The Chemical Composition of the Local Interstellar Dust

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Dear LOC, SOC, colleagues and friends,

my apologies for my absence.

I wish you a very productive IAU GA and SpS12.

@ Norbert: thank you for presenting this!

Fernanda Nieva

Chemical composition of ISM dust

- presence of dust in cold/warm ($<10^4$ K) ISM: reddening & extinction
- chemical composition difficult to be determind directly: lack of spectroscopic indicators

► indirect methods

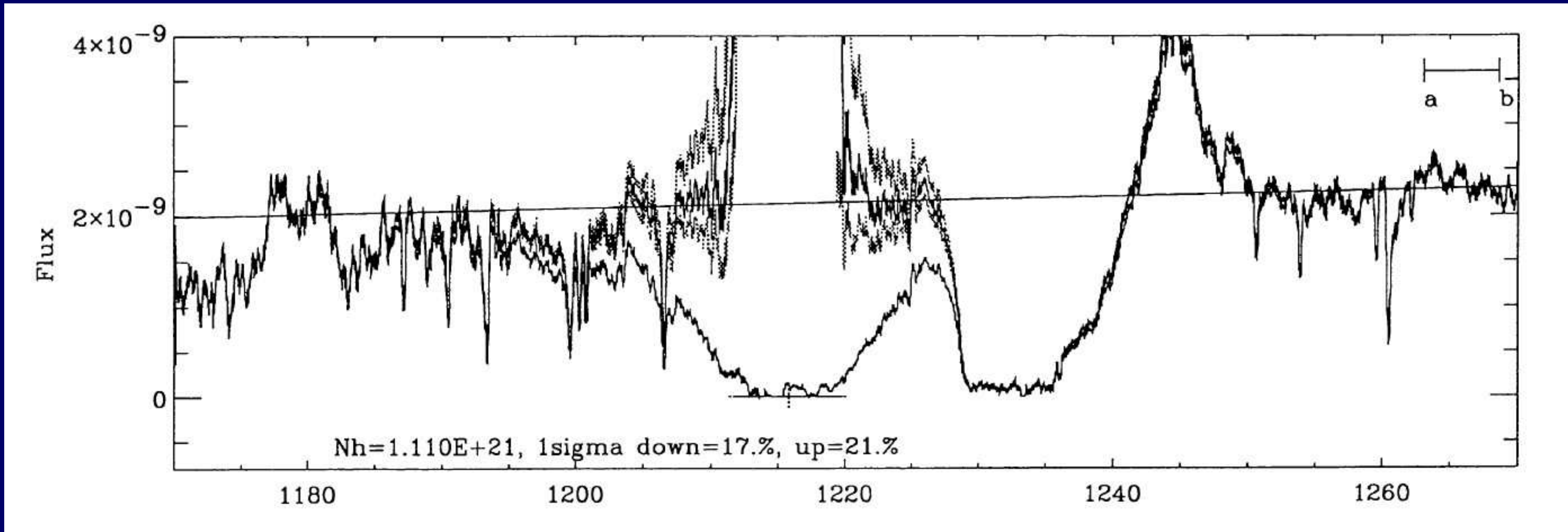
$$\mathbf{(X/H)_{dust} = (X/H)_{ref} - (X/H)_{gas}} \qquad \text{[ppm]}$$

astrophysical notation for elemental abundances:

$$\varepsilon(X) = \log \frac{N(X)}{N(H)} + 12$$

Chemical composition of ISM gas #1

- determination of hydrogen column density: via IS Lyα damping wings
  - ► e.g. continuum reconstruction technique (Bohlin 1975)



Diplas & Savage (1994)

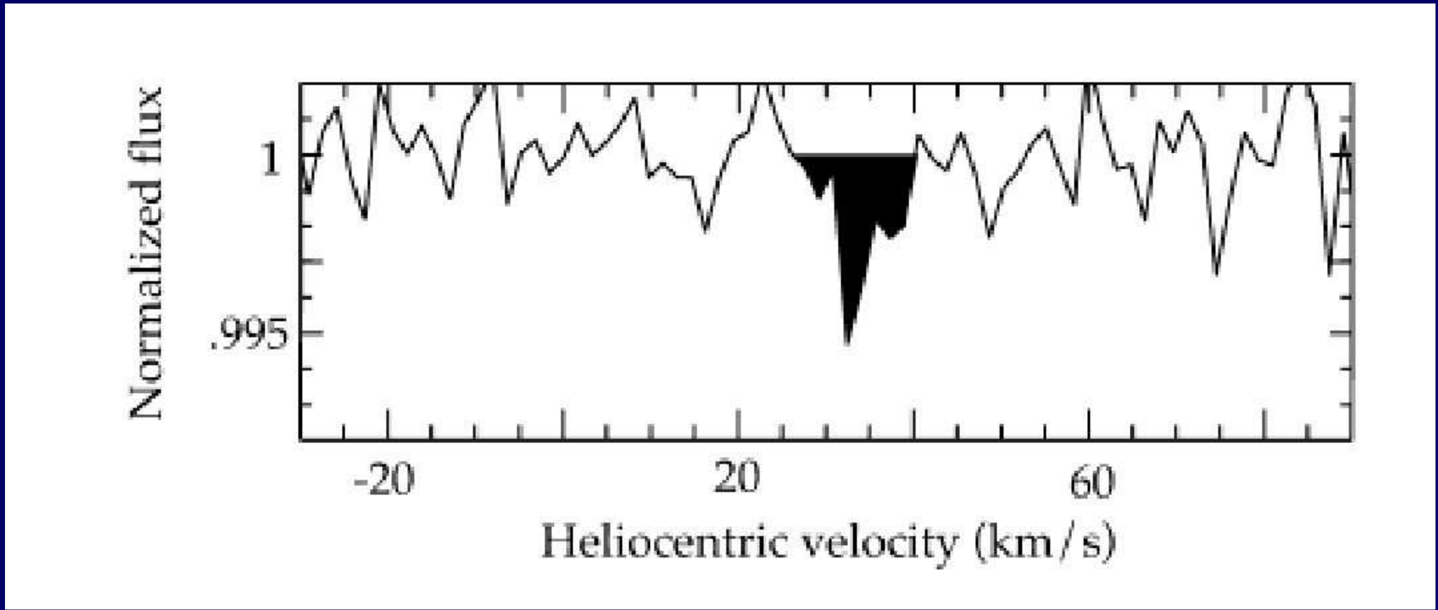
multiplication of flux by $e^{\tau(\lambda)} = e^{\sigma(\lambda)\, N(HI)}$ to correct for damping

$$\sigma(\lambda) = \frac{4.26 \cdot 10^{-20}\ \mathrm{cm}^2}{6.04 \cdot 10^{-10} + (\lambda - \lambda_0)^2} \qquad \lambda_0 = 1215.67\text{Å}$$

hydrogen column density: $N(H) = N(HI) + N(H_2)$

Chemical composition of ISM gas #2

- metal abundances from unsaturated lines from ground states
  e.g. semi-forbidden CII] λ2325Å



HST GHRS: S/N~850 $W_\lambda \sim 0.2$ mÅ

Sofia (2004)

- metal column density via $W_\lambda \sim N(X) \cdot f_{ij} \cdot \sigma(\lambda)$

- chemical homogeneity of gas-phase in solar neighbourhood from many sightlines: C, O, Mg, Si, S, Fe, Zr, Kr, ...

Quest for a Suitable Abundance Reference

abundance reference: Sun, local F & G stars, B stars

Sun: + star that can be studied best
+ independent abundances from different indicators
- 4.56 Gyr old, representative for present-day ISM?

F&G stars: + differential abundances relative to Sun
+ increased number statistics
- difficult age determination
- non-LTE & 3D-corrections (convection) not considered

early B stars: + short-lived: formed out of presen-day ISM
+ simple atmospheric physics
- non-LTE dominated

Sofia & Meyer (2001): recommendation of Sun and F&G stars

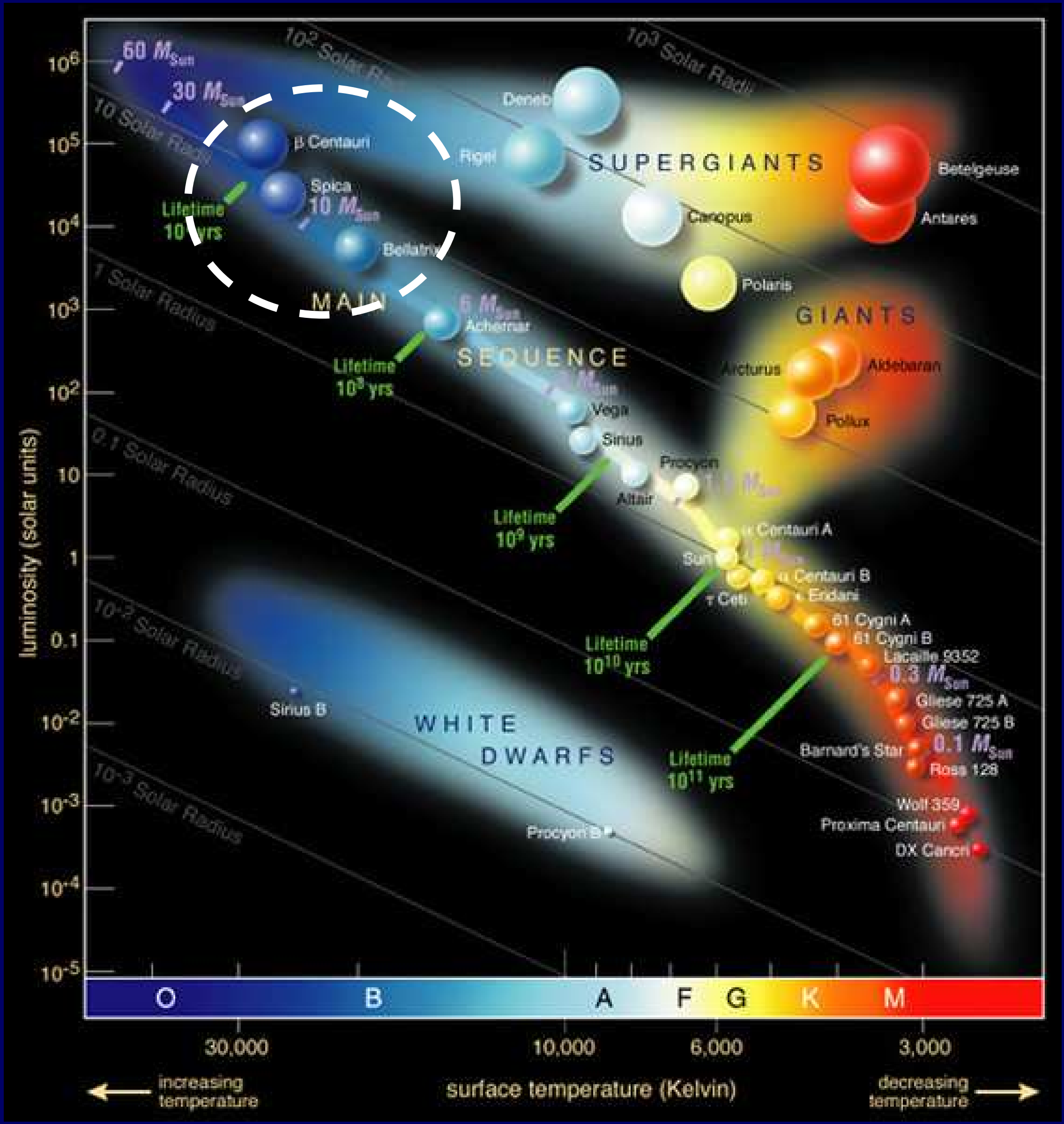
since then: revision of solar abundances, **new work on early B stars**

Early B-type stars

objects considered:
- spectral type: B0 – B2
- LC V – III
  (ZAMS to TAMS)

- masses: 8 ... 18 $M_\odot$
  ► lifetime of up to few tens of Myr
- T_{eff}: 18000 ... 32000 K
- luminosity: 10^4 ... 10^5 $L_\odot$

► constraints on **elemental abundances @ present day**



Non-LTE Diagnostics: Stellar Parameters & Abundances

using **hybrid non-LTE approach, robust analysis methodology** & **comprehensive model atoms**

minimising systematics !

- ionization equilibria ► T_{eff}/log g

  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

  ΔT_{eff} / T_{eff} ~ 1…2% usually: 5…10%

- Stark broadened hydrogen lines ► log g/T_{eff}

  Δ log g ~ 0.05…0.10 (cgs) usually: 0.2

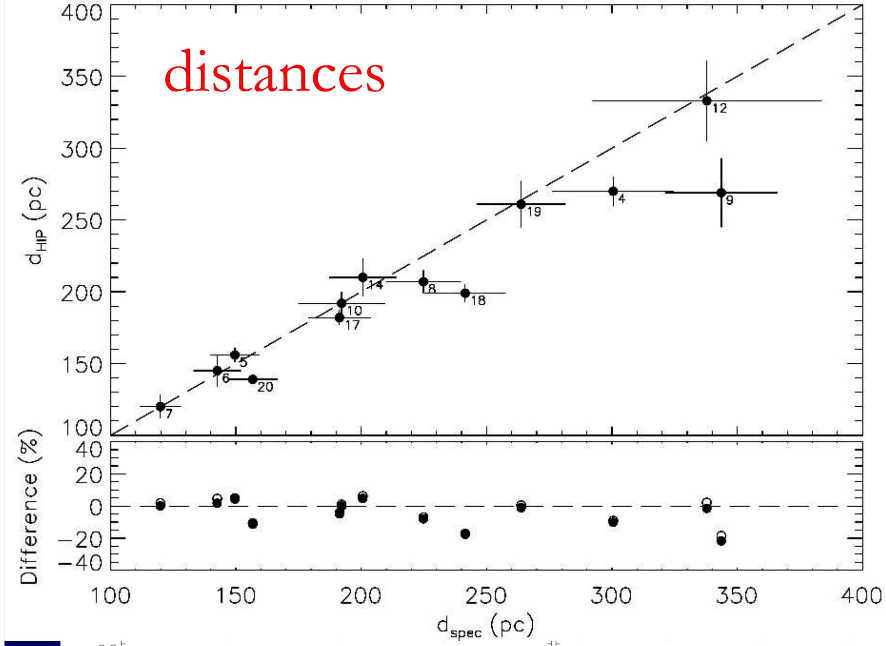
- microturbulence, helium abundance, metallicity

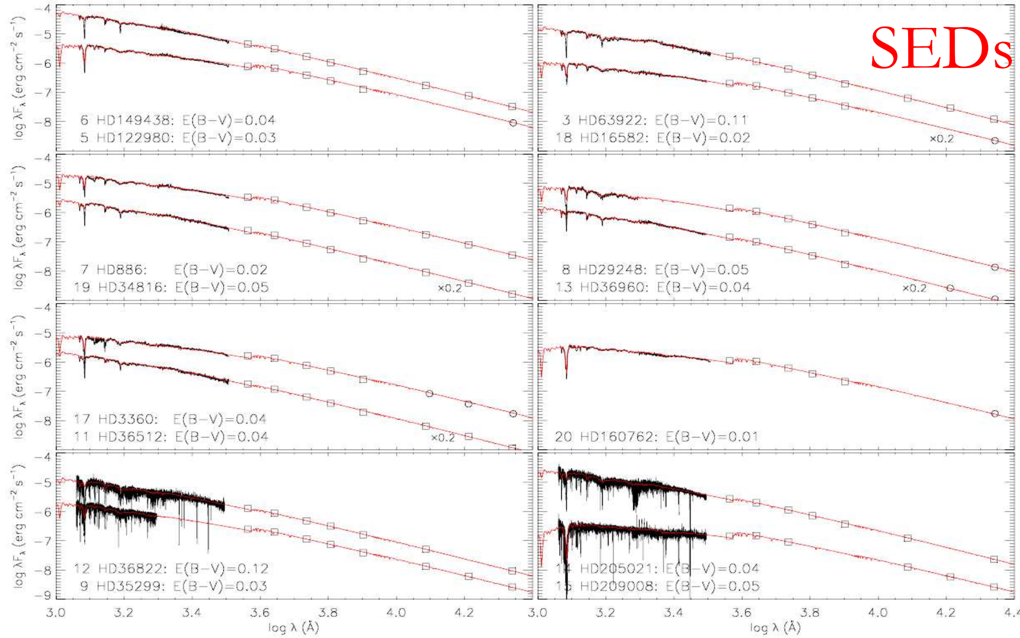
  \+ other constraints, where available: SED's, near-IR, …

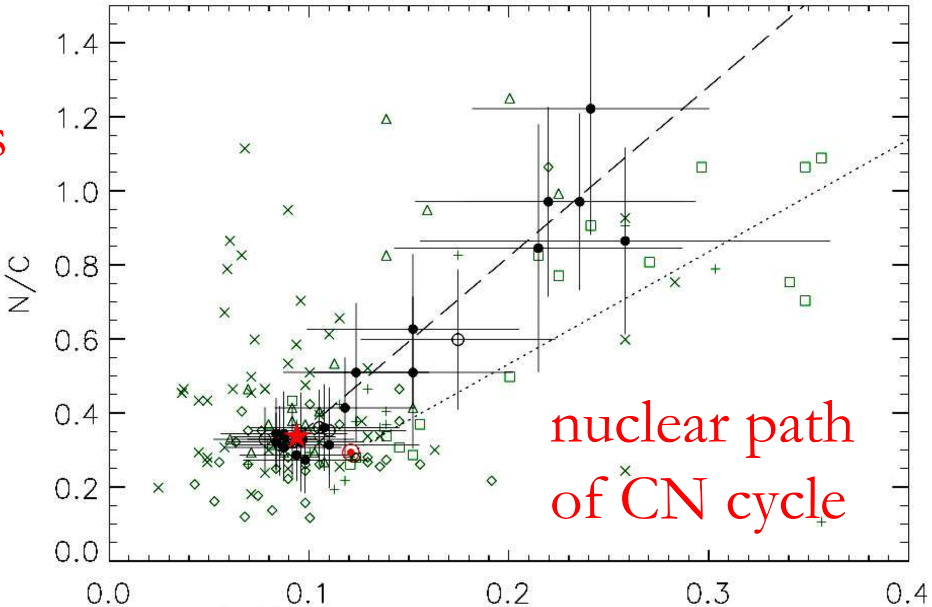
- abundances: **Δloge ~ 0.05...0.10 dex** (1s-stat.) usually: factor ~2

  Δloge ~ 0.07...0.12 dex (1s-sys.) usually: ???

Non-LTE Diagnostics: Tests & Additional Constraints



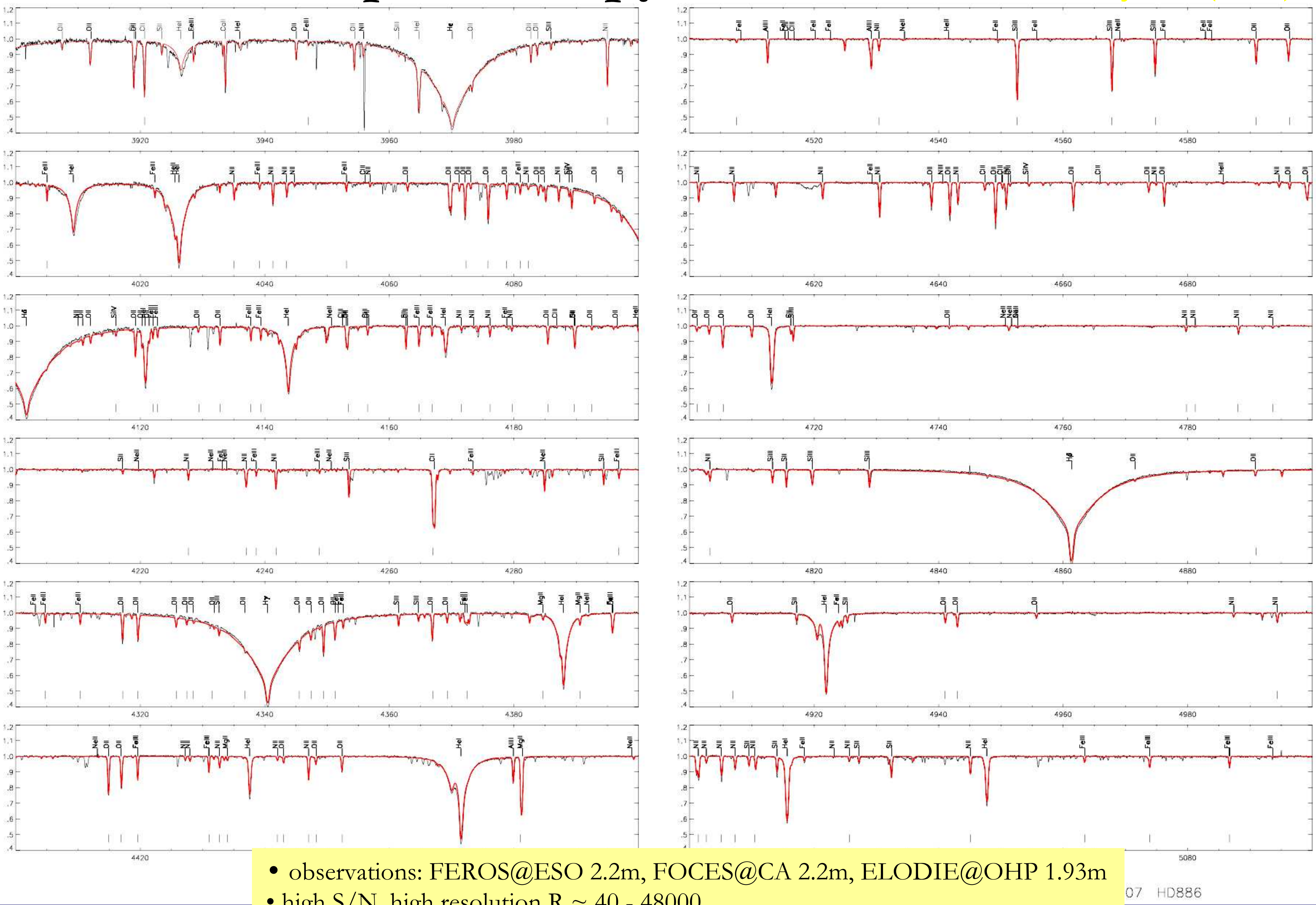




Nieva & Przybilla (2012)

Quantitative Spectroscopy

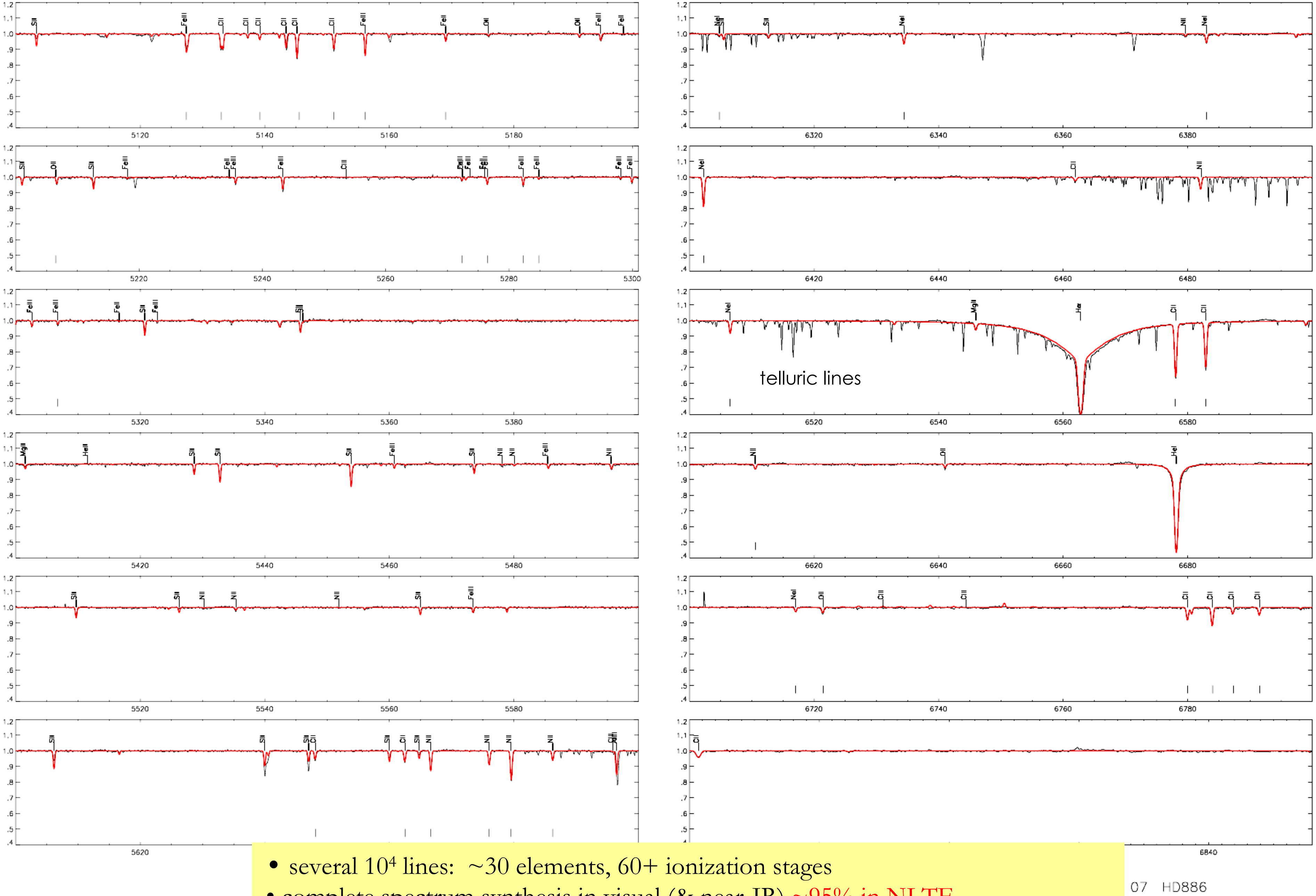
Nieva & Przybilla (2012)



- observations: FEROS@ESO 2.2m, FOCES@CA 2.2m, ELODIE@OHP 1.93m
- high S/N, high resolution R ~ 40 - 48000

Quantitative Spectroscopy

Nieva & Przybilla (2012)



- several 10^4 lines: ~30 elements, 60+ ionization stages
- complete spectrum synthesis in visual (& near-IR) ~95% in NLTE

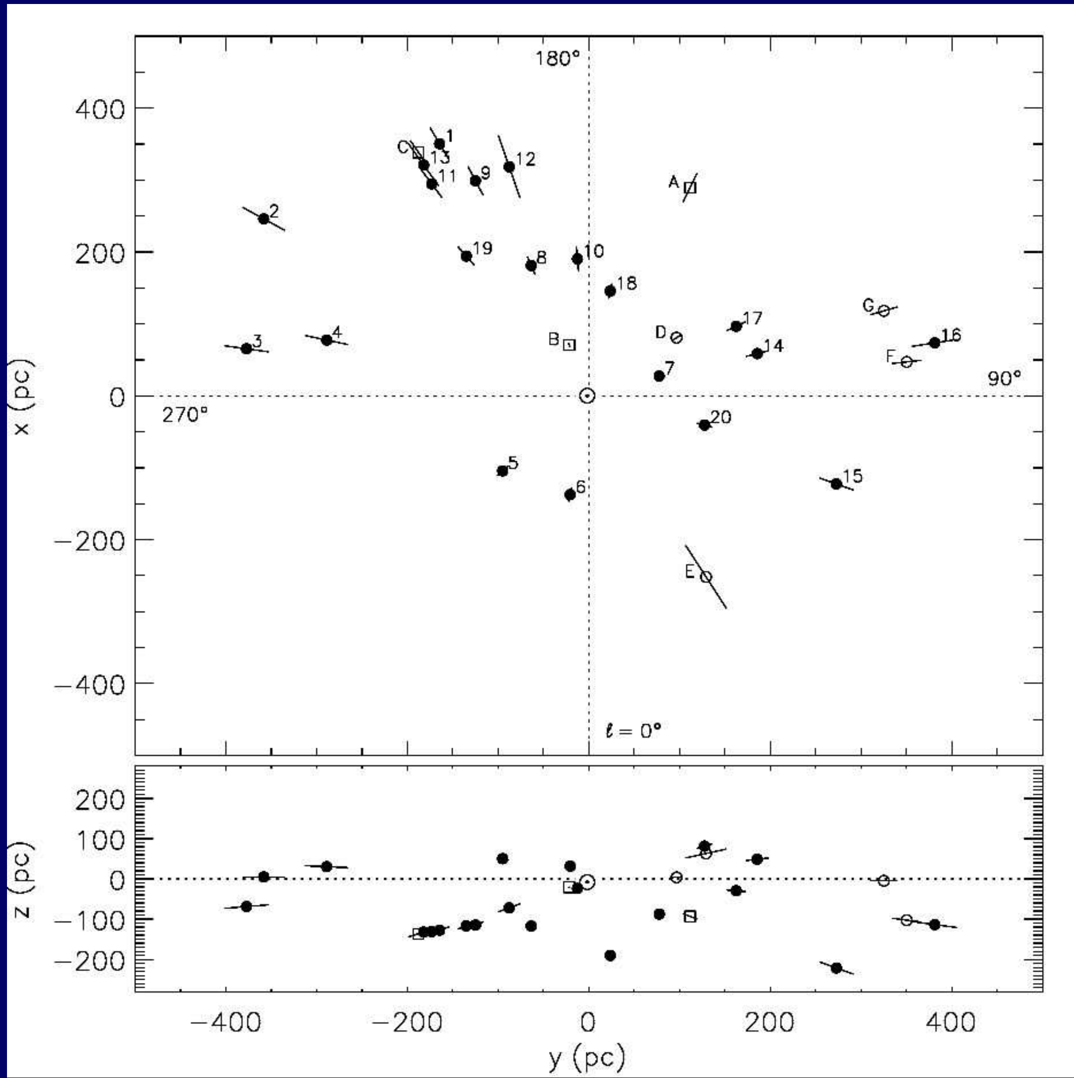
Spatial Distribution of Sample Stars

solar neighbourhood
d ≤ 400 pc

associations:
- Sco-Cen
- Ori OB1
- Per OB2
- Lac OB1
- Cas-Tau

+ field stars

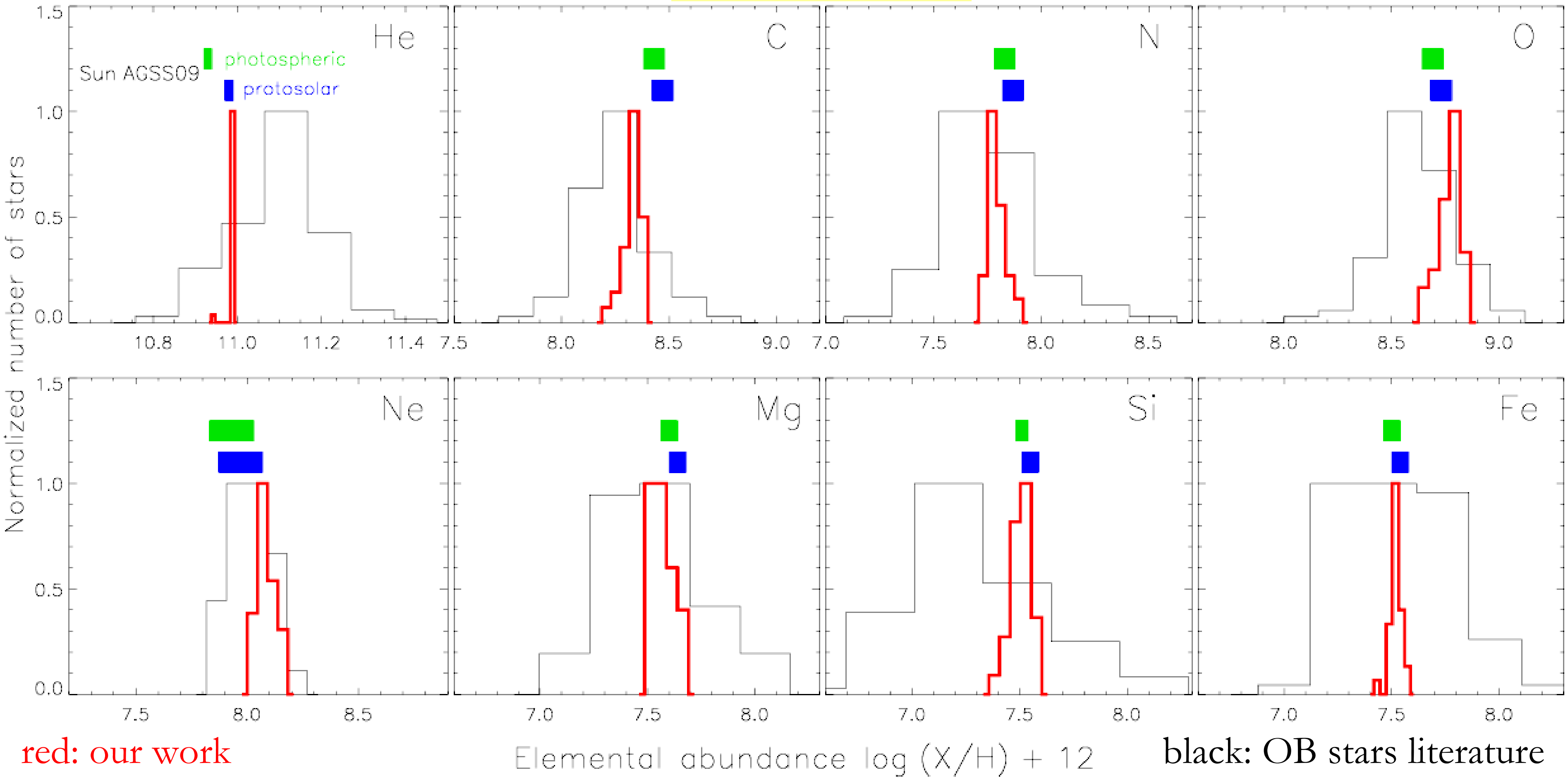
+ Ori OB1 Ia-Id sample
of Nieva & Simon-Diaz (2011)



Nieva & Przybilla (2012)

Chemical composition of solar neighbourhood @ present day

1σ ~ 0.05 dex



red: our work

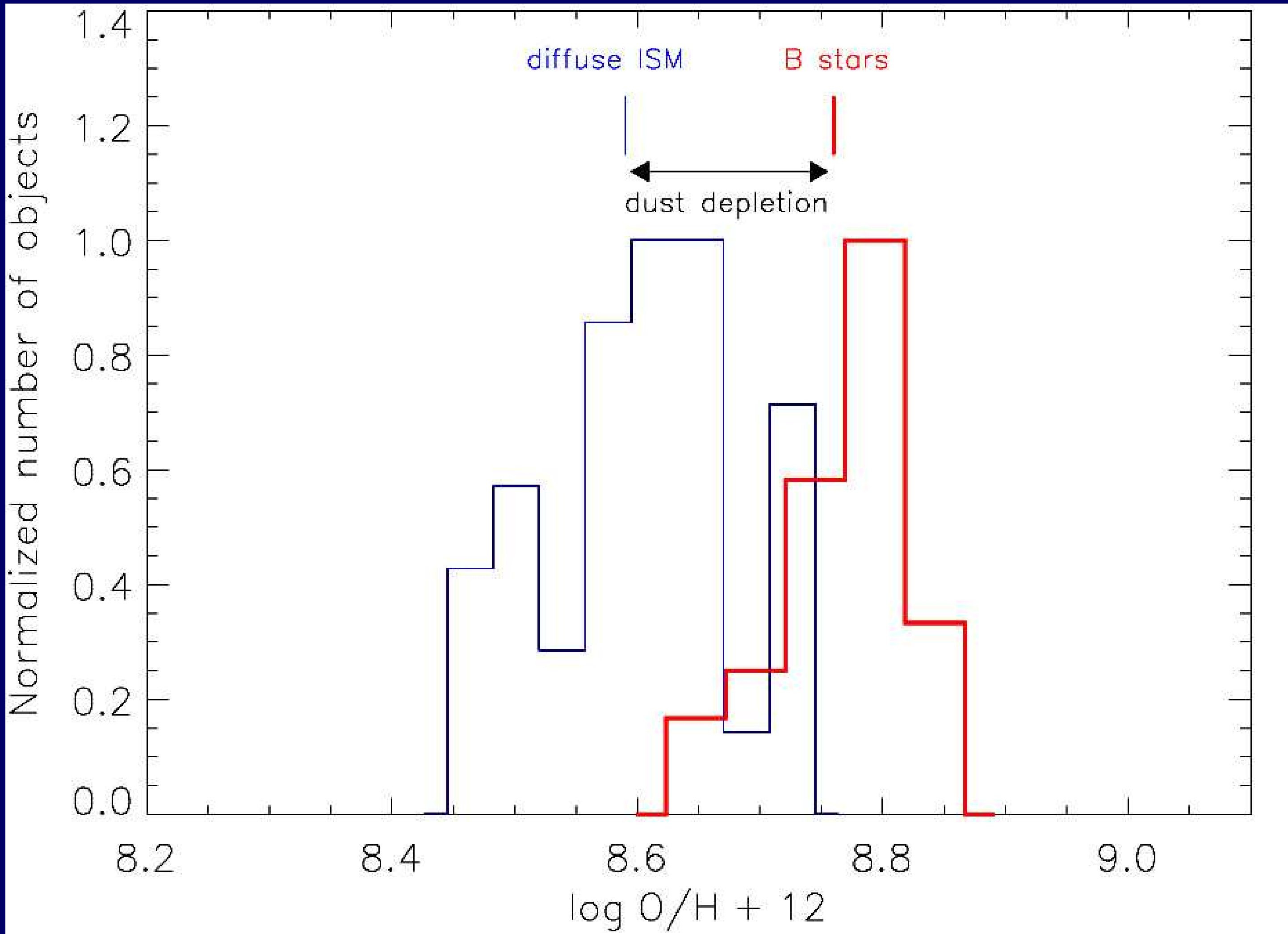
black: OB stars literature

Nieva & Przybilla (2012)

chemical homogeneity ► Cosmic Abundance Standard

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

Dust Depletion



Nieva & Przybilla (2012)

- similar abundance distributions in gas & stars

CAS & Consequences for Dust Composition

Table 9. Chemical composition of different object classes in the solar neighbourhood.

Nieva & Przybilla (2012)

	Cosmic Standard		Orion nebula		Young	ISM		Sun[k]		
Elem.	B stars – this work[a]		Gas	Dust[d]	F&G stars[e]	Gas	Dust[j]	GS98	AGSS09	CLSFB10
He	10.99 ± 0.01	...	10.988 ± 0.003^b	...	...	...	...		10.93 ± 0.01	
C	8.33 ± 0.04	214 ± 20	8.37 ± 0.03^c	~0	8.55 ± 0.10	7.96 ± 0.03^f	123 ± 23	8.52 ± 0.06	8.43 ± 0.05	8.50 ± 0.06
N	7.79 ± 0.04	62 ± 6	7.73 ± 0.09^b	...	...	7.79 ± 0.03^g	0 ± 7	7.92 ± 0.06	7.83 ± 0.05	7.86 ± 0.12
O	8.76 ± 0.05	575 ± 66	8.65 ± 0.03^c	128 ± 73	8.65 ± 0.15	8.59 ± 0.01^h	186 ± 67	8.83 ± 0.06	8.69 ± 0.05	8.76 ± 0.07
Ne	8.09 ± 0.05	123 ± 14	8.05 ± 0.03^c	...	...	...	...	8.08 ± 0.06	7.93 ± 0.10	...
Mg	7.56 ± 0.05	36.3 ± 4.2	$6.50{:}^c$	$33.1 \pm 4.2{:}$	7.63 ± 0.17	6.17 ± 0.02^i	34.8 ± 4.2	7.58 ± 0.05	7.60 ± 0.04	...
Si	7.50 ± 0.05	31.6 ± 3.6	6.50 ± 0.25^c	28.4 ± 4.3	7.60 ± 0.14	6.35 ± 0.05^i	29.4 ± 3.6	7.55 ± 0.05	7.51 ± 0.03	...
Fe	7.52 ± 0.03	33.1 ± 2.3	6.0 ± 0.3^c	32.1 ± 2.5	7.45 ± 0.12	5.41 ± 0.04^i	32.9 ± 2.3	7.50 ± 0.05	7.50 ± 0.04	7.52 ± 0.06

Notes. [(a)] Including nine stars from Orion (NS11), in units of log(El/H) + 12 / atoms per 10^6 H nuclei – computed from average star abundances (mean values over all individual lines *per element*, equal weight per line), the uncertainty is the standard deviation; [(b)] Esteban et al. (2004); [(c)] Simón-Díaz & Stasińska (2011); [(d)] difference between the cosmic standard and Orion nebula gas-phase abundances, in units of atoms per 10^6 H nuclei; [(e)] Sofia & Meyer (2001); [(f)] value determined from strong-line transitions (Sofia et al. 2011), which is compatible with data from the analysis of the [C II] 158 μm emission (Dwek et al. 1997). Weak-line studies of C II] λ2325 Å indicate a higher gas-phase abundance $\varepsilon(C) = 8.11 \pm 0.07$ (Sofia 2004), which corresponds to 84 ± 28 ppm of carbon locked up in dust; [(g)] Meyer et al. (1997), corrected accordingly to Jensen et al. (2007); [(h)] Cartledge et al. (2004); [(i)] Cartledge et al. (2006). The uncertainty in the ISM gas-phase abundances is the standard error of the mean; [(j)] difference between the cosmic standard and ISM gas-phase abundances, in units of atoms per 10^6 H nuclei; [(k)] photospheric values of Grevesse & Sauval (1998, GS98), Asplund et al. (2009, AGSS09) and Caffau et al. (2010, CLSFG10).

- Dust in diffuse ISM: relatively **carbon poor** & **silicate-rich**
- checksum Mg+Si+Fe vs. O match (some extra O may be in unidentified constituent)
- comparison with Orion dust: **graphite minor species ► C in PAHs**
- homogeneity over hundreds of parsecs: **highly efficient mixing**