Spectroscopic variability in giant and supergiant massive stars

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Resumen / Las estrellas masivas ($M_{\rm ZAMS} \gtrsim 8$ M$_\odot$) están entre los objetos astronómicos más importantes y difíciles de caracterizar. Sus principales características todavía se conocen poco. Este conocimiento es particularmente limitado en el caso de las estrellas masivas gigantes y supergigantes. El relevamiento OWN *Survey* detectó variaciones, cuyo origen aún no está claro, en los espectros de varias O gigantes y supergigantes. Hemos seleccionado una muestra de 17 de estas estrellas que estamos observando en forma intensiva. Intentamos caracterizar su variabilidad espectral y establecer si la misma es originada por la multiplicidad o por otras causas. En este trabajo presentamos algunos resultados preliminares de este estudio: el descubrimiento de que HD 152314 es un sistema múltiple formado por dos binarias de largo período; la confirmación de que HD 152424 y HD 152723 son sistemas binarios; y la detección de variaciones de velocidad radial en intervalos cortos en estas estrellas.

Abstract / Massive stars ($M_{\rm ZAMS} \gtrsim 8$ M$_\odot$) are among the most challenging and important astronomical objects. However, their main characteristics are still poorly known. This scant knowledge is particularly limited among giants and supergiants. The OWN Survey has detected variations of undetermined origin in the spectra of several giant and supergiant O-stars. We are conducting an intensive observational study of a sample of 17 stars, aiming at characterize their spectral variability and establish if it is originated by multiplicity or other causes. In this work we present some preliminary results of this study, i.e.: the discovery that HD 152314 is a multiple system of two long-period binaries, the confirmation that HD 152424 and HD 152723 are binary systems, and the detection of short term radial velocity variations in these stars.

Keywords / stars: massive — binaries: spectroscopic — supergiants — stars: early-type — stars: individual (HD 152314, HD 152424, HD 152723)

1. Introduction

Massive stars, those ending their evolution as core collapse supernova, play a key role in the chemical and dynamical evolution of galaxies. Having masses $\gtrsim 8$ M$_\odot$ when arrive at the Zero Age Main Sequence, and spectral types earlier than B3, they also originate black holes and neutron stars. However, their main characteristics are still poorly known, specially among giants and supergiants. Most massive stars are found in binaries and multiple systems (Barbá et al., 2017; Sana et al., 2012). These binaries are specially interesting because they allow to determine several fundamental parameters of its components.

In 2006 begun the OWN Survey (Gamen et al., 2008; Barbá et al., 2017): a long-term, high-resolution spectroscopic monitoring of all southern O-stars catalogued in GOSC v1.0 (Maíz-Apellániz et al., 2004) and some WN stars from the VIIth catalogue of galactic Wolf-Rayet stars (van der Hucht, 2001). This survey is specially focused on determining the multiplicity status of these stars and, when possible, to calculate orbital parameters and masses of systems components.

Currently, the database of the OWN Survey includes more than 8 000 high-quality spectra of ~ 300 stars. Analyzing this database was appreciated that the multiplicity rate seems to be smaller among supergiants than in dwarf and giants O-stars (Barbá et al., 2017). This result, if confirmed, could have an important impact on evolutionary models and arose the question on whether this peculiarity was due to an observational bias or not.

On the other hand, a quick look at the spectra of giants and supergiants indicated that some of them showed different kind of variations with time (i.e. changes in radial velocity, intensity and shape of spectral lines). This observations motivated the doctoral thesis of R.H., who is conducting a detailed analysis of these variations by using mainly spectroscopic observations designed specifically to address this matter.

In this work we outline this observational project, its targets and methodology. We present also some relevant preliminary results found in three of the stars under study.

2. Target selection and observations

We selected, from the OWN Survey database, giant and supergiant stars with variations of at least 10 km s^{-1} detected in primary radial velocity (RV) measurements. Some of the stars in this sample are binaries with known periods, while others only have RV variations that do not present evidence of periodicity. In Table 1, we listed the stars of the sample, their spectral classifications and

Oral contribution

Table 1: Stars selected for this study.

Name	Spectral classification	V
HD69464	O7Ib(f)	8.8
HD75211	O8.5II((f))	7.5
HD75222	O9.7Iab	7.4
HD76968	O9.2Ib	7.2
CPD -47 2963	O5Ifc	8.5
HD93160	O7III((f))	7.6
HD101545A	O9.2II	6.9
HD114737	O8.5III	8.0
HD152314	O9.2IV(n)	7.7
HD152405	O9.7II	7.3
HD152424	OC9.2Ia	6.3
HD152723	O6.5III(f)	7.1
HD153919	O6Iafcp	6.5
HD154643	O9.7III	7.2
HD169582	O6Iaf	8.7
HD117797	O7.5fp	9.2
HD322417	O6.5IV((f))	10.2

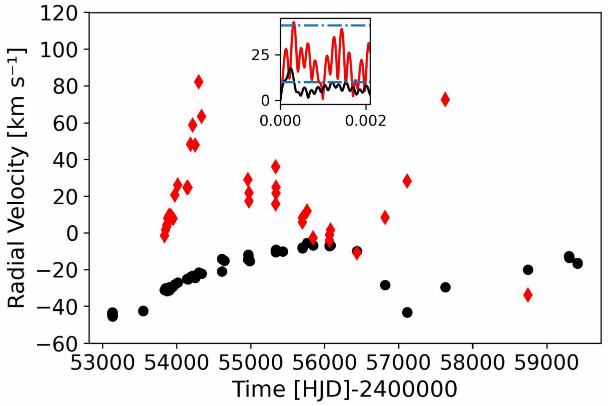

Figure 1: RVs of HD 152314 measured on He II lines (black) and Si III and Fe II (red). Inset (same in following figures): Fourier spectrum (amplitude vs. frequency [d^{-1}]); blue line: three times the noise level.

magnitude.

Our main set of spectra comes from the OWN Survey database and was secured with the instruments described in Table 2. Besides, we are observing the stars of our sample from CASLEO with the highest possible temporal rate. Our technique consist in observing each target as long as possible each night, taking one spectra after another.

The spectra obtained at CASLEO and LCO were reduced using the package IRAF*. Those secured with FEROS were extracted using the MIDAS pipeline provided by the European Southern Observatory (ESO) .

3. Analysis

We measured RVs of the stars by fitting gaussian profiles to several spectral lines on each star. This fit was performed using the task `splot` on the package `onedspec` of IRAF. In each star we tried to pick isolated lines from different ions. The error in RVs was estimated as the standard deviation of RVs in Na I interstellar lines.

All the RVs available for a given star were plotted against time and visually inspected, paying attention to the possible existence of more than one component and to long-term trends. On each spectrum, the RVs measured in different lines were compared and eventually averaged if they showed a similar trend. Then we look for periodic oscillations in the RVs. To do it, we calculated a Fourier spectrum for each star using Period04 (Lenz & Breger, 2005). We considered as candidate periods those corresponding to a peak in the Fourier spectrum three times higher than the noise level. Then, we visually inspected the aspect of the RVs when phased using these periods. Finally we fitted preliminary orbital solutions to the RVs using FOTEL (Hadrava, 2004).

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4. Results

4.1. HD152314

HD152314 (ALS 3817; $\alpha = 16^{\mathrm{h}}\,54^{\mathrm{m}}\,32\overset{\mathrm{s}}{.}0$, $\delta = -41^\circ\,48'\,19''$) is a O9.2IV(n) (Sota et al., 2014) member of the open cluster NGC 6231 (Baume et al., 1999). It was proposed by Sana et al. (2008) to be a double-line spectroscopic binary (SB2). We also found lines from two stars in our spectra. However, the RVs that we measured, plotted against time (see Fig. 1), show different shapes and periods for each star. The earlier star (the one that exhibit He II lines), is a single-line spectroscopic binary (SB1) with a period of 4085±46 days. The latter one instead (having Si III lines) is another SB1, but with a period of 3022±55 days. Sana et al. (2014) found evidence that HD152314 has two more components. The second period can be from one of these components.

4.2. HD152424

HD152424 (ALS 3829, $\alpha = 16^{\mathrm{h}}\,55^{\mathrm{m}}\,03.33^{\mathrm{s}}$, $\delta = -42^\circ\,05'\,26.99''$) is also a member of NGC 6231 (Baumgardt et al., 2000), preliminary considered an SB1 by Sota et al. (2014). We are studying 85 spectra of it, taken since 2008. 41 of them were obtained in two consecutive nights.

We measured RVs from He I $\lambda\lambda$ 4922, 5875, He II λ 5411 and C IV λ 5801 identifying a probable orbital period of 217 days previously unknown (see Fig. 2). Besides, the dense temporal sampling allowed us to note variations in RV within hours, superimposed to the orbital motion, in three consecutive nights of July 2021 (see Fig. 3).

4.3. HD152723

HD152723 (ALS 3854, $\alpha = 16^{\mathrm{h}}\,56^{\mathrm{m}}\,54.67^{\mathrm{s}}$, $\delta = -40^\circ\,30'\,44.46''$) is an SB1. We are analyzing 53 spectra of this system, taken since 2006. We measured He I

Table 2: Instruments used in this work.

Observatory	Telescope	Instrument	Spectral coverage [Å]	R
CASLEO	Jorge Sahade (2.15-m)	REOSC-DC	3600–6100	15 000
Las Campanas	Irénée du Pont (2.5-m)	échelle	3450–9850	40 000
Las Campanas	Landon Clay (6.5-m)	MIKE	3300–9500	33 000
ESO/La Silla	MPG (2.2-m)	FEROS	3570–9200	48 000

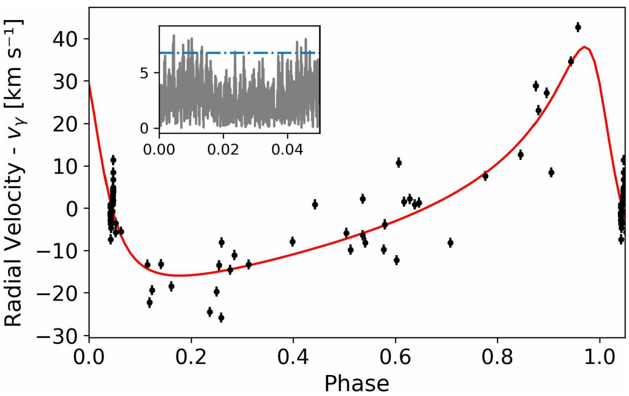

Figure 2: RVs of HD 152424 folded with period ≈ 217 d (v_γ: systemic velocity). Red line: fitted orbital solution.

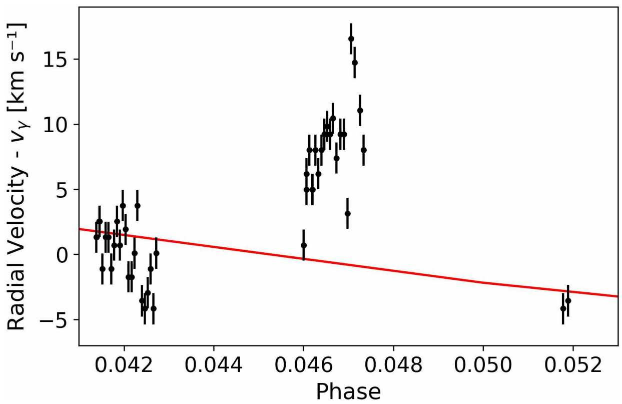

Figure 3: RVs of HD 152424. Detail on phases of three consecutive nights in July 2021 from Fig. 2.

λ 5875, He II $\lambda\lambda$ 4542 and 5411, confirming an orbital period of 18.9 days (cf. Sota et al., 2014). We noticed variations added to the orbital motion that deserve further observation (see Fig. 4).

5. Summary and future work

The long-term coverage, quality and spectral resolution of OWN Survey data, added to a carefully measurement of RVs in the targets selected, and the new, intensive observations of these systems, allowed us to gain new insights into the spectral variability of them. The multiple status of a system (HD 152314) is being clarified, and the periodicity of a couple of binaries (HD 152424 and HD 152723) is becoming evident. Additionally, we added new evidence of non-orbital RV variations, that

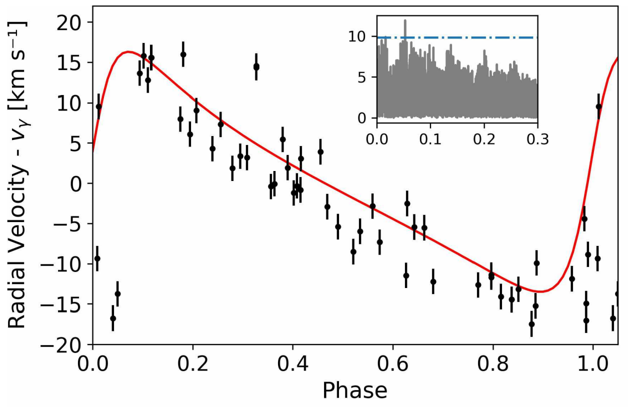

Figure 4: RVs of HD 152723 folded with period ≈ 18.9 d (v_γ: systemic velocity). Red line: fitted orbital solution.

would allow to better characterize it later. We plan to complete this analysis by including photometric observations from different missions (e.g. TESS, Kepler, K2) and a contrast with theoretical models.

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