The IACOB project: synergies for the Gaia era

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Abstract

The IACOB spectroscopic survey of Galactic OB stars is an ambitious observational project aimed at compiling a large, homogeneous, high-resolution database of optical spectra of massive stars observable from the Northern hemisphere. The quantitative spectroscopic analysis of this database, complemented by the invaluable information provided by Gaia (mainly regarding photometry and distances), will represent a major step forward in our knowledge of the fundamental physical characteristics of Galactic massive stars. In addition, results from this analysis will be of interest for other scientific questions to be investigated using Gaia observations. In this contribution we outline the present status of the IACOB spectroscopic database and indicate briefly some of the synergy links between the IACOB and Gaia scientific projects.

1 Introduction

The Gaia mission will gather a complete astrometric, photometric and spectroscopic dataset of over one billion stars. Its instrument performance (see e.g., \textsuperscript{[Prusti 2011]}) is designed to provide information about proper motions, radial velocities, photometric variability, distances, interstellar reddening, rotational velocities, atmospheric parameters, and element abundances of the observed stars. The Gaia observations will hence definitely challenge many aspects of our present view of the stellar component in the Milky Way.

While Gaia photometric and spectroscopic observations will allow a proper characterization of the stellar properties of late-B and cooler stars (including abundances), a similar study in the case of O and early-B type stars will be somewhat limited. On the one hand, the Balmer jump (planned to be observed by the Blue Photometer) is less accurate as indicator...
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Figure 1: IACOB-sweg spectra of four representative O stars in the optical (panels A and B) and Gaia (panel C) spectral ranges. Contrary to the optical range, the Gaia range is almost empty of stellar features in the case of O and early B-type stars. Note that the small narrow lines in the Gaia range (apart from the CII line) are telluric.

of the stellar temperature in this type of stars than in the case of cooler stars. On the other hand, as illustrated in Figure 1, the spectral range observed by the Radial Velocity Spectrometer is almost empty of spectral features which could be used to determine rotational velocities, and stellar parameters/abundances (contrarily to the optical range). Although Gaia observations will allow to distinguish between early/mid-O, late-O, and early-B type stars, a proper (accurate) determination of the stellar parameters will require to combine these observations with optical spectra (see more details in Section 2.2).

Complementing the Gaia database with optical spectroscopic observations of O and early-B stars is hence of crucial importance for any Gaia scientific project involving stellar parameters and/or abundances of massive stars. Some examples in the context of this conference include the full characterization of the IMF of stellar clusters (also accounting for the high-mass tail), the study of the impact of massive stars on the formation and dynamical evolution of young stellar clusters and associations, or the investigation of self-pollution by SNe Type II products in stellar associations with signatures of triggered star formation.

Although originally motivated by scientific drivers not directly related to Gaia, large (ongoing) optical spectroscopic surveys of O and B-type stars such as GOSSS (P.I. Maíz Apellániz), OWN (P.I. Barbá), NoMaDS (P.I. Pellerin), IACOB (P.I. Simón-Díaz), and IACOB-sweg (P.I. Negueruela) will become very valuable in the Gaia era. All these surveys, initially independent, are now coordinated and the corresponding spectroscopic databases are planned to be made public in the future for their maximum exploitation in different scientific contexts.

1The GREAT (Gaia Research for European Astronomy Training) networking programme also plans to observe massive stars in selected clusters as part of more general long term spectroscopic surveys preparing and following Gaia (see Blomme et al., 2011).
This contribution concentrates on the *IACOB spectroscopic database* and its scientific exploitation, specially remarking some of the synergy links between the IACOB and Gaia scientific projects. Notes on the other surveys can be found elsewhere (e.g. Barbá et al., 2010; Sota et al., 2011; Maíz Apellániz et al., 2011).

2 The IACOB project

The *IACOB project* (P.I. Simón-Díaz) aims at progressing in our knowledge of Galactic massive stars using a large, homogeneous, high-quality spectroscopic dataset and modern tools for the quantitative spectroscopic analysis of O and B-type stars. The project is divided into six main working packages. The first one is devoted to the compilation of the *IACOB spectroscopic database of Northern Galactic OB stars*, a very important piece of the project. The other five refer to the scientific exploitation of this unique database of high-resolution spectra, covering several aspects of interest in the massive star research:

| WP-1 | WP-2 | WP-3 | WP-4 | WP-5 | WP-6 |
|------|------|------|------|------|------|
| The *IACOB spectroscopic database* | Line-broadening in OB stars | Quantitative spectroscopic analyses | Abundances in OB-type stars | Binary/multiple systems | massive stars and the ISM |

The number of studies planned to be developed in the framework of the IACOB project (i.e. using spectra from the IACOB database) is large. At present, we are concentrating our efforts on the investigation of the so-called *macroturbulent* broadening affecting the line-profiles of massive stars and its possible connection to stellar pulsations (e.g. Simón-Díaz et al., 2010), on the revision of rotational velocities of Galactic OB stars, and on the accurate determination of the stellar and wind parameters of the single O and B stars in the sample. Some IACOB spectra have also been used to investigate the degree of chemical (in)homogeneity of B-type stars in the Ori OB1 association (Simón-Díaz, 2010; Nieva & Simón-Díaz, 2011), or to provide a firm confirmation of the presence of a third massive star component in the σ Ori AB system (Simón-Díaz, Caballero & Lorenzo, 2011).

Gaia observations will have a definite importance in some of the outcomes of the IACOB project (mainly regarding WP3). In addition, the analysis of spectra from the IACOB database (in combination with Gaia observations) will provide unvaluable information for other scientific projects studying our Galaxy and/or some of its components. Some examples of the synergies between IACOB and Gaia will be provided in Sect. 2.2, but first we briefly summarize the present status and some future prospects of the *IACOB database*.

2.1 The IACOB spectroscopic database: updates and future prospects

The first spectra for the *IACOB spectroscopic database* were obtained with the FIES instrument attached to the Nordic Optical Telescope (NOT) in El Roque de los Muchachos Observatory (La Palma, Spain) in November 2008. Since then, and up to August 2011, we have compiled ∼1000 spectra of over 200 bright Galactic OB stars with δ ≥-25 deg. The present version of the database (v2.0) is mainly built on the IACOB v1.0 (Simón-Díaz et al., 2010).
plus the following updates: (1) the number of observed stars and compiled multi-
epoch spectra has increased during 14 new observing nights from 105 and 720 to 204 and
984, respectively; (2) the database is now complete up to V = 8 mag in the case of O-type
stars; (3) the number of observed B0–B2 stars has also increased (now also including giants,
and not only dwarfs and supergiants).

New observations are already scheduled with FIES for September 2011. We plan (1)
to observe fainter O stars (up to V = 9 mag) with a somewhat lower resolution (R = 23 000),
(2) to increase the number of B-type stars in the database, (3) to obtain at least 3 epochs
for the whole sample, and (4) to follow up some of the detected binary/multiple systems.

Since June 2011 (and planned to be completed in November 2011) the IACOB database
also counts on a new supplement (IACOB-sweg, P.I. I. Negueruela). These new observations,
obtained with the HERMES spectrograph attached to the Mercator telescope in La Palma,
extend further to the red (up to 9000 Å) than the FIES spectra. They were planned to
investigate the spectroscopic behavior of MK standars with spectral types earlier than B9 in
the Gaia range for a optimal future exploitation of the GAIA spectra of this type of stars.

2.2 Quantitative spectroscopic analyses of massive stars in the Milky Way

As discussed in Sect. 1 and illustrated in Figure 1, the Gaia spectroscopic observations will be
empty of spectral features which could be used to extract information about the fundamental
physical parameters of OB-type stars. The situation is different when we consider the optical
spectral range. The quantitative spectroscopic analysis of this spectral range makes it possible
to determine the rotational velocities, effective temperatures, gravities and abundances of
these stars (see e.g. the recent review by Martins, 2011, and references therein). When
the optical analyses are complemented with the information provided by other spectroscopic
diagnostics (mainly the UV) we can also constrain the wind properties of the analyzed stars.

Nowadays we count with very powerful tools, such as advanced stellar atmosphere codes
and stellar evolution models, which have allowed us to make a remarkable progress in our
knowledge of the physical and wind properties of massive stars (see review by Puls, 2008). The
outcome of the quantitative spectroscopic analysis of medium and high resolution optical spec-
tra of Galactic OB-type stars by means of modern stellar atmosphere codes is now accepted
to have reached a high degree of reliability (viz. Herrero et al., 2002; Repolust et al., 2004;
Lefever et al., 2007; Markova & Puls, 2008; Simón-Díaz, 2010; Nieva & Przybilla, 2010). How-
ever, it is important not to forget that our interpretation of these results may be clearly biased
in some cases, mainly due to observational limitations.

The first point refers to the stellar luminosities, radii and masses. To obtain these
fundamental parameters we need to combine the derived spectroscopic parameters with in-
formation about the distance and extinction to the star. At present, the distance to most
massive stars in our Galaxy are poorly constrained and hence luminosities, radii and masses
resulting from our analyses are somewhat uncertain in many cases. Table 1 illustrates how
critical is this point in the case of the O9 V star 10 Lac (d ~ 580 pc). Fortunately, this situation
will change very soon thanks to Gaia.

The second point refers to binarity/multiplicity. Most or all massive stars are suspected
to be born as part of multiple systems (see e.g., Zinnecker & Yorke, 2007; Mason et al., 2006).
Table 1: Results from the analysis of 10 Lac (O9 V) assuming the present accuracy in distance, photometry and stellar parameters. The uncertainties in \( R \), \( L \), and \( M \) due to error propagation of the uncertainties in stellar parameters (\( T_{\text{eff}} \) and \( \log g \)) and distance are indicated separately. The later one (in brackets) clearly dominates. We need more accurate distances.

| Parameter | Value         | Reference                          |
|-----------|---------------|------------------------------------|
| \( d \)   | 589±79 pc     | Megier et al. (2009)               |
| \( m_v \) | 4.879±0.008   | Maíz Apellániz et al. (2004)       |
| \( B-V \) | -0.201±0.010  | Maíz Apellániz et al. (2004)       |
| \( A_v \) | 0.214±0.03    | Martins & Plez (2006)              |
| \( M_v \) | -4.15±0.30    |                                    |
| \( T_{\text{eff}} \) | 35000±600 K   |                                    |
| \( \log g \) | 3.87±0.10 dex |                                    |
| \( R/R_\odot \) | 7.52±0.09 [±1] |                                    |
| \( L/L_\odot \) | 4.88±0.02 [±0.12] |                                |
| \( M/M_\odot \) | 16±3 [±5] |                                    |

and references therein). Many of these binary/multiple systems remain still unresolved; therefore, it would not be so strange to find studies of massive stars in which its multiple nature has not been detected (since these are based on single-epoch spectroscopic and photometric observations) and consequently the derived stellar parameters are erroneous.

Finally, even in isolated objects, other secondary properties such as mass-loss rate and rotation also have an important impact on stellar evolution of massive stellar objects (Meynet & Maeder, 2000); while it would be desirable to consider a sample of isolated stars large enough to investigate in a systematic manner the effect of all these parameters, the number of objects analyzed up to now in a consistent way is still limited.

Quantitative spectroscopic analyses of multi-epoch, large sample observations of Galactic OB stars (combining spectroscopy, photometry, and accurate distance determinations) are hence one of the important steps to improve our knowledge of massive stars and clarify some of the gaps that still remain in this important field of Astrophysics. The IACOB project is following this approach in the case of Galactic stars. At present, we are performing the analysis of the stars included in the IACOB spectroscopic database following an automatic best-fit strategy based on a extensive grid of synthetic HHe spectra computed with the FASTWIND stellar atmosphere code (see details in Simón-Díaz et al., 2011b). As a results of this analysis, the project will provide a complete database of stellar parameters of Galactic OB stars homogeneously determined. As commented above, the use of accurate distances and multi-band photometry will be of crucial importance to complete the stellar parameters determined spectroscopically with luminosities, radii, and masses. In this sense, Gaia observations will come right on time.

The final aim of the IACOB spectra and the associated database of stellar parameters (including also rotational velocities and abundances) is to increase the amount of observational constraints which may help to advance in some of the still outstanding problems in the field of massive stars. In addition, they can be used to study e.g. the kinematics of some of the Galactic OB clusters and associations, or the impact that massive stars have on the formation of other stellar objects (via their strong winds and ionizing fluxes). Finally, we plan to provide the spectral energy distributions (SEDS) predicted by the FASTWIND code for all the analyzed stars so they can be then used in the study of the interstellar extinction along different line of sights (when combined with the observed SEDs provided by Gaia).
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