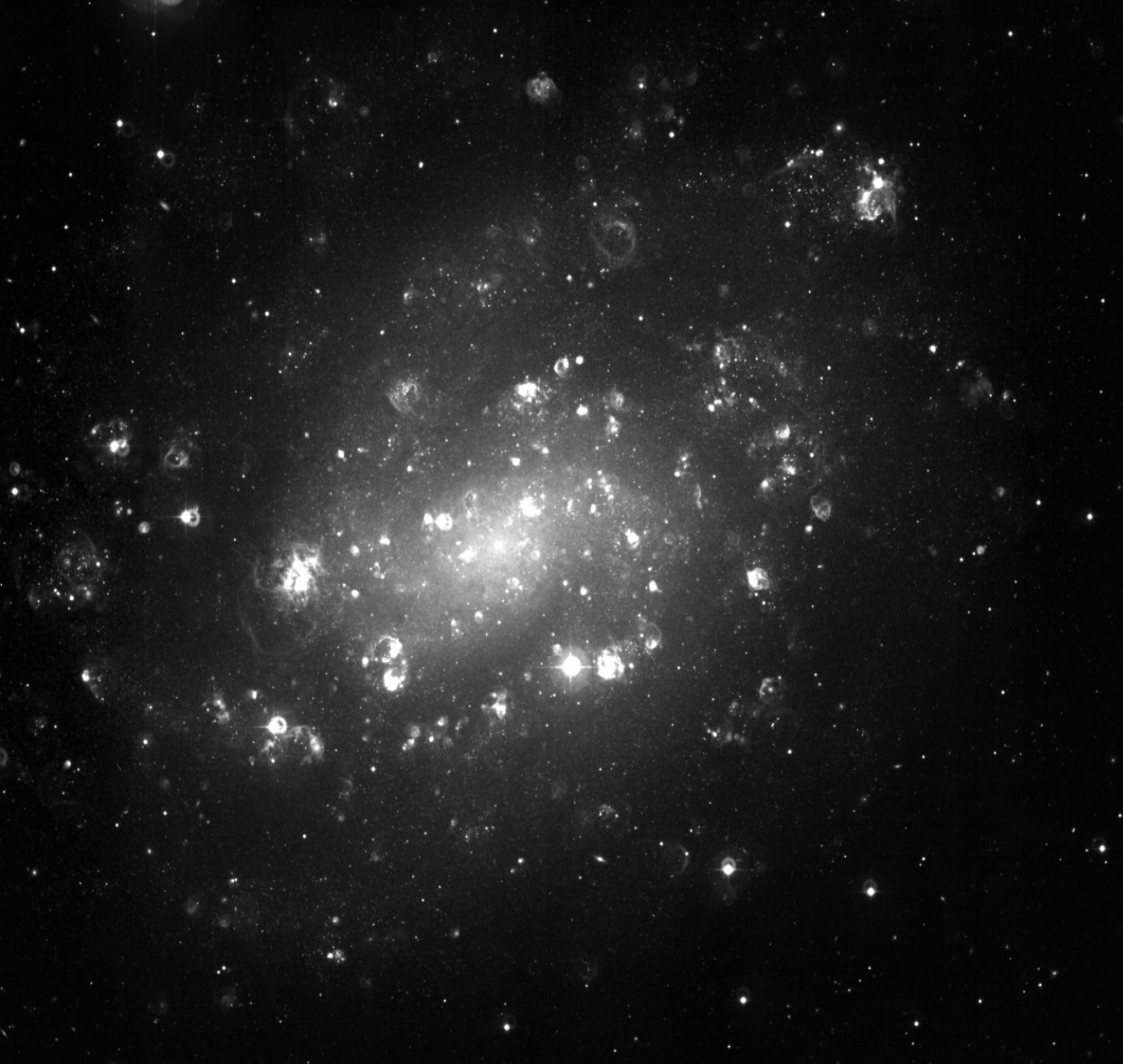


- chemical homogeneity of solar neighbourhood:
3rd independent indicator (HII-regions)
- near-solar abundances over ~ 4 kpc
- flat abundance gradient

➔ tight observational constraints for Galactochemical evolution

Extragalactic Abundances

- so far:
HII regions
only indicators for abundances
in nearby galaxies:
He, N, **O**, Ne, S
- **verification** and **extension** via **stars**
- evidence for systematic bias in published work



Spiral Galaxy NGC 300 (H-alpha band)
(MPG/ESO 2.2-m + WFI)

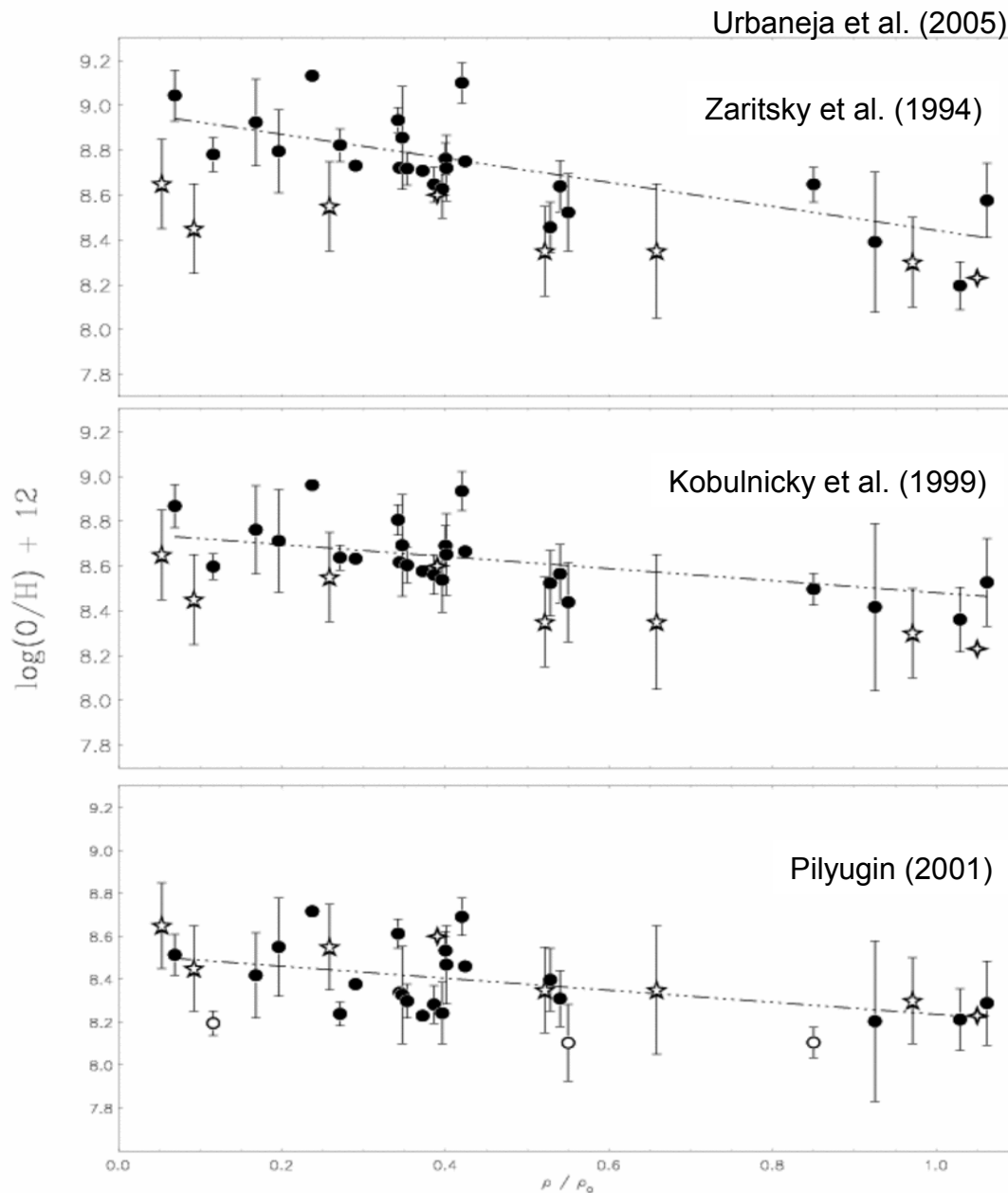
ESO PR Photo 18c/02 (7 August 2002)

Friedrich-Alexander-Universität
Erlangen-Nürnberg



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NGC300: Abundance Gradient

- radial trend of O abundances
- different trends for HII-regions from 3 different R_{23} -calibrations

• independent verification and extension via stellar analyses

+ 24 BA-supergiants
Kudritzki et al. (2008)

Summary

precision spectroscopy
is possible
(via improved modelling & analysis)

galactochemical evolution

- highly uniform abundances in solar vicinity
→ cosmic abundance standard
- flat Galactic abundance gradient
- abundance gradients in other spirals?