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

Spatial distribution of Spectral Types

7' ~ 100 pc
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

### Table: Cluster Selection

<table>
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<th>Cluster</th>
<th># Pointings</th>
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- 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)

Wind diagnostic

Teff diagnostic He II

Teff diagnostic He I

Teff diagnostic Si III
Observation strategy (Giraffe HR03)

Gravity diagnostic

Teff diagnostic Si II

Teff diagnostic Si IV

Teff diagnostic He I

Gravity diagnostic

Hδ
Observation strategy (Giraffe HR06)

Observation strategy (Giraffe HR14A)

Wind diagnostic

Teff diagnostic He II

Hα

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

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Affiliation</th>
<th>Country</th>
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<td>Ronny Blomme</td>
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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)

→ ATLAS + DETAIL + SURFACE = ADS method

3. Employs a well-trained automatic global fit method
OB Dwarfs and Giants (15 kK \leq T_{eff} \leq 35 kK)

N. Przybilla (Obs. Bamberg)

\begin{align*}
\log g \text{ (cgs)} & \quad 0 \\
T_{eff} \text{ (K)} & \quad 50000 10000 5000
\end{align*}

O9 to B4
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 $\gamma$ 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)

![Graph showing [Fe/H] vs R_G (kpc)]


- B Stars
- Open Clusters (Friel et al. 2002)
- Open Clusters (Chen, Hou & Wang 2003)
- PNe (Maciel, Costa & Uchida 2003)
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

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

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 an asterisk, the abundance estimates have been calculated using LTE rather than non-LTE methods as discussed in Sect. 3.4.

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<td>$T_{\text{eff}}$ (K)</td>
<td>32.500 ± 1000</td>
<td>27.500 ± 1000</td>
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<td>log $g$ (dex)</td>
<td>4.25 ± 0.20</td>
<td>3.90 ± 0.20</td>
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<td>$\xi$ (km s$^{-1}$)</td>
<td>5 ± 5</td>
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<td>±0.29(2)</td>
<td>±0.18(2)</td>
<td>±0.31(1)</td>
<td>±0.20(22)</td>
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<td>±0.11(1)</td>
<td>±0.15(7)</td>
<td>±0.23(4)</td>
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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 $M_{\text{spec}}$ vs. $M_{\text{evol}}$

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

Herrero et al. (1992)
OB supergiants: 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 H\(\delta\) and H\(\gamma\) 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 abundances 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 each other, and possibly apply common data analysis tools.
Thanks and all hands on deck!