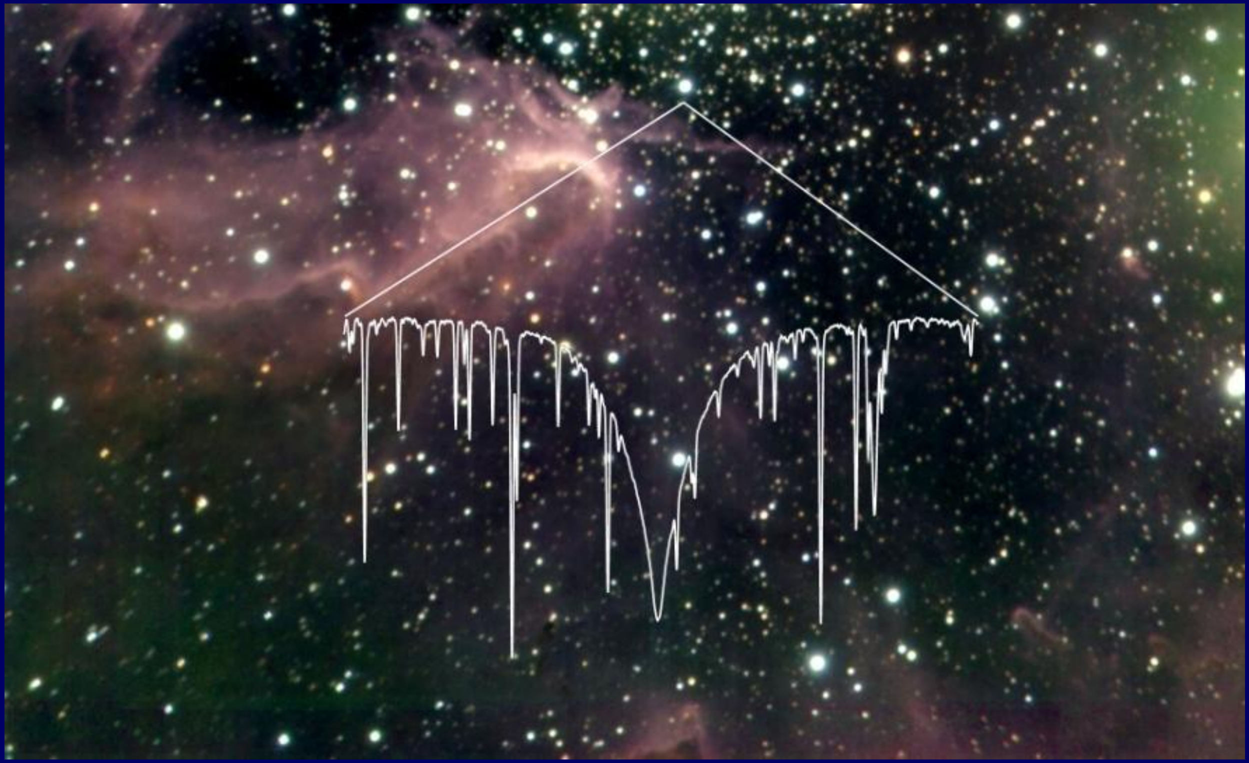
High-precision stellar parameter and abundance determinations

OB dwarfs and BA supergiants



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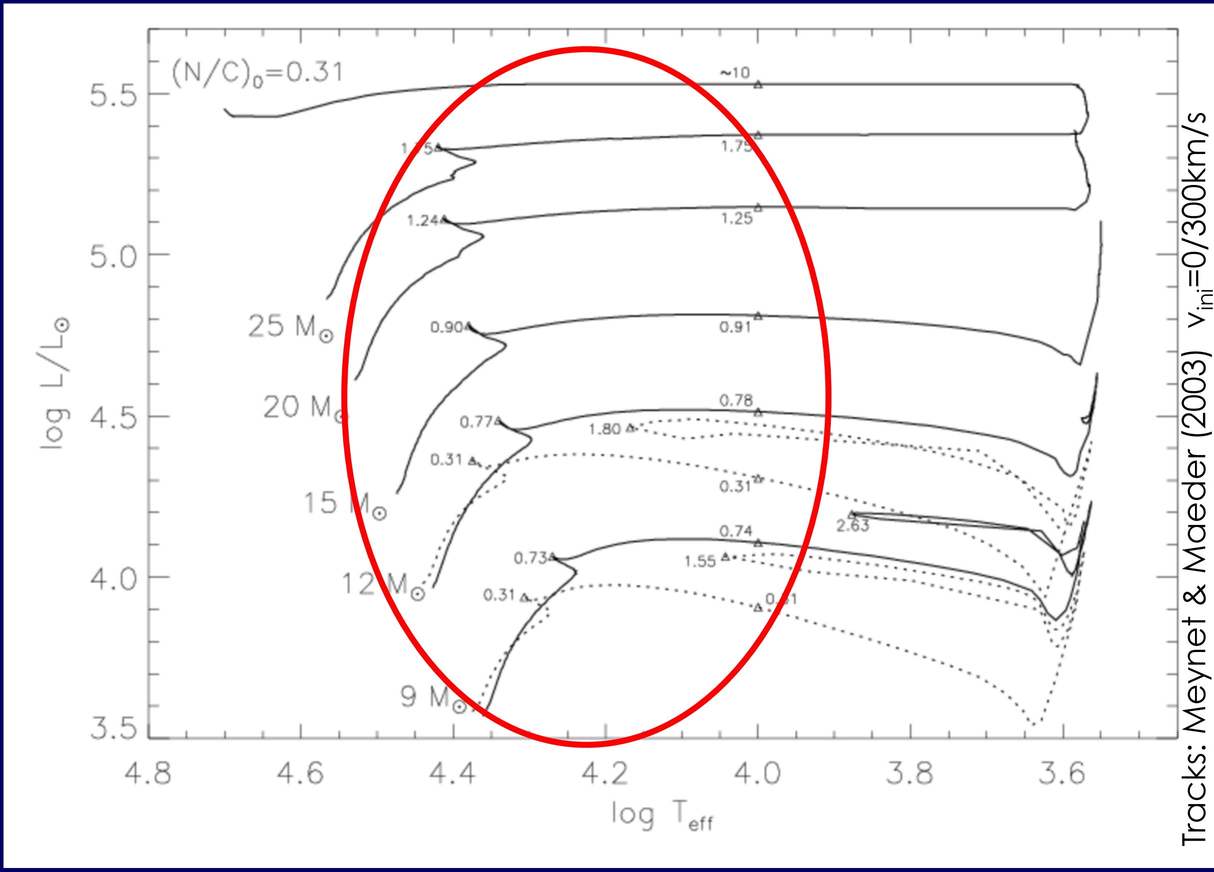
Overview

- OB dwarfs and BA supergiants
- The models (spectrum synthesis)
- The analysis
- Parameter vs. NLTE-effects
- Consequences for stellar evolution
- Consequences for Galactic evolution

OB dwarfs: progenitors of BA supergiants

→ radiative envelope
→ thin atmosphere (1D)

in contrast to cool stars:
→ no convective envelope (3D)
→ no chromosphere (heating)



absolute chemical composition
(independently from solar values)

Our contribution

Improvement of the spectral modeling (NLTE)

Talk N. Przybilla

Improvement of the spectral analysis (self consistent)

Investigation of >20 systematic effects involved in chemical abundance determinations

NEW:

Computation of large grids and implementation of a „well-trained" automatic fitting procedure to analyse numerous stars

The models

Hybrid non-LTE approach:

Good approximation!

(Nieva & Przybilla 2007)

Classical model atmospheres

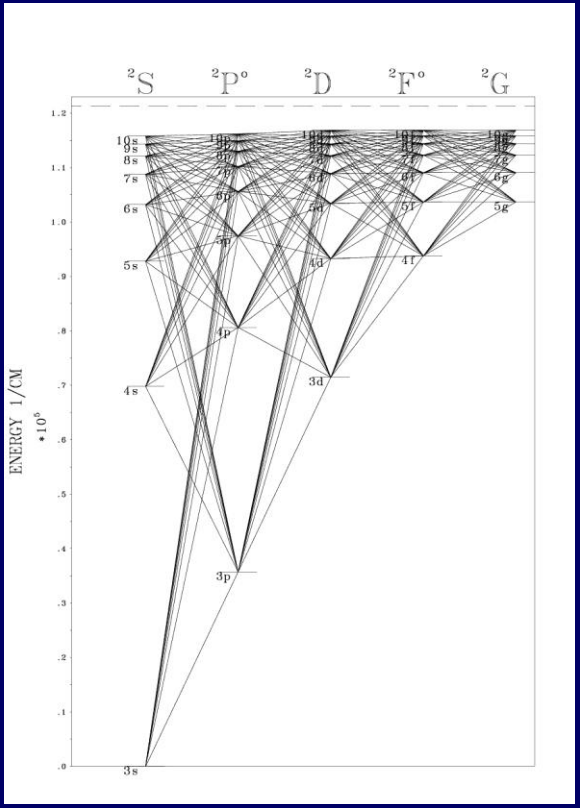
plane-parallel, hydrostatic & radiative equilibrium, LTE

Non-LTE line formation

radiative transfer & statistical equilibrium

- Level populations: DETAIL
- Formal solution: SURFACE

(Giddings, 1981; Butler & Giddings 1985; updated by K. Butler, LMU)



Green: species implemented in NLTE in DETAIL & SURFACE (model atoms tested!)

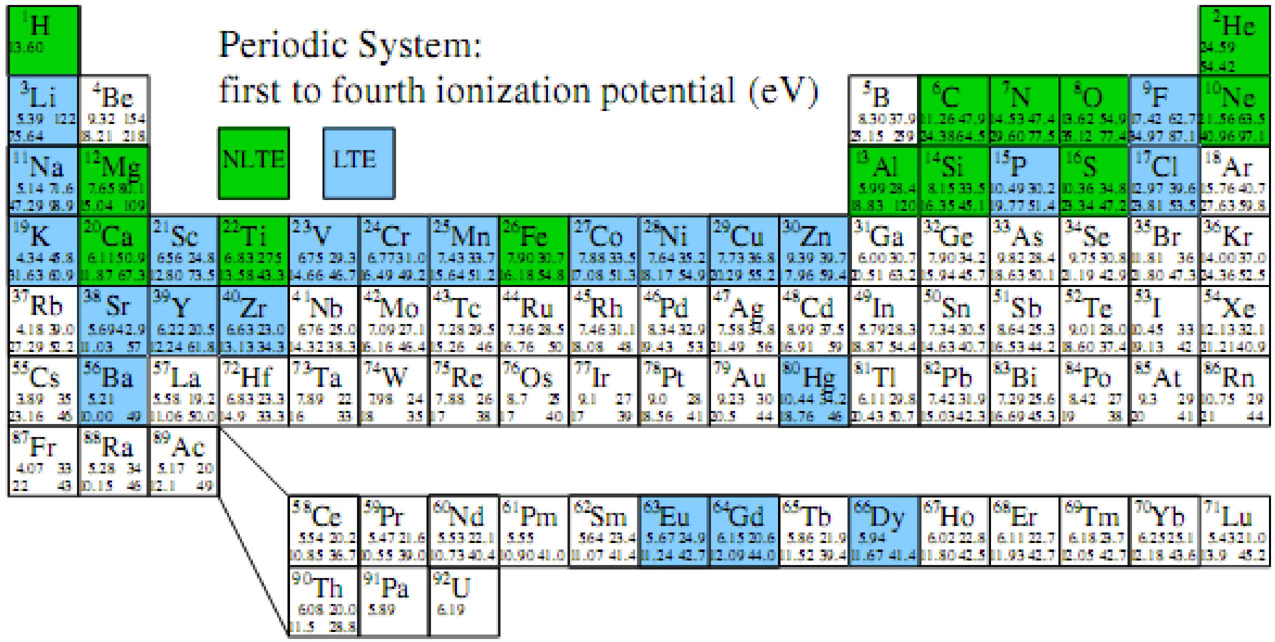


Figure 2.5: Schematic periodic system, indicating the current status of the spectrum synthesis computations with DETAIL/SURFACE. Elements which are implemented in non-LTE are marked in green (see Table 2.1), those in LTE in blue. For each element, the first to fourth ionization potential (in eV, Cox 2000; NIST) is given.

Table 2.1: Non-LTE model atoms for use with DETAIL/SURFACE

Ion	Source	Ion	Source
H	Przybilla & Butler (2004a)	Mg I/II	Przybilla et al. (2001a)
He I/II	Przybilla (2005)	Al III	Dufton et al. (1986)
C I	Przybilla et al. (2001b)	Si II/III/IV	Przybilla & Butler (in prep.)
C II/III/IV	Nieva & Przybilla (2006, 2008)	S II/III	Vrancken et al. (1996), updated
N I/II	Przybilla & Butler (2001)	Ca I/II	Mashonkina et al. (2007)
O I	Przybilla et al. (2000)	Ti II	Becker (1998)
O II	Becker & Butler (1988), updated	Fe II	Becker (1998)
Ne I/II	Butler (in prep.)	Fe III	Butler (in prep.)

Przybilla (2008)

The analysis

Self-consistent spectral analysis

Simultaneous reproduction of all spectroscopic indicators

	HD	T_{eff} 10^3 K	H	He I	He II	C II	C III	C IV	O I	O II	Ne I	Ne II	Si III	Si IV	Fe II	Fe III
11	36512	33.4	•	•	•	•	•	•		•		•	•	•		•
6	149438	32.0	•	•	•	•	•	•		•	•	•	•	•		•
3	63922	31.2	•	•	•	•	•	•		•		•	•	•		•
19	34816	30.4	•	•	•	•	•			•	•	•	•	•		•
12	36822	30.0	•	•	•	•	•	•		•	•	•	•	•		•
13	36960	29.0	•	•	•	•	•			•	•	•	•	•		•
1	36591	27.0	•	•	•	•	•			•	•	•	•	•		•
14	205021	27.0	•	•	•	•	•			•	•	•	•	•		•
2	61068	26.3	•	•	•	•	•			•	•	•	•	•		•
9	35299	23.5	•	•		•	•		•	•	•	•	•	•	•	•
16	216916	23.0	•	•		•	•		•	•	•	•	•	•	•	•
4	74575	22.9	•	•		•	•		•	•	•	•	•	•	•	•
7	886	22.0	•	•		•	•		•	•	•		•	•	•	•
8	29248	22.0	•	•		•	•		•	•	•		•	•	•	•
18	16582	21.0	•	•		•	•		•	•	•		•	•	•	•
5	122980	20.8	•	•		•	•		•	•	•		•		•	•
10	35708	20.7	•	•		•	•		•	•	•		•	•	•	•
17	3360	20.7	•	•		•	•		•	•	•		•	•	•	•
20	160762	17.5	•	•		•			•	•	•		•		•	•
15	209008	15.8	•	•		•			•	•	•		•		•	•

Solution:

precise values of

T_{eff}

log g

microturbulence

v sin i

elemental abundances

But also:

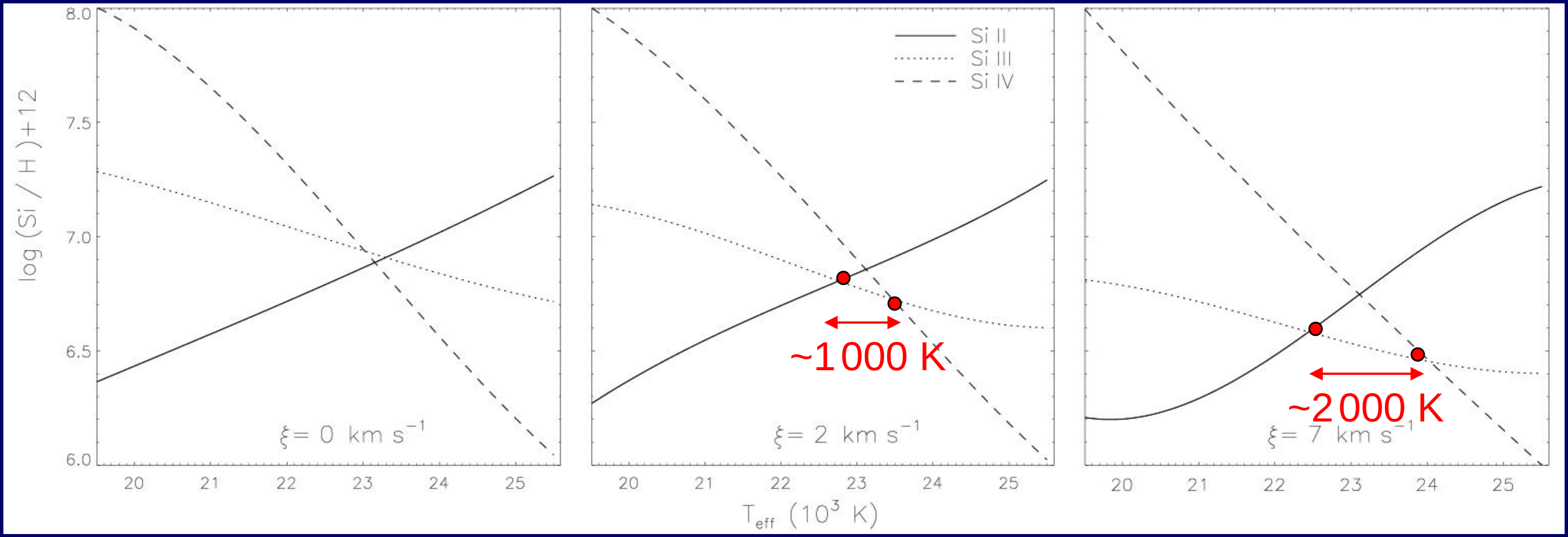
distances

masses

luminosities

bolometric corrections

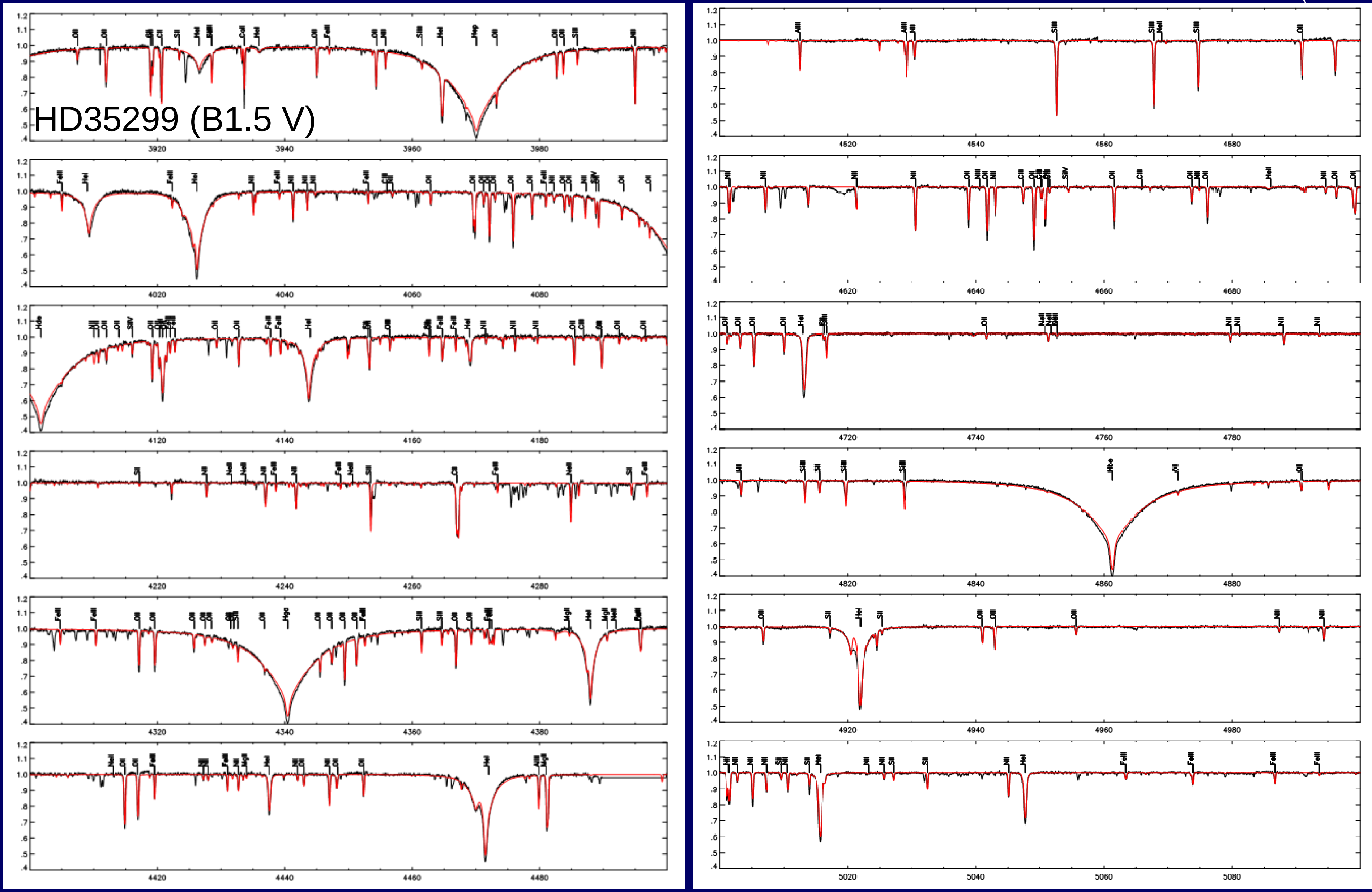
Why do we need more than 1 ionization equilibrium to derive Teff, and microturbulence (and logg) simultaneously ?



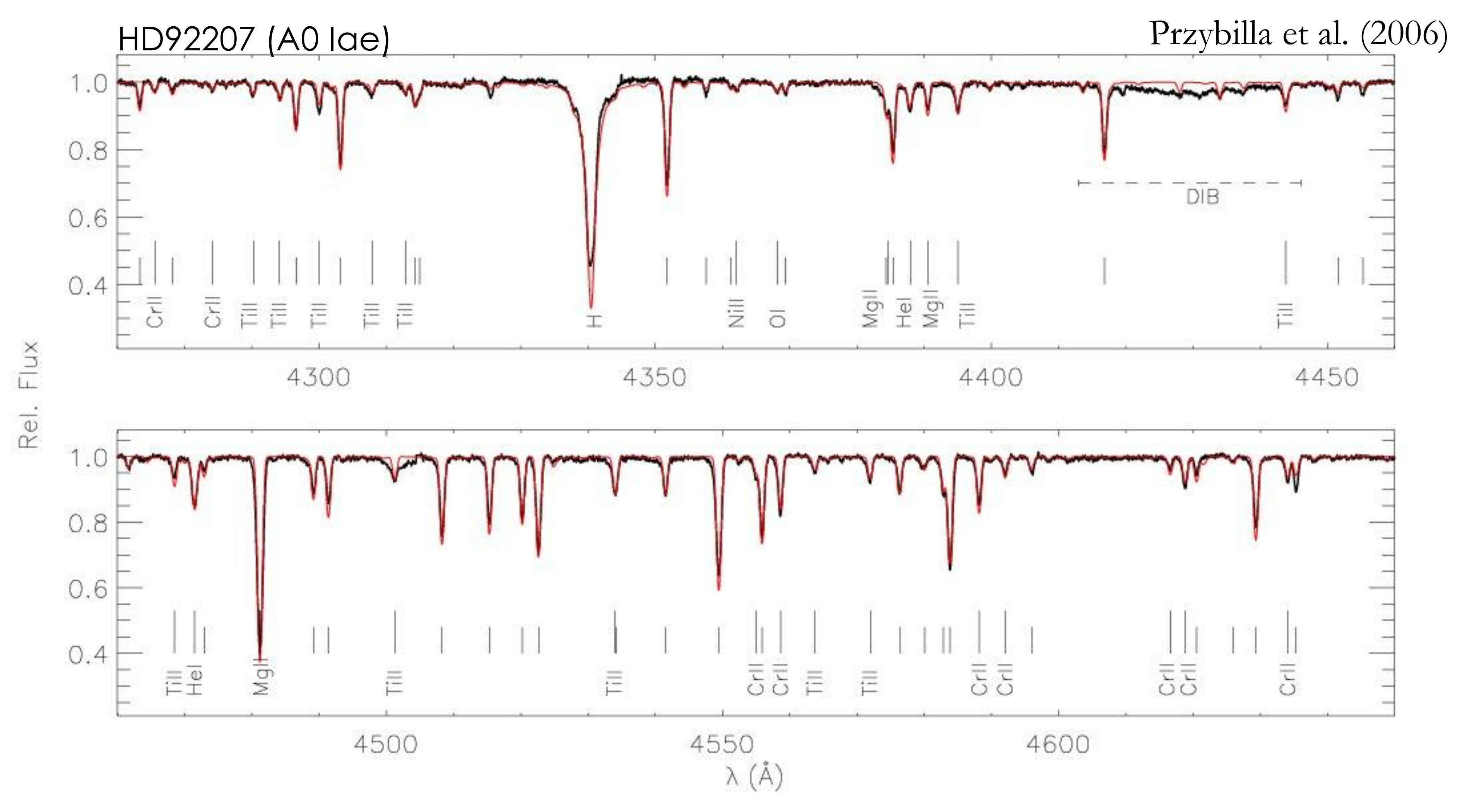
Nieva (2007), PhD Thesis

Global fit to all modeled lines

Nieva & Przybilla (2011)
Nieva & Simon-Diaz (2011)



Global fit to all modeled lines

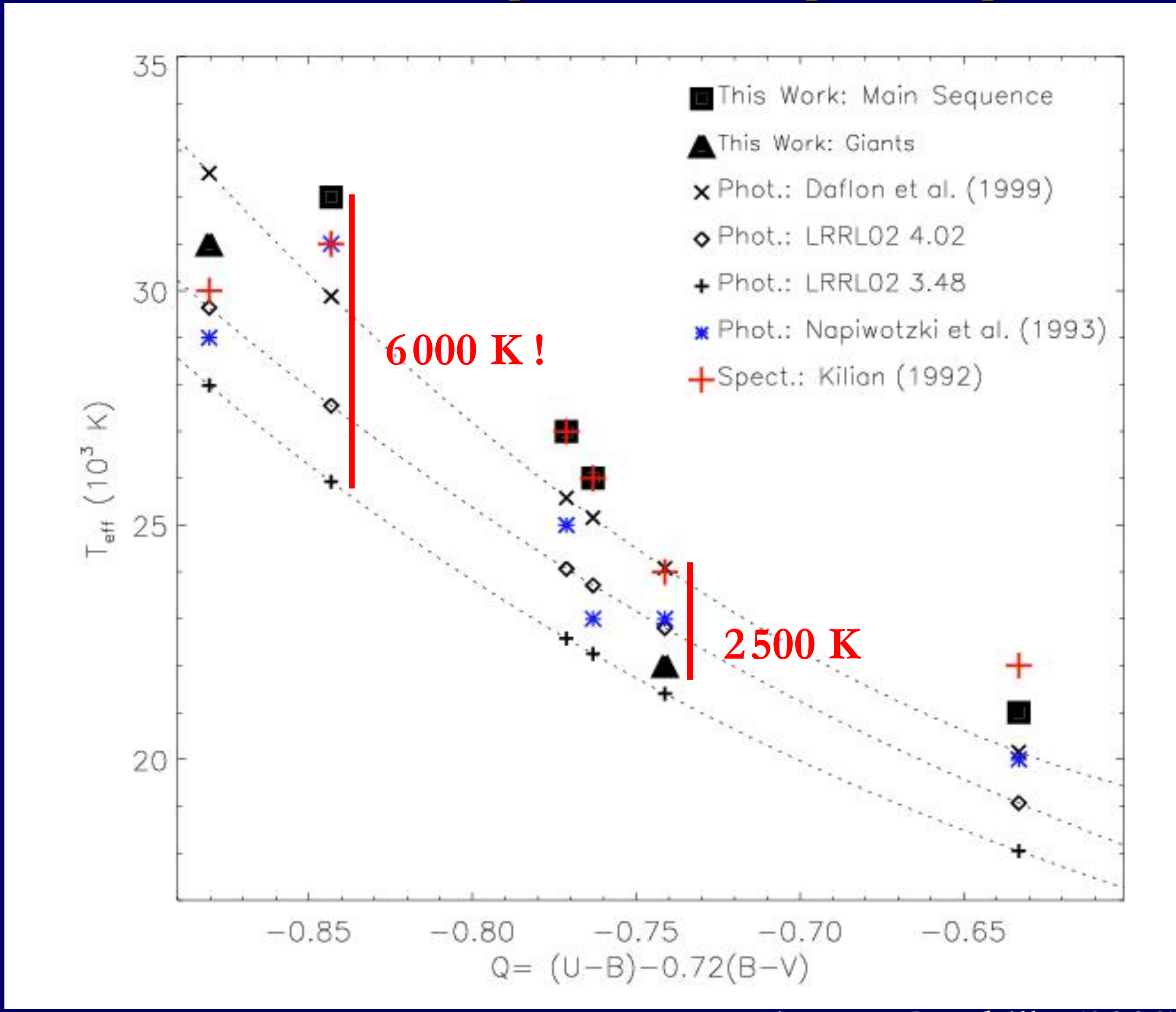


- several 10^4 lines: ~30 elements, 60+ ionization stages
- complete spectrum synthesis in visual (& near-IR) ~70-90% in NLTE

Parameter vs. NLTE effects

T_{eff} scales

Our approach (several ionization equilibria)
vs. Literature (photometric & spectroscopic)



Nieva & Przybilla (2008)

Atmospheric parameter vs. non-LTE effects

$T_{\mathrm{eff}} \geq$ non-LTE effects! (for this example)

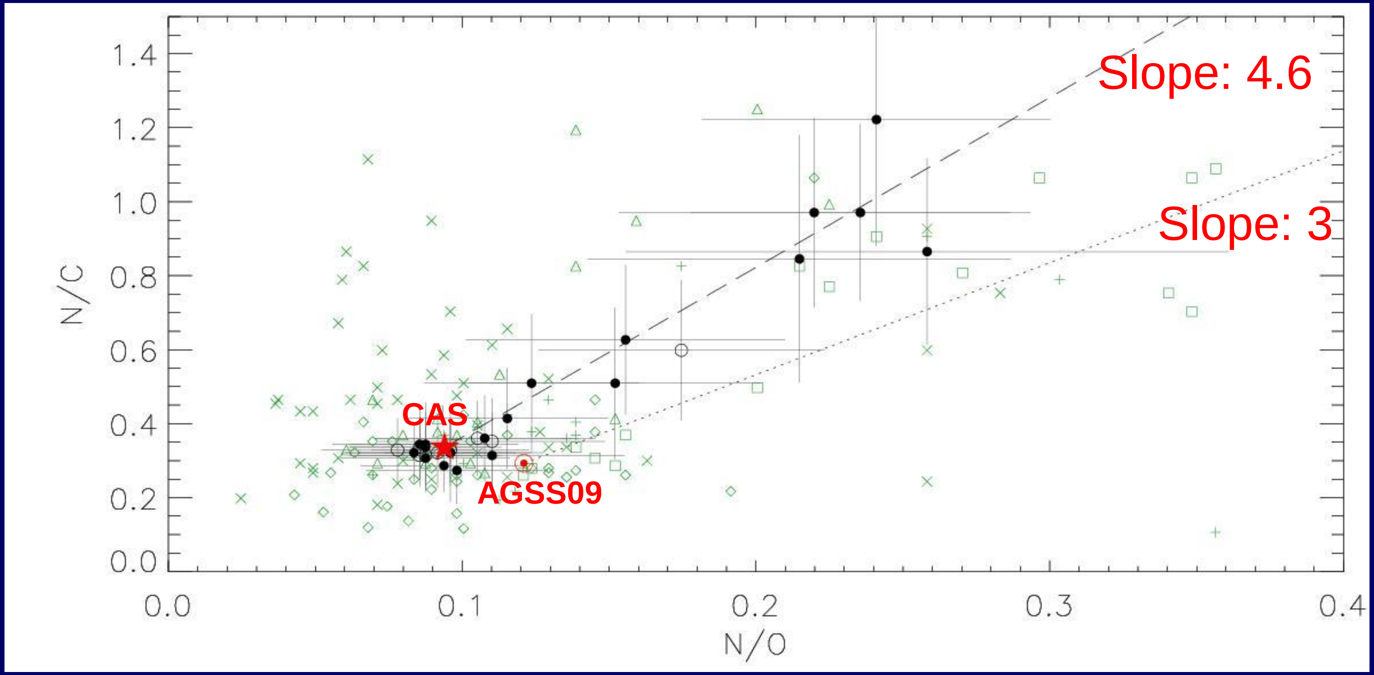
	HR 3055	ΔT_{eff}	$\Delta \log g$	$\Delta \xi$	LTE
	B0 III	-2000 K	$+0.2$ dex	$+5\,\mathrm{km\,s^{-1}}$	
C II	4267.2	−0.33	−0.11	−0.16	−0.40
	5145.2	−0.32	−0.09	−0.02	0.00
	5662.5	−0.33	−0.13	0.00	0.00
	6578.0	−0.40	−0.15	−0.10	−0.01
C III	4056.1	+0.21	+0.06	−0.04	+0.08
	4162.9	+0.28	+0.09	−0.03	+0.25
	4186.9	+0.35	+0.15	−0.08	+0.07
	4663.5	+0.22	+0.07	−0.03	+0.22
	5272.5	+0.16	+0.01	0.00	0.00
C IV	5801.3	+1.06	+0.46	−0.03	+0.39

Nieva & Przybilla (2008)

Consequences for stellar evolution

Stellar Evolution

Observational constraints on the (magneto-)hydrodynamic mixing of CNO-burning products in massive stars

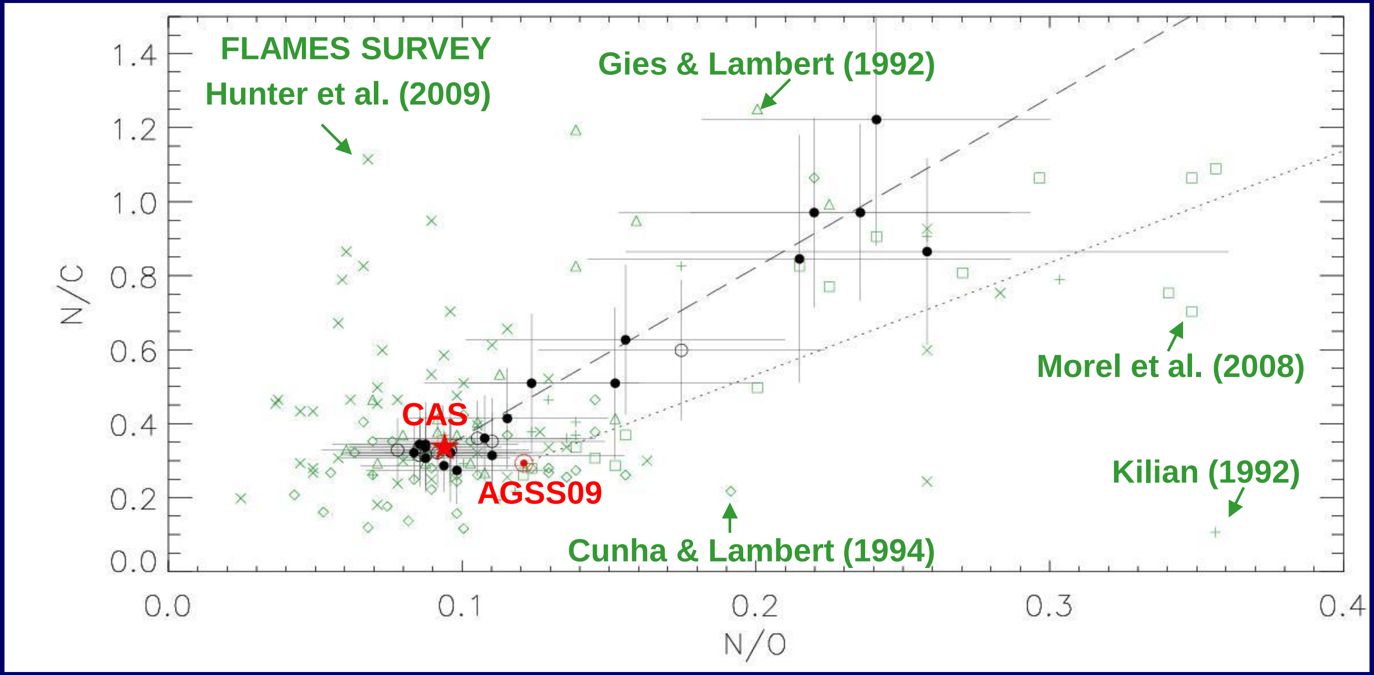


Nieva & Przybilla (2011)

In the Main Sequence, the slope depends only on the initial abundance, regardless on any other ingredient of the models (mass, rotational velocity, etc.)

Stellar Evolution

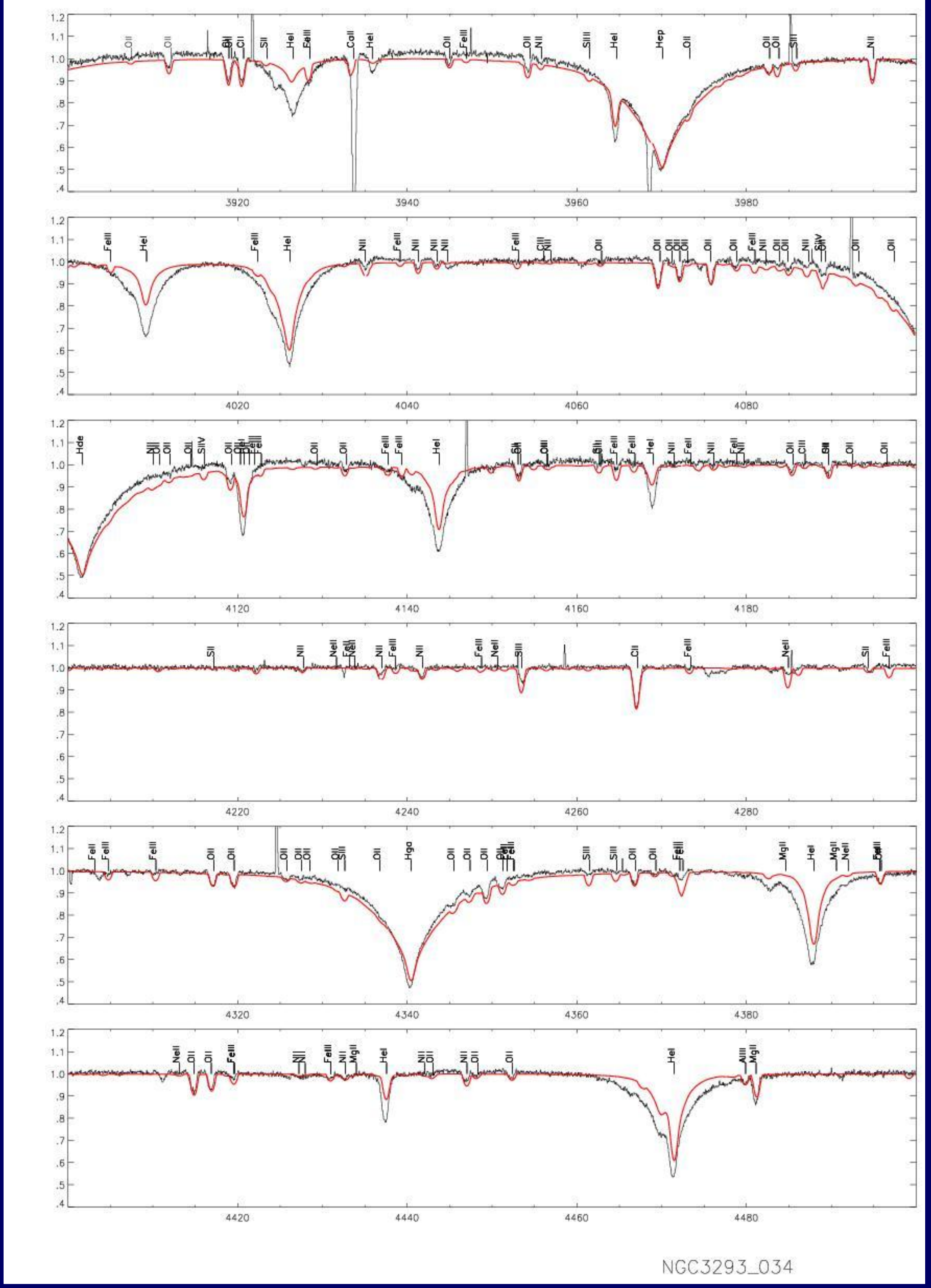
Observational constraints on the (magneto-)hydrodynamic mixing of CNO-burning products in massive stars



Nieva & Przybilla (2011)

In the Main Sequence, the slope depends only on the initial abundance, regardless on any other ingredient of the models (mass, rotational velocity, etc.)

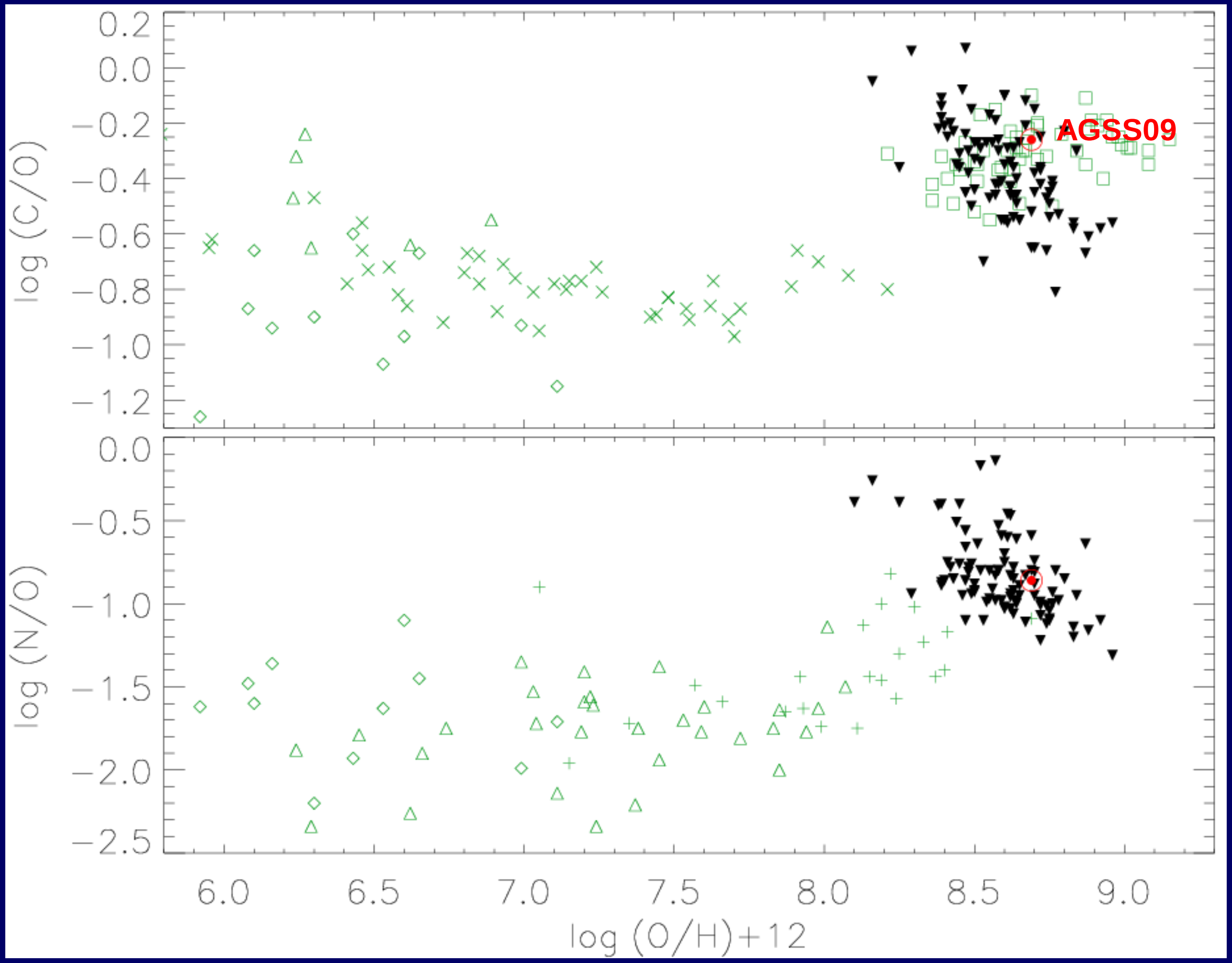
A global fit to a spectrum from the *Massive Star FLAMES Survey* using parameters and abundances from Hunter et al. (2009)



Consequences for Galactic evolution

Galactic Chemical Evolution

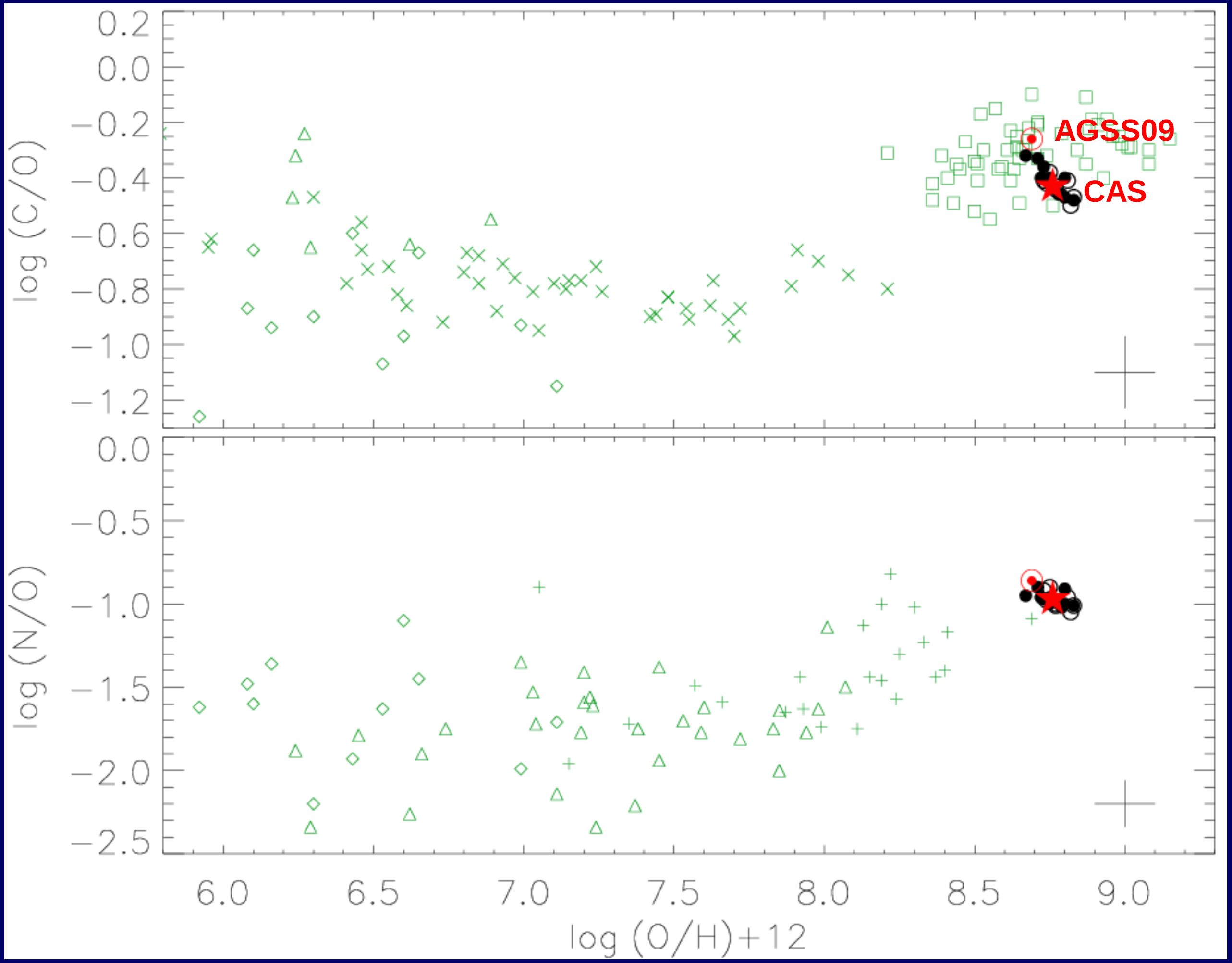
OB stars: end point of GCE models



Nieva & Przybilla (2011)

Galactic Chemical Evolution

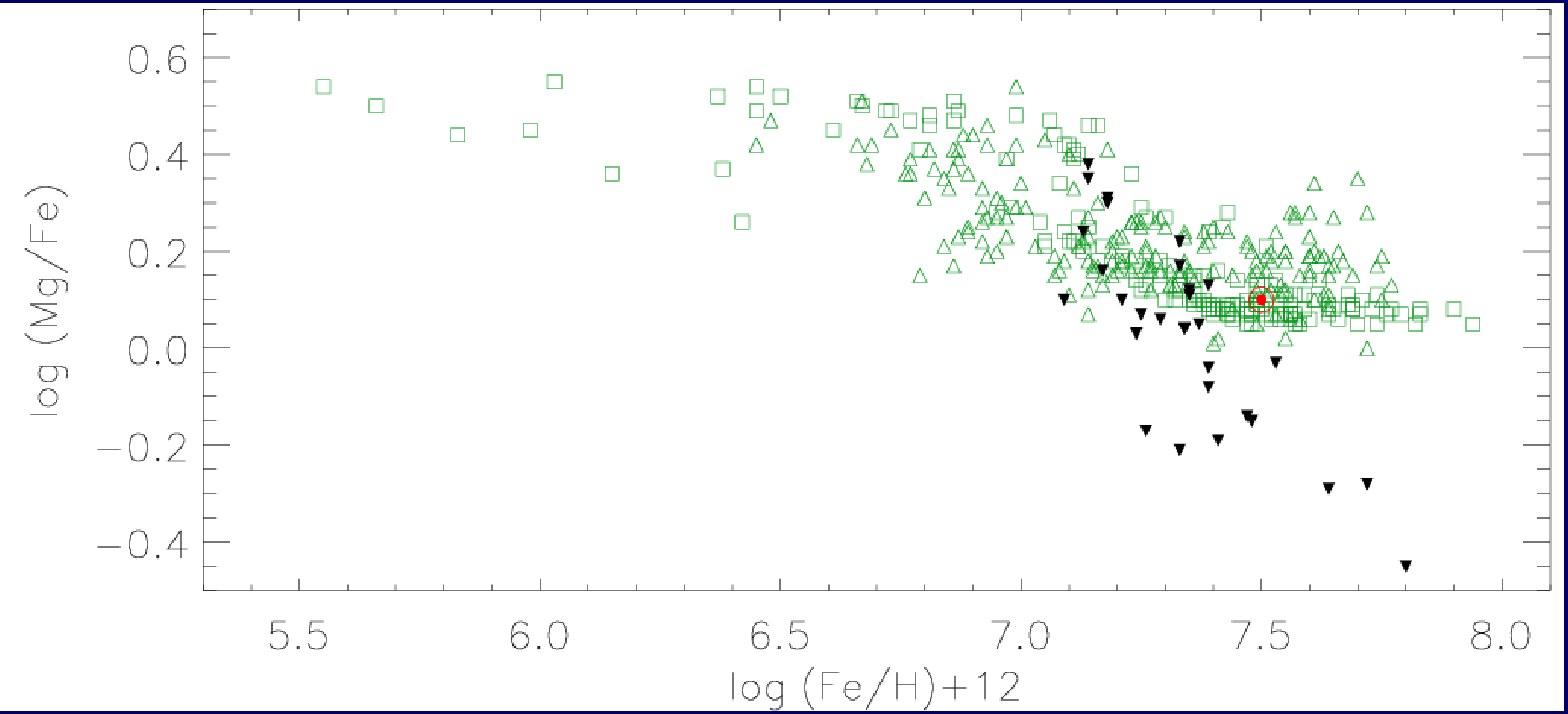
OB stars: end point of GCE models



Nieva & Przybilla (2011)

Galactic Chemical Evolution

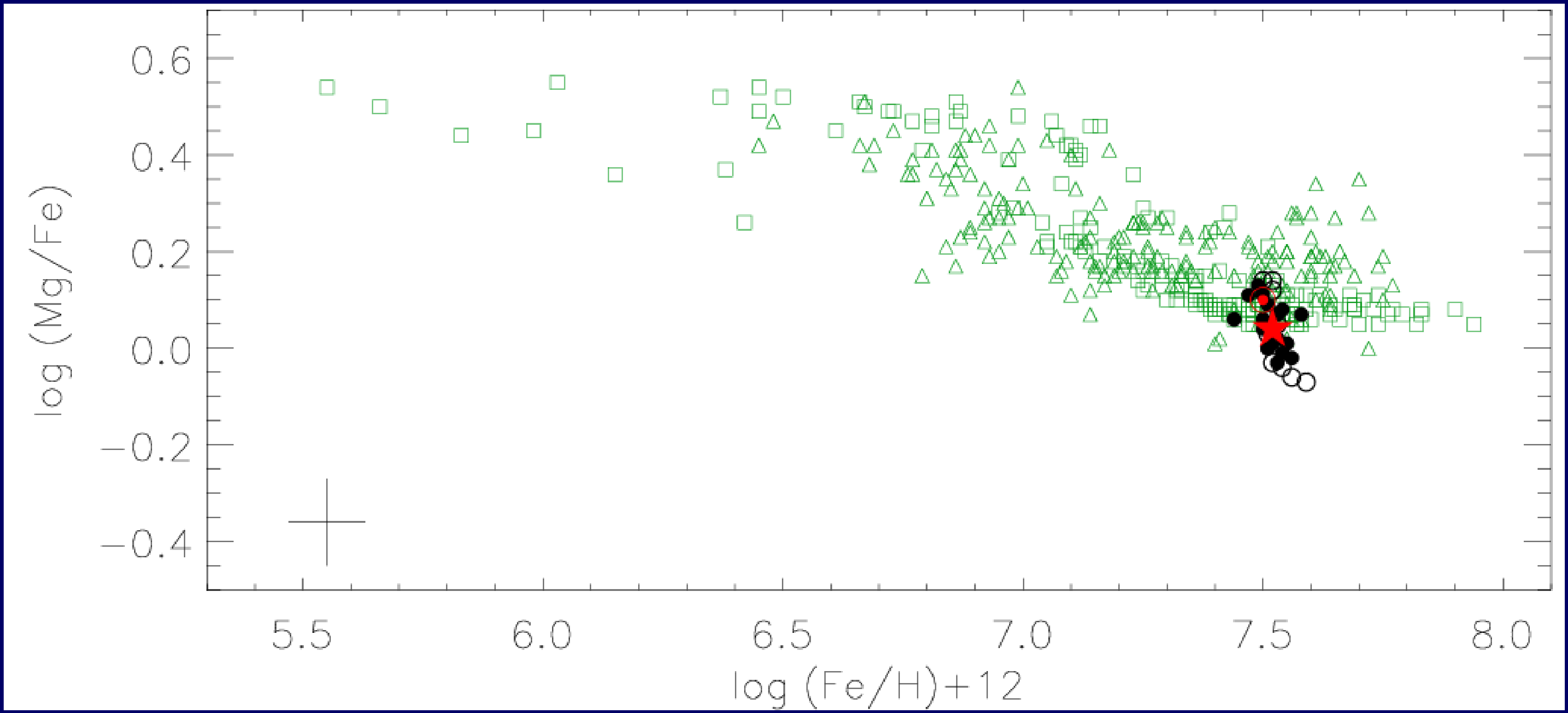
OB stars: end point of GCE models



Nieva & Przybilla (2011)

Galactic Chemical Evolution

OB stars: end point of GCE models



Nieva & Przybilla (2011)

To take home

- **A careful spectral analysis is as important as a proper spectrum modeling**

- **Then, we can learn about stellar and Galactic evolution**

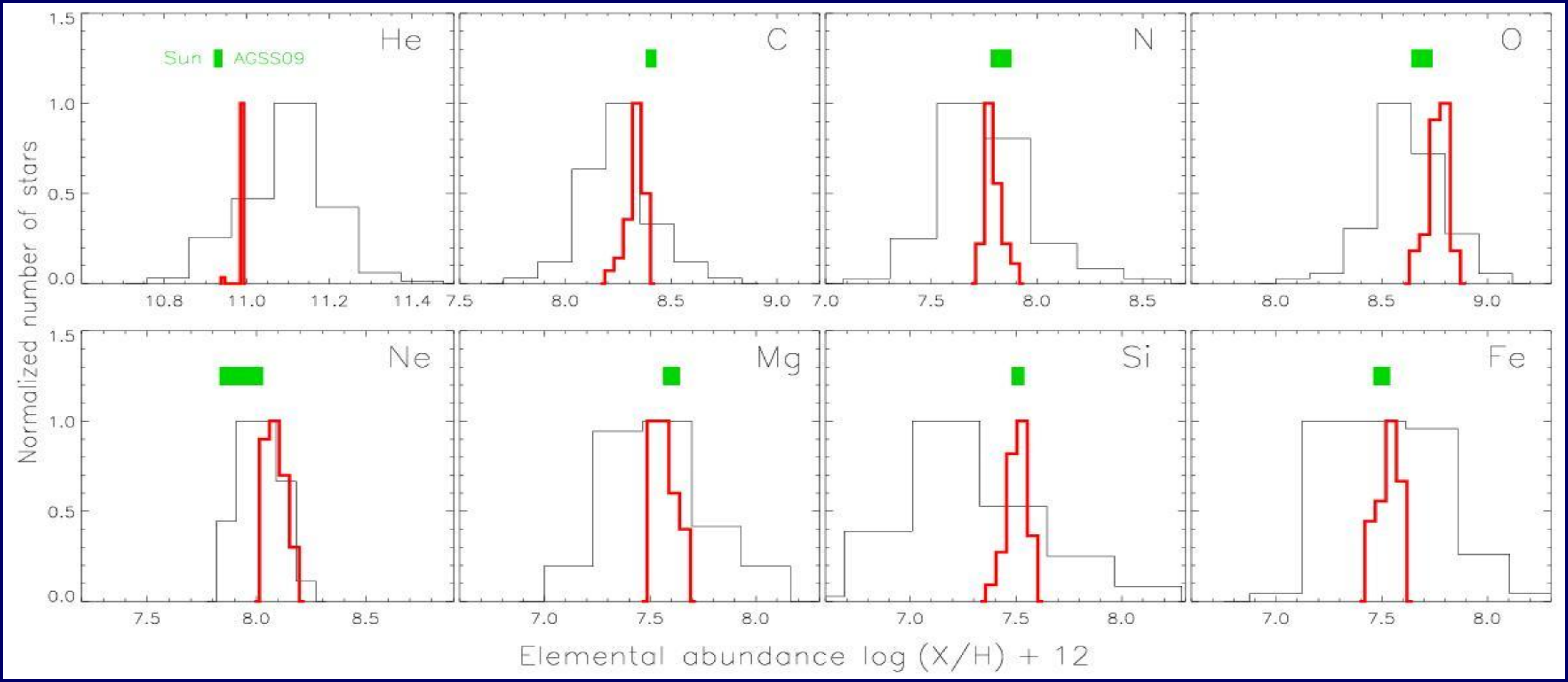
- **We can analyse many more stars at similar precision with a "well-trained" automatic fitting procedure**

- **Shortcomings like in the recent analyses from the *Massive Stars Flames Survey* (e.g. Hunter et al.) could be avoided in the next GAIA science**

A present-day cosmic abundance standard

Nieva & Przybilla (2011)

Chemical homogeneity (~10%) = ISM !

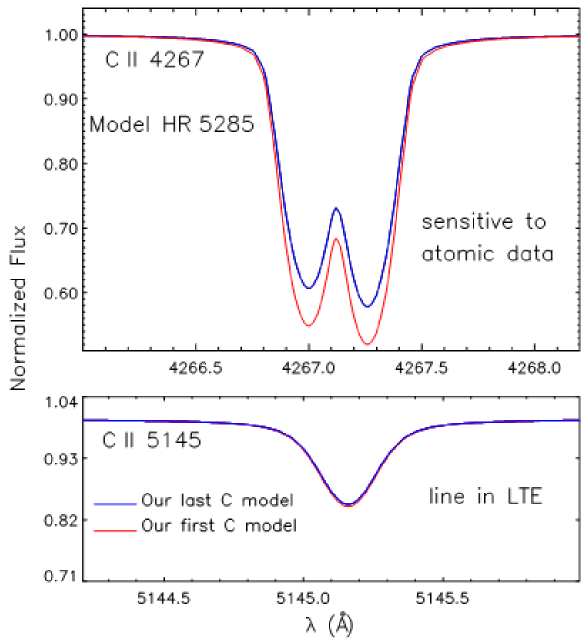


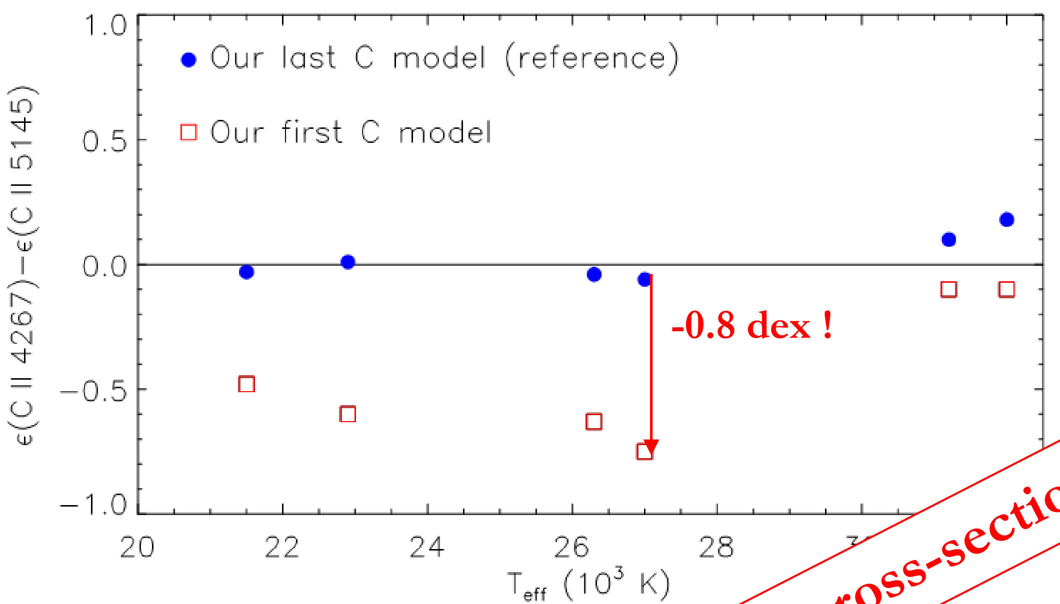
Recommended mass fractions:

$X = 0.715$, $Y = 0.271$, and $Z = 0.014$ **≠ 0.020!**

Systematics from atomic data

Consistent non-LTE vs. 'erroneous' non-LTE





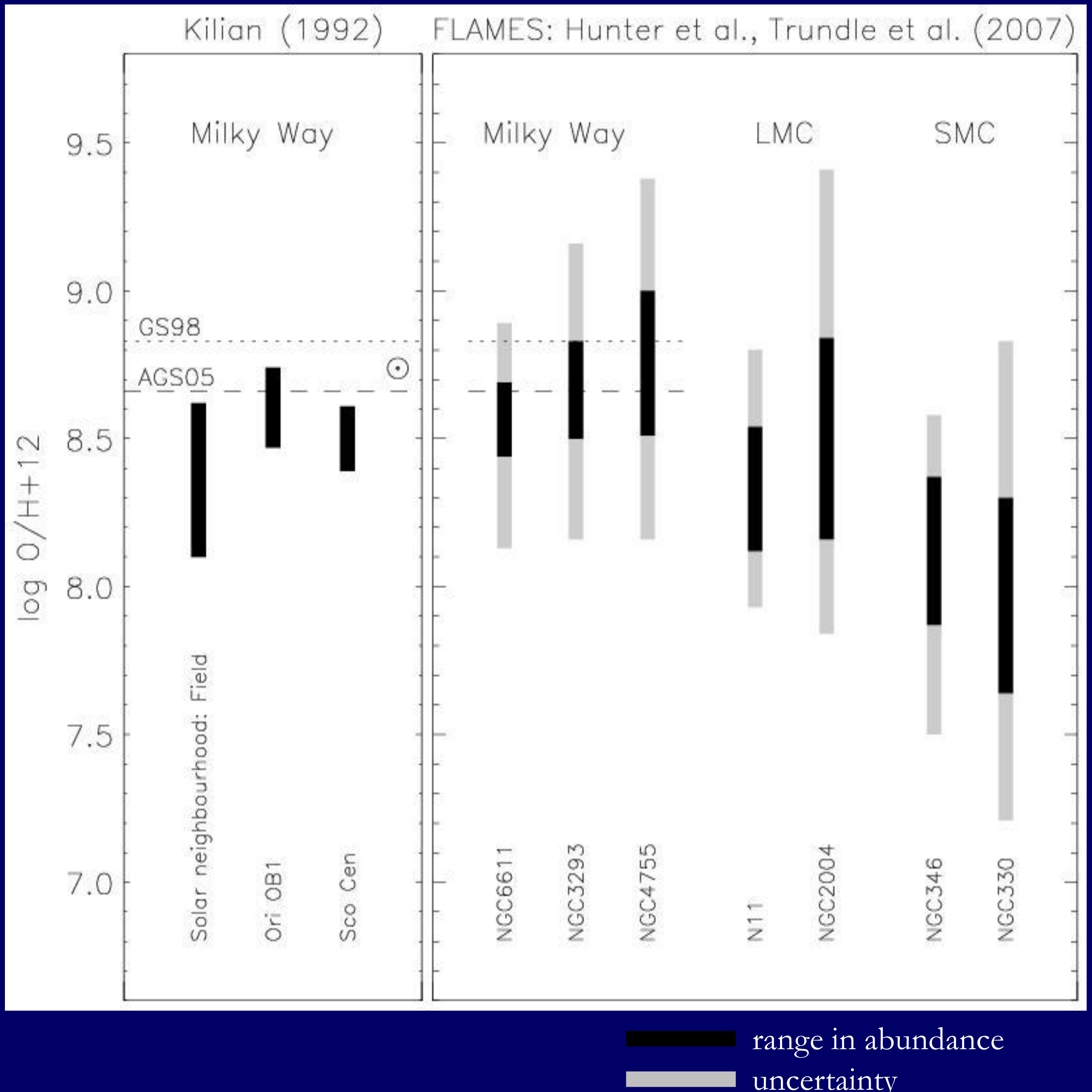
C II λ4267 Å **very sensitive** to non-LTE

C II λ5145 Å **not sensitive** to non-LTE

Here: only photoionization cross-sections!

Nieva & Przybilla (2008)

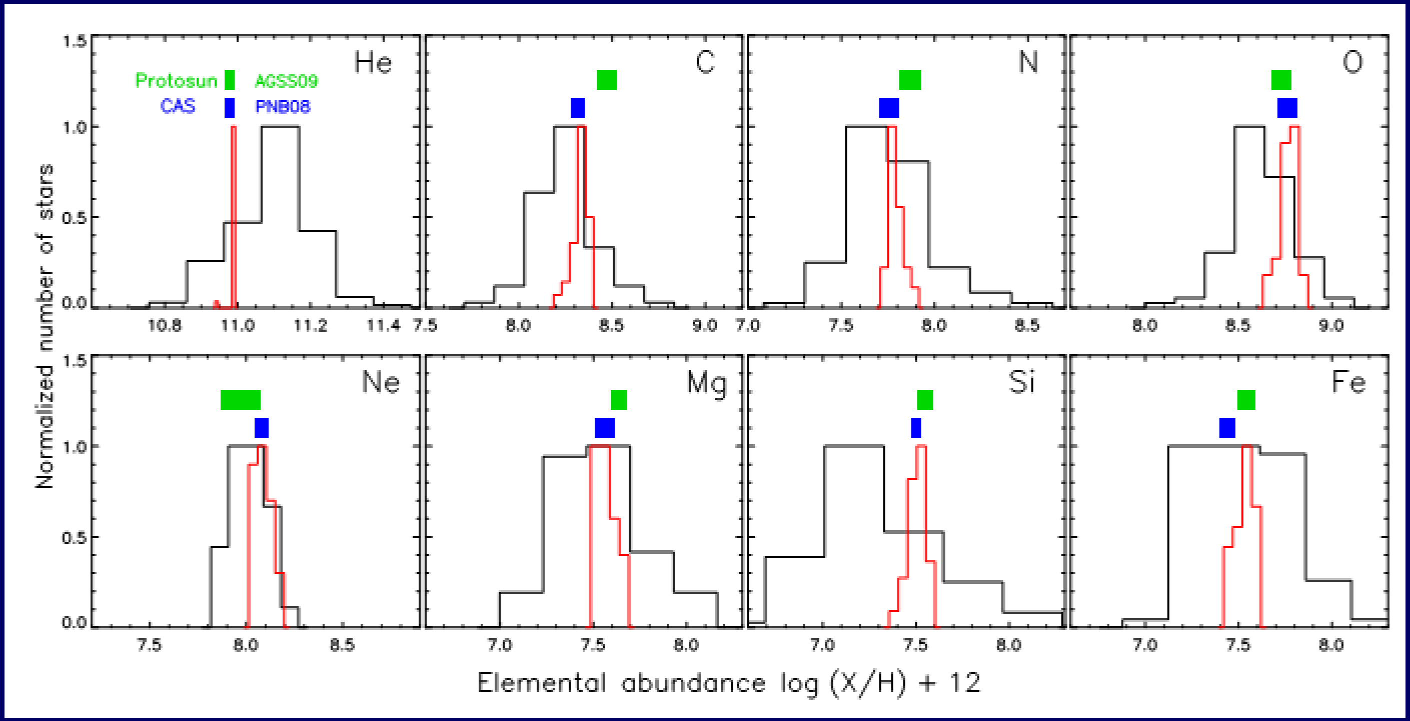
Metals in Solar Neighbourhood/Star Clusters



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

BUT

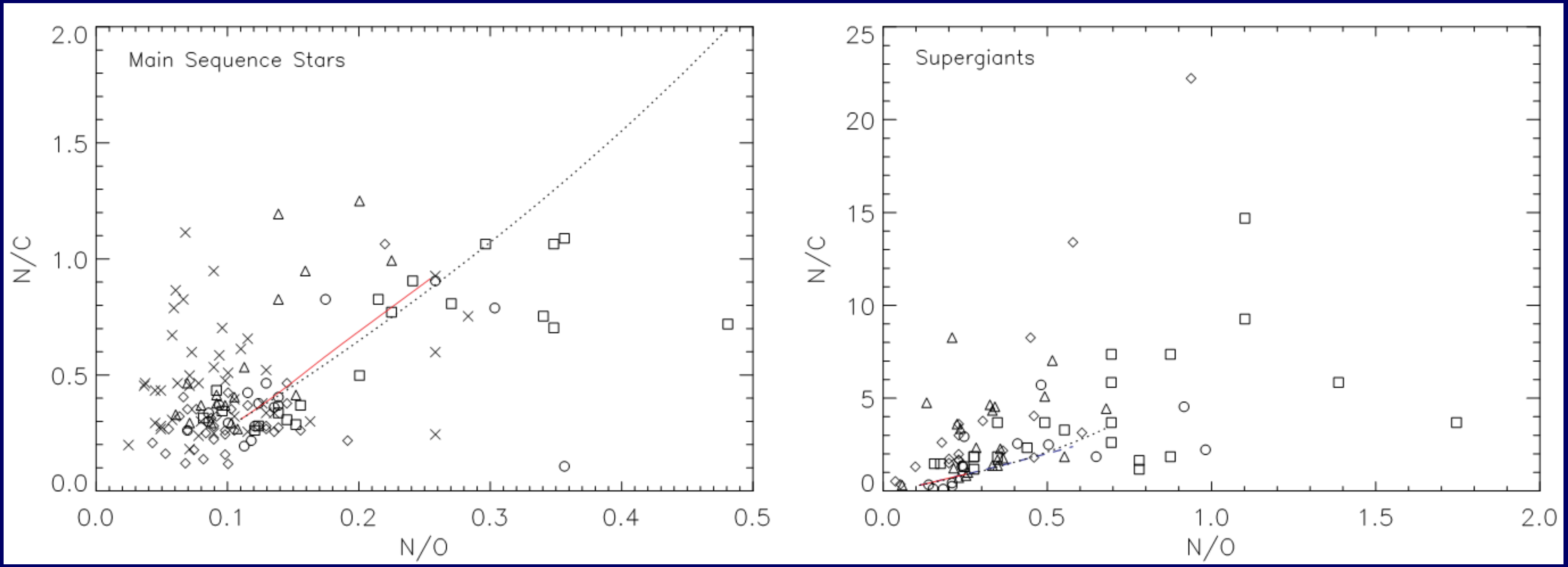
- gas-phase of ISM in solar neighbourhood homogeneous (Sofia & Meyer 2001)
- efficient mixing mechanisms → homogeneity
- solar abundances peculiar?



Protosun
AGSS09
CAS
PNB08
He
C
N
O
Ne
Mg
Si
Fe
Normalized number of stars
Elemental abundance log (X/H) + 12

Stellar Evolution

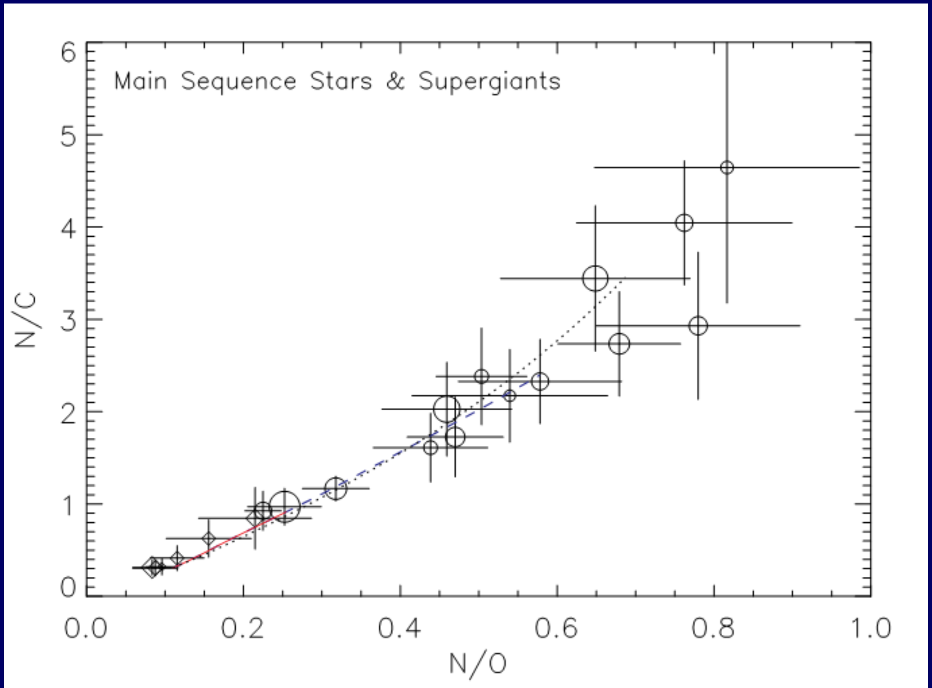
Observational constraints on the (magneto-)hydrodynamic mixing of CNO-burning products in massive stars



Literature

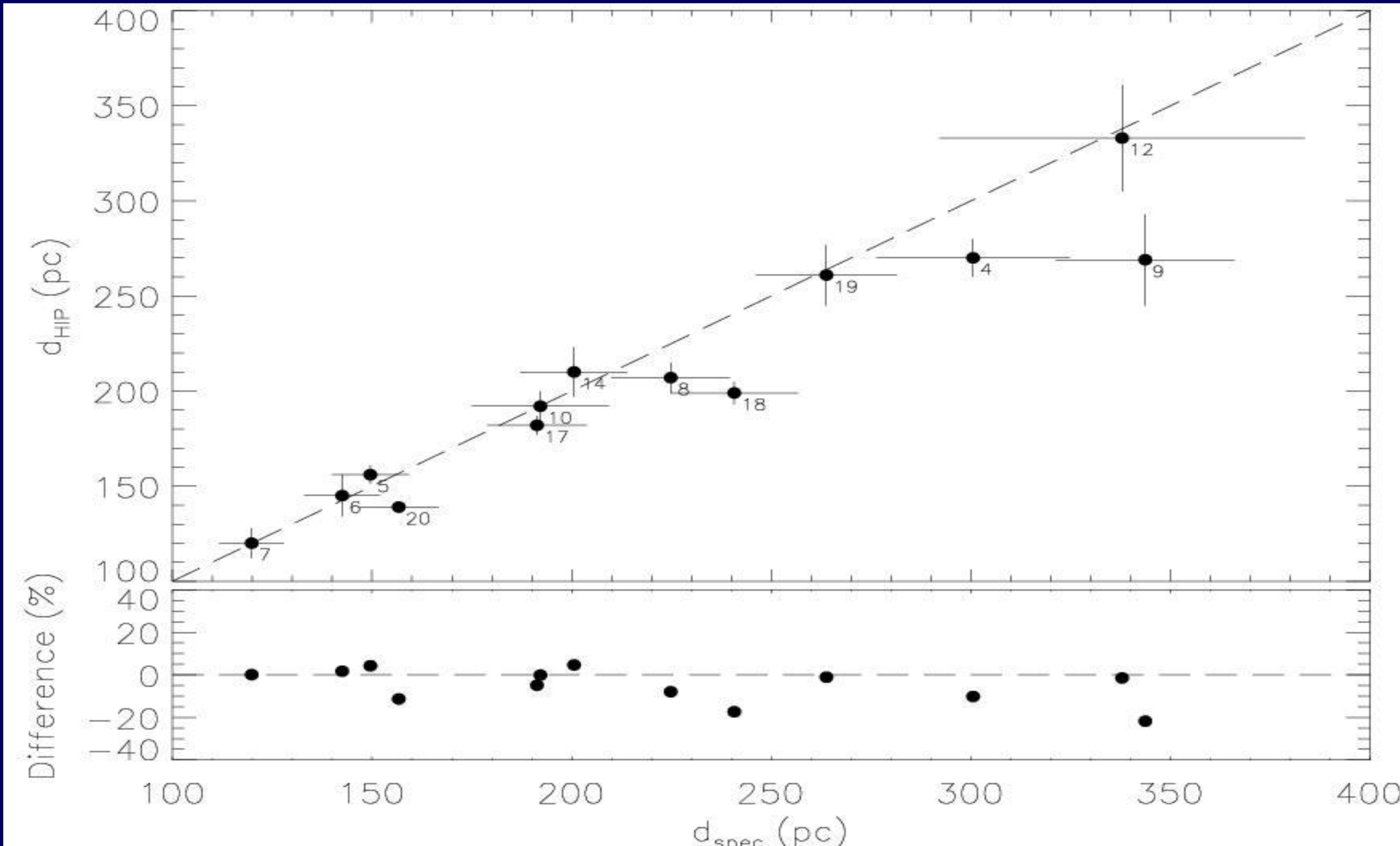
Stellar Evolution

Observational constraints on the (magneto-)hydrodynamic mixing of CNO-burning products in massive stars

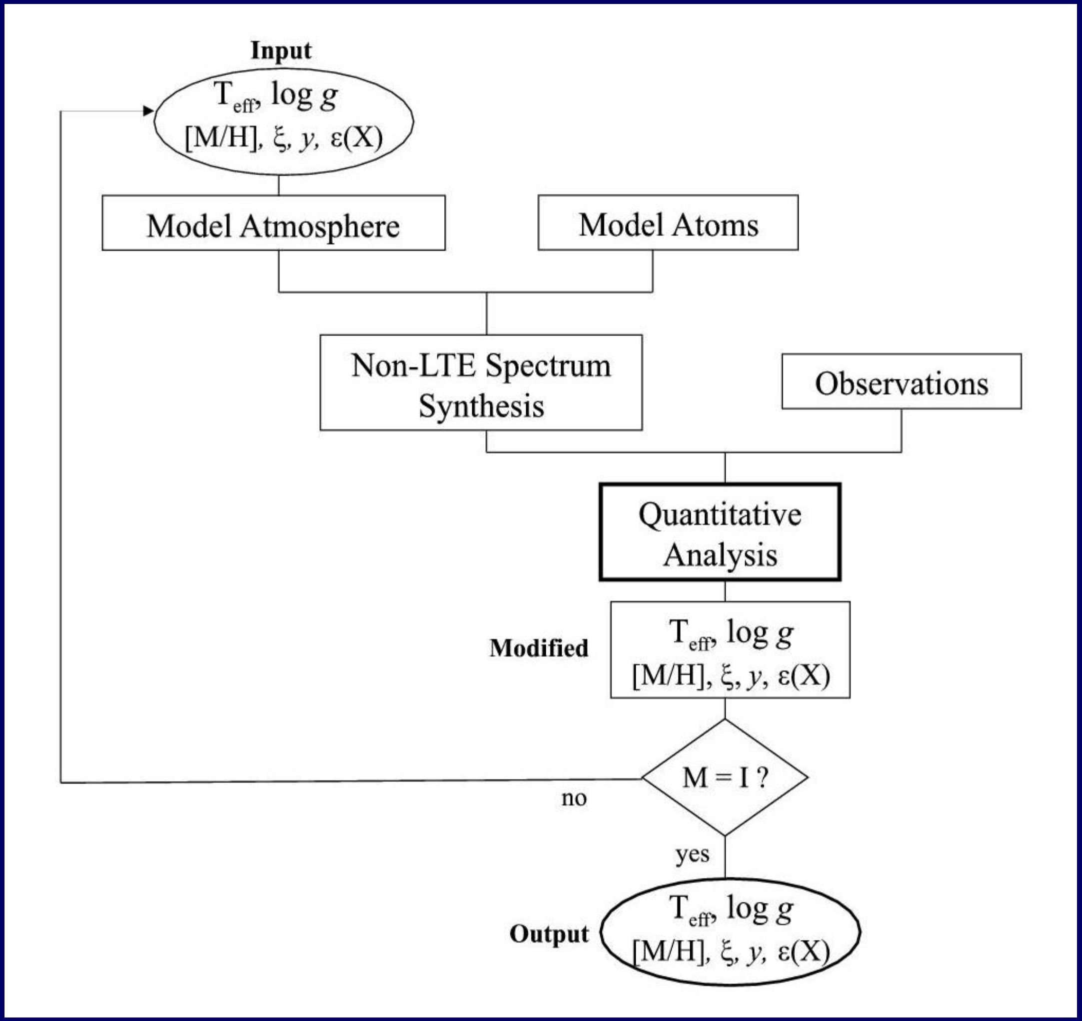


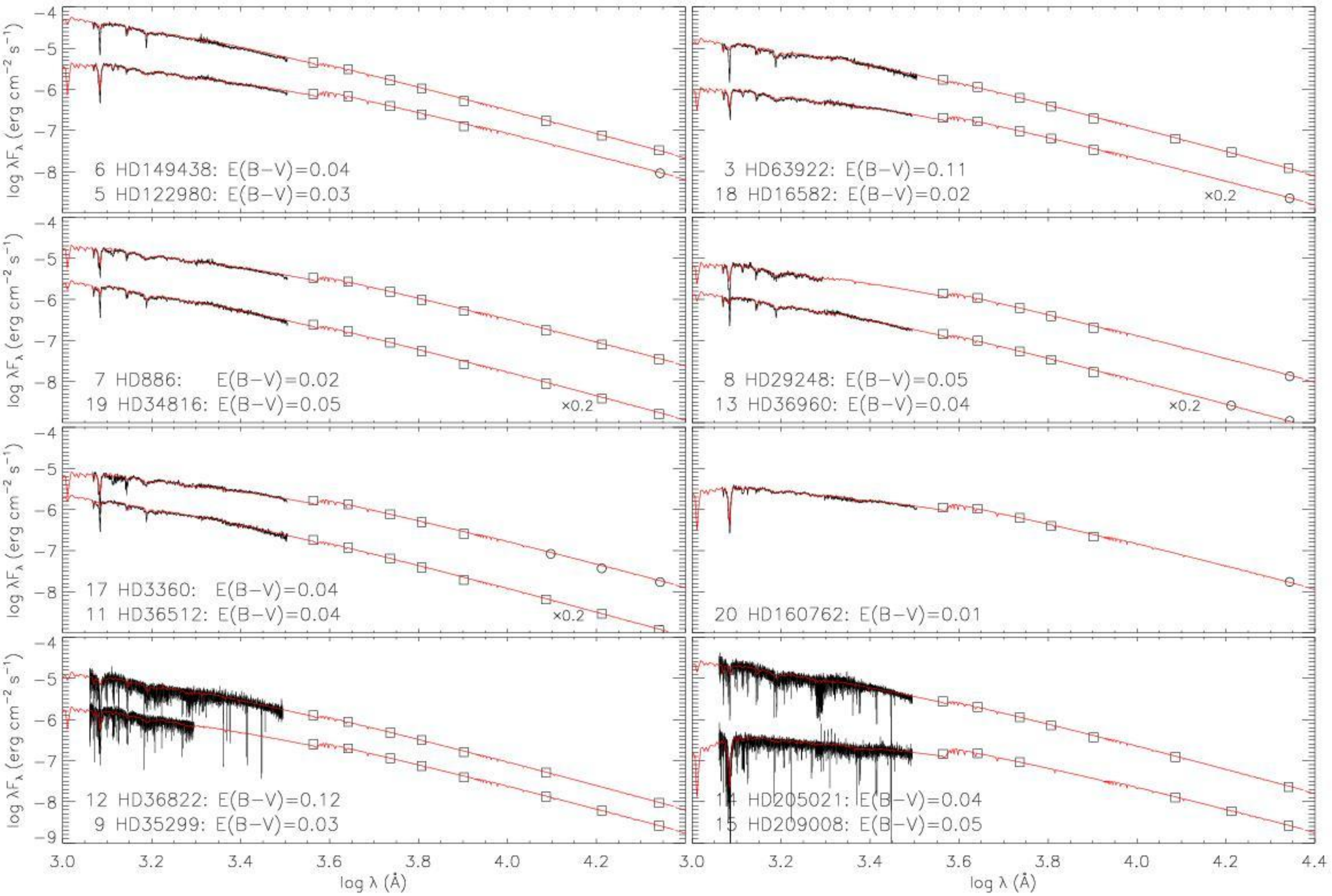
Our work

Przybilla, Firnstein, Nieva, Meynet, Maeder (2010, A&A)



400
350
300
250
200
150
100
d_{HIP} (pc)
12
4
9
19
14
8
18
10
17
5
6
20
7
Difference (%)
40
20
0
−20
−40
100
150
200
250
300
350
400
d_{spec} (pc)


Input
T_eff, log g
[M/H], ξ, y, ε(X)
Model Atmosphere
Model Atoms
Non-LTE Spectrum Synthesis
Observations
Quantitative Analysis
Modified
T_eff, log g
[M/H], ξ, y, ε(X)
M = I ?
no
yes
Output
T_eff, log g
[M/H], ξ, y, ε(X)



log λF_λ (erg cm^-2 s^-1)
6 HD149438: E(B−V)=0.04
5 HD122980: E(B−V)=0.03
3 HD63922: E(B−V)=0.11
18 HD16582: E(B−V)=0.02
×0.2
7 HD886: E(B−V)=0.02
19 HD34816: E(B−V)=0.05
×0.2
8 HD29248: E(B−V)=0.05
13 HD36960: E(B−V)=0.04
×0.2
17 HD3360: E(B−V)=0.04
11 HD36512: E(B−V)=0.04
×0.2
20 HD160762: E(B−V)=0.01
12 HD36822: E(B−V)=0.12
9 HD35299: E(B−V)=0.03
14 HD205021: E(B−V)=0.04
15 HD209008: E(B−V)=0.05
log λ (Å)

	HD	T_{eff} 10^3 K	H	He I	He II	C II	C III	C IV	O I	O II	Ne I	Ne II	Si III	Si IV	Fe II	Fe III
11	36512	33.4	•	•	•	•	•	•		•		•	•	•		•
6	149438	32.0	•	•	•	•	•	•		•	•	•	•	•		•
3	63922	31.2	•	•	•	•	•	•		•		•	•	•		•
19	34816	30.4	•	•	•	•	•			•	•	•	•	•		•
12	36822	30.0	•	•	•	•	•	•		•	•	•	•	•		•
13	36960	29.0	•	•	•	•	•			•	•	•	•	•		•
1	36591	27.0	•	•	•	•	•			•	•	•	•	•		•
14	205021	27.0	•	•	•	•	•			•	•	•	•	•		•
2	61068	26.3	•	•	•	•	•			•	•	•	•	•		•
9	35299	23.5	•	•		•	•		•	•	•	•	•	•	•	•
16	216916	23.0	•	•		•	•		•	•	•	•	•	•	•	•
4	74575	22.9	•	•		•	•		•	•	•	•	•	•	•	•
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17	3360	20.7	•	•		•	•		•	•	•		•	•	•	•
20	160762	17.5	•	•		•			•	•	•		•		•	•
15	209008	15.8	•	•		•			•	•	•		•		•	•

Fits to all modeled lines