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The IACOB project: *Hunting for spectroscopic binaries in the OB supergiant domain. The pulsational variability menace*

Abstract: *A large percentage of massive stars are born as part of binary or multiple systems. This statement, which has been defended by some authors during the last 3 decades – and has important consequences on the evolution, final fate and chemo-dynamical feedback of massive stars – has been recently confirmed by intensive spectroscopic, interferometric, and lucky imaging surveys of O-type stars. While this result has motivated many on-going theoretical and modelling developments, it is also of prime importance to extend the empirical studies to the blue and red supergiant domains in order to provide further empirical insights about the percentage and characteristics of binary systems along the evolution of massive stars. In this contribution, we concentrate in the OB supergiant domain and show the importance of taking into account the effect of stellar oscillations to properly identify actual spectroscopic binaries, avoiding erroneous results about the percentage of binaries in the evolved descendants of the Main Sequence O-type stars.*

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Context

Recent spectroscopic and high-angular resolution surveys of O-type stars have provided fresh insights on the **multiplicity properties of main sequence massive stars** (see *Sana 2017, Barbá et al. 2017, Vanbeveren 2017*, and references therein):

- the observed fraction of **spectroscopic binary/multiple** systems with at least **one O star** component reported by several medium and large size spectroscopic surveys ranges between **42% and 68%.**
- when information from high-angular resolution surveys is also considered, the observed multiplicity fraction of **Galactic O-type stars with close-by companions** can reach up to **90%**.

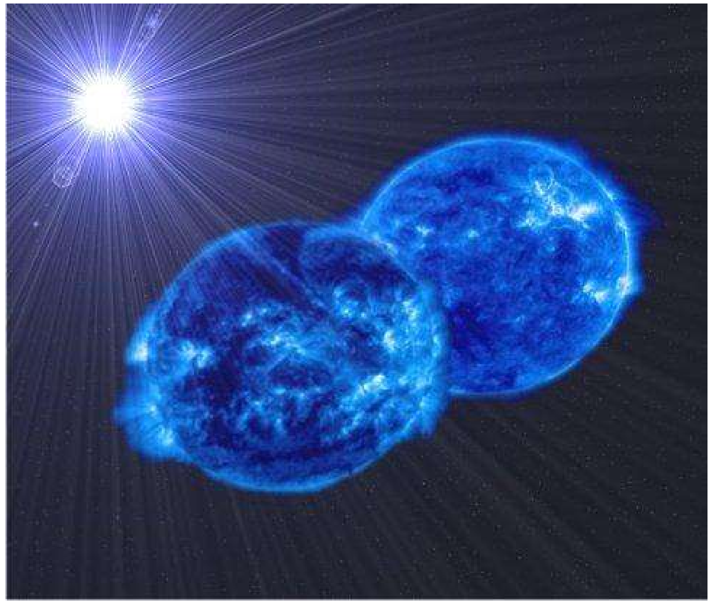


Image credit: J. Lorenzo (U. Alicante)

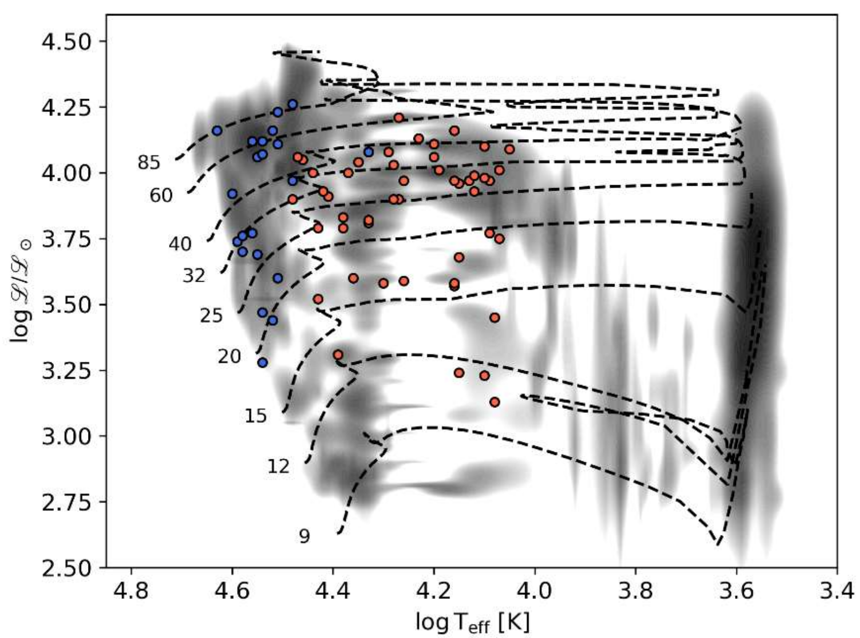
These observational results have definitely reinforced the long-standing statement that **we should not forget binary interaction when investigating massive star evolution** (e.g., *Vanbeveren 1993*). Indeed, based on empirical arguments, *Sana et al. (2012)* proposed that **25%** of the massive binary systems will interact while both components are still on the main sequence, and nearly **70%** of all massive stars will exchange mass with a companion at some point during their evolution.

Theoreticians and modelers are working hard with the aim of investigating the impact that binary interaction may have on our present knowledge about massive stars evolution (e.g. *Song et al. 2013, 2016, 2018; de Mink et al. 2013, 2016; Eldridge et al. 2017*). We are also increasing the amount of available information about the **orbital and physical properties of O-type binaries** (e.g., *Almeida et al. 2017; Barbá et al. 2017; Sana 2017; Martins et al. 2017; Maíz Apellániz et al. 2019*). This is allowing us to build empirical distributions of binary periods, mass ratios, and eccentricities using statistically significant samples of binary and multiple systems in different environments.

Time is ripe to perform similar observational studies in **other phases of the evolution of massive stars beyond the main sequence** (e.g. the so-called **blue and red supergiants**). Eventually, this is a very important and necessary step if we want to empirically constrain any theoretical attempt to connect the early evolutionary phases of massive binaries and their end products (represented by the O and B main sequence star, and the **black hole and neutron star binaries** leading to gravitational wave emission - if they merge at some point of their lifetimes -, respectively).

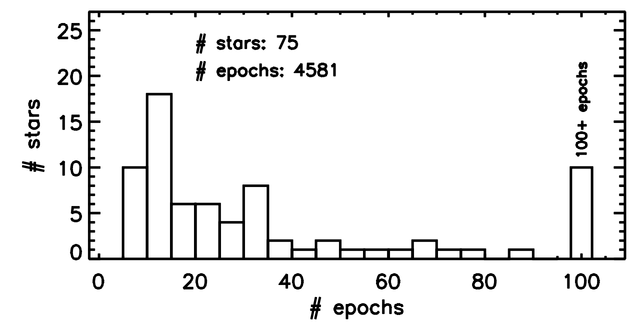
Aims, sample, observations and methodology

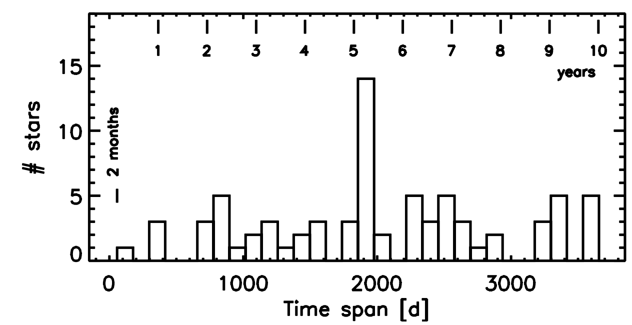
- We want to **establish the percentage of spectroscopic binaries** (SB) in a statistically representative sample of **evolved Galactic OB supergiants** (Sgs) by means of high quality multi-epoch spectroscopy.
- We benefit from more than 4500 high-resolution spectra of 56 Galactic O and B supergiants (plus 13 O-type dwarfs/subgiants and 6 early-B giants) gathered by the IACOB project (*Simón-Díaz et al. 2015, 2020*) during several observing runs allocated between 2008 and 2018.
- We apply modern semi-automatized techniques to obtain estimates for some of the spectroscopic parameters of each star (not identified as double line spectroscopic binary) in our working sample.
- We (visually) identify SB2 systems. We obtain radial velocity (RV) estimates for all available spectra in our working sample, and compute the associated peak-to-peak amplitude RV variations using appropriate photospheric diagnostic lines (O III 5592, Si III 4552, Si II 6347).
- We carefully inspect the detected line-profile variability in all stars with RV_{pp} > 3 $km s^{-1}$ to separate the clear SB1 systems from those stars in which the detected variability is produced by stellar oscillations or the effect of a non-homogeneous stellar wind.



Location of the **investigated sample** of Galactic O stars (blue) and B-Gs/Sgs (red) – not identified as SB2 – in the spectroscopic HR diagram. For reference, we also include in the background a gray scale representation of the probability density distribution of a sample of 575 Galactic massive stars (from *Castro et al. 2014*).

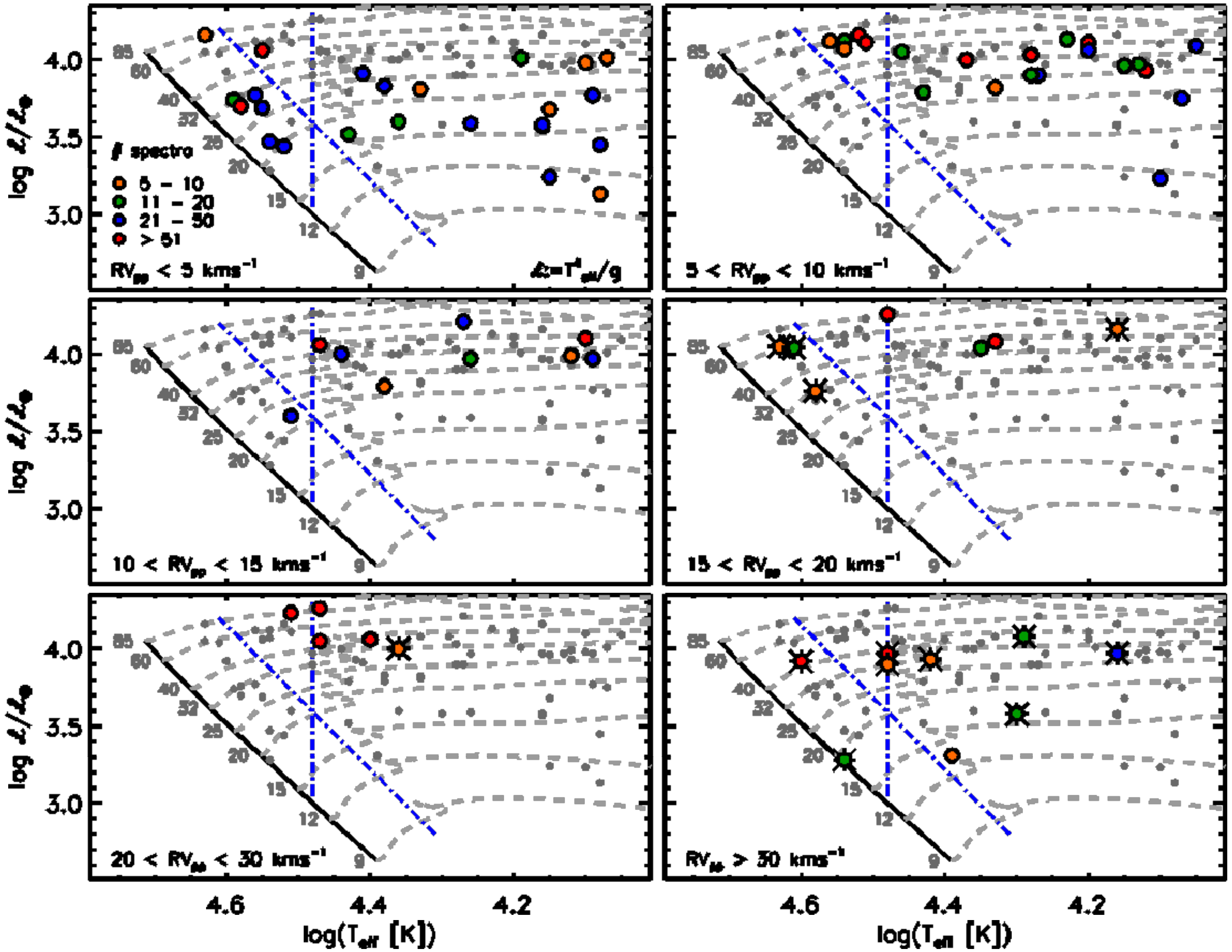
Histograms with the **number of epochs** (top) and the **time-span** of the observations (bottom) associated with the studied sample of O stars, B-Sgs and early B-Gs.

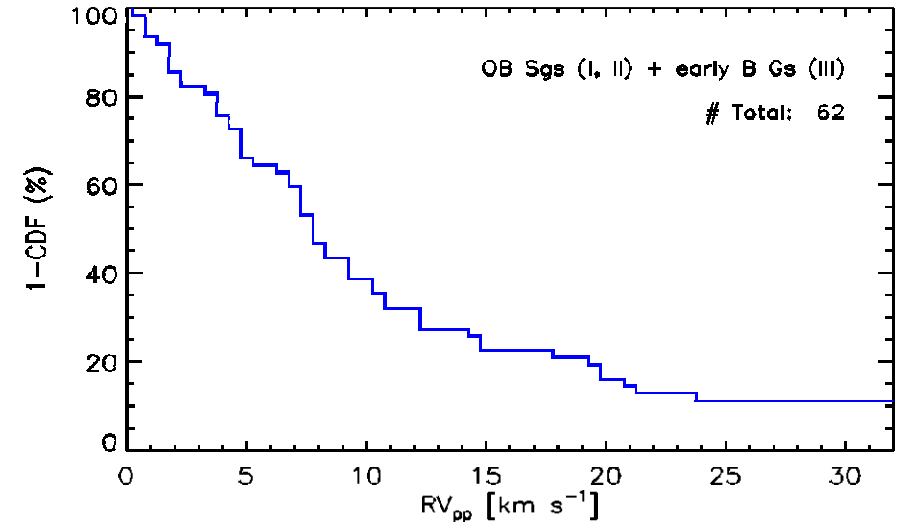




Results: Distribution of RV variability in the sHRD

Spectroscopic HR diagram for the studied sample of stars (excluding SB2) separated and ordered by **RV_{pp} bins**. Big circles are colored differently depending on the **number of epochs** available for the corresponding star. ZAMS and evolutionary tracks from non-rotating models by *Ekström et al. (2012)*. Vertical dashed-dotted line roughly separates the **O and B star domain**. The inclined line parallel to the ZAMS roughly separates **dwarf/subgiant stars** from **the more evolved giants/supergiants**. Stars highlighted with an asterisk are **confirmed spectroscopic binaries**.



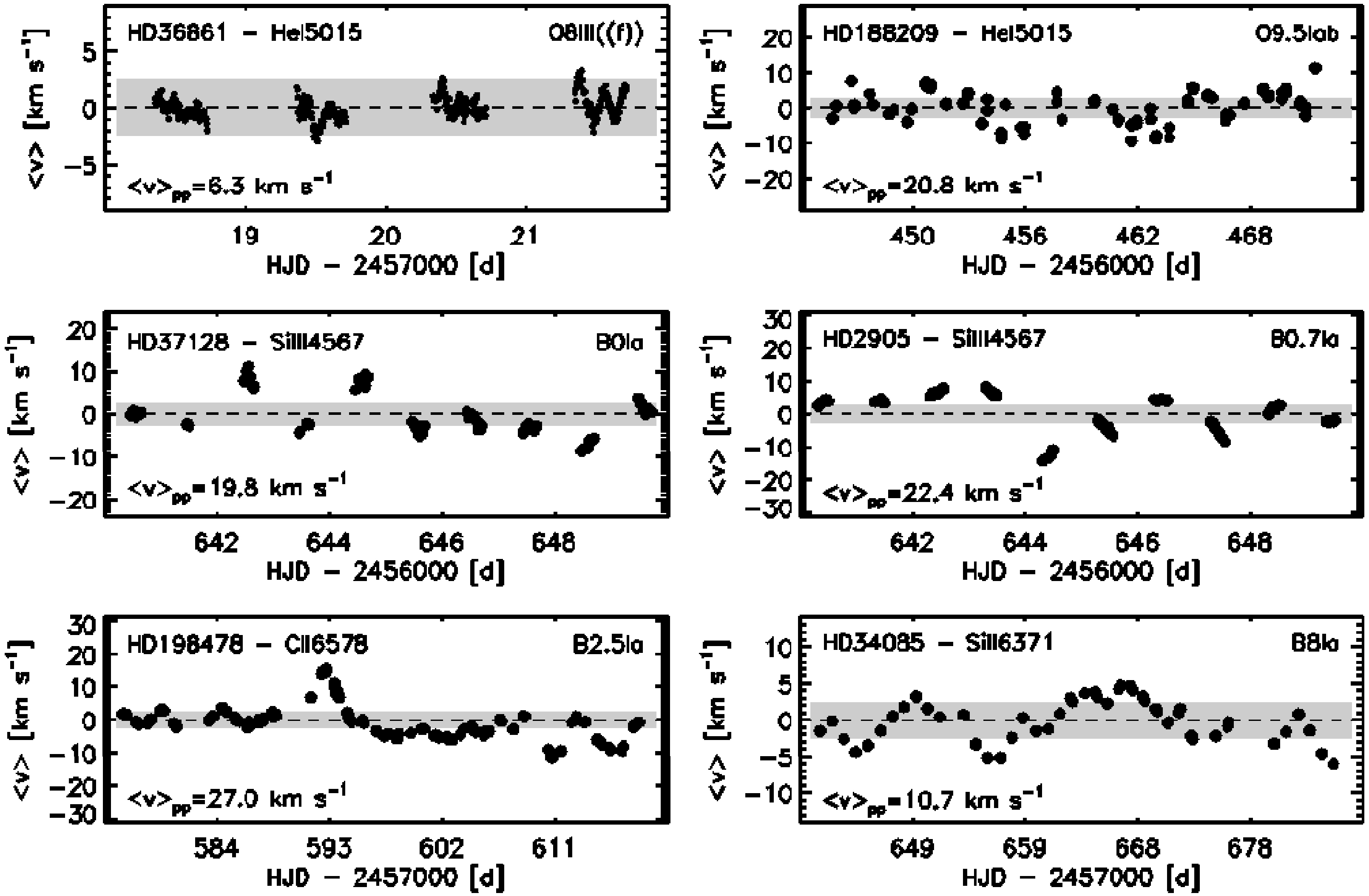


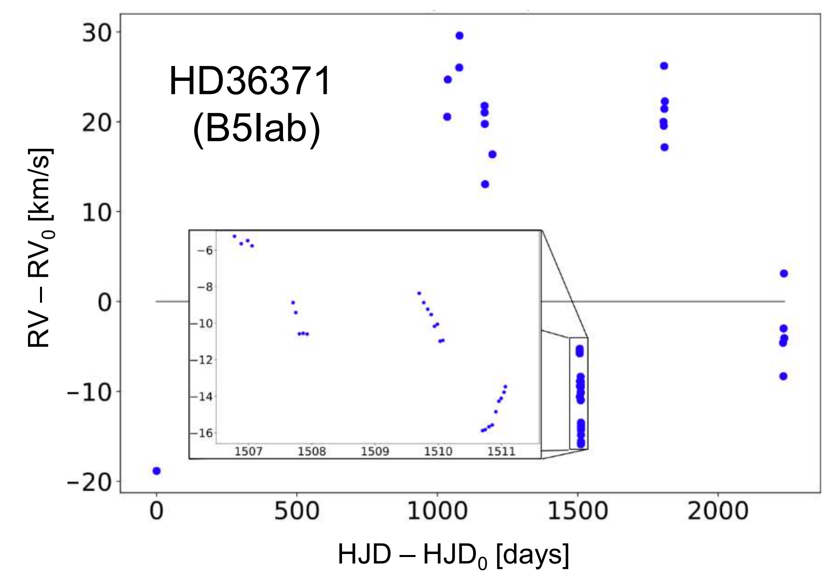
Percentage of detected SB1 depending on the considered **threshold** used to separate the effect of **intrinsic variability** from RV variations associated with the **orbital motion** in a binary system.

Given the high accuracy of our RV measurements (better than 1-2 km/s), if we assume no intrinsic variability, the percentage of detected SB1 systems in the OB Sg domain would reach **80-90%**.

A **more realistic threshold**, accounting for intrinsic variability (25-30 km/s, see next slide), moves down this percentage to **10-15%**.

Illustrative examples of **RV curves obtained for single stars** in the OB Sg domain. The detected variability, which in this case is clearly not associated with the orbital motion in a binary system, but with **stellar oscillations** of different type (e.g. heat driven p- and g- modes, internal gravity waves) and /or stellar wind variability, can reach up to **25 – 30 km/s** in some cases. A careful inspection of the detected variability (specially in the case of multi-epoch observations with a poor duty cycle) is compulsory in those case with RV_{pp} < 30 km/s to avoid spurious detections of spectroscopic binaries. Note the different time scales and amplitude of variability detected for the various stars **depending on the spectral type** (i.e. in the case of massive stars, evolutionary status)





Obviously, intrinsic variability of similar amplitude is also present in the case of spectroscopic binaries. Despite in this case the detection of the SB1 system is clear, a proper characterization of the RV curve requires a proper sampling of both the orbital motion and the intrinsic variability.

Wrapping up! (for the moment)

- Our study has lead to a percentage of detection of clear spectroscopic binaries in the OB Sg domain of 10-15%
- We have established that intrinsic variability phenomena present in the OB Sg domain can lead to RV variations up to 25-30 km/s.
- Hence, it is important to design appropriate observing campaigns, including a combination of long term (years) low duty cycle (days/months) and short term (days/weeks) higher duty cycle (hous) observations to eliminate as much as possible spurious detections of SB1 stars.
- The same argument applies when aiming for a proper characterization of the orbital motion in those massive binaries including at least one OB Sg by means of the RV curve.
- The established percentage of SB systems among evolved blue massive stars is much lower than the usual percentage of Main Sequence O-type stars established by large spectroscopic surveys (42-68%).
- However, the former could be somewhat higher if we take into account that some of the SB1 system including one OB Sg are expected to have RV_{pp} amplitudes below 15-20 km/s. In this case the RV associated with the orbital motion cannot be efficiently disentangled from the effect of intrinsic stellar variability.

- We are presently extending the number of investigated targets to provide a more robust result about the percentage of SBs in the OB Sg domain.
- We plan to search for correlations between the detected RV variability and photometric variation (as provided by the TESS mission) in a large sample of OB Sgs with the aim of defining an empirical strategy which helps to establish – in a case-by-case basis – the minimum threshold in RV to be considered in a given star to ascertain that the detected peak-to-peak amplitude of RV variation is due to binarity and not intrinsic variability.