Chemical abundances of fast-rotating OB stars

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Abstract

Fast rotation in massive stars is predicted to induce mixing in their interior, but recent observations have challenged this concept by revealing a population of fast-rotating stars with normal nitrogen abundances at their surface (Hunter et al. 2009, A&A, 496, 841; Brott et al. 2011, A&A, 530, A116, but see Maeder et al. 2014, A&A, 565, A39). However, as the binary fraction of these stars is unknown, the importance of mass-transfer processes cannot be quantified. As a result, no definitive statements about the ability of single-star evolutionary models including rotation to reproduce these observations can be made. Our work combines for the first time a detailed surface abundance analysis with a radial-velocity monitoring for a sample of bright, fast-rotating Galactic OB stars to put strong constraints on stellar evolutionary and interior models.

The project

By determining the abundances of the key elements expected to be affected by mixing (i.e., He, C, N, O) for a large sample of fast-rotating, bright O8–B0 dwarfs in our Galaxy, our project aims at addressing the efficiency of rotational mixing in these objects.

Several facilities are used: mainly el TIGRE (HEROS), complemented with archival data from the 1.93m telescope at the Observatoire de Haute-Provence (SOPHIE, ELODIE), various ESO telescopes (FEROS, UVES), NOT, AAT, as well as XMM-*Newton* that will not only allow us to validate the results obtained in the optical, but will also provide access to elements such as Ne, Si, Mg, and Fe that are not easily measured in the optical domain.

Parameters determination

Prior to any atmospheric parameters determination, radial velocities and projected rotational velocities, $v \sin i$, are estimated with the IRAF package RVSAO that makes use of the cross-correlation technique (Kurtz & Mink 1998, PASP, 110, 934) and the Fourier method (Gray 2005, The Observation and Analysis of Stellar Photospheres; Simón-Díaz & Herrero 2007, A&A, 468, 1063), respectively.

The T_{eff}, $\log g$, and helium abundance by number, $y = N(He)/[N(H) + N(He)]$, are estimated by finding the best match between a set of observed H and He line profiles, and a grid of rotationally-broadened, synthetic profiles (see Rauw et al. 2012, A&A, 546, A77). These have been computed using the non-LTE line-formation code DETAIL/SURFACE and Kurucz models. A microturbulence of 10 km s^{-1} was adopted.

An iterative scheme is used:

- T_{eff} is taken as the value providing the best fit to the He I and He II lines with the same weight given to these two ions;
- $\log g$ is determined by fitting the wings of the Balmer lines;
- y is determined by fitting the He I features.

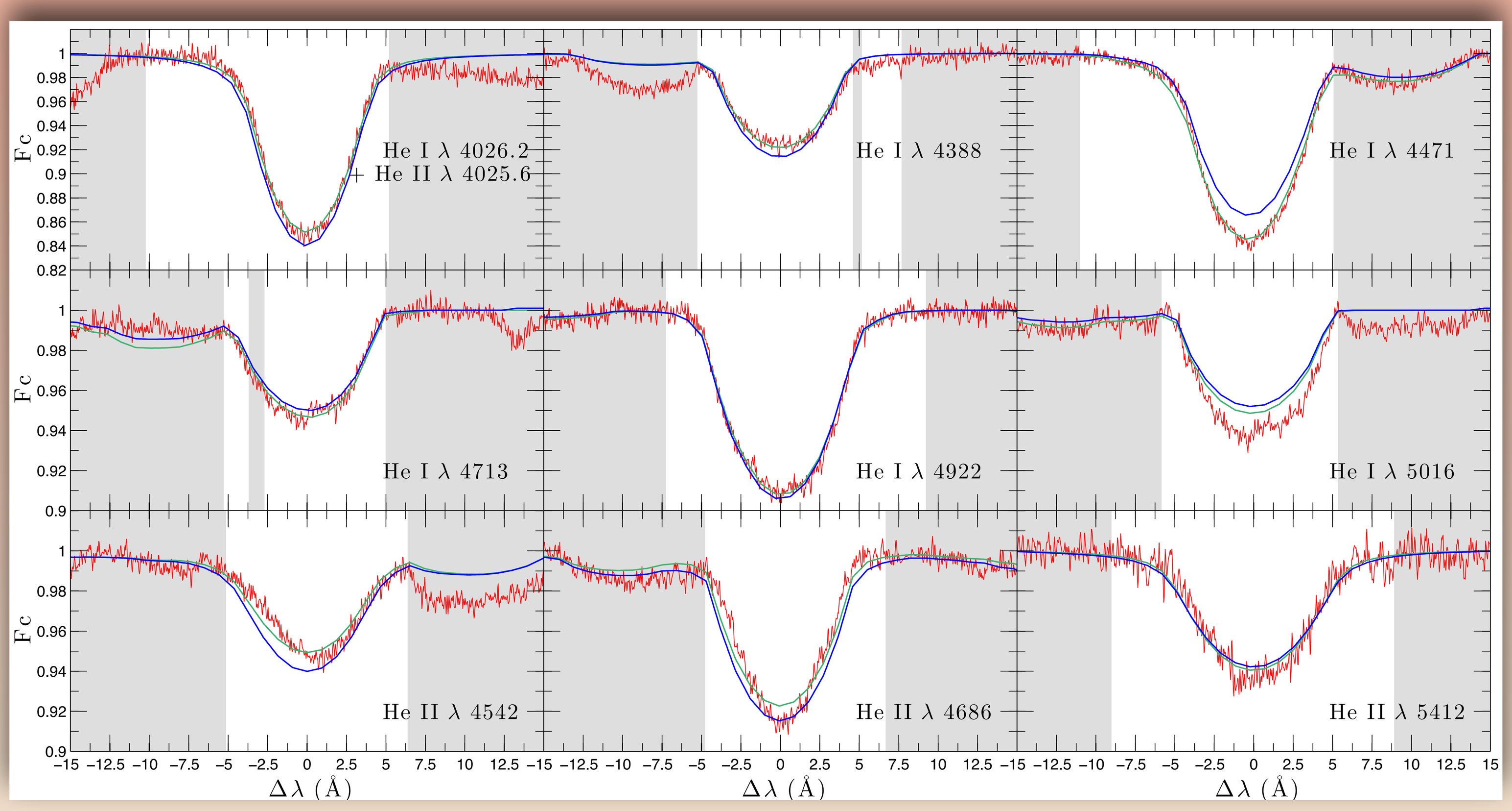

Fig. 1 – Comparison for HD 90087 (O9.2 III(n)) between the observed FEROS data (red) and best-fit He synthetic line profiles (green). The blue line stands for the line profiles computed for the final, mean parameters. The whitened areas delineate the regions where the quality of the fit has been evaluated.

CNO determination

After determining T_{eff} and $\log g$, CNO abundances are estimated by fitting synthetic profiles to three spectral domains in which the contribution of other elements can be neglected.

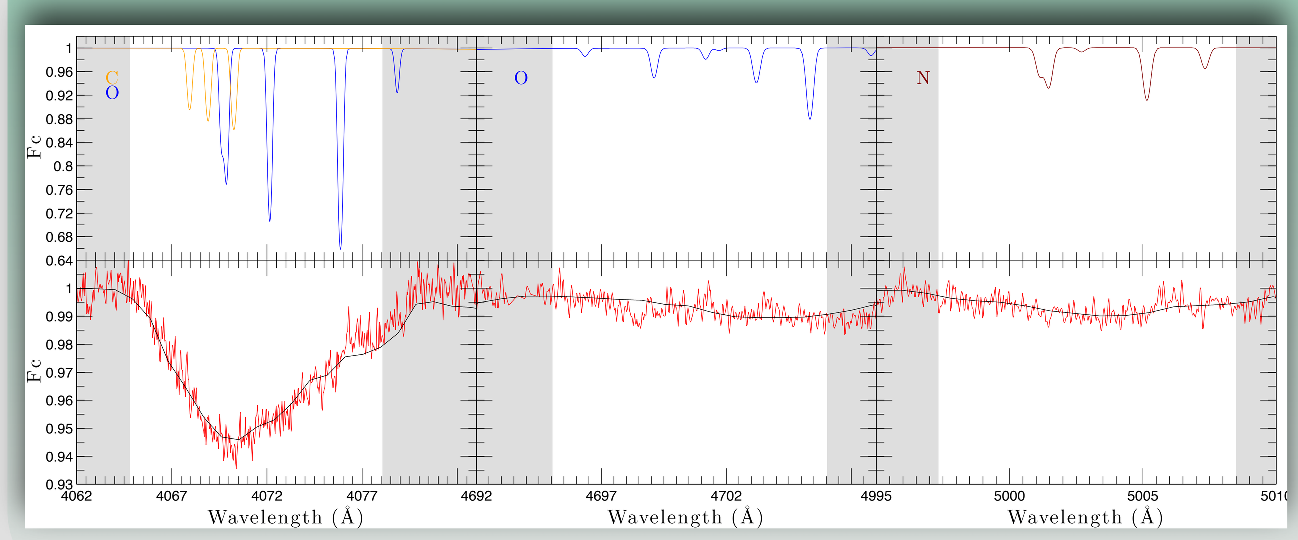

Fig. 2 – Comparison for HD 90087 between the observed profiles (red) and best-fit synthetic metal line profiles (black). The whitened areas delineate the regions where the quality of the fit has been evaluated. The top panels show the (non-rotationally broadened) synthetic profiles computed for the final parameters and abundances.

Results

A slowly-rotating star, 10 Lac (O9 V), was analysed to validate the procedure used to derive the atmospheric parameters and abundances. This star has its parameters and abundances derived from standard, curve-of-growth techniques (see Rauw et al. 2012 for another validation test involving two other stars).

	T_{eff} [kK] (±1.0 kK)	$\log g$ [dex] (±0.15 dex)	$v \sin i$ [km s (±7 kms	y (±0.03)	log ϵ(C) [dex] (±0.19 dex)	log ϵ(N) [dex] (±0.3 dex)	log ϵ(O) [dex] (±0.3 dex)	[N/C] (±0.32 dex)	[N/O] (±0.17 dex)
10 Lac	34.2	4.20	27	0.078	8.22	7.4	8.3	-0.84	-0.91
ζ Oph	31.9	3.78	390	0.151	8.04	7.9	8.4	-0.11	-0.51
1 Cam	30.7	3.90	280	0.121	8.00	7.6	8.4	-0.44	-0.88
HD 90087	31.4	3.60	282	0.181	7.62	7.7	8.3	+0.08	-0.55
HD 93521	30.9	3.67	390	0.178	7.56	8.0	8.2	+0.41	-0.27
HD 102415	33.3	4.00	357	0.174	7.24	8.3	8.0	+1.02	+0.22

Table 1 – Atmospheric parameters and metal abundances of the studied targets.

As seen in Fig. 3 and Table 1, the studied stars follow within the errors the prediction of N enrichment and C depletion at their surface, induced by rotational mixing. The photosphere of HD 102415 appears to be nitrogen overabundant at a level expected for a red supergiant, but HD 102415 is a main-sequence star: a single star analysis is thus inappropriate to describe this object, raising the possibility of a mass transfer in a binary (see, e.g., Ritchie et al. 2012, A&A, 537, A29).

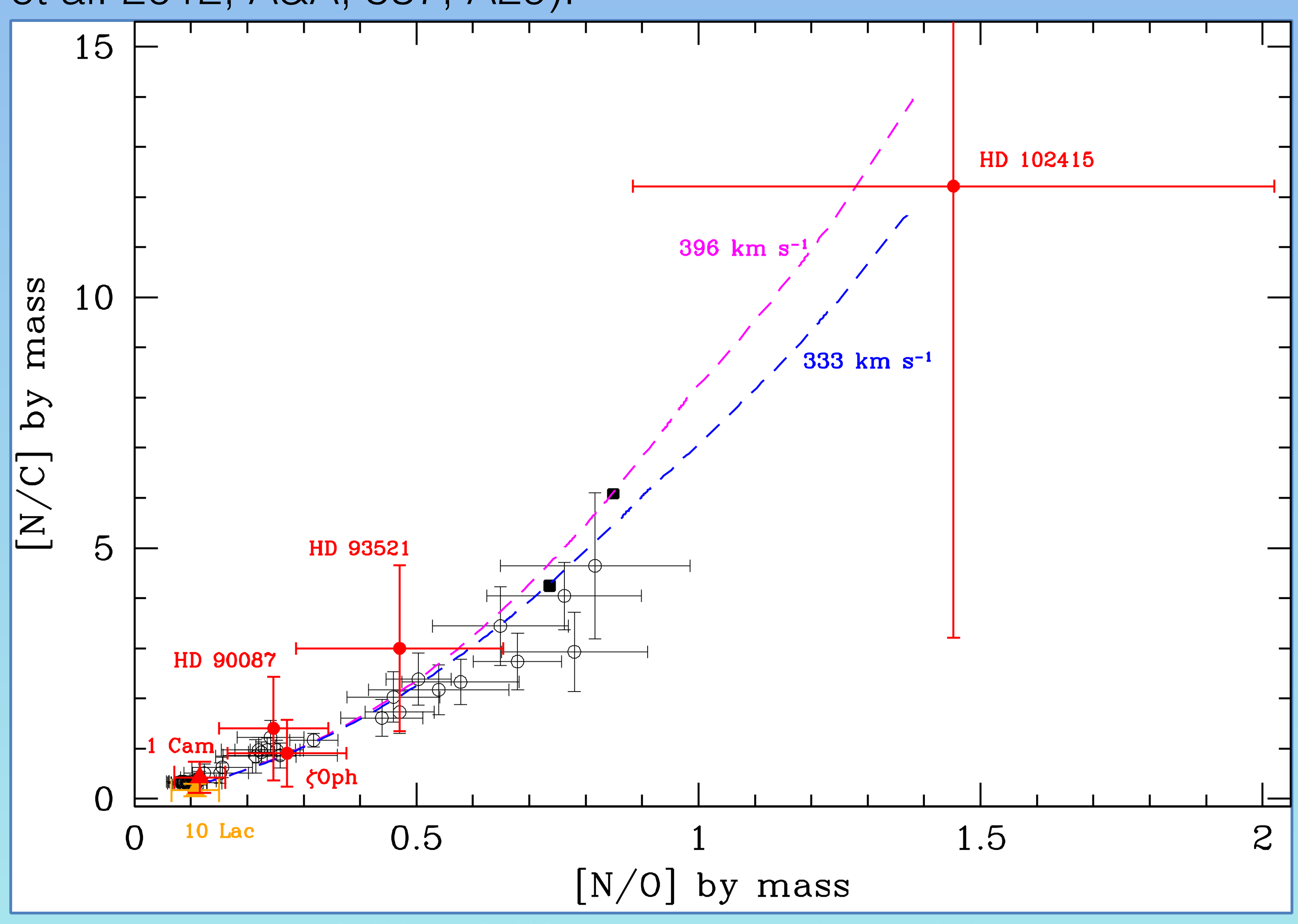

Fig. 3 – Dependence between the [N/C] and [N/O] abundance ratios (by mass). Open black circles: B stars from Przybilla et al. (2010, A&A, 517, A38). Solid red symbols stand for fast-rotating stars. Solid circles and triangles represent archival and el TIGRE data, respectively. Dashed lines show the predictions of Geneva models (Georgy et al. 2013, A&A, 553, A24) for 15 $M_{\odot}$, Z = 0.014, and two initial rotational velocities. Solid black squares indicate the beginning of the red supergiant phase.

Future work

- New el TIGRE data have recently been acquired (up to 34 time-resolved spectra per star) to enlarge the sample of studied stars;
- A radial-velocity monitoring will be performed;
- Results will be compared to the predictions of models to investigate the relevance of the conclusions presented by Hunter et al. (2009);
- We will account for the non-spherical shape due to fast rotation and the resulting gravity darkening.

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