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DETECTION AND CHARACTERISATION OF DOUBLE-LINED SPECTROSCOPIC BINARIES IN THE GAIA-ESO SURVEY

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Abstract. Binary systems are ideal targets to test theories of stellar formation, stellar evolution and nucleosynthesis. Numerous questions are still open and among them, that of the frequency of binary systems. A crucial step to shed new light on this topic is to identify and characterise those objects. Thanks to the medium-to-high resolution spectra provided by the Gaia-ESO survey, it is possible to derive precise radial velocities and then, to hunt new multiple stellar systems across the Milky Way.

Keywords: surveys: Gaia-ESO survey, stars: binaries: spectroscopic, methods: data analysis, techniques: radial velocities, techniques: spectroscopic

1 Introduction

The Gaia-ESO survey (Gilmore et al. 2012; Randich et al. 2013) is an on-going large spectroscopic survey, aiming at providing the community with precise radial velocities and chemical abundances for 10^5 stars. The FLAMES/UVES and FLAMES/GIRAFFE multi-fibre spectrographs are used with different configurations to record high- ($R \sim 47\,000$) and medium ($R \sim 20\,000$) resolution spectra, over a broad range of wavelengths (from 4200 Å to 8990 Å). The fifth internal data release (iDR5) comprises the data obtained from the start of the observation campaign, on December 31st 2011 until January 1st 2016. About 400 000 individual spectra have been recorded for more than 80 000 unique targets.

Our work takes advantage of the numerous spectra recorded by the Gaia-ESO in order to identify and characterise spectroscopic binaries among faint sources (V from 12 to 19, with a median $V = 15$). We focus on Milky Way disc stars observed with the GIRAFFE setups HR10 and HR21, which amounts to nearly 200 000 individual spectra, corresponding to 42 000 unique targets.

2 Method

Merle et al. (2017) developed a semi-automated pipeline, Detection Of Extrema (Doe), to identify double-lined (or more) spectroscopic binaries (SB$n \geq 2$) among Gaia-ESO spectra. We remind the main steps of the analysis: 1/ a cross-correlation function (CCF) is simultaneously smoothed by a Gaussian kernel and derived three times; 2/ first and third derivatives are used to look for local maxima and/or inflexion points; 3/ the positions of those remarkable points provide the velocity of the stellar components forming the suspected multiple stellar system; 4/ multi-epoch and multi-setting observations are used to qualitatively (with flags: probable, possible or tentative) estimate the probability that the stellar multiplicity is real.

We noted that the detection efficiency of SB2 varies between HR10 and HR21 CCFs: with HR10 observations, we are able to detect systems with a velocity difference Δv as small as $25\,\mathrm{km\,s^{-1}}$ while the minimum Δv is $60\,\mathrm{km\,s^{-1}}$ for HR21 observations. The reason is that the HR21 wavelength range ([8475, 8985 Å]) comprises strong and saturated lines like the near-infrared Ca II triplet and H Paschen lines. Those lines tend to broaden the profile of the HR21 CCFs and hamper the detection of stellar components.

We defined new cross-correlating masks by carefully selecting weakly blended, not saturated absorption lines in the HR10 and HR21 spectral domains. We performed this selection for eight (HR10) and twelve (HR21) spectral types, which sample the FGK dwarf and giant parameter space. We then used these new masks to

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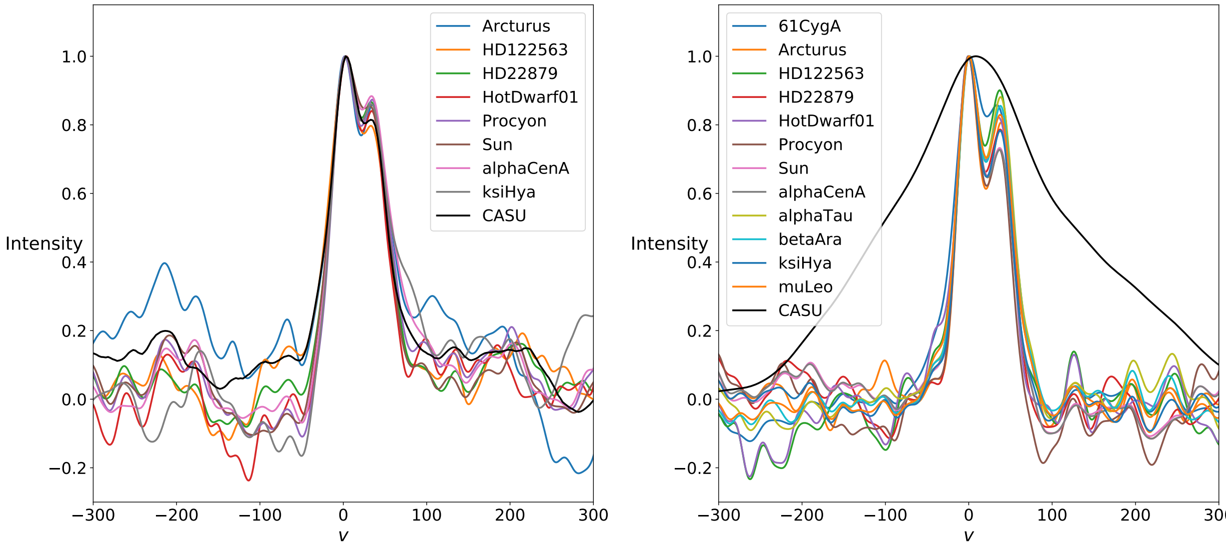

Fig. 1. *Left panel:* Gaia-ESO (black line) and NCP (other coloured lines) HR10 CCFs for 07272578-0310066. The model star used to build a given NCP mask is indicated in the legend. *Right panel:* Gaia-ESO and NCP HR21 CCFs for the same object. The HR10 and HR21 observations are obtained the same night. The binary nature is detected only in HR10 when we use the Gaia-ESO CCF while it is detected in both setups with our CCFs.

recompute the CCFs (NCP CCFs, hereafter) for all of the Gaia-ESO HR10 and HR21 observations. Figure 1 shows a comparison of the Gaia-ESO CCFs (black curve) and the NCP CCFs (other coloured curves) for an object observed with HR10 (left) and HR21 (right) setups. On the one hand, the new HR10 CCFs exhibit little improvement: it was expected since the efficiency was already good and it shows that the reduced number of lines in the cross-correlating masks does not prevent the detection of the two stellar components. On the other hand, the new HR21 CCFs are strikingly different: the two stellar components are visible in the NCP CCFs while they were hidden in the Gaia-ESO CCF.

3 Results and discussion

Figure 2 shows the distribution of the velocity differences (Δv) of the detected SB2 systems obtained after the analysis of the Gaia-ESO CCFs (left) and the NCP CCFs (right). Thanks to the new CCFs, the distribution of Δv are very similar for HR10 and HR21. In particular, the smallest detectable Δv is now $25\,\mathrm{km\,s^{-1}}$ for both setups. While the same selection of spectra were considered, Figure 2 also shows that the number of detection is multiplied by 1.5 when we use the new NCP CCFs.

When an SB2 system has radial velocity measurement for more than one epoch, we were able to derive the mass-ratio by linearly fitting the relation v_{primary} vs. $v_{\mathrm{secondary}}$ (see left panel of Fig. 3). Figure 3 shows the distribution of the mass-ratio q for ~ 30 SB2 systems. It exhibits a huge excess of systems with q close to 1: indeed, spectroscopic binaries with two systems of lines in their spectrum are expected to have a similar spectral type, and therefore similar masses.

We retrieved for the Gaia-ESO targets the parallax, G magnitude, BP and RP colour indices from the Gaia DR2 (Gaia Collaboration et al. 2018; Evans et al. 2018) in order to derive the colour-magnitude diagram displayed in Fig. 4. The full sample of Gaia-ESO targets observed with the GIRAFFE HR10 and HR21 setups are in black while the detected SB2 are in red. We notice that all our SB2 are main-sequence stars and that the locus of the SB2 is shifted upward compared to the locus of single stars: double-lined spectroscopic binaries are expected to be twin stars, in general, and thus the total magnitude of the two stars is 0.75 lower than the magnitude of only one star.

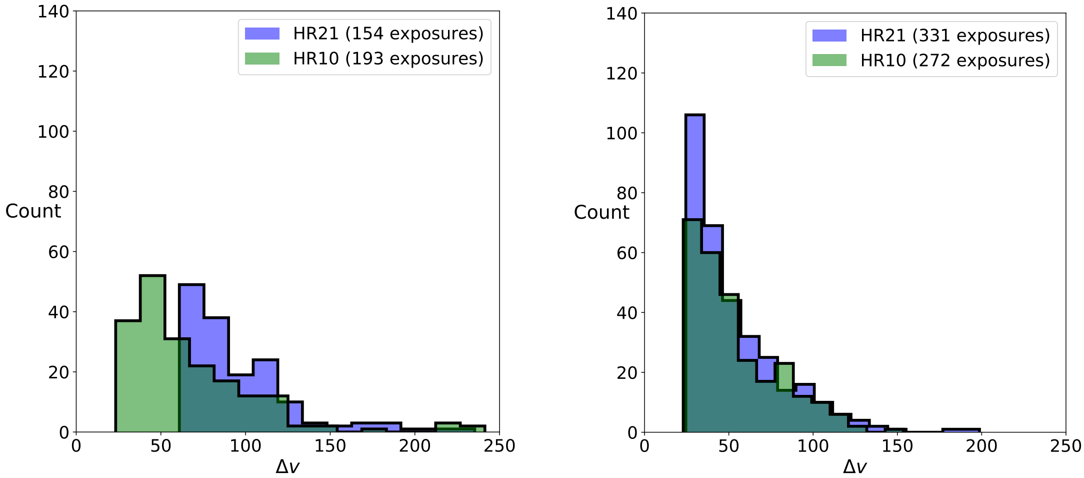

Fig. 2. Distributions of the velocity differences Δv when we use the Gaia-ESO CCFs (left panel) and the NCP CCFs (right panel). HR10 detections are in green; HR21 detections are in blue. The distribution is meant "per observation" which means that a given SB2 system may appear more than once if the binary nature has been detected at different epochs. We remind the reader that the same sample of HR10 and HR21 spectra was analysed to derive the left and right distributions, only the CCFs change.

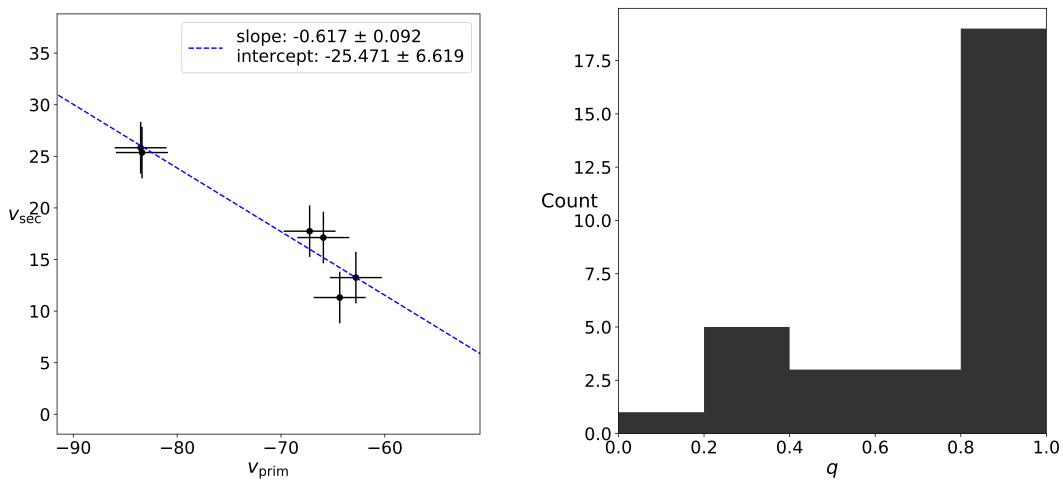

Fig. 3. *Left panel*: example of linear fit to derive the mass-ratio q of the SB2 21594936-4747133. *Right panel*: Mass-ratio distribution.

4 Conclusion

We developed a semi-automated pipeline to compute narrow cross-correlations and analyse them to identify multi-lined spectroscopic binaries. Using Gaia-ESO HR10 and HR21 spectra with a signal-to-noise ratio ≥ 4, we were able to detect systems with a velocity difference as low as $25\,\mathrm{km\,s^{-1}}$. We found 320 SB2 out of the 37 565 analysed objects: the detected SB2 are main-sequence stars with a mass-ratio biased towards 1.

References

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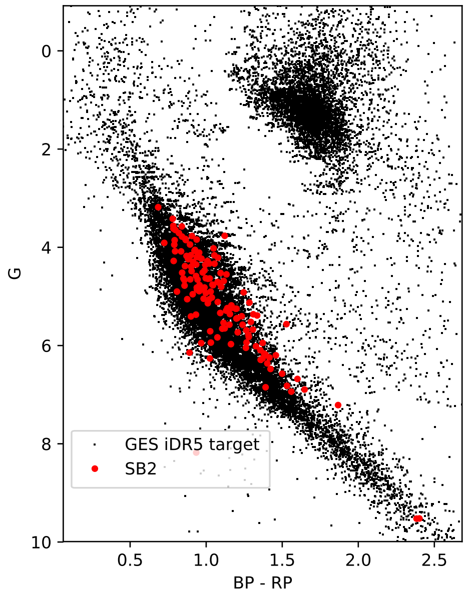

Fig. 4. Colour-magnitude diagram of the Gaia-ESO HR10+HR21 sample (Milky Way disc stars) in black. Red dots stand for the detected SB2. The G magnitude has been corrected for the parallax. We did not apply any reddening correction.

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