Gaia-ESO Survey WG13: OBA-star Spectrum Analyses

September 2011

A. Lobel, R. Blomme, Y. Frémat, T. Morel,
& participants of GesWG13

O, B, A-type stars in young/massive-star clusters

Science

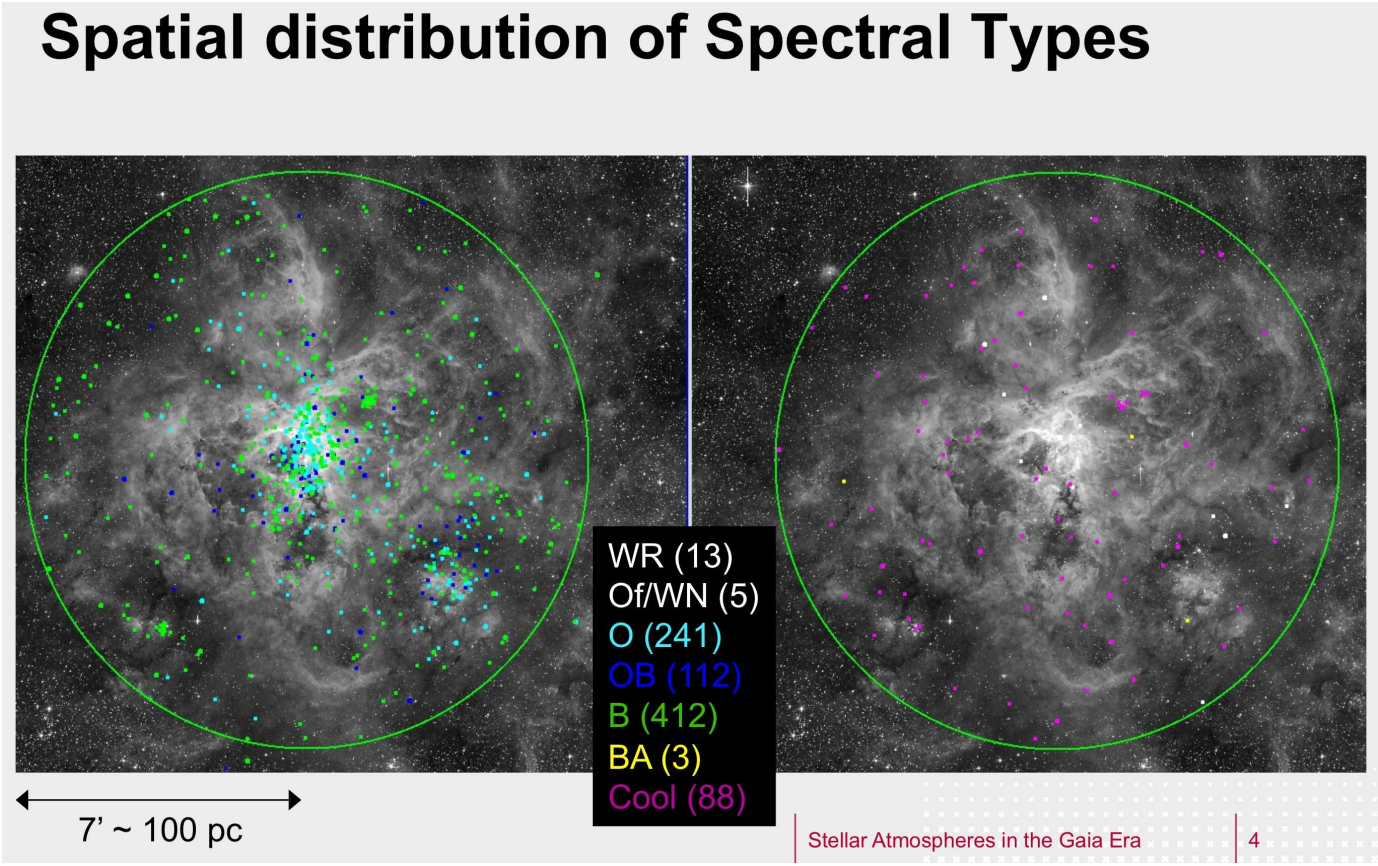
- Accurate determination of stellar parameters
  - ➢ More reliable abundances of C, N, O, (& metals)
    - ❑ Galactic abundance gradients: a large range in distance, present-day abundances
    - ❑ Quantitative tests of stellar evolution

      Mixing in OB stars; N abundance enhancement correlated with rotation, important evolutionary effects observed?

- Improving Galactic census of massive stars
  - ➢ More reliable wind parameters and mass-loss rates
    - ❑ physics of hot star winds, driving mechanism(s), wind structure
    - ❑ better understanding of short-lived evolutionary phases with very large mass-loss rates LBV, W-R
    - ❑ Compare with evolutionary tracks, Mspec vs. Mevol problem
    - ❑ Constrain the upper IMF (B/R supergiants is metallicity dependent and provides sensitive test of stellar evolution)

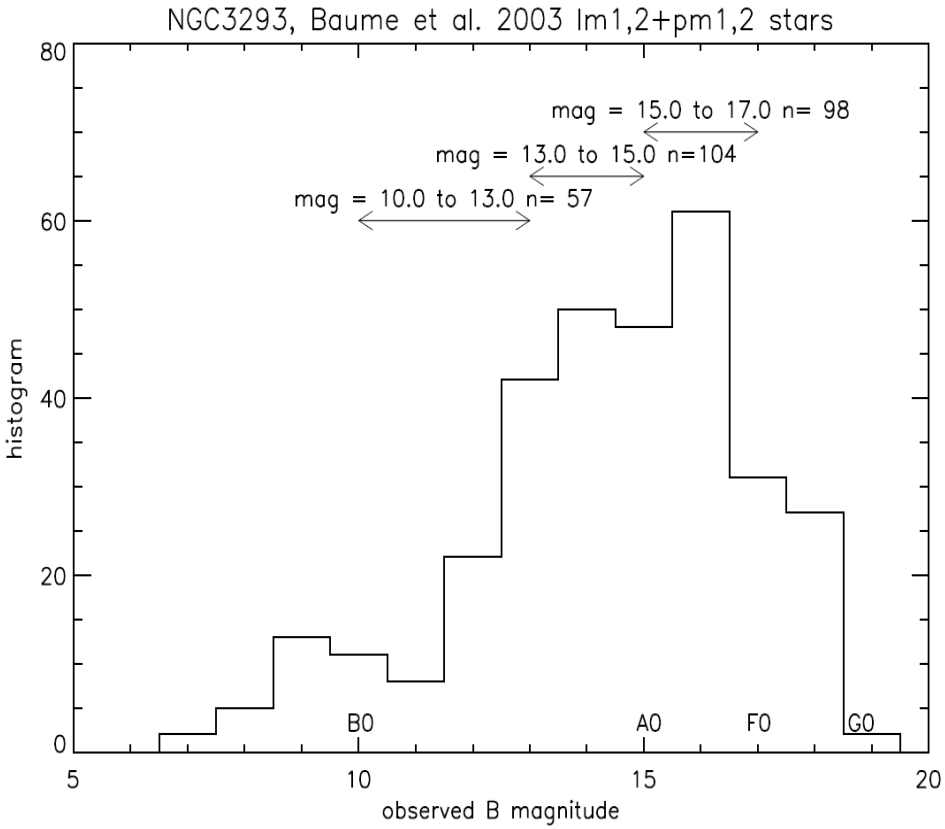
Observation strategy for hot stars in GES

- VLT/FLAMES Tarantula Survey Evans et al. (2011)
- Multi-epoch spectroscopy of 1,000 most massive stars in 30 Dor



Observation strategy for hot stars in GES

- Massive-star clusters, 106 h requested
- Young-clusters, 52 h requested
- Nominal integration time of 1 h per cluster



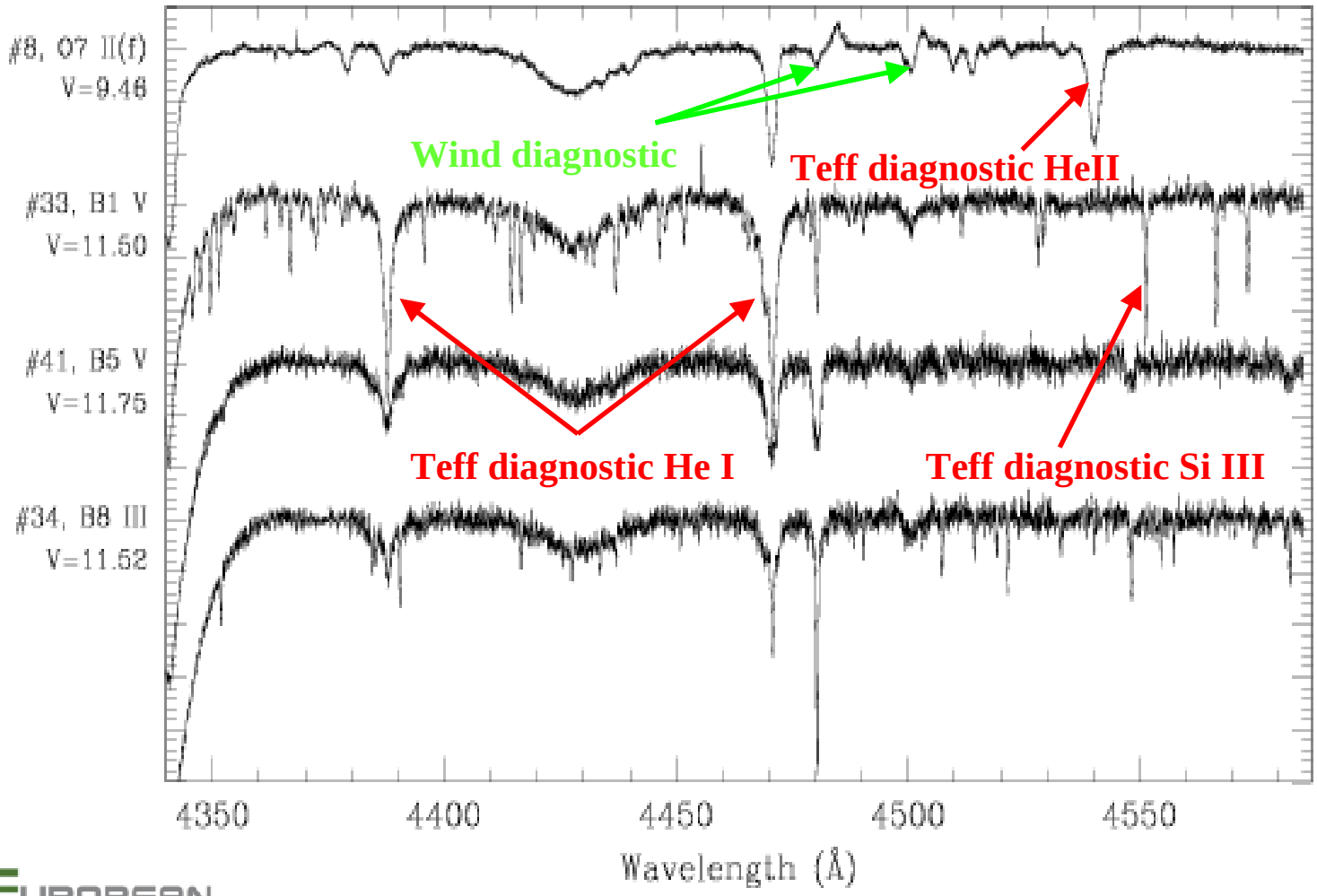
cluster	# pointings	cluster	# pointings
NGC 3293	3	NGC 4755	3
Trumpler 16	4	Dolidze 25	3
NGC 3766	2	Collinder 228	2
Trumpler 27	2	Westerlund 2	1
NGC 6649	5	IC 2944	2

- Preliminary list of clusters selected for massive star content
- Science interest
- Cluster membership
- Efficient use of ~130 FLAMES fibers
- Limited magnitude range

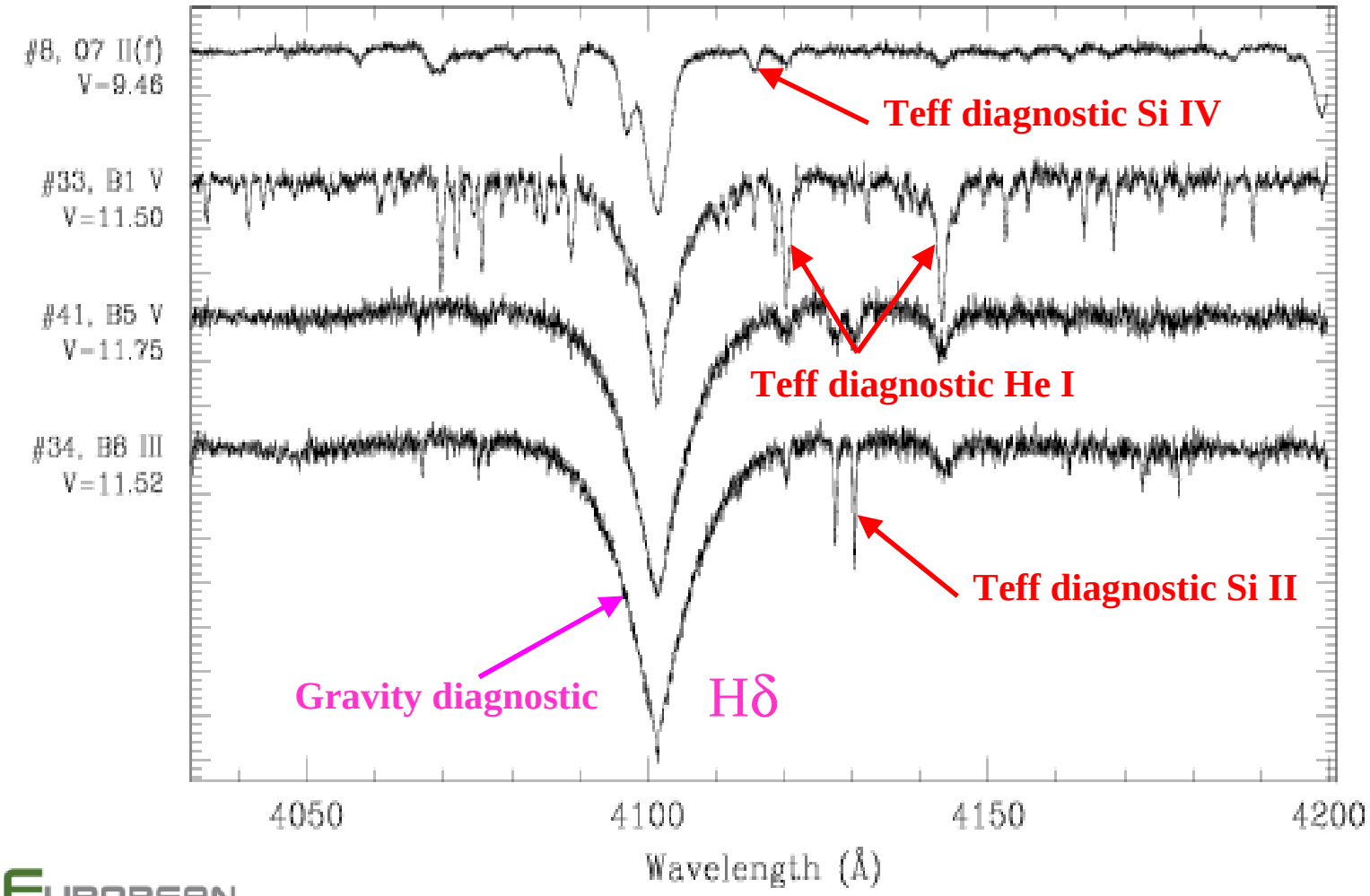
Observation strategy (Giraffe R~17000)

- FGK Stars (HR10, HR15N, HR21 red gratings)
- O, B Stars (need 4 bluer HR gratings)
  - HR03 (4033 - 4201 Å)
    - Hδ 4102 O+B stars, O stars
    - He I 4121, 4144, Si IV 4089, 4116, Si II 4129 B stars
    - O II 4075, 4133, 4157, 4185
  - HR05A (4340 - 4587 Å)
    - He I 4387, 4471 O+B stars; He II 4542
    - Si III 4552, 4568, 4575, Mg II 4481 B stars
    - N II 4447, O II 4350, 4367, 4396, 4415, 4452
  - HR06 (4538 - 4759 Å)
    - He I 4713, He II 4541, 4686 (wind line) O+B stars
    - Si IV 4631, 4654, Si III 4560 B stars
    - C III 4650, N II 4601, 4614, 4631, 4643, O II 4595, 4640-70, 4700
  - HR14A (6308 - 6701 Å)
    - Hα (wind line) O stars
    - He I 6678, He II 6527, 6683, Si II 6347 B stars
    - C II 6580

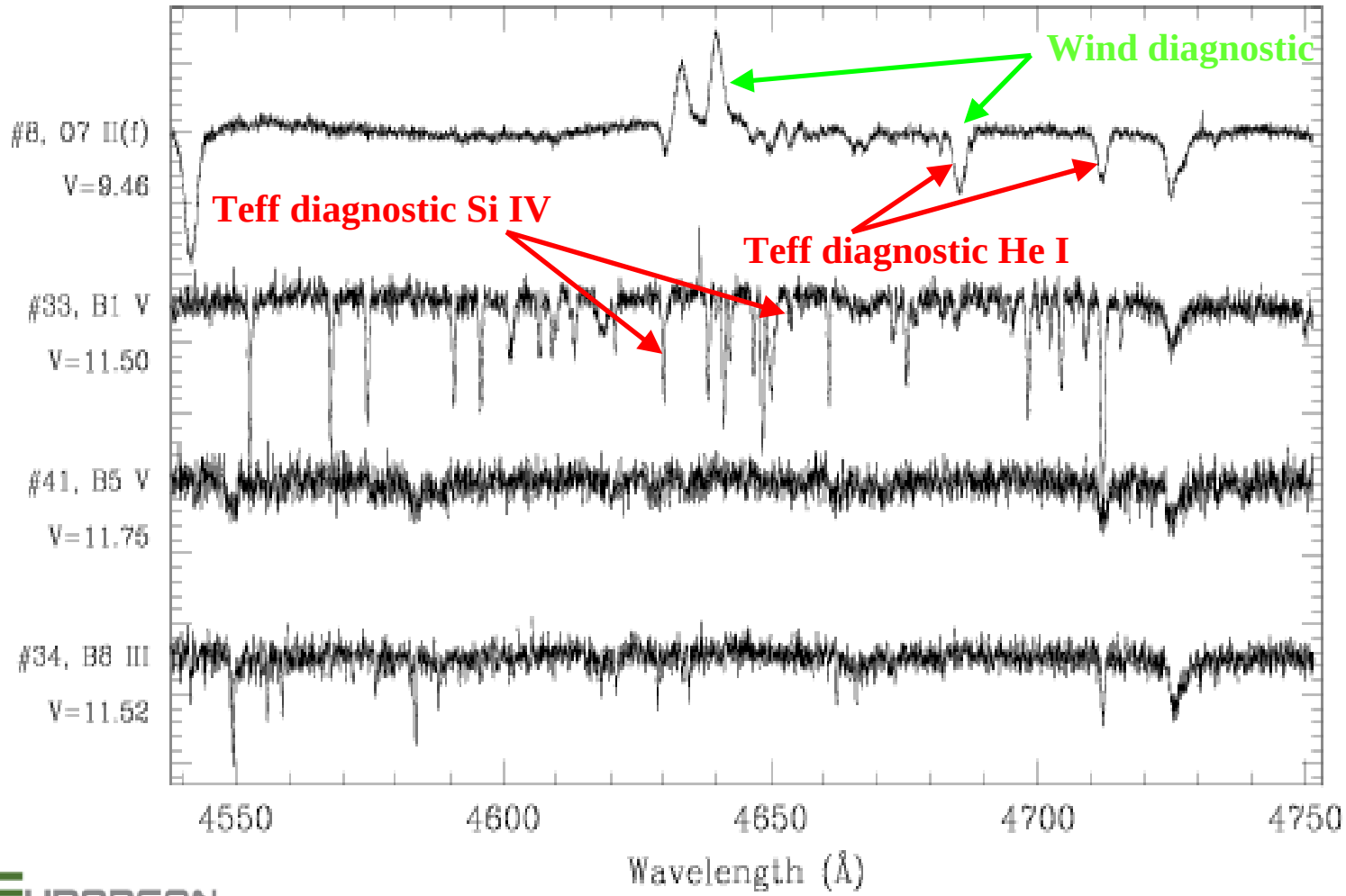
Observation strategy (Giraffe HR05A)



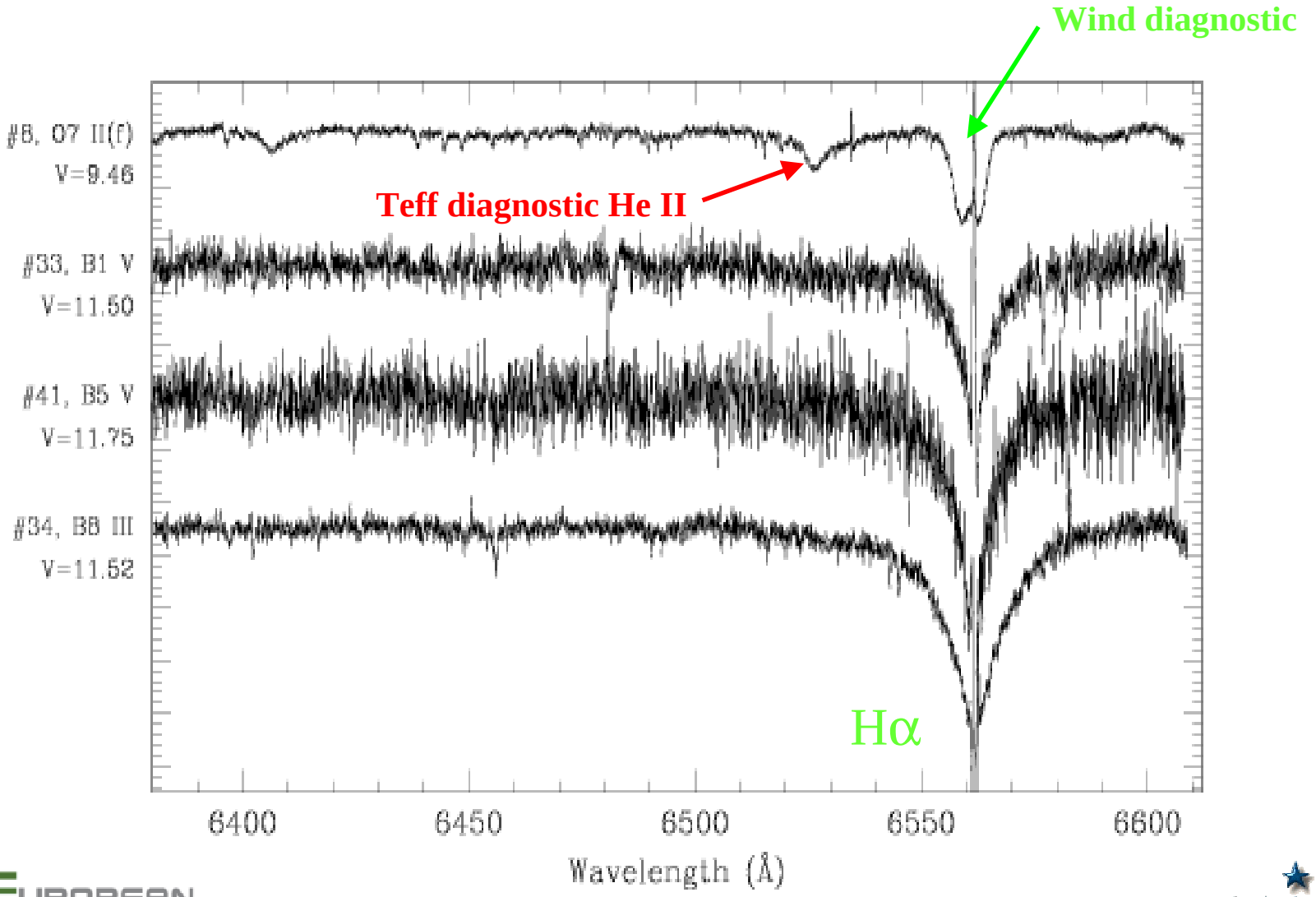
Observation strategy (Giraffe HR03)



Observation strategy (Giraffe HR06)



Observation strategy (Giraffe HR14A)



Observation strategy (UVES R=47000 6 fibers)

- UVES: CD#3, 520 and 580 nm central wavelength settings

  Note: 520 setting (4140 – 6210 Å)

  includes Si III 4550 triplet, but excludes Hα

  580 setting (4760 – 6840 Å)

  excludes Si III 4550 triplet, but includes Hα

- Expect ~10000 O, B, A stars observed with Giraffe in GES
- S/N = 100 needed for RV accuracy of 0.5 km/s

- Expect ~500 with UVES of S/N>50 useful for good abundance determinations

- Currently 29 persons from 20 inst. involved/interested
- Coordinator & Contact **Ronny.Blomme@oma.be**

Name	Function	Affiliation	Country	FTE allocated	Expertise
Ronny Blomme	OBA stars - coordinator	Royal Obs Belgium	BE	0.3	Coordination
Yves Fremat	B,Be stars	Royal Obs Belgium	BE	0.2	A, B and Be type stars, parameter determination (with special emphasis on v.sin i and radial velocity)
Alex Lobel	A stars	Royal Obs Belgium	BE	???	A
Ignacio Negueruela	OB stars	Alicante	ES	???	Massive clusters. Spectral classification. Supervision.
Carlos González-Fernández	OBA stars	Alicante	ES	0.05 (2years)	Target selection
Ricardo Dorda	OBA stars	Alicante	ES	0.1 (4years)	Target selection; OB preparation (starting Oct 2011)
Jesus Maiz-Apellaniz	O stars	Granada	ES	0.1	Other spectroscopic surveys. Spectroscopic classification, IMF+effect on surroundings. Incorporate results into GOSC. Target selection for clusters with O stars.
Olivier Schnurr	WR stars	AIP	DE	0.1	Flames survey, target selection, WR stars
Artemio Herrero	O stars, BA supergiants	IAC	ES		O and B stars parameter determination. Also LBVs FASTWIND but could use others as well. Open cluster selection, continuum rectification
Richard Monier	A stars	Univ. Nice	FR	0.6(5years)	late-B to late F-stars, LTE+NLTE abundance determinations, parameter determination. A-type stars
Thierry Morel	B stars	Liege	BE		chemical composition analysis O and B stars; could also help on UVES data reduction
Eric Gosset	O stars	Liege	BE		
Laurent Mahy	O stars	Liege	BE		
Yael Naze	O stars	Liege	BE		
Jorick Vink	OB stars	Armagh	UK		OB, LBV, WR. Mass loss and evolution modelling, spectroscopy
Jean Zorec	B,Be stars	Paris	FR	0.2	Fundamental parameters, evolving stars with rotation (Be). Interpretation data
David Barrado	OBA stars	Calar Alto	ES	0.1	Ancillary data: photometry, spectroscopy, complete IMF
J. Lillo-Box	OBA stars	Calar Alto	ES	0.1	
P. Cruz	OBA stars	Calar Alto	ES	0.1	
Anna Pasquali	OB, LBV, WR	ZAH	GE	0.1	OB stars in association, LBVs, WRs. Optical+near-IR spectroscopy. Isochrones+stellar tracks.
C. Bailer-Jones	WG9 coordinator	MPIA	GE	--	leader WG9, Discrete Classification
De Ridder	no answer yet	Leuven			
Huelamo	no answer yet	Madrid-ESA			
Kochukhov	no answer yet	Uppsala			
Napiwotzki	no answer yet	Herts			preliminary pipeline + A stars
Groh	no answer yet	MPIfR			
Przybilla	no answer yet	Bamberg			Abundance determination
De Koter, Sana	no answer yet	Amsterdam			OB stars stellar parameter determination, Flames survey
Martayan	no answer yet	ESO			

In search of more A-type star expertise!

Overview of WG13 RT modeling codes

- **O to early B stars (including supergiants)**
  - FASTWIND and CMFGEN
  - Non-LTE & spherical symmetry
  - Hydrostatic photosphere + stellar wind
  - Parameters: Teff, log g, R_*, microturbulence, abundances, vinf, beta (velocity law), Mdot, clumping

  Differences FASTWIND and CMFGEN
  - CMFGEN has more detailed line blanketing than FASTWIND
  - FASTWIND needs considerably less computing time than CMFGEN

- **(Later) B stars (dwarfs and giants)**
  - ATLAS-DETAIL-SURFACE method

Overview of WG13 RT modeling codes

- **B and A stars**
  - SYNSPEC/TLUSTY
  - Uses the Plane-parallel TLUSTY BSTAR and OSTAR model grids for Teff > 15000 K
  - Uses Plane-parallel Kurucz LTE models + NLTE level populations (computed by TLUSTY) for Teff < 15000 K
  - Possible input/overlap with FGK community?

- **Atomic data / line lists**
  - Each group within WG13 uses their own atomic data/line lists
  - It is TBD if a common line list will be adopted
  - Using the same line list across different codes is non-trivial, because of changes in format

Spectrum modeling ADS method

1. Hybrid non-LTE method (Nieva & Przybilla 2007)
   - Classical atmosphere models 1-D, plane-parallel, hydrostatic, LTE
   - ATLAS9 model grid (Castelli, Kurucz 2003)
   - Atmosphere models and SED fluxes close to LTE by comparison with TLUSTY/SYNSPEC non-LTE models

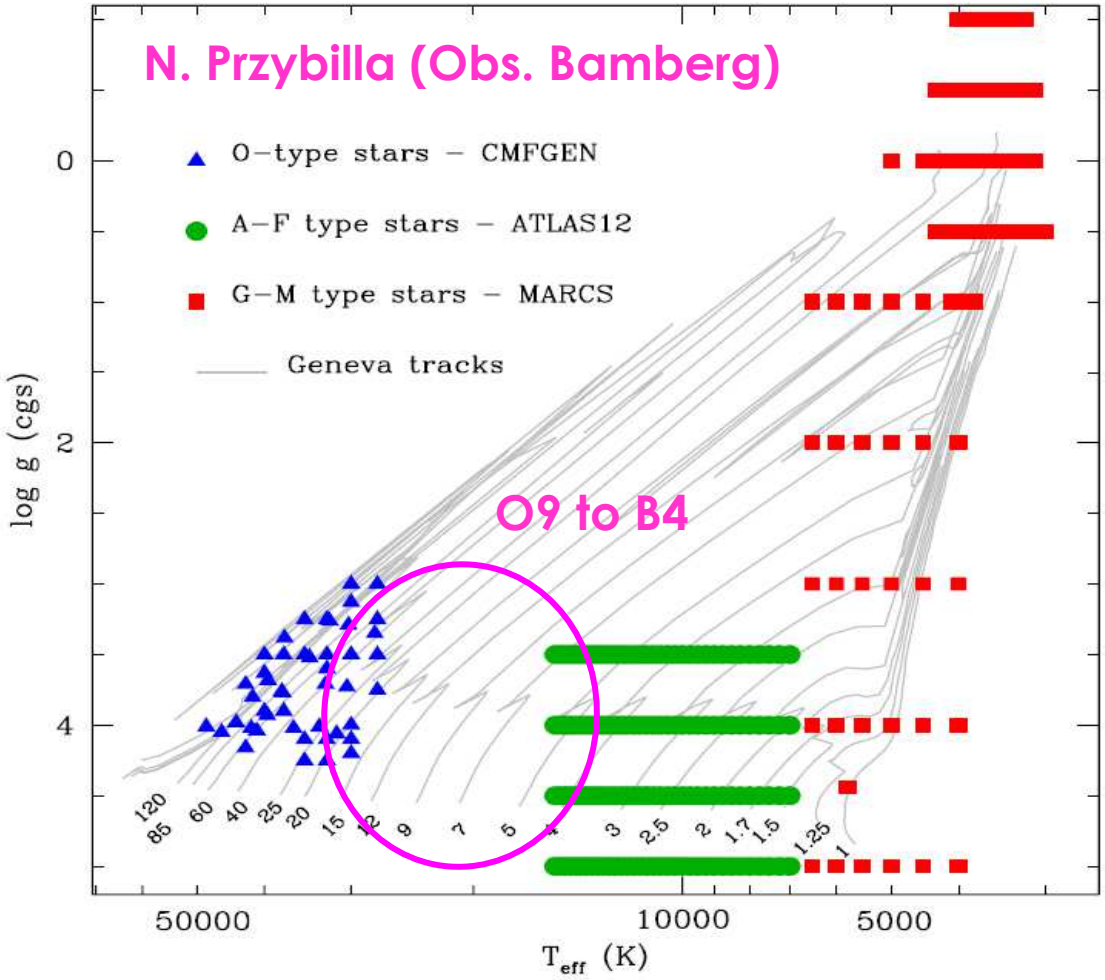
2. Non-LTE line formation
   - statistical equilibrium and radiative transfer w detailed model atoms
   - Level populations: DETAIL
   - Spectrum synthesis: SURFACE

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

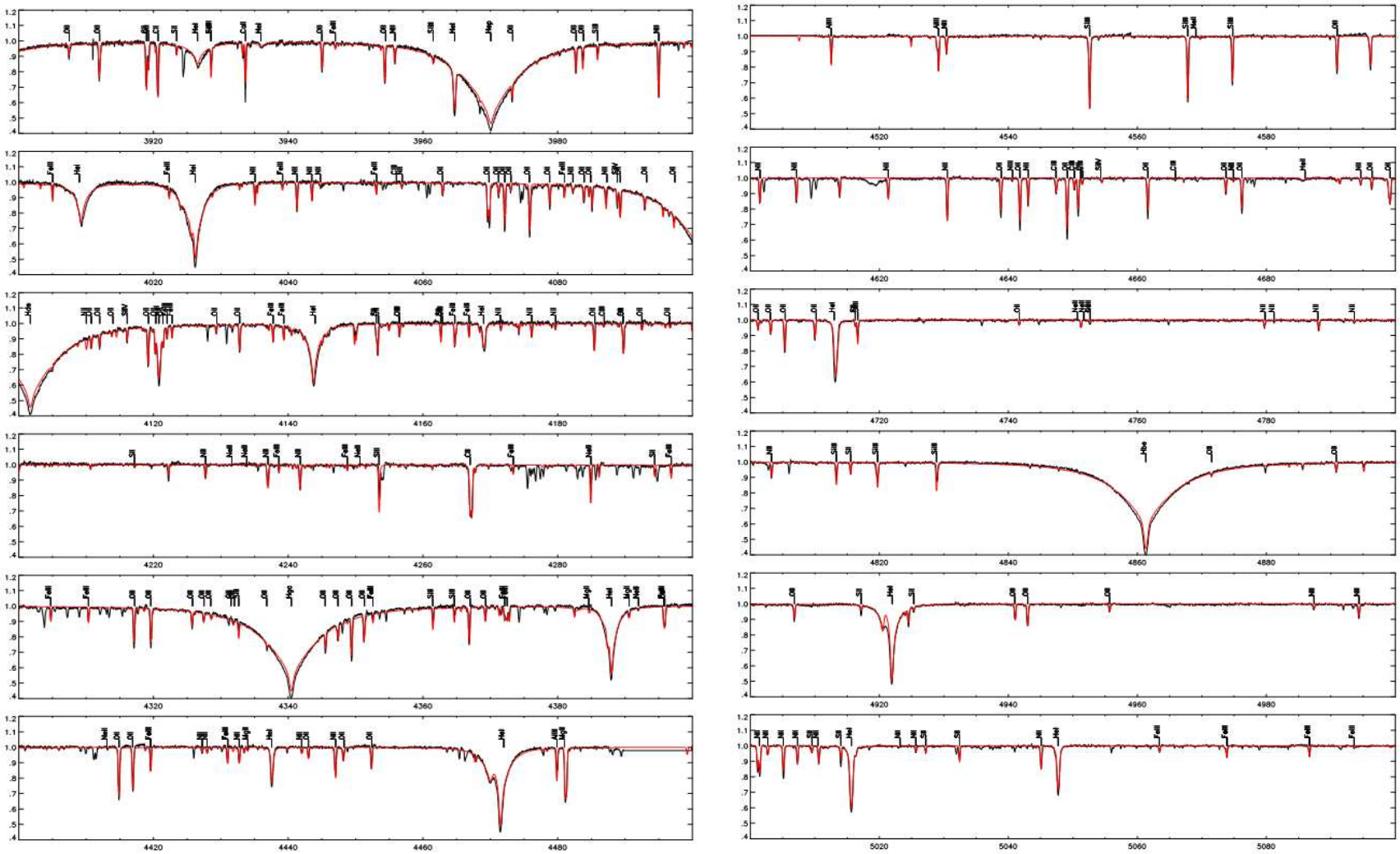
→ **A**TLAS+**D**ETAIL+**S**URFACE = **ADS** method

3. Employs a well-trained automatic global fit method

OB Dwarfs and Giants (15 kK ≤ Teff ≤ 35 kK)

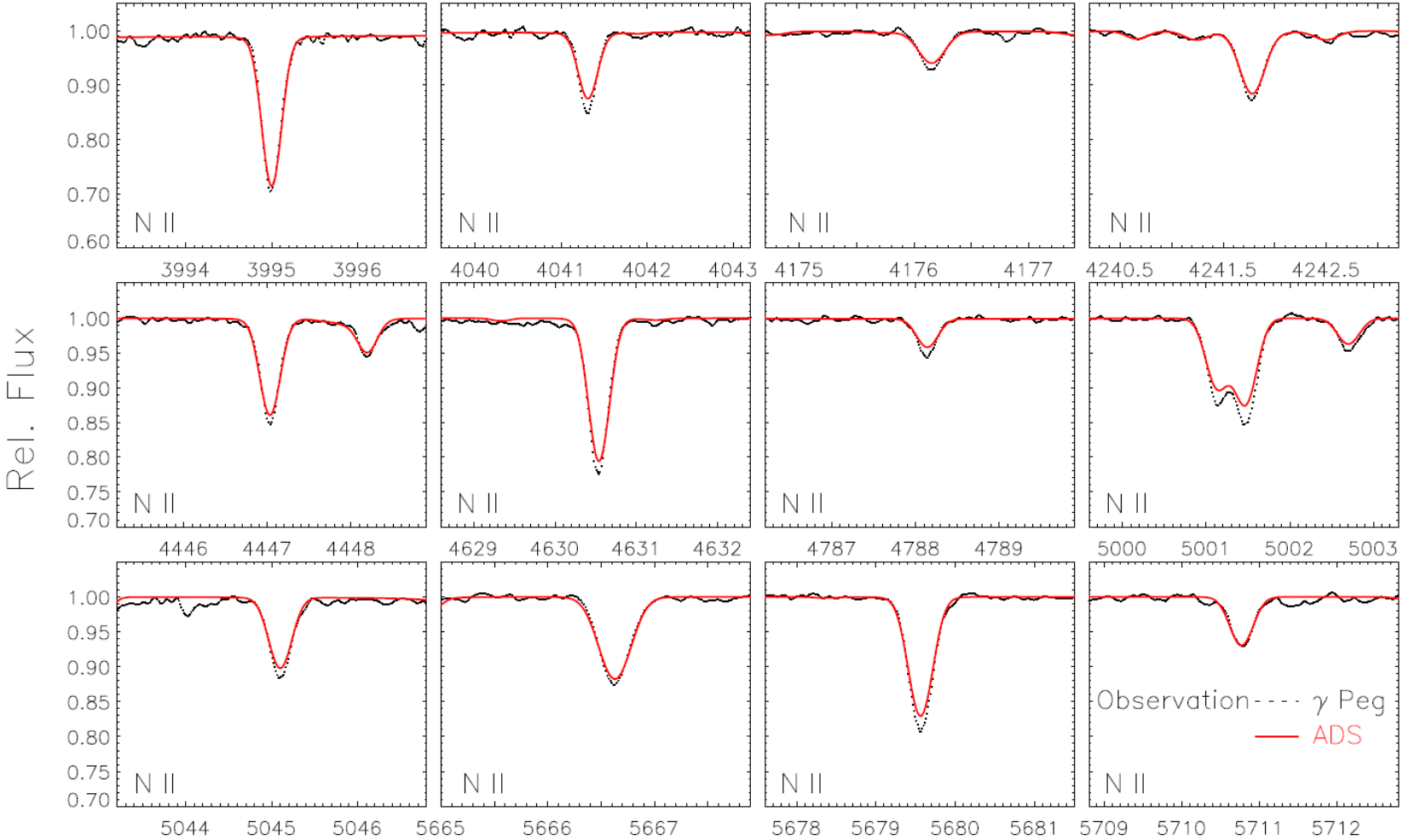


ADS global fit to modeled lines of HD 35299 (B1.5 V)



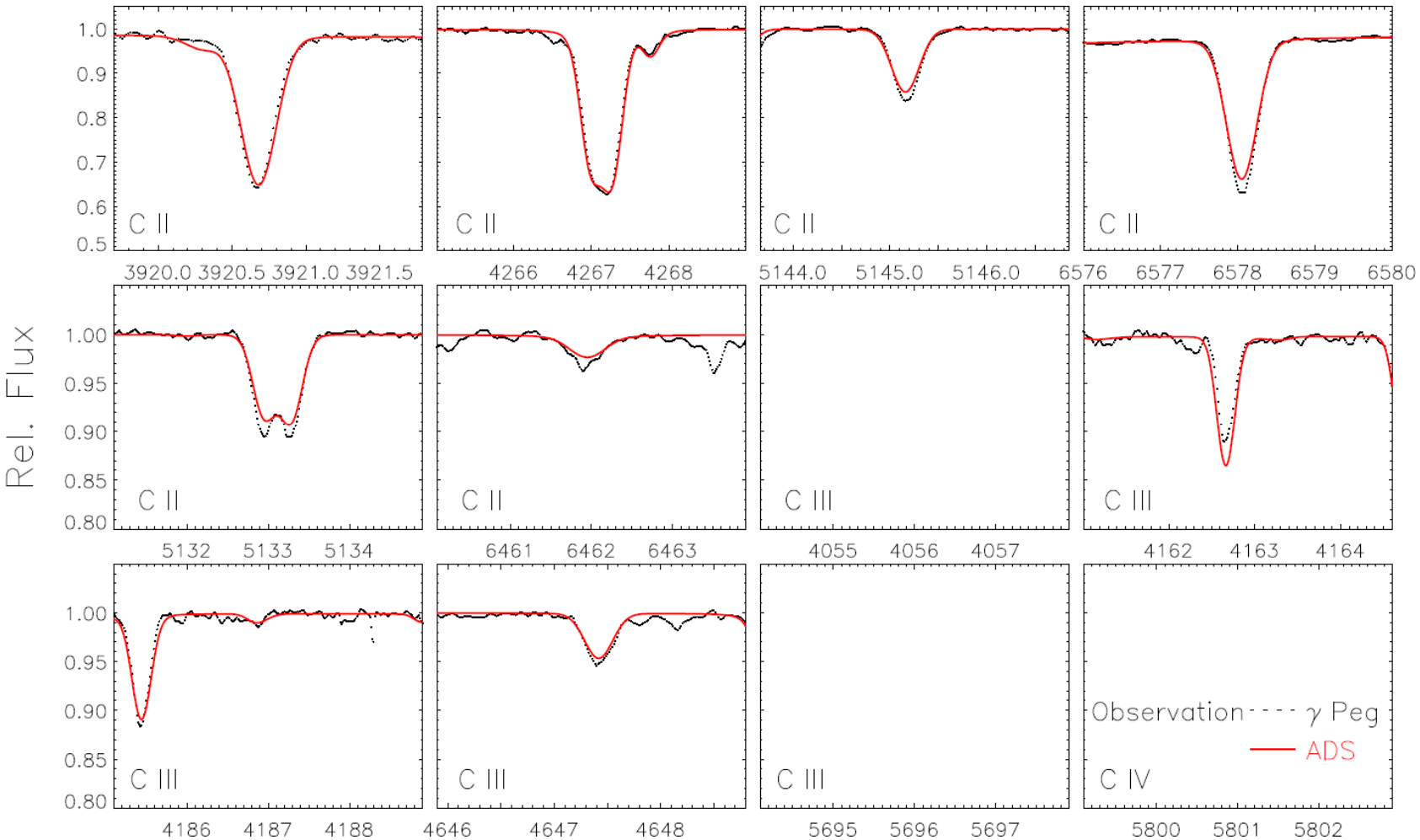
Nieva & Przybilla (2011)

ADS global N II line fits in γ Peg (22000, 4.0)

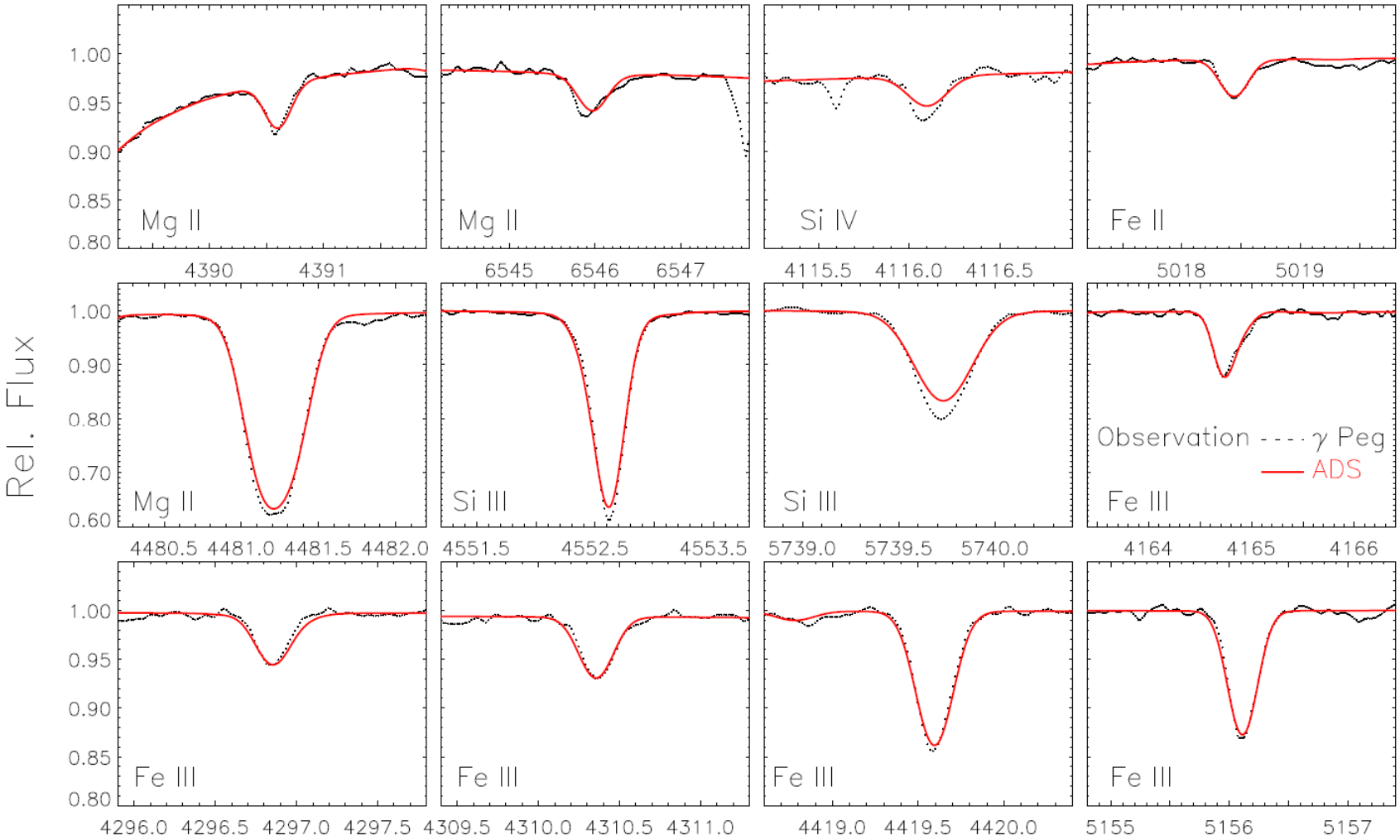


"Good" abundances require S/N > 50

ADS C II/III/IV line fits in γ Peg



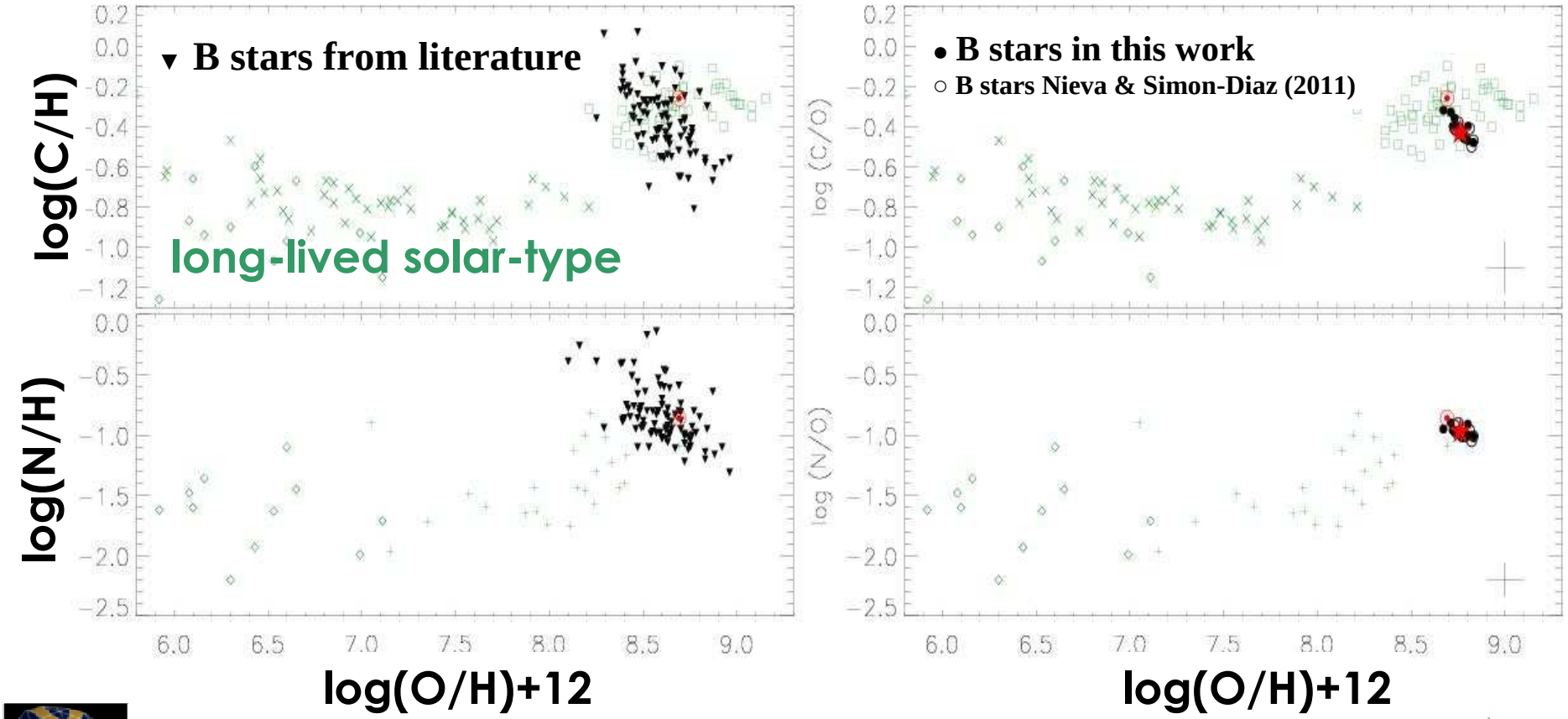
ADS Mg II, Si III/IV, Fe II/III line fits in γ Peg



More accurate abundances in OB dwarfs

- increase of surface C & N abundance over time with [O/H]
- smaller spread in abundances of B-stars with better spectral modeling

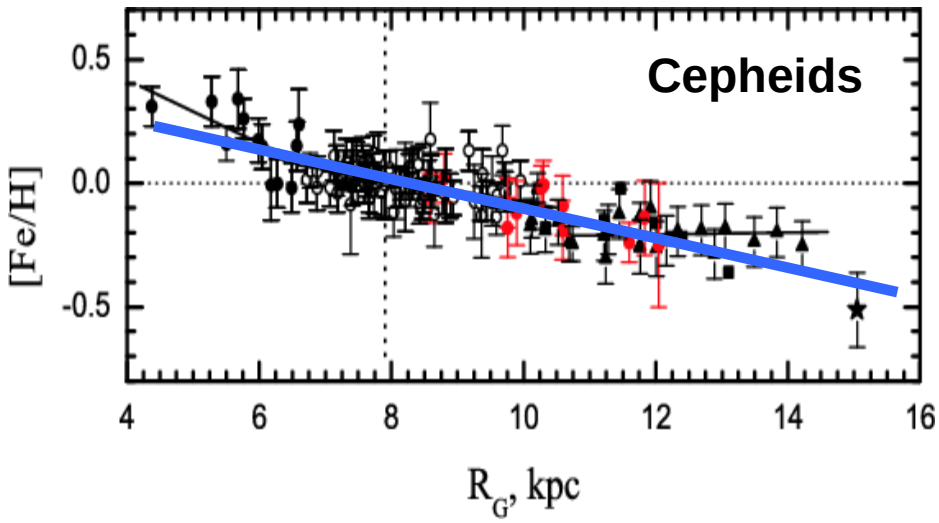
Nieva & Przybilla (2011)



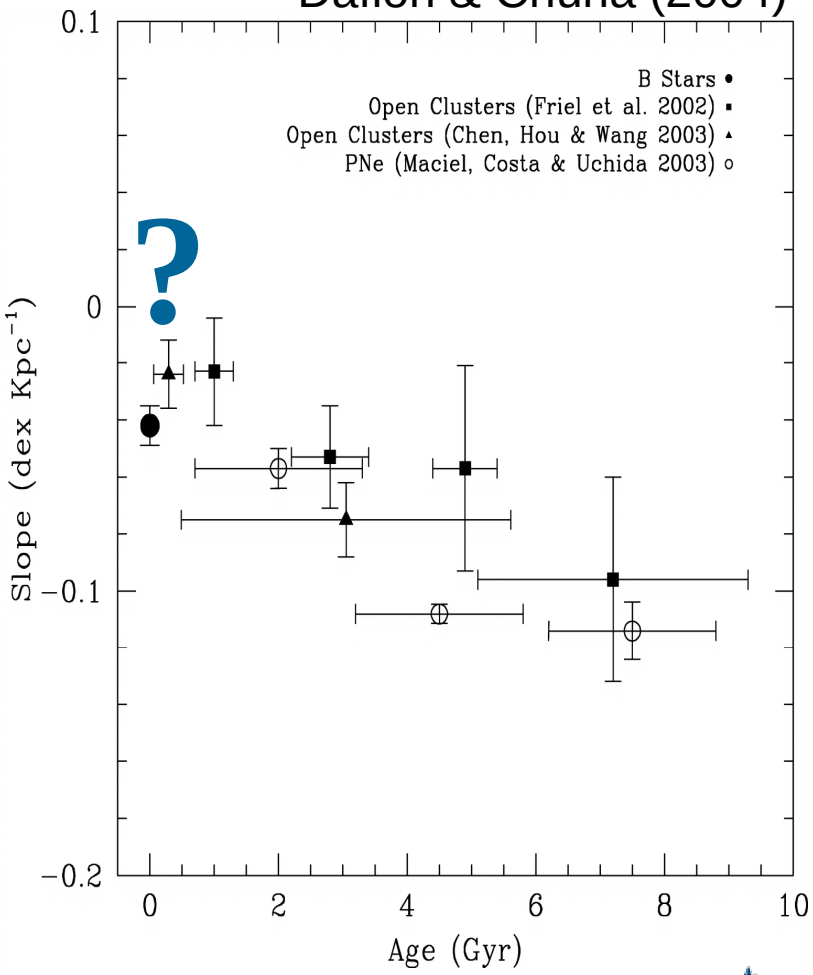
Present-day chemical composition of the ISM

- Observed Galactic gradient vs distance (time)
- OB stars can be used to test it

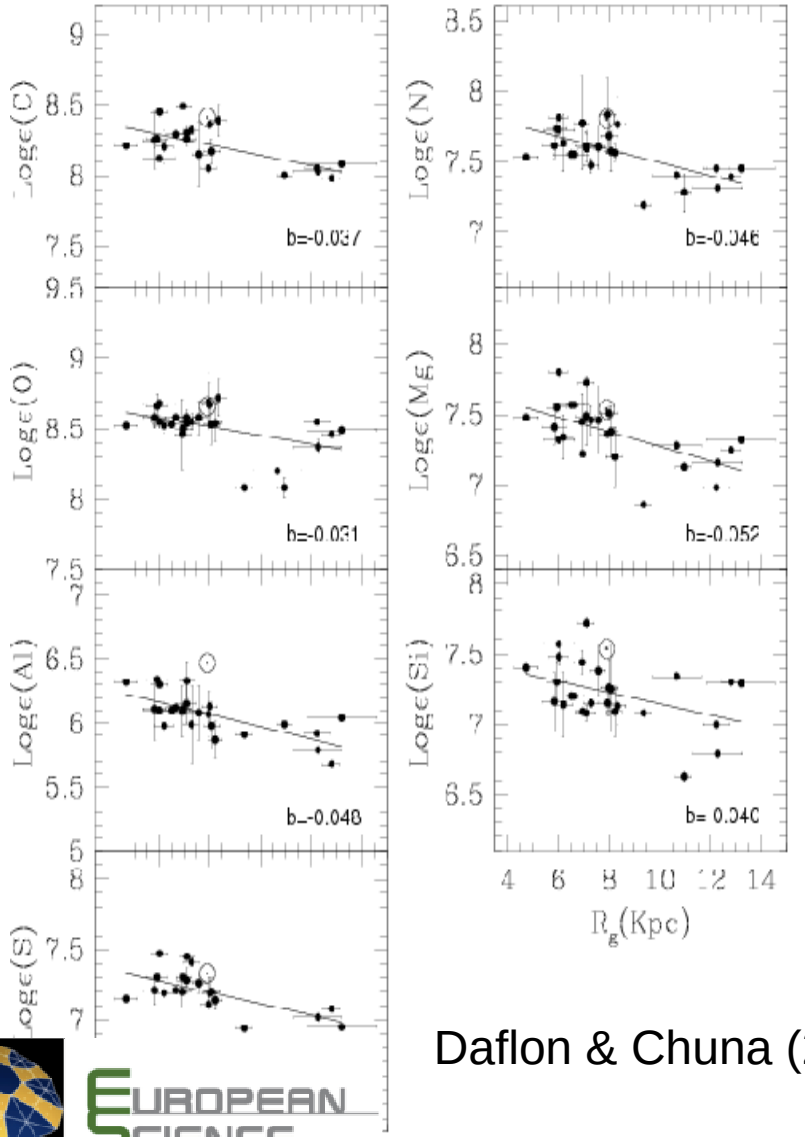
Andrievsky (2005)



Daflon & Chuna (2004)



Galactic chemical gradient from OB stars



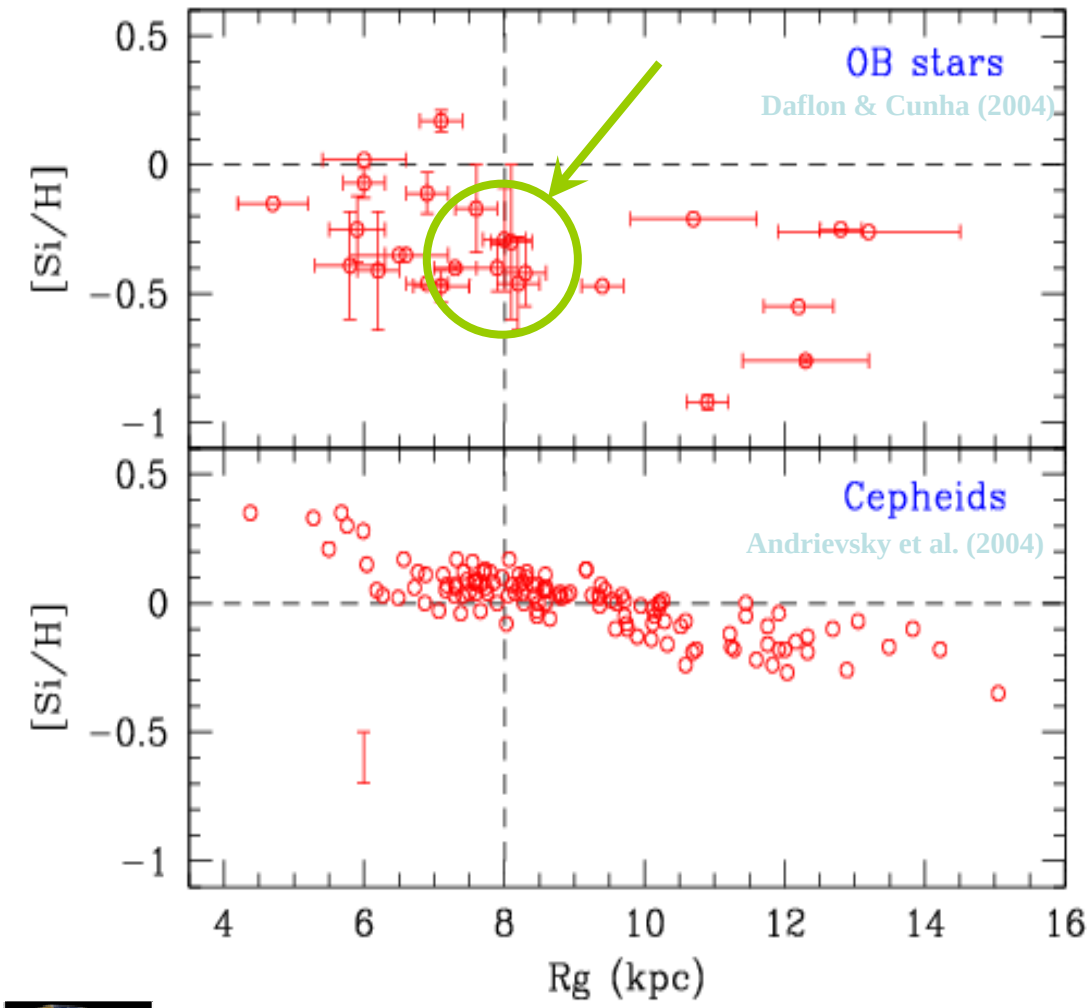
- Elements available:
  C, N, O, Mg, Al, Si, S, Ne
  No iron-peak elements

- 69 late O- to early B-type stars in 25 young open clusters

- –0.031 < slope (dex kpc^{-1}) < –0.052 (similar to H II regions)

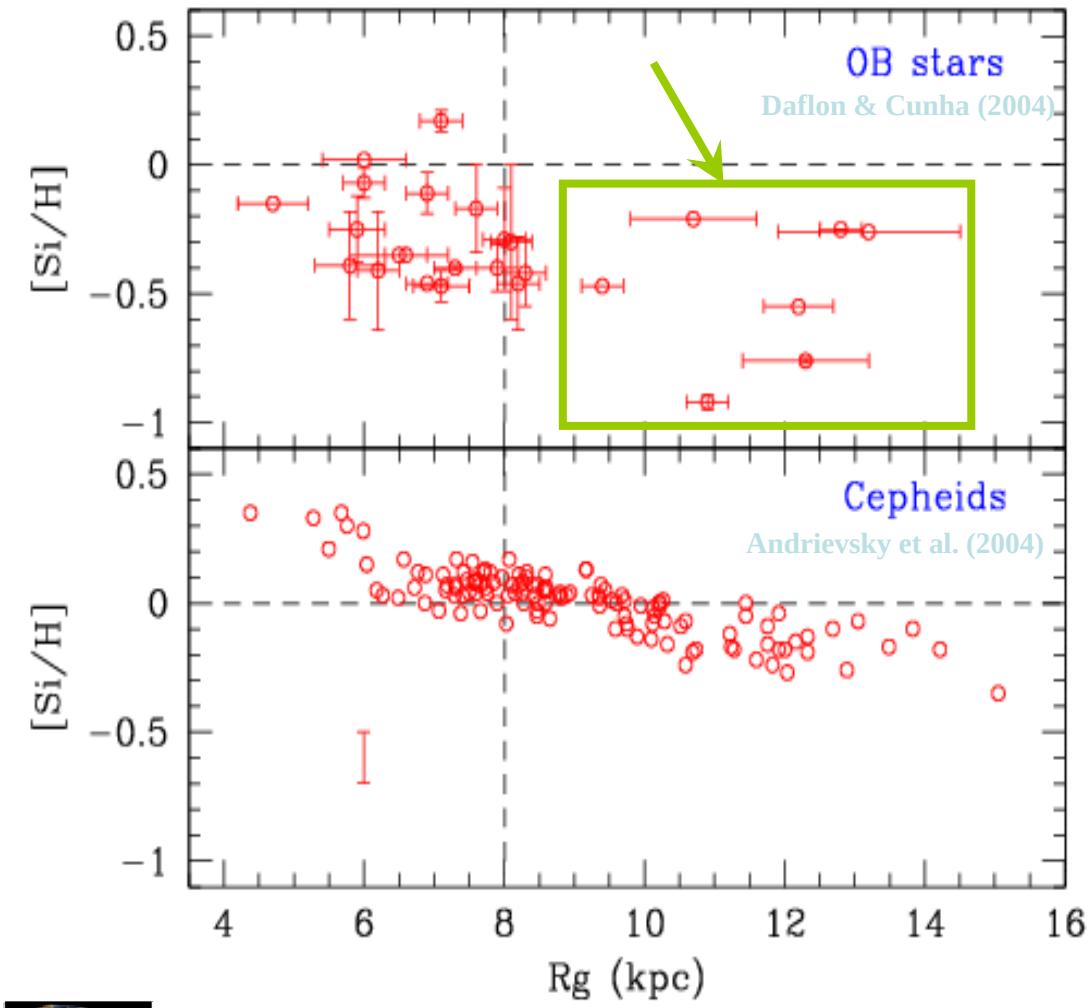
Daflon & Chuna (2004)

Current limitations



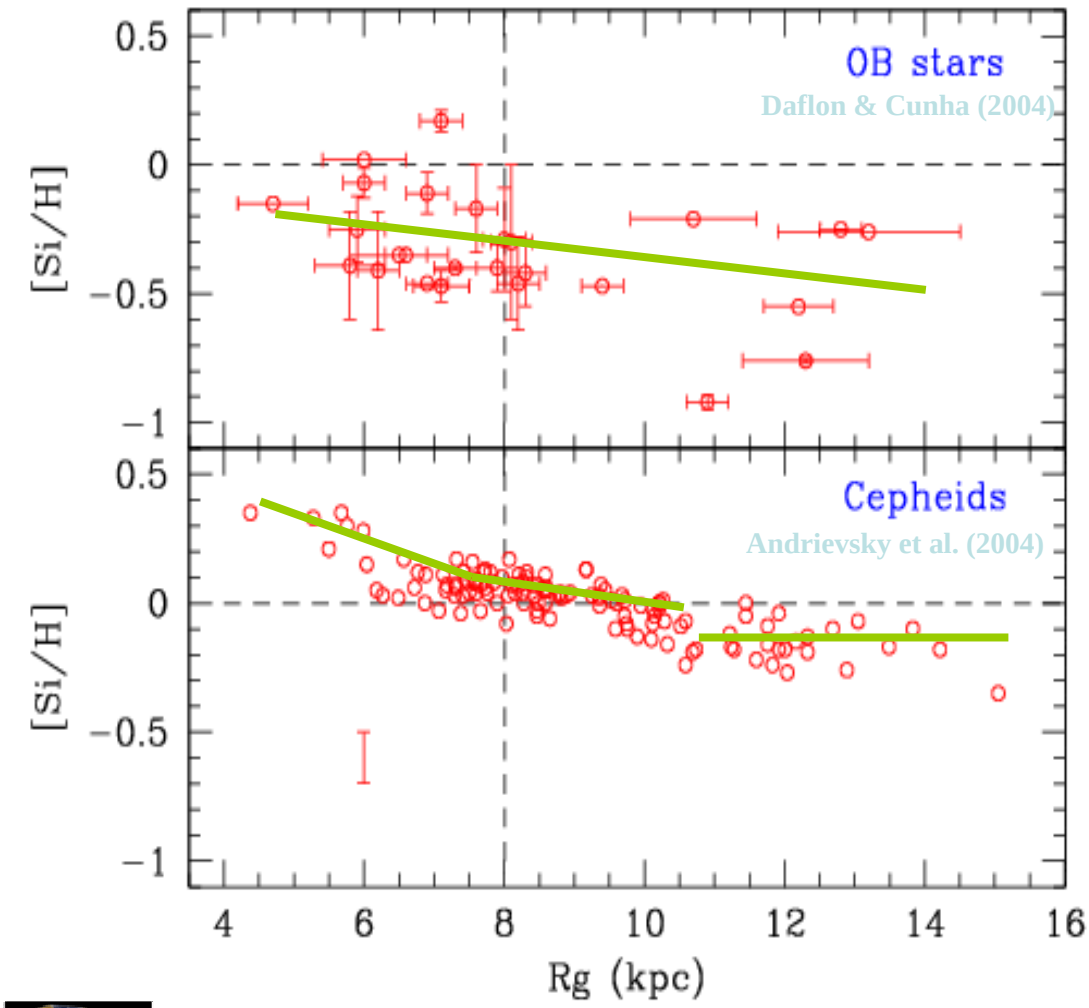
- B-type stars appear metal-poor with respect to the Sun

Current limitations



- B-type stars appear metal-poor with respect to the Sun
- Outer disk poorly sampled (9 stars in 7 clusters): strongly biases results
- Large scatter of ~0.7 at given Rg

Current limitations

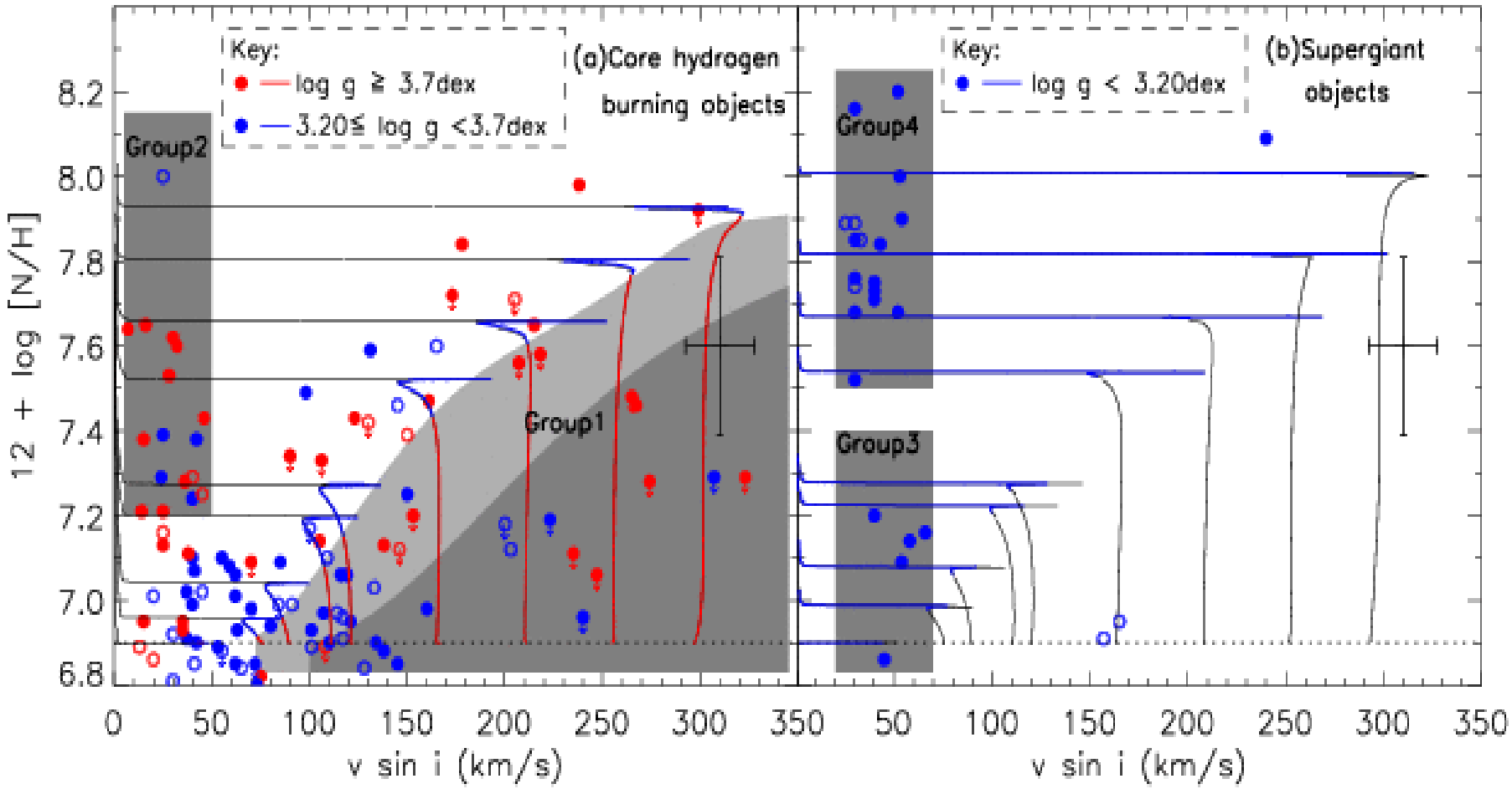


- B-type stars appear metal-poor with respect to the Sun
- Outer disk poorly sampled (9 stars in 7 clusters): strongly biases results
- Large scatter of ~0.7 at given Rg
- Interpretation will dramatically improve with larger sample of OB stars and more accurate abundance analyses & distances

Mixing in OB stars

LMC

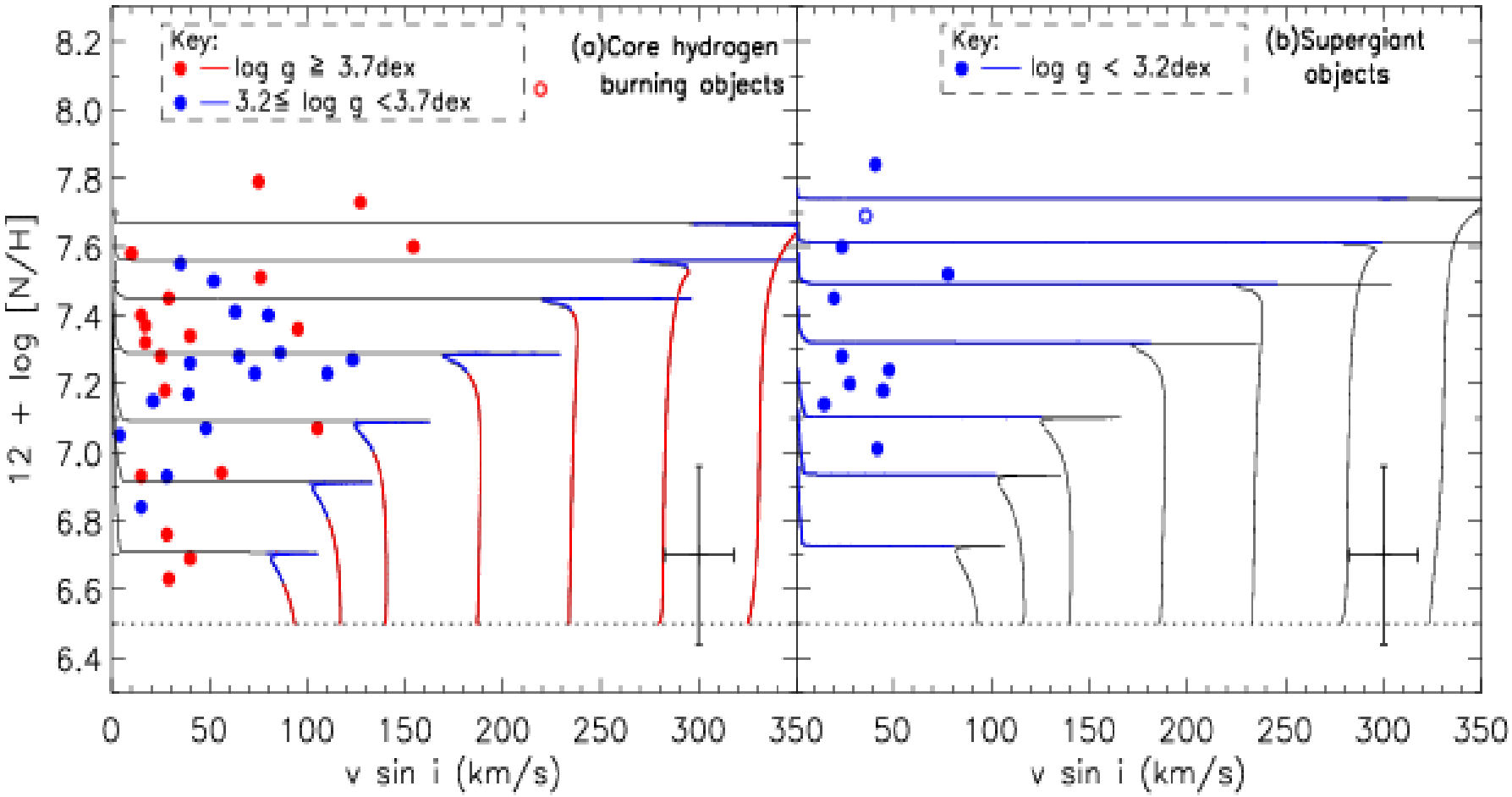
Hunter et al. (2009)



Mixing in OB stars

SMC

Hunter et al. (2009)



Mixing in OB stars

Table 2. The stellar parameters and absolute abundance estimates, together with their estimated uncertainties, for NGC 346-11 and AV 304. The quantities inside brackets are the number of lines used to estimate the abundances. For the ions denoted with a * the abundance estimates have been calculated using LTE rather than non-LTE methods as discussed in Sect. 3.4.

	NGC 346-11			AV 304		
$T_{\rm eff}$ (K)	32 500	±1000		27 500	±1000	
$\log g$ (dex)	4.25	±0.20		3.90	±0.20	
ξ (km s^{-1})	5	±5		3	±3	
Spectral Type	B0V			B0.5V		
C II	7.45	±0.29	(2)	7.36	±0.12	(3)
C III	7.44	±0.18	(2)	7.66	±0.30	(2)
N II	6.73	±0.31	(1)	6.55	±0.18	(1)
O II	7.82	±0.20	(22)	8.13	±0.10	(42)
Mg II	6.77	±0.23	(1)	6.77	±0.16	(1)
Si III	6.42	±0.25	(3)	6.76	±0.19	(4)
Si IV	6.39	±0.27	(3)	6.73	±0.44	(2)
Ne II*	–	–		7.84	±0.16	(2)
Al III*	–	–		5.33	±0.11	(1)
S III	–	–		6.40	±0.15	(7)
Fe III*	–	–		6.63	±0.23	(4)

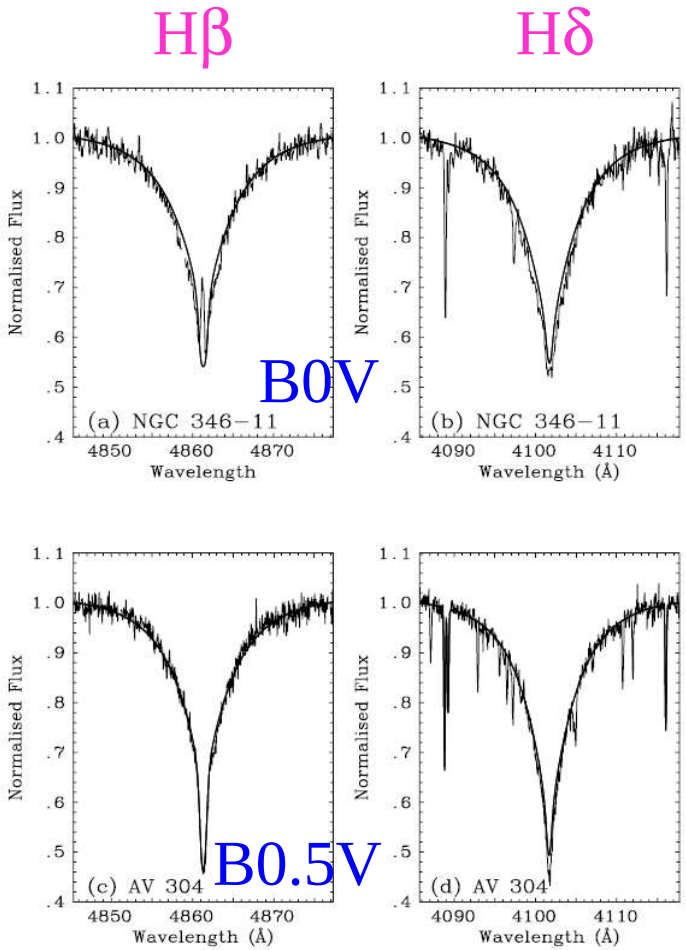
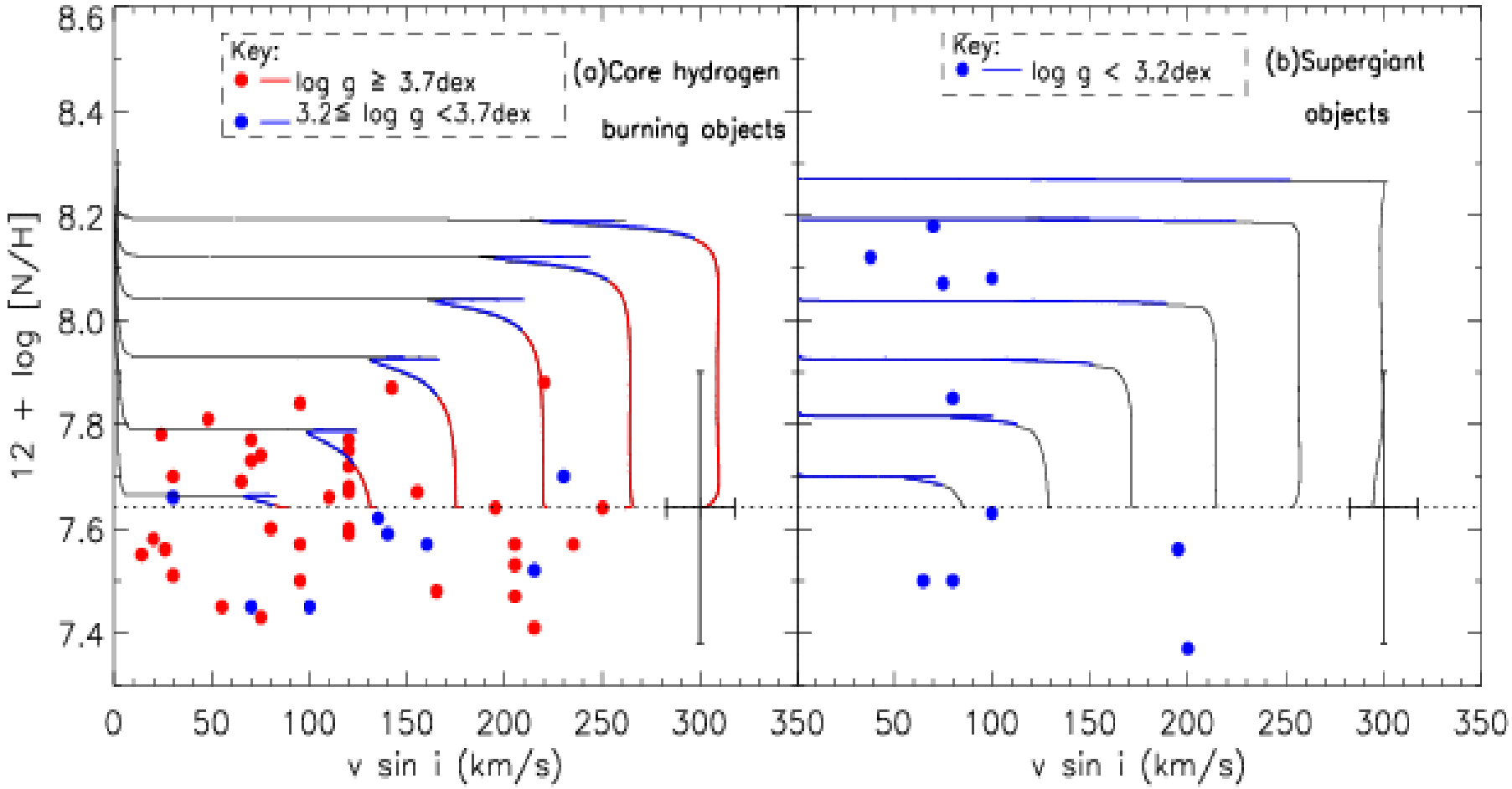


Fig. 3. Examples of the agreement between observed and theoretical (generated using the atmospheric parameters listed in Table 2) Balmer line profiles.

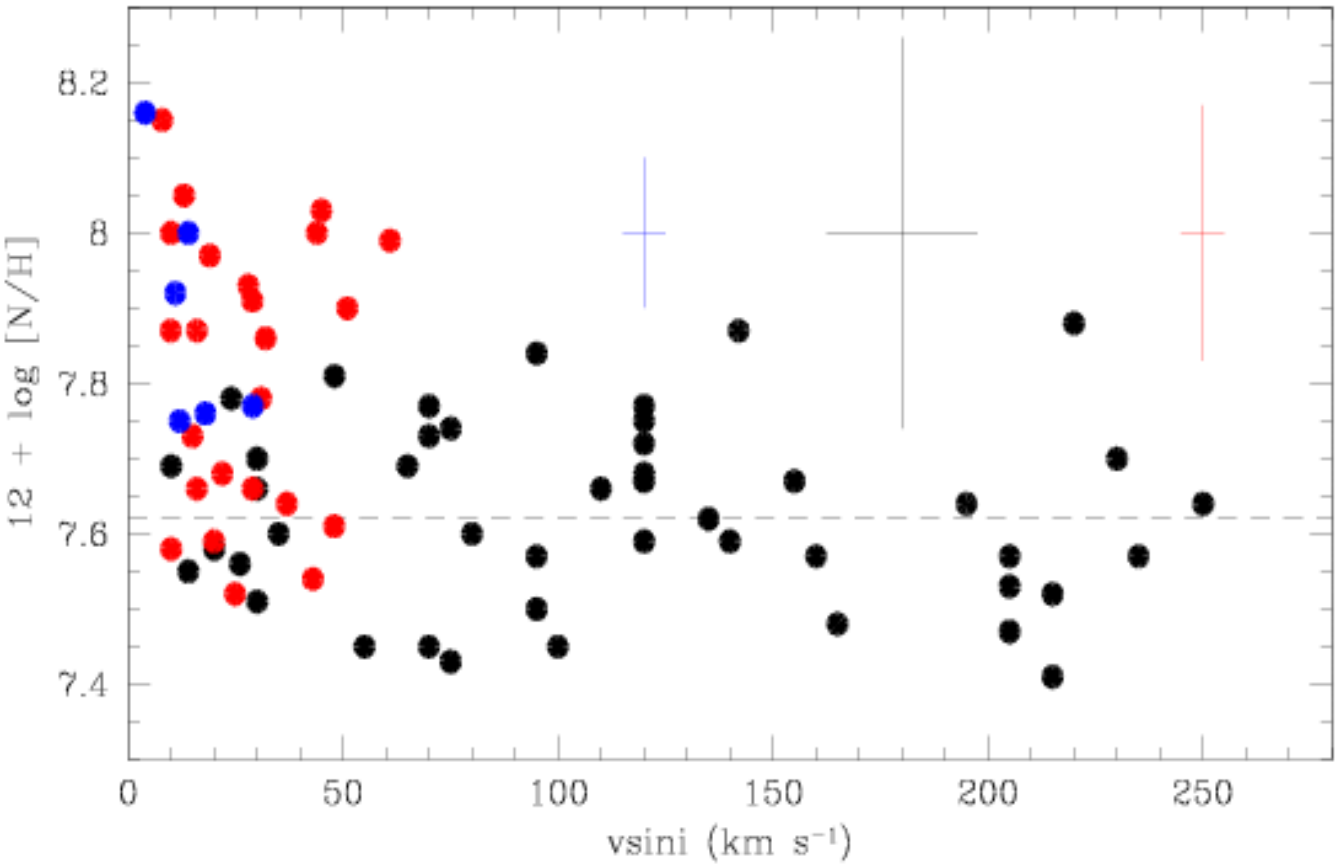
Mixing in OB stars

Galaxy

Hunter et al. (2009)



Mixing in OB stars



Hunter et al. (2009)

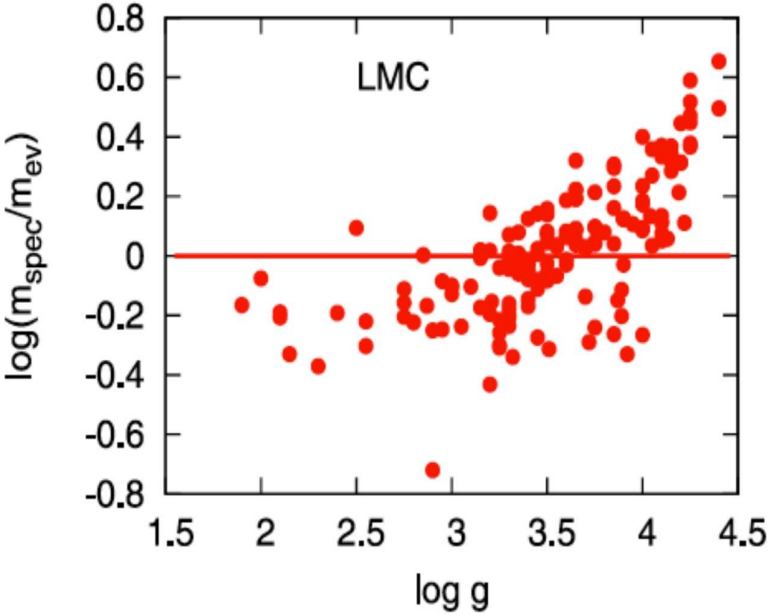
Przybilla et al. (2008)

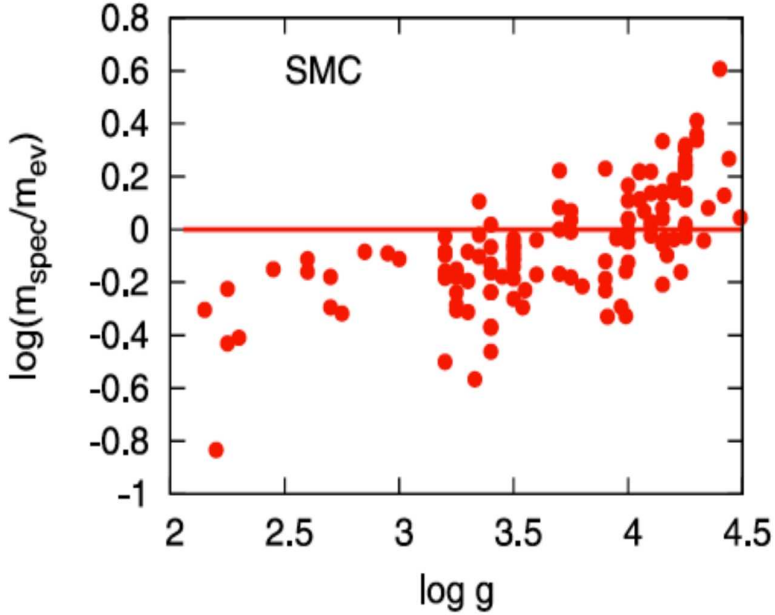
Morel et al. (2008)

~80 stars with sample bias?

O stars: mass discrepancy Mspec vs. Mevol

Herrero et al. (1992)

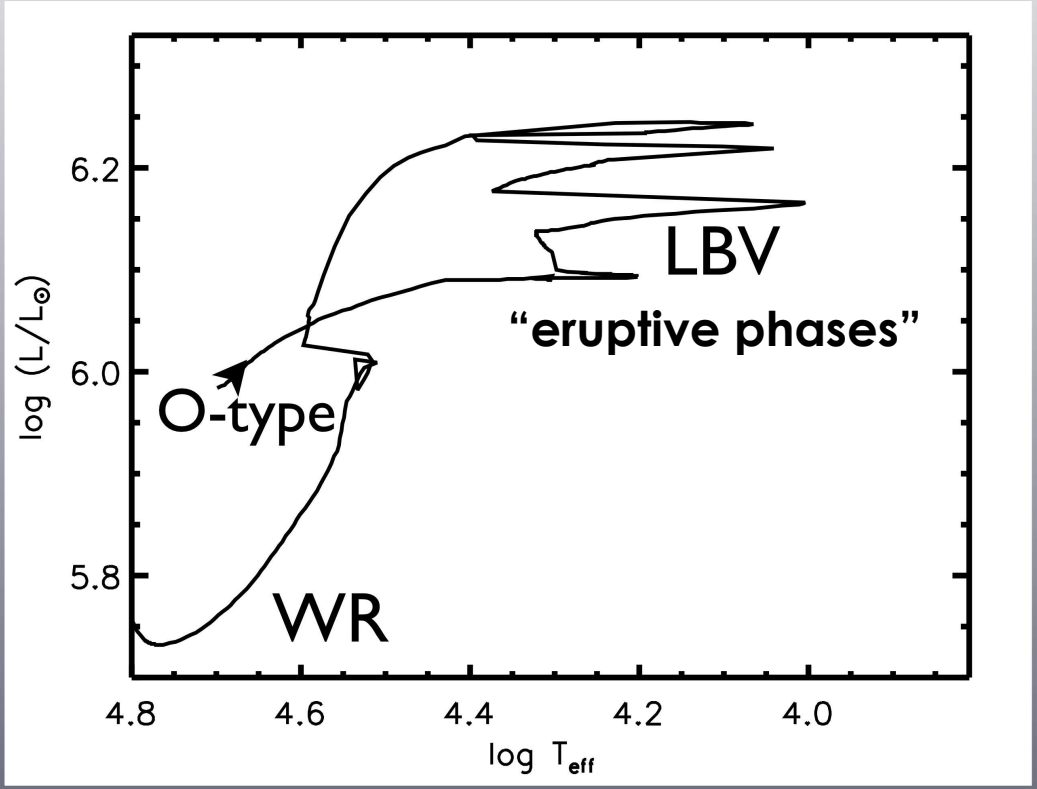




- More accurate log *g* & distances to O stars in clusters
- Also requires better evolutionary tracks including mass-loss and rotation

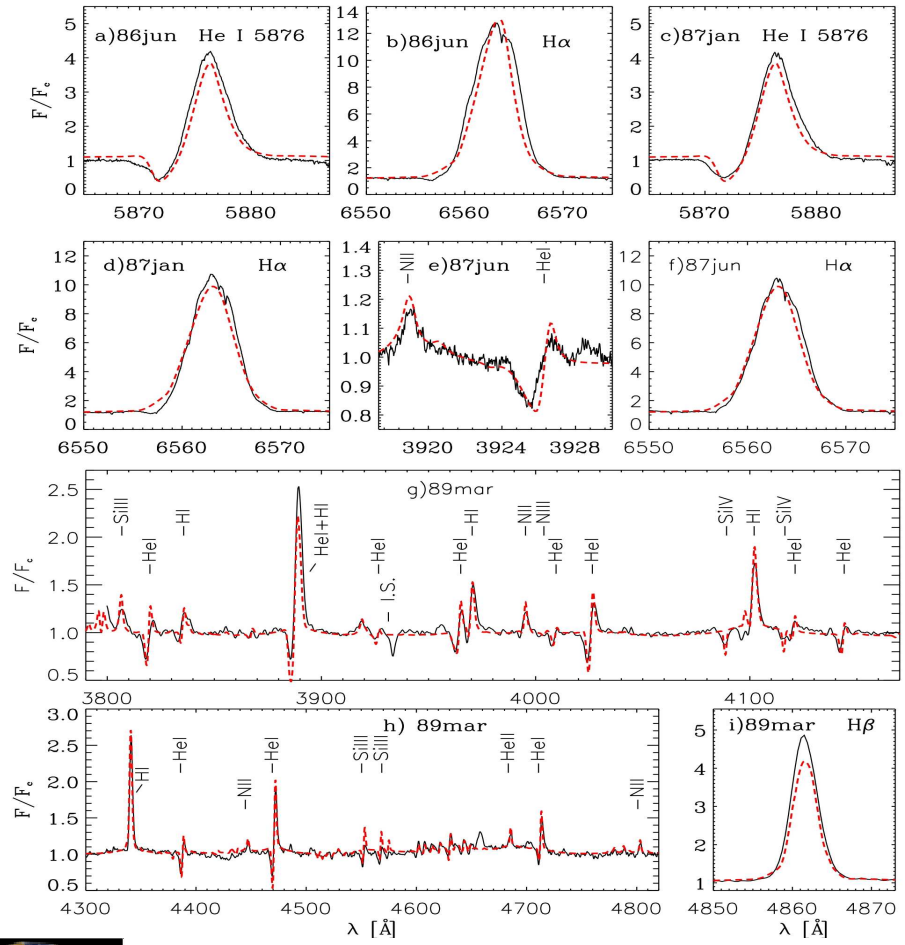
OB supergaints: evolution of 85 Msun star

O-type → Luminous Blue Variable → WR → SN



(evol. tracks from Meynet & Maeder 2003)

Spectroscopic analysis of massive hot stars in short-lived evolutionary stages

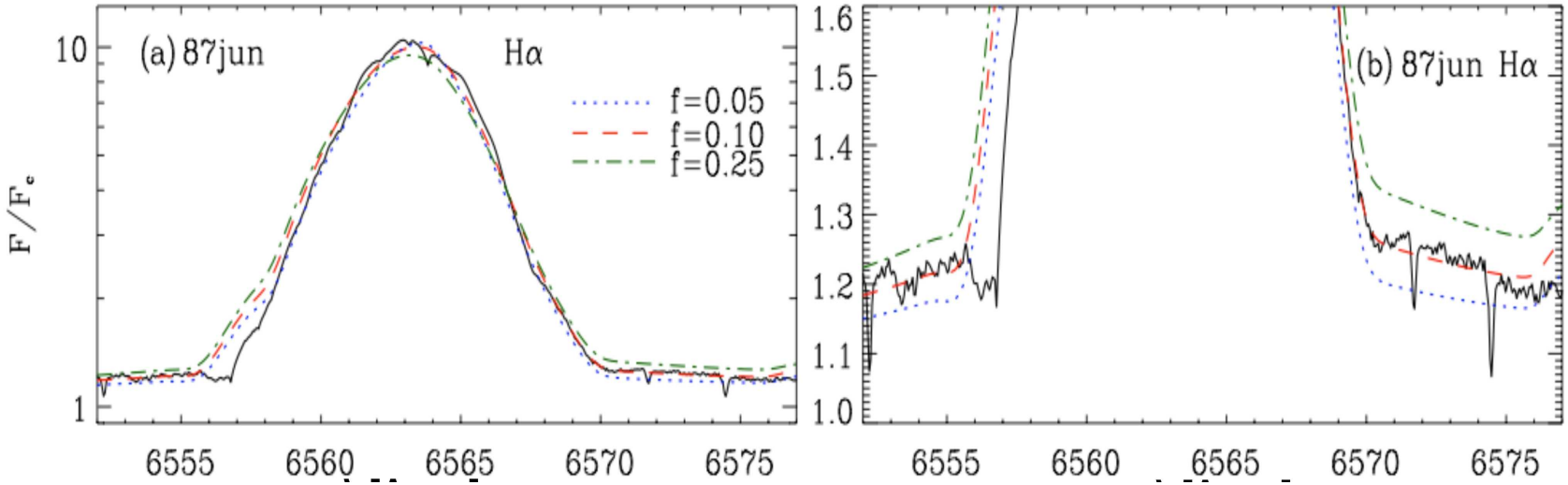


Example: AG Car (LBV)

- Teff from ionization balance: fitting lines of different ionization stages of the same element
- log *g* from pressure broadened Hδ and Hγ absorption lines
- Mdot from detailed fits to wind lines are 3 times over-estimated

Groh et al. (2009)

Spectroscopic analysis of massive hot stars in short-lived evolutionary stages



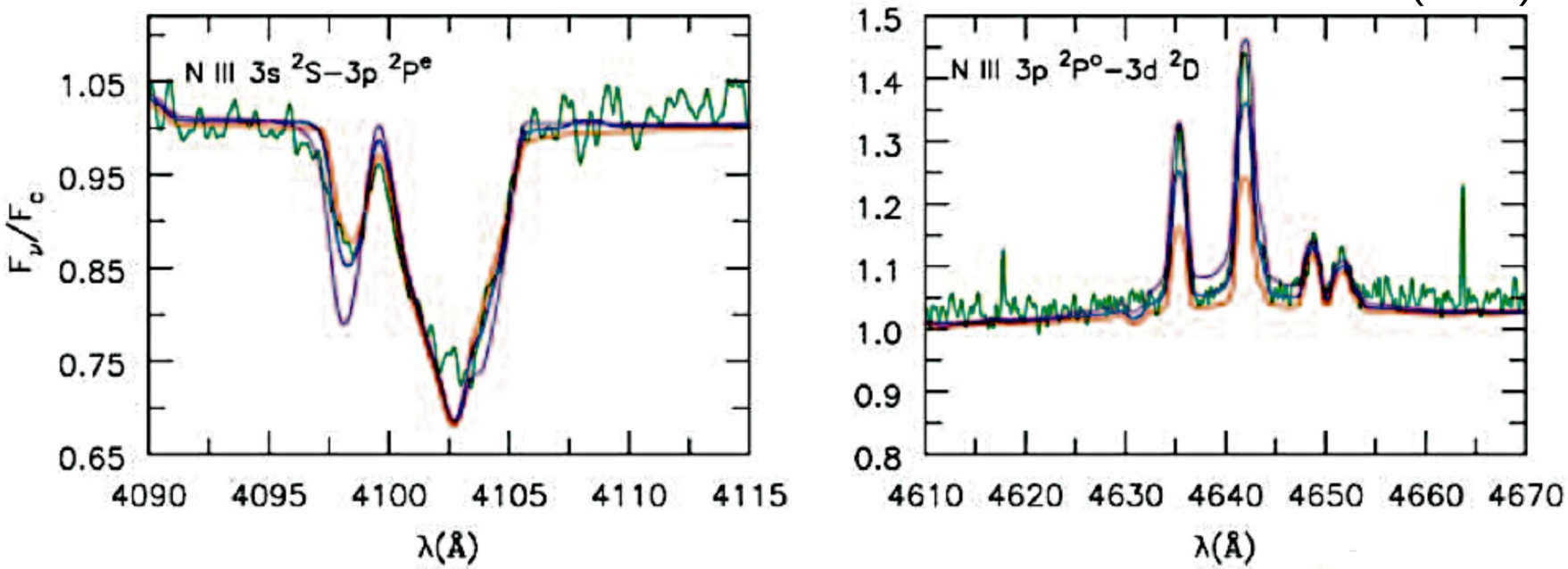
- Mdot and micro-clumping from fits to electron scattering wings of strong recombination lines such as Hα (requires S/N>50)

- Provides new clues about internal structuring (filling factors) of radiation-driven winds, formation of LBV nebulae, etc.

Spectroscopic analysis of massive hot stars in short-lived evolutionary stages

AV 83 (O7 Iaf+)

Hillier et al. (2003)



- C, N, O adundances from lines of a given species that are less affected by model details; best to use lines from two or more ionization stages

IN CONCLUSION

- Hot star spectra in GES will be studied by several research groups with a variety of scientific objectives, applying different models, RT codes, atomic data,...

- Important coordination issues for data processing and analysis are currently addressed.

- We expect a substantially smaller amount of hot star spectra compared to FGK stars, but both communities can learn from eachother, and possibly apply common data analysis tools.

Thanks and all hands on deck!