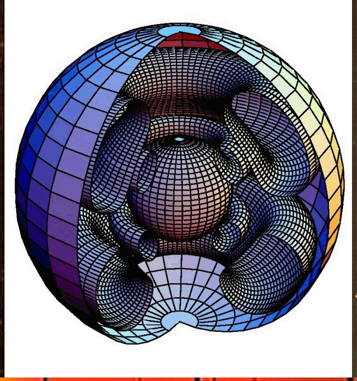
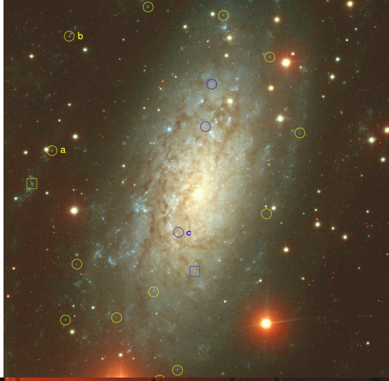
$$n_i \sum_{j\neq i}(R_{ij}+C_{ij}) = \sum_{j\neq i} n_j(R_{ji}+C_{ji})$$

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





Quantitative Spectroscopy of Early B-Type Stars: the Impact of High-Quality Atomic Data

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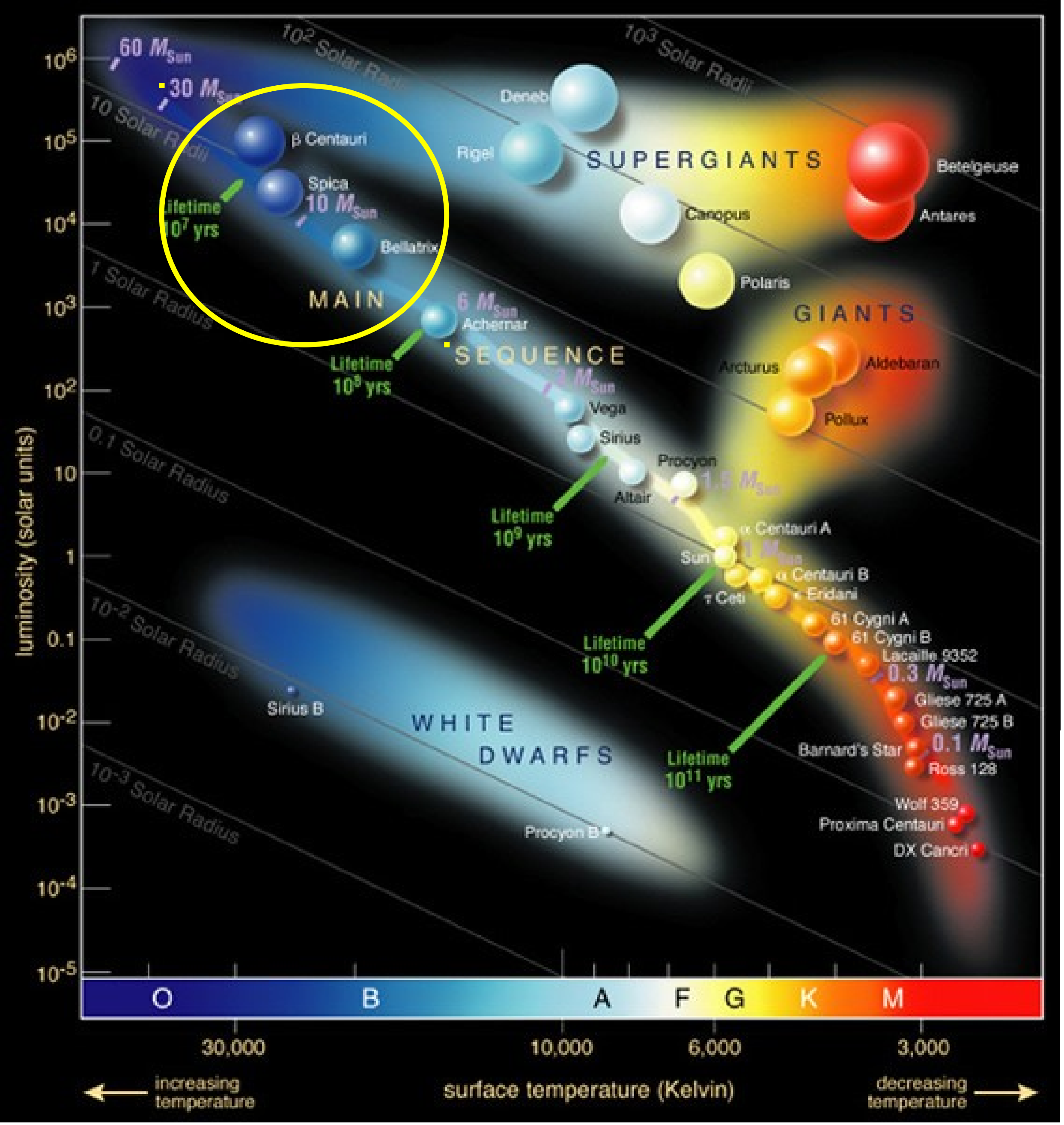


Early B-type Stars

(Main Sequence)

- massive

  M: ~ 8 ... 18 $M_{\odot}$

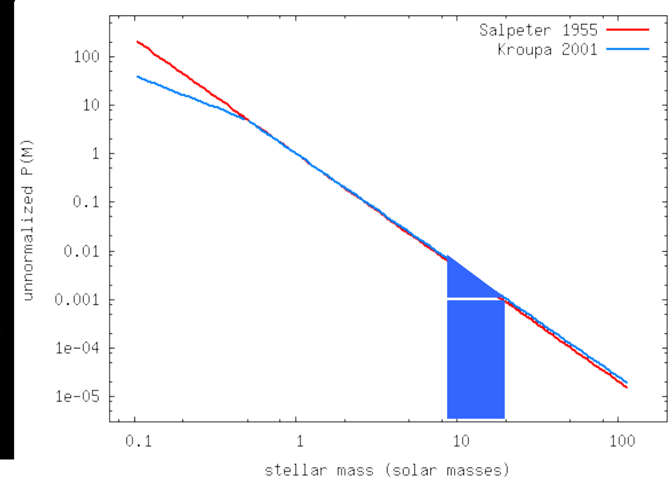
- hot

  T_{eff}: ~ 16000 ... 32000 K

- luminous

  L: ~ several 10^3 ...10^4 $L_{\odot}$

- „numerous“



Abundance Standards: Solar vs. Cosmic

Sun

- 4.56 Gyr old
- potentially far from Galactic birth radius
- highly detailed observations
- complex atmosphere: convection (3D), chromosphere
- overall small departures from LTE
- diffusion: photospheric vs. bulk composition
- **laboratory studies of CI chondrites feasible**
- one object: typical or special?

Early B-type stars

- young: ~ 10 Myr
- close to parental star-formation region
- (bright) point sources
- simple atmospheres: radiative equilibrium (1D)
- line spectra: ubiquous non-LTE effects
- weak stellar winds: no diffusion, no impact on atmospheric structure
- no dust depletion unlike in HII regions & the diffuse ISM
- pollution with CNO-cycled material possible
- several ten objects in solar neighbourhood (d<500pc) tracing Gould`s belt

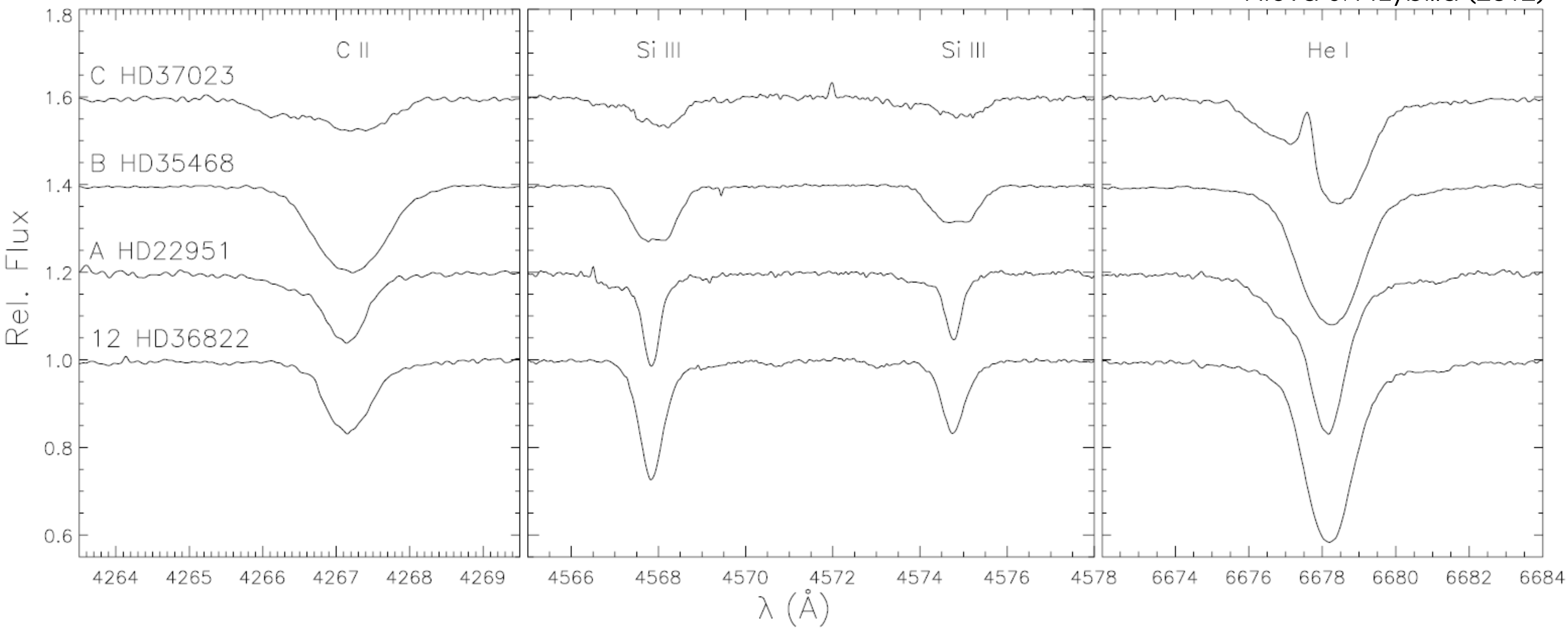
- both subject to intense study

Sample/Observational bias

currently: ~50 usable objects, many more problematic for analysis
- identification of problematic objects before analysis starts:

- binarity: impact of second light

Nieva & Przybilla (2012)



- Be stars: impact of light from disk on photospheric spectrum: veiling
- CP phenomenon: rare among early B-type stars
  but: He-strong, He-weak stars

Codes

- LTE model atmospheres:
  ATLAS9 (Kurucz)

- radiative transfer & statistical equilibrium (trace species approx.)
  DETAIL (Giddings, Butler + many recent updates/extensions)

- formal solution:
  SURFACE (Giddings, Butler + many recent updates/extensions)

→ hybrid non-LTE: **ADS**

(Restricted) NLTE Problem

Non-Local Thermodynamic Equilibrium

- transfer equation

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

- statistical equilibrium:

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

- radiative rates:

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

non-local

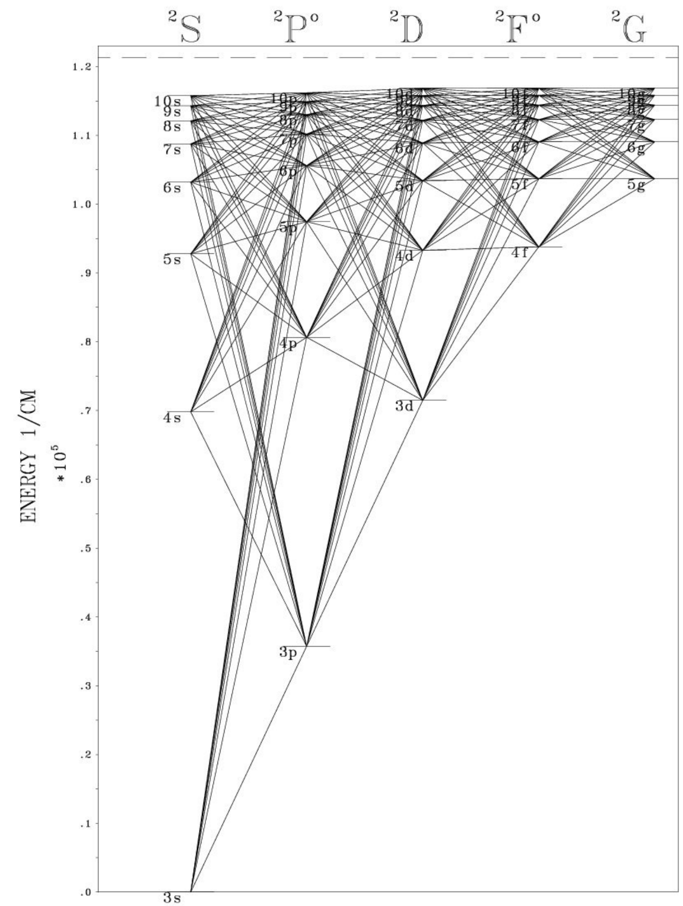
- collisional rates:

$$C_{ij} = n_e \int \sigma_{ij}(v) f(v) v \, \mathrm{d}v$$

local

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

→ model atoms



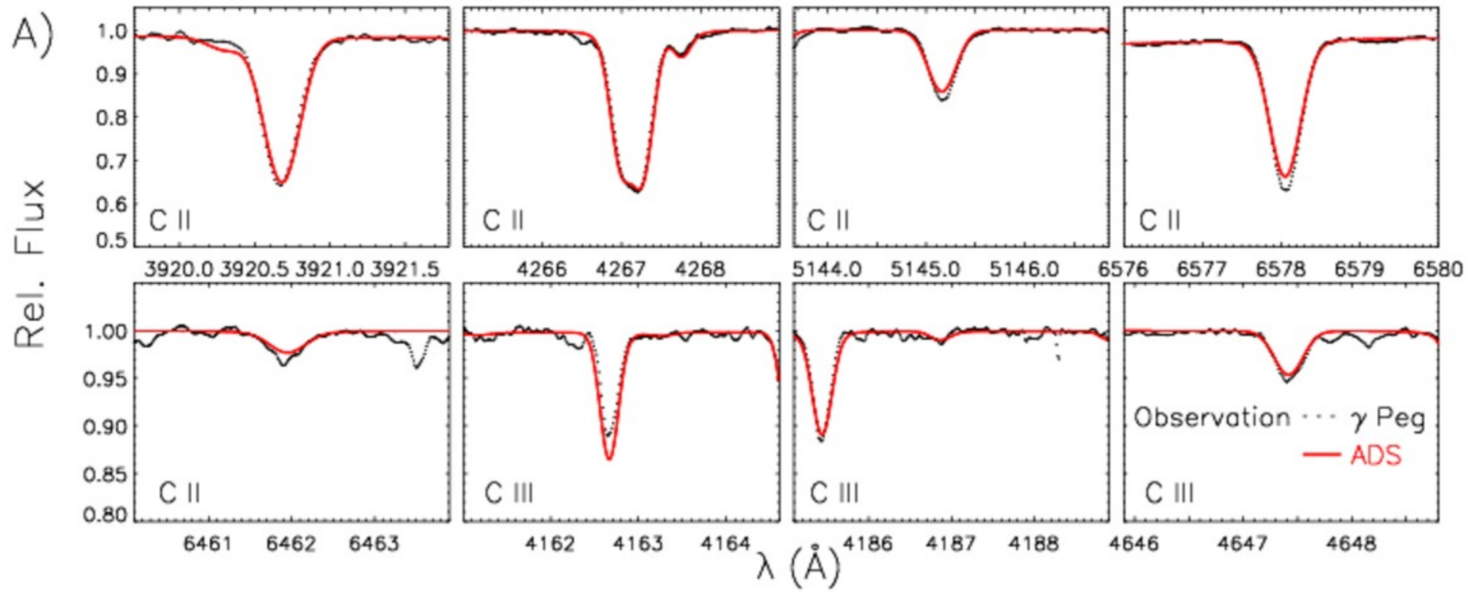
MgII: Przybilla et al. (2001)

huge amounts of atomic data: OP/IRON Project & own

formal solution: experimental gf & **MCHF/MCDHF**

Consequences for models

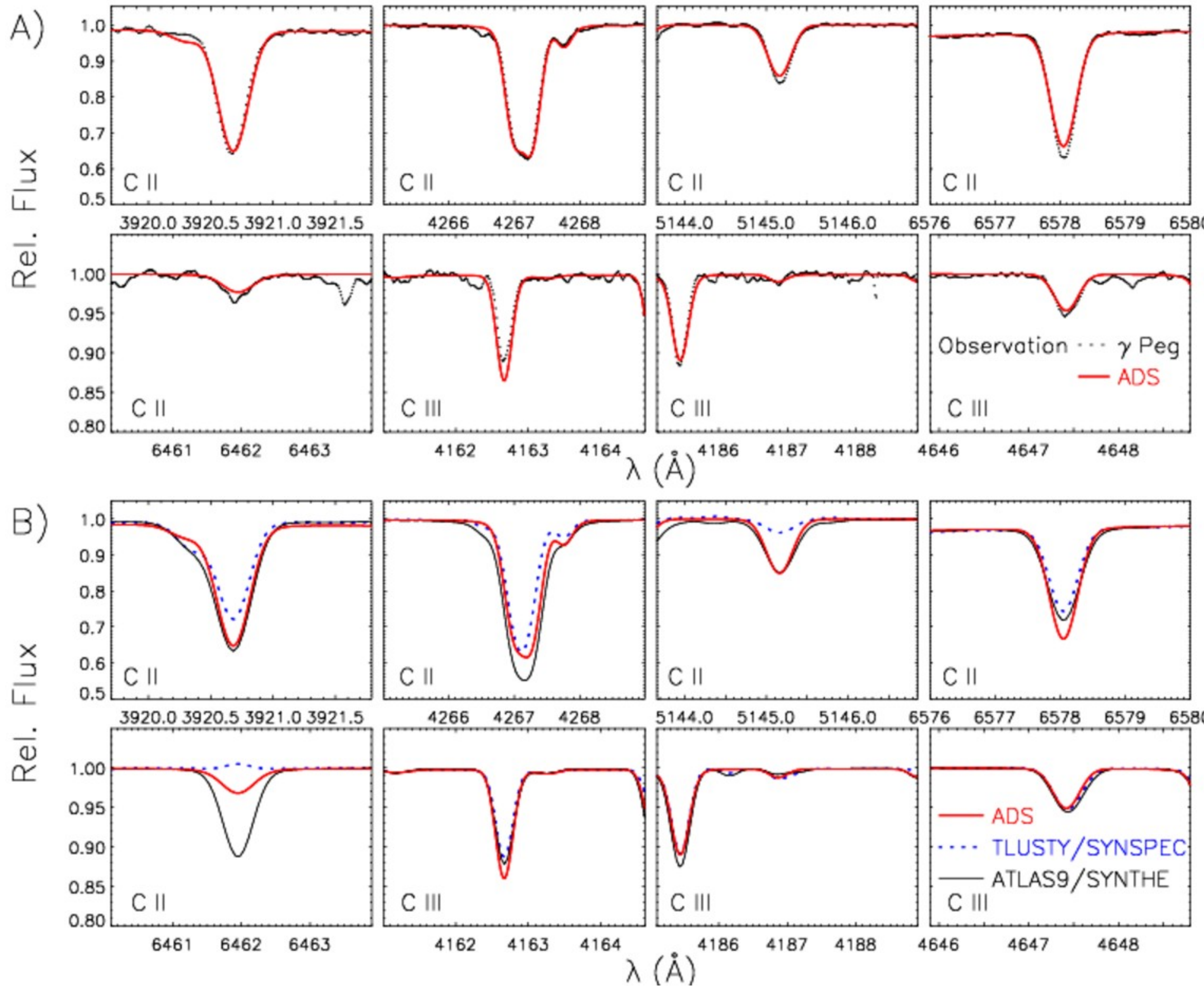
Przybilla, Nieva & Butler (2011)



fit to observation: our model, using model atom of Nieva & Przybilla (2008)

Consequences for models

Przybilla, Nieva & Butler (2011)



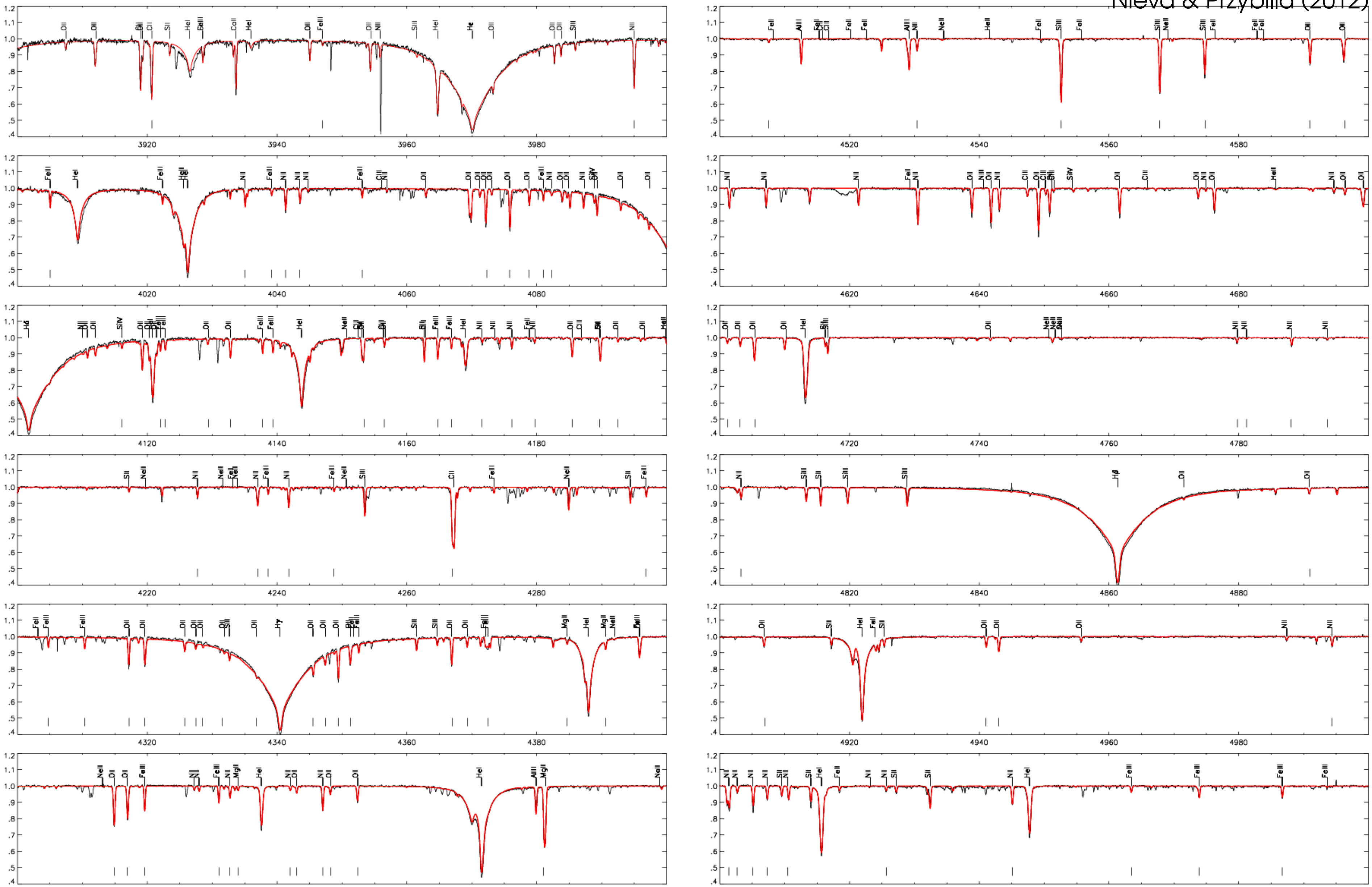
fit to observation: our model, using model atom of Nieva & Przybilla (2008)

model comparison

→ **input atomic data crucial**

Quantitative Spectroscopy with Little Systematics

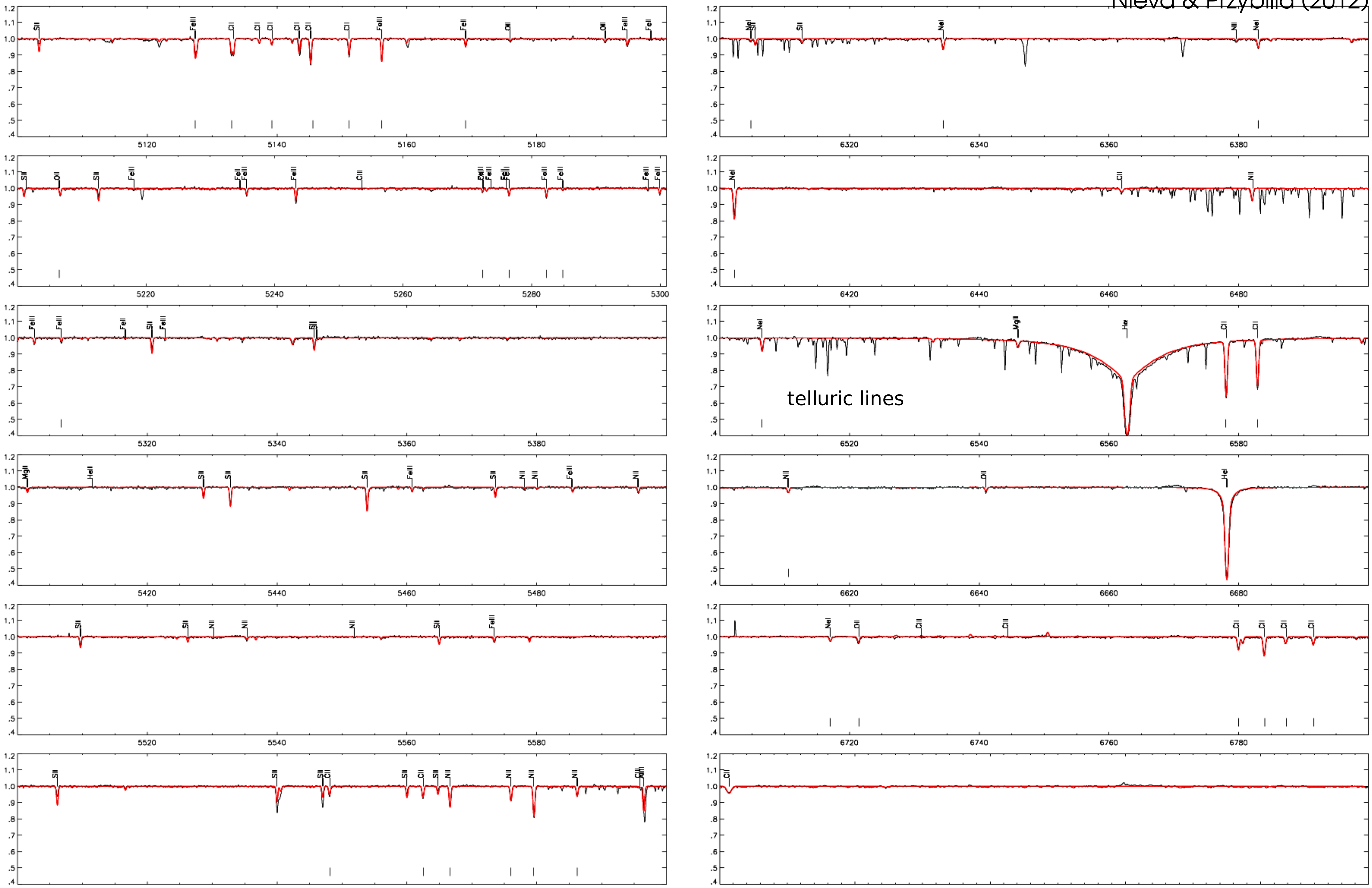
Nieva & Przybilla (2012)



- ~10^5 lines: ~60 elements, 200+ ionization stages
- OB stars: complete spectrum synthesis in visual & near-IR, up to ~95% in NLTE

Quantitative Spectroscopy with Little Systematics

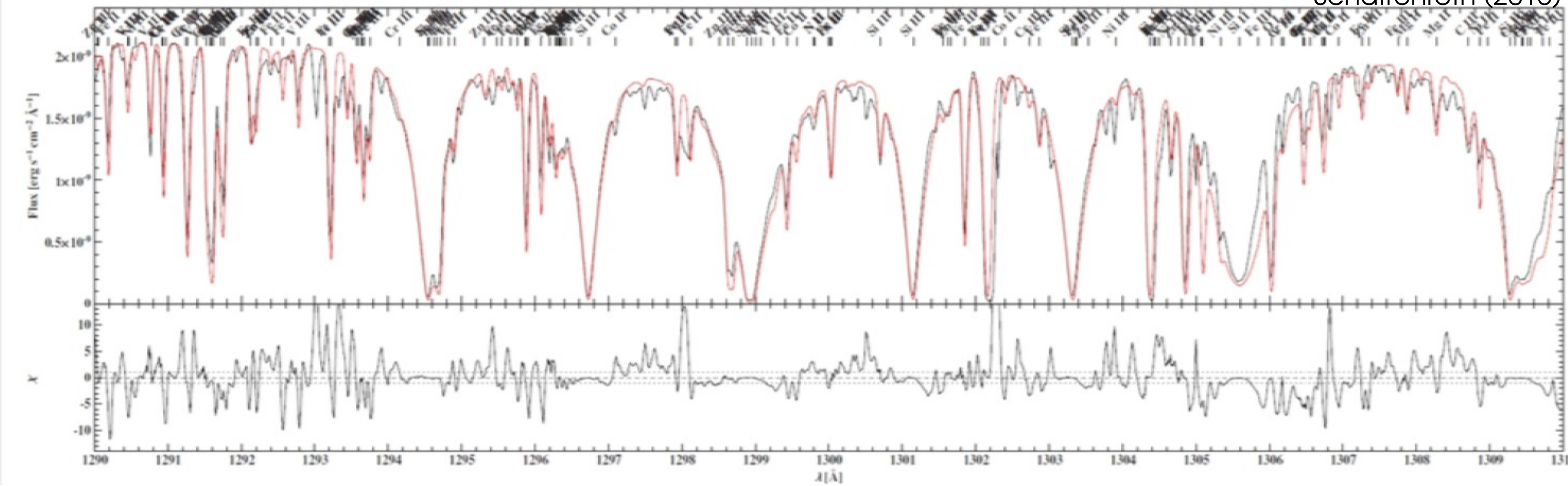
Nieva & Przybilla (2012)

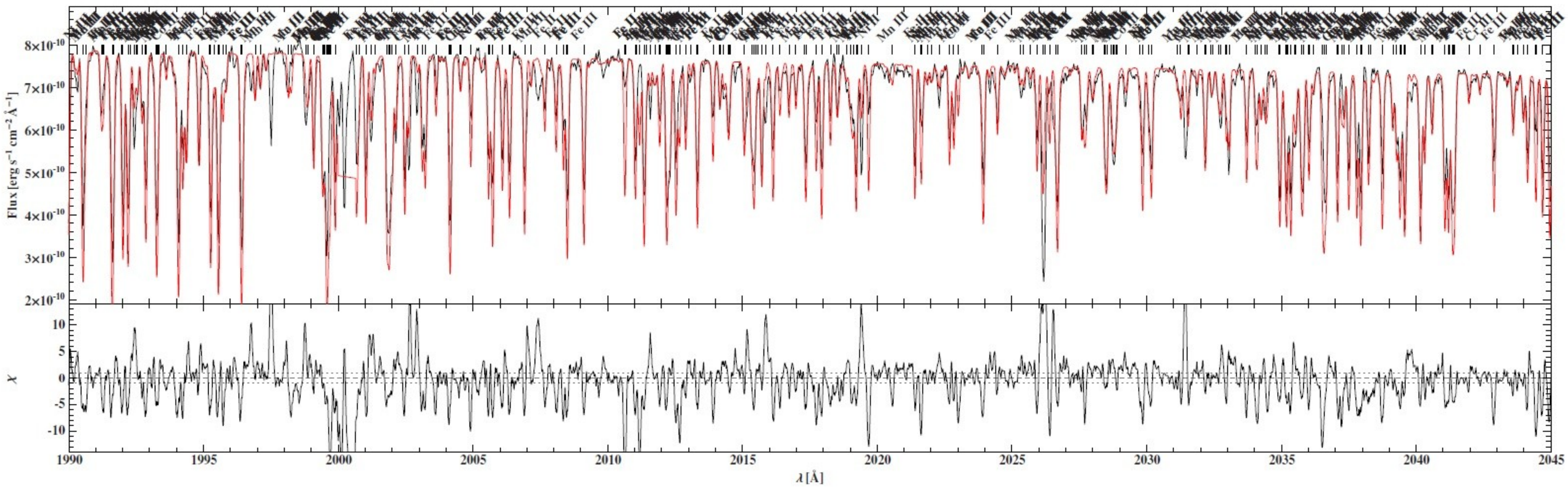


- ~10^5 lines: ~60 elements, 200+ ionization stages
- OB stars: complete spectrum synthesis in visual & near-IR, up to ~95% in NLTE

UV Spectral Range with HST/STIS

Schaffenroth (2015)

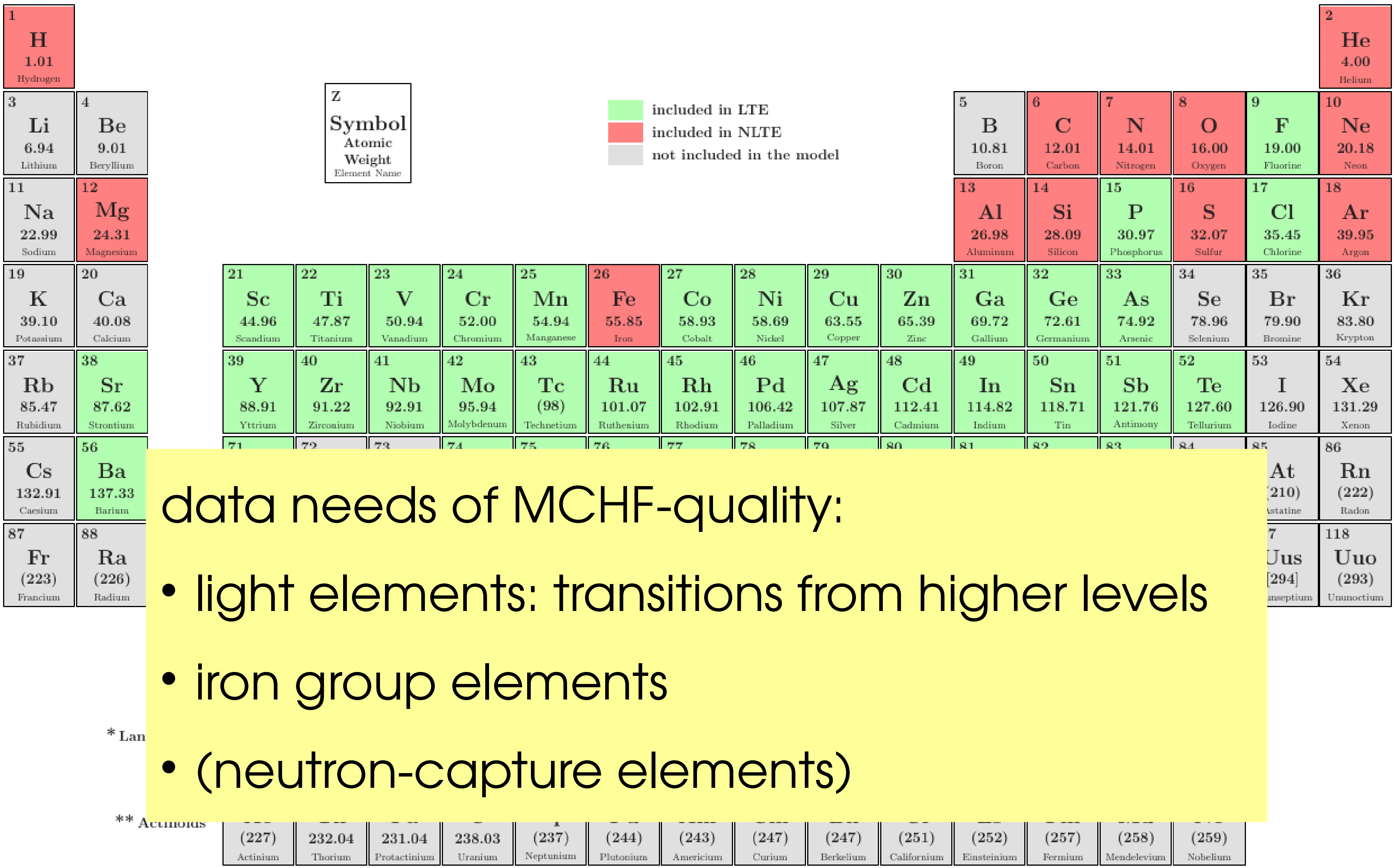




- ~10^5 lines: ~60 elements, 200+ ionization stages
- OB stars: UV ~50% of lines in NLTE, rest LTE – **atomic data missing**, high-quality observations

Extending the elemental coverage in the UV

Schaffenroth (2015)



data needs of MCHF-quality:

- light elements: transitions from higher levels
- iron group elements
- (neutron-capture elements)

Quantitative Spectroscopy using NLTE Diagnostics

using **high-quality spectra**,
robust analysis methodology &
comprehensive model atoms

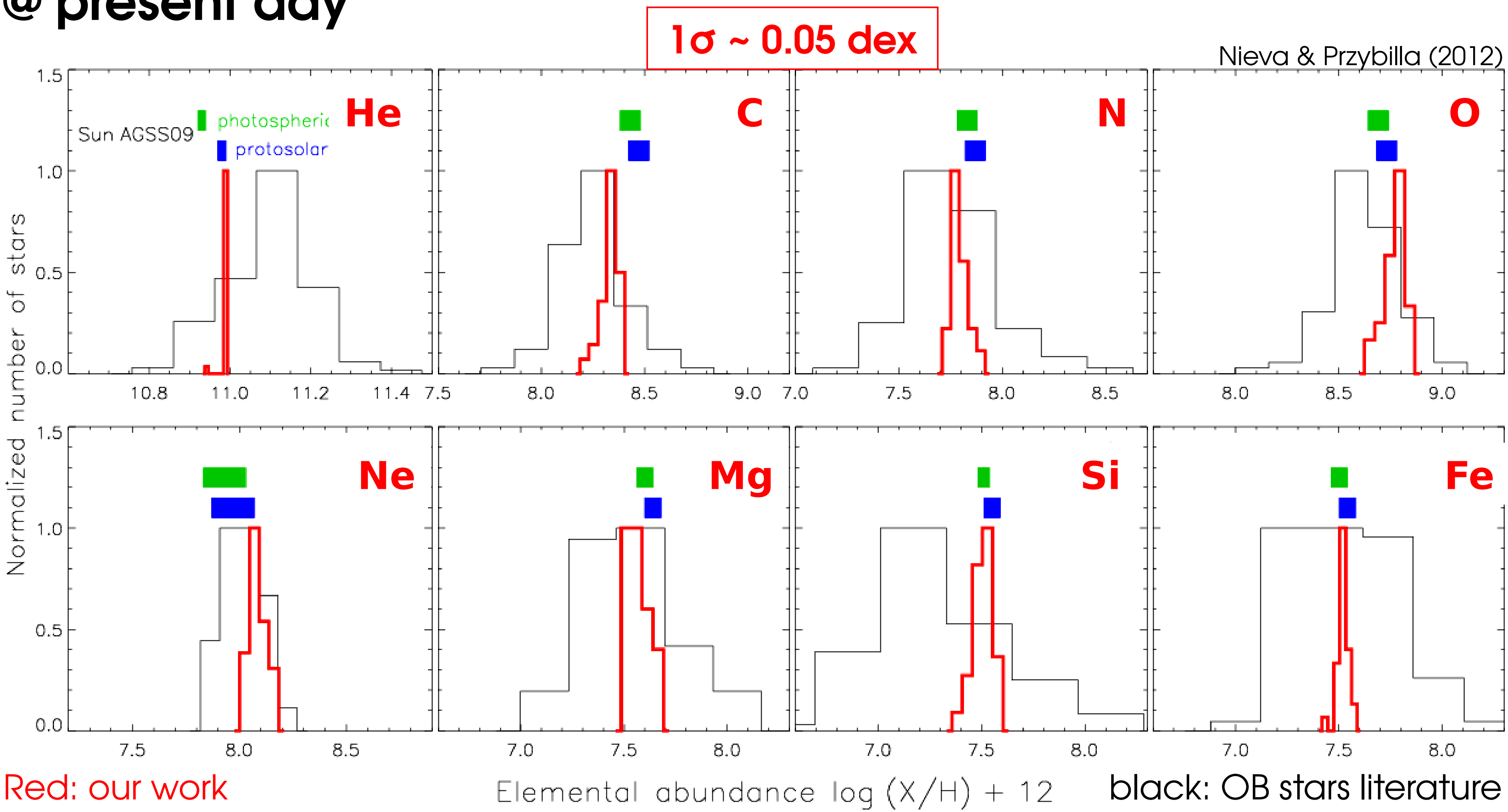
getting rid of systematics !!!

- ionization equilibria → T_{eff}
  elements: e.g. He I/II, C II/III/IV, O I/II, Ne I/II, Si II/III/IV, S II/III, Fe II/III
  $\Delta T_{eff} / T_{eff}$ ~ 1%
- Stark broadened hydrogen lines → log g
  Δ log g ~ 0.05…0.10 (cgs)
- microturbulence, helium abundance, metallicity

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

- abundances: **Δlogε ~ 0.05...0.10 dex** (1σ-stat.) usually: factor ~2
  Δlogε ~ 0.07...0.12 dex (1σ-sys.) ???

Chemical composition of the solar neighborhood @ present day



Chemical homogeneity → cosmic abundance standard

X=0.715 Y=0.271 **Z=0.014**

universität innsbruck

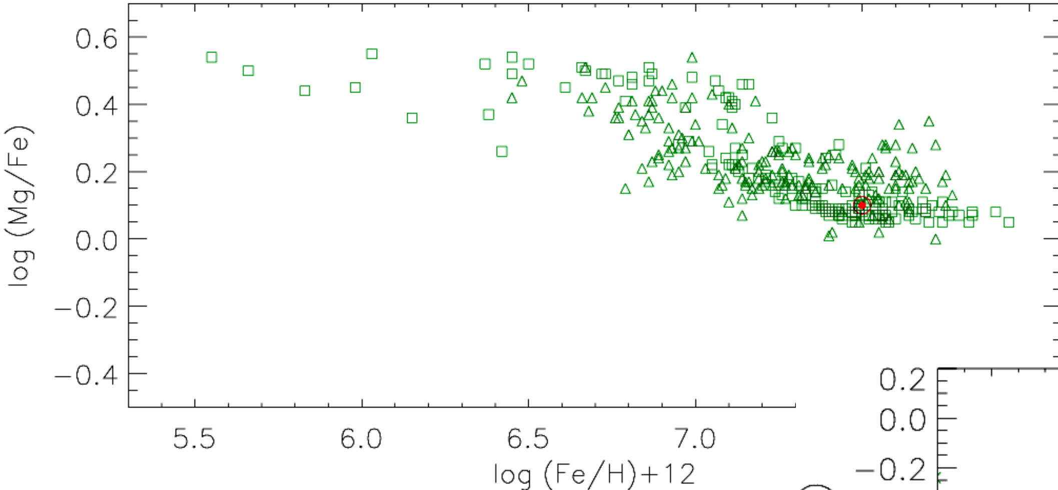
Comparison CAS & Solar Standard

Element	CAS	Sun (photospheric) Asplund et al. (2009)	Δ(CAS-⊙)
C	8.33±0.04	8.43±0.05	-0.10
N	7.79±0.04	7.83±0.05	-0.04
O	8.76±0.05	8.69±0.05	0.07
Ne	8.09±0.05	(7.93±0.10)	0.16
Mg	7.56±0.05	7.60±0.04	-0.04
Al (prelim.)	6.28±0.07	6.45±0.03	-0.17
Si	7.50±0.05	7.51±0.03	-0.01
S (prelim.)	7.16±0.06	7.12±0.03	0.04
Ar (prelim.)	6.50±0.06	(6.40±0.13)	0.10
Fe	7.52±0.03	7.50±0.04	0.02

- Sun a bit more metal rich according to Caffau et al. (2010)
- confirmation of CAS from a few BA-type supergiants
- **surprising good agreement ... suspicious**
- Protosun is even more metal rich

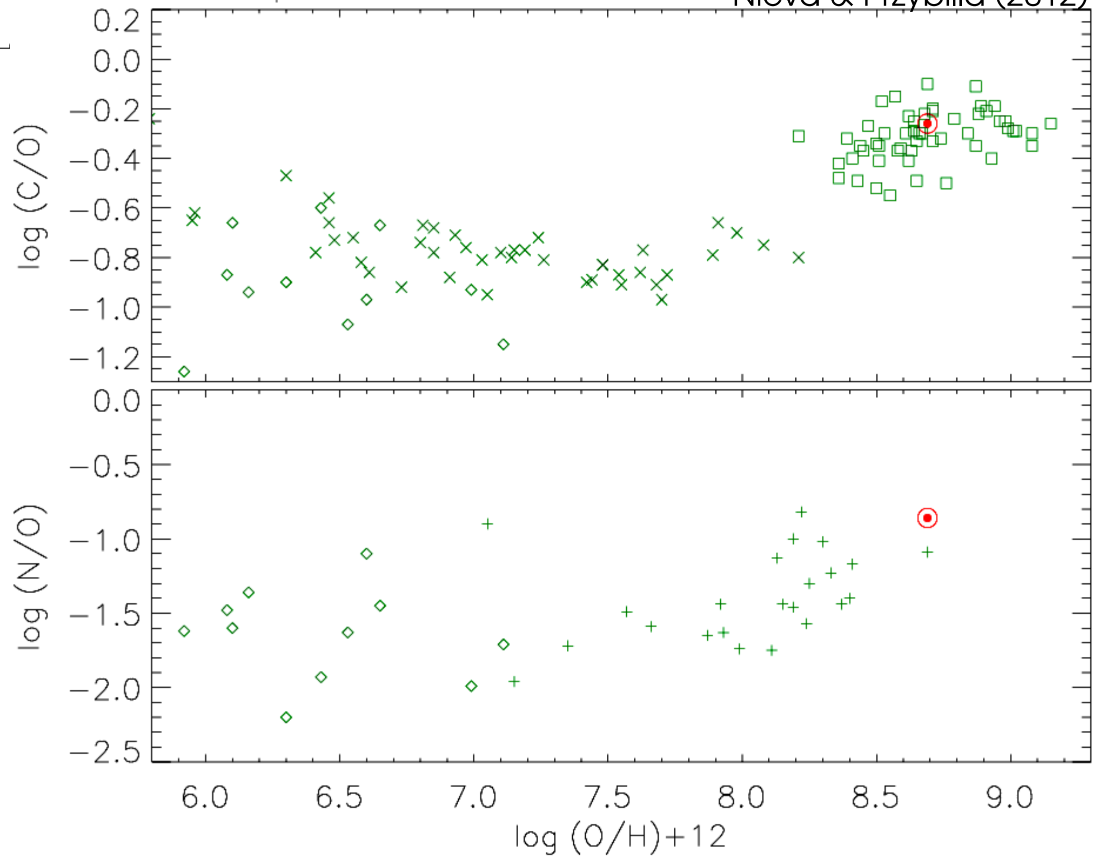
... no GCE over past 4.56 Gyrs ?

Genesis of Heavy Elements over Cosmic History



α-enhancement:
delay of **SN Ia** w.r.t. **SNII**

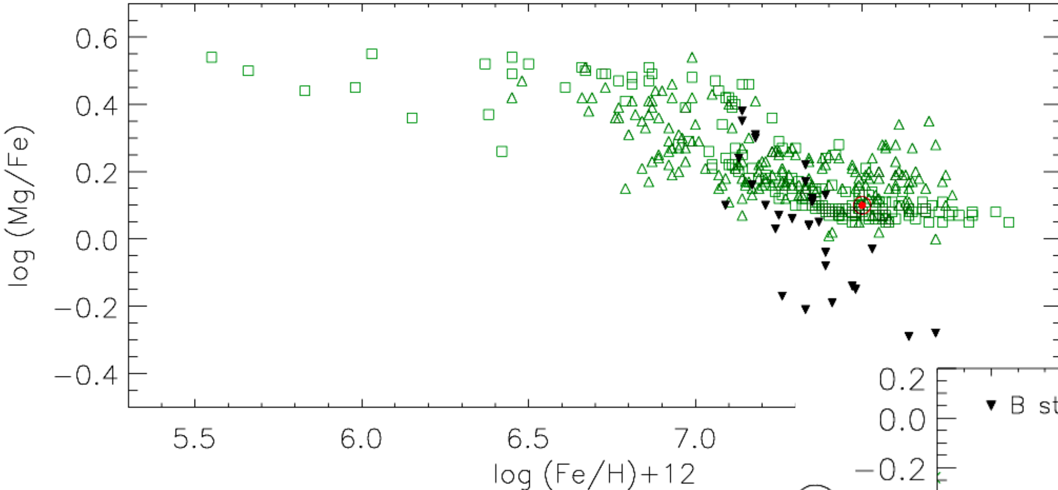
Nieva & Przybilla (2012)



- **solar-type stars** (long-lived): constraints on Galactochemical evolution over time

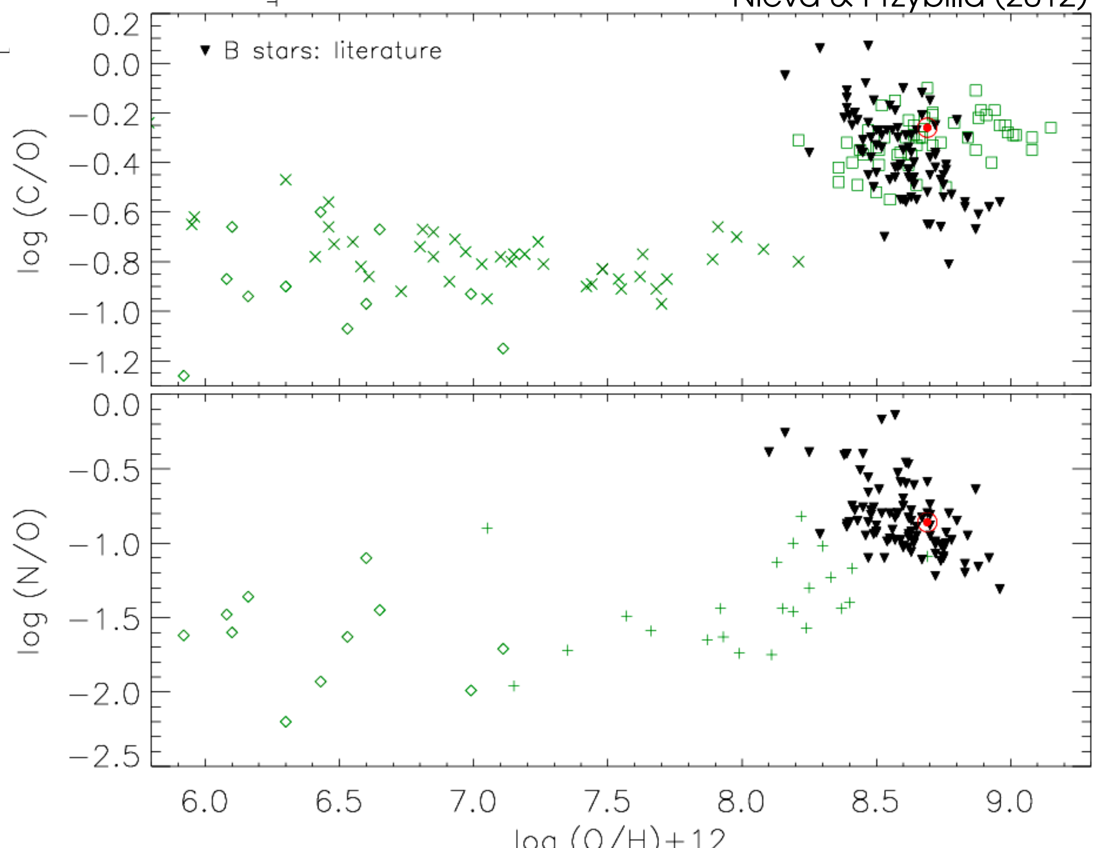
delayed CN-production in intermediate-mass stars

Genesis of Heavy Elements over Cosmic History



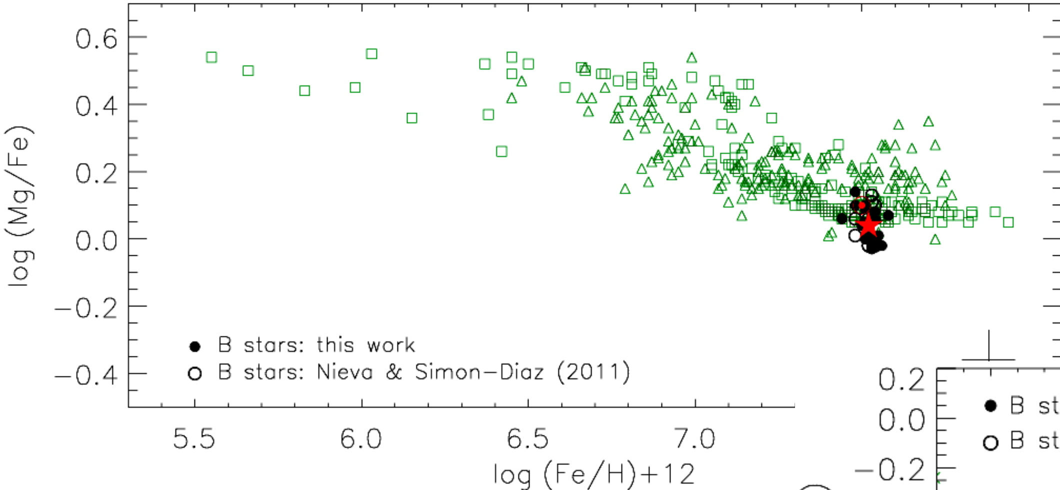
- comparison with literature on early B stars

Nieva & Przybilla (2012)



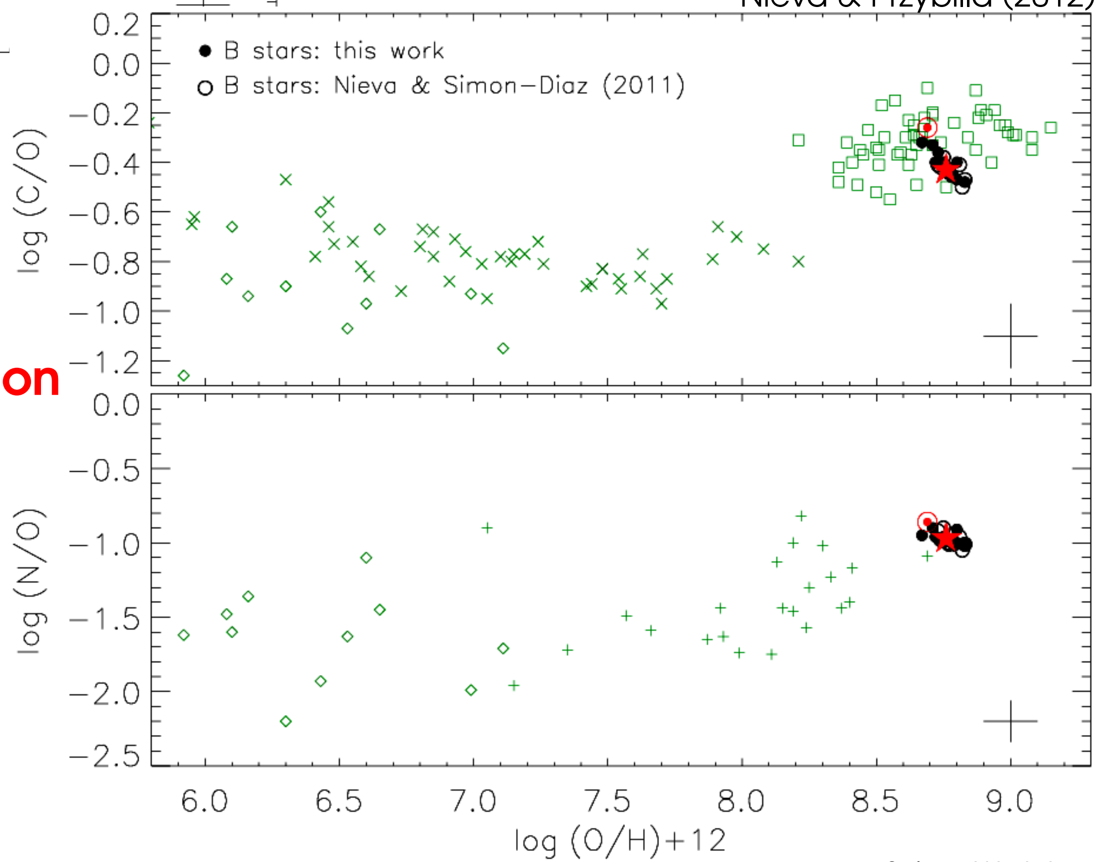
- **early B-type stars** (short lived): boundary values @present time

Genesis of Heavy Elements over Cosmic History



- comparison with our data on early B stars

Nieva & Przybilla (2012)



tight constraints !

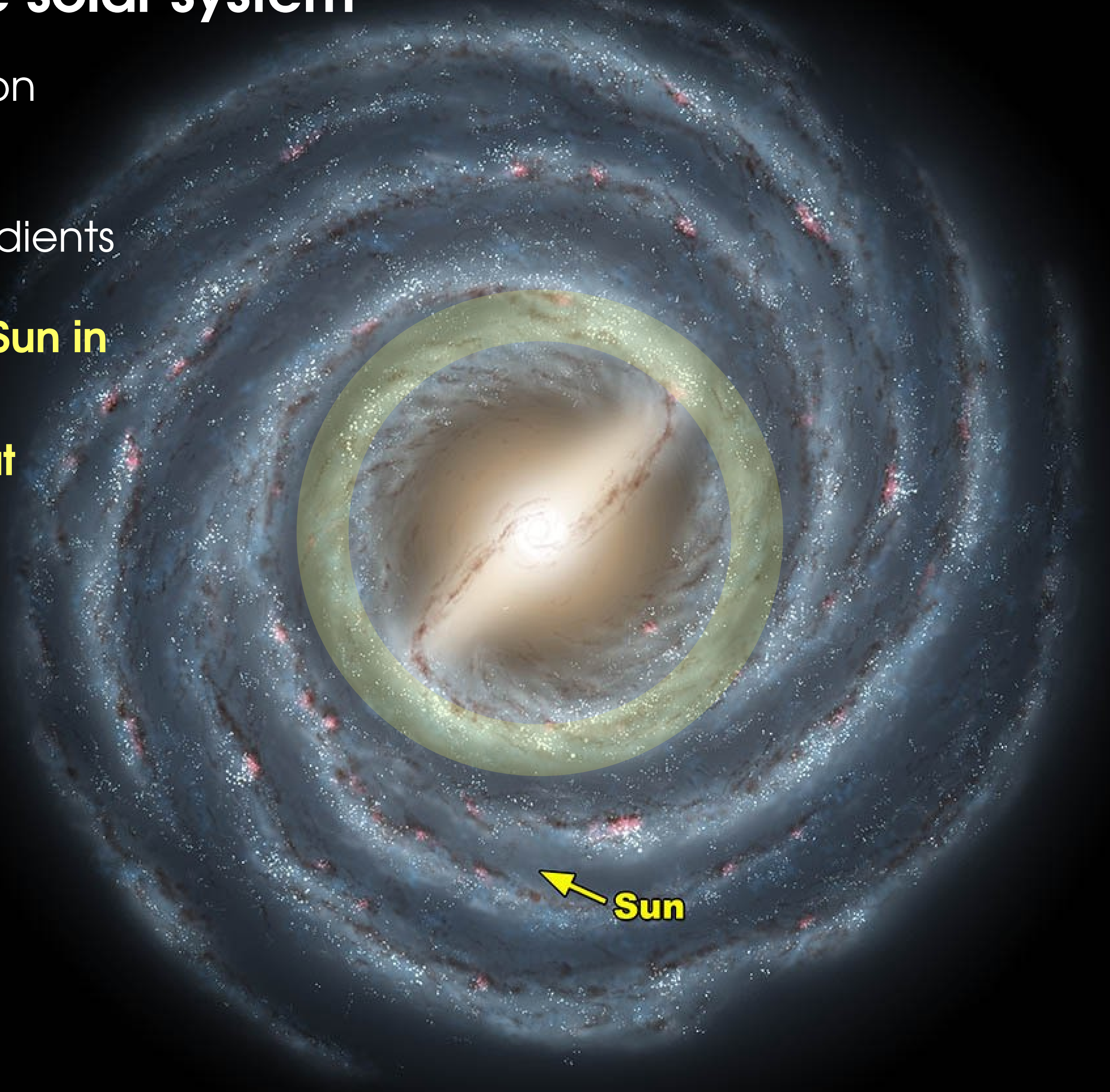
present-day chemical composition of solar neighbourhood at odds with solar composition

Place of birth of the solar system

Galactochemical evolution
over cosmic history
&
Galactic abundance gradients

→ **radial migration of Sun in Milky Way disk**

birth radius of Sun at R_g~5-6 kpc



Summary

- early B-type stars excellent probes for spatial distribution of chemical abundances @ present day

- early B-stars in solar neighbourhood chemically hogeneous

  → **C**osmic **A**bundance **S**tandard

- similarities and differences with respect to solar standard

  → chemical tagging of the Sun`s birth radius

- many applications, e.g.
  - quantifying depletion onto dust grains in the ISM
  - spatial distribution of elemental abundances in Milky Way
  - initial composition for modelling stellar evolution
  - boundary condition for GCE modelling