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SPECTROSCOPIC BINARIES WITH GAIA AND LARGE SPECTROSCOPIC SURVEYS

M. Van der Swaelmen[1], T. Merle[2], S. Van Eck[2] and A. Jorissen[2]

Abstract. Binary stars are ubiquitous in the universe and across the Hertzsprung-Russell diagram. Thanks to the Gaia mission, a big step in our understanding of stellar multiplicity will be made with the discovery of millions of (astrometric, spectroscopic, eclipsing) binaries. In parallel, large spectroscopic surveys, like the Gaia-ESO survey, can already be combined with the Gaia data releases to hunt for and characterise new spectroscopic binaries. We present our latest results about the identification and characterisation of single-lined and double-lined spectroscopic binaries (SB1, SB2) with the Gaia-ESO survey+Gaia. In particular, our results about the dependency of the SB1 fraction with metallicity and the distribution of the mass-ratio for SB2 will be discussed.

Keywords: Techniques: radial velocities, Techniques: spectroscopic, Binaries: spectroscopic, Surveys

1 Spectroscopic binaries among the Gaia-ESO survey

1.1 Introduction

The Gaia-ESO survey (Gilmore et al. 2012; Randich et al. 2013) is an ambitious spectroscopic survey carried out at Very Large Telescope, Chile. It uses the multi-object spectrographs FLAMES/GIRAFFE ($R \sim 20\,000$; Pasquini et al. 2000) and FLAMES/UVES ($R = 47\,000$) to record the spectra of 10^5 Milky Way (MW) stars belonging to the Galactic bulge, thin/thick disks, halo and stellar clusters. The science goal is to characterise the stellar populations of the MW from a kinematical and chemical point of view, in order to put constraints on the chemical evolution and formation history of our galaxy.

More than 75 % of the observations have been made with the GIRAFFE setups HR10, HR21 (mainly field stars) and HR15N (mainly stars in the vicinity of or belonging to stellar clusters). The V magnitude of the faintest objects is $V = 20$; most of the targets have two or four exposures. In this work, we focused on the analysis of HR10 and HR21 spectra of the fifth internal data release (iDR5).

Though the Gaia-ESO survey is not designed for the detection and the study of spectroscopic binaries, the fact that a large fraction of stars benefit from two or more visits allow us to address the question of binarity. Stellar multiplicity is indeed ubiquitous across the Galaxy and the Hertzsprung-Russell diagram, and thus, stellar systems are expected among the Gaia-ESO targets.

1.2 Detection of SB2

SBn ($n \geq 2$) are spectroscopic binaries which exhibit n stellar components in their spectra. It is therefore possible to detect them by inspecting their cross-correlation functions (CCFs) and look for those with two or more stellar components. Merle et al. (2017) designed the tool Doe – Detection Of Extrema – to automatise the analysis of the $\sim 200\,000$ HR10+HR21 CCFs (as of iDR5) of Gaia-ESO targets. Our tool computes the smoothed first-, second- and third-derivatives of the CCFs and uses them to detect multi-peaked CCFs, i.e. objects with two or more stellar components.

[1] INAF - Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125, Firenze, Italy
[2] Institut d'Astronomie et d'Astrophysique, Université Libre de Bruxelles, Campus Plaine C.P. 226, Boulevard du Triomphe, 1050, Bruxelles, Belgium

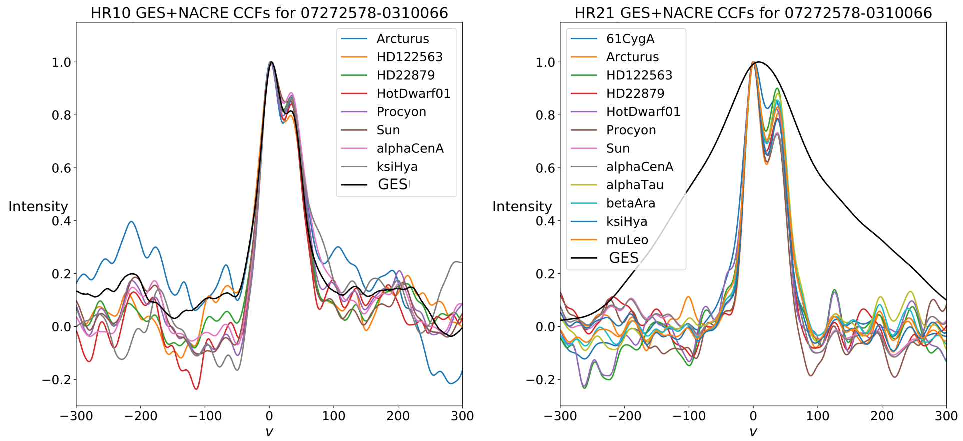

Fig. 1. Left: Example of cross-correlation functions of a Gaia-ESO SB2 observed with the GIRAFFE setup HR10. The black line is the CCF released by the Gaia-ESO while the coloured lines are the NACRE CCFs. **Right**: Same as left but for an HR21 observation of the same object. The Gaia-ESO CCF does not display the two stellar components while our NACRE CCFs do.

Van der Swaelmen et al. (*in prep.*, see also Van der Swaelmen et al. 2018) improved the detection by designing specific cross-correlating masks (called NACRE masks) which produce more narrow CCFs, and therefore allow to detect SB2 with a smaller radial velocity difference. We notice, indeed, that some objects are seen as an SB2 when looking at their HR10 CCFs but exhibit a single stellar component in their HR21 CCFs. It is for example the case of the star shown in Fig. 1. The black CCFs, released by the Gaia-ESO collaboration, is double-peaked for HR10 (left) but single-peaked for HR21 (right). Since the observations were taken within 24 h and have a good signal-to-noise ratio (≥ 15), we suspected that the binary nature was hidden in the HR21 CCFs. Our investigation showed that the HR21 wavelength range, around the near-infrared Ca II triplet, tends to host numerous strong and saturated lines (compared to the HR10 wavelength range) that broaden the CCFs. Our NACRE masks exclude these strong features to keep only weak, mildly-blended atomic lines and produce more narrow CCFs. The coloured lines in Fig. 1 show the NACRE CCFs for both HR10 and HR21 observations and for different spectral types. One sees that the binary nature is now detected in both cases. We therefore re-computed the CCFs for the $\sim 200\,000$ individual HR10 and HR21 spectra and analysed them with DOE. Some of our results are discussed in Sec. 2.1.

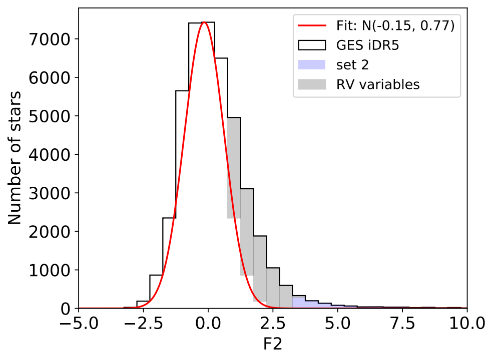

Fig. 2. F2 distribution for the Gaia-ESO iDR5 stars. The red line is the expected F2 distribution when the variation in radial velocities are explained by (Gaussian) random errors. The histogram displays the actual Gaia-ESO distribution. The departure from normality in the right tail is due to radial-velocity variables. A fraction of those variables exhibit photometric variability (grey shading) and has to be removed from the analysis to keep only the SB1 (blue shading for a selection at the 3σ confidence level).

1.3 Detection of SB1

The detection of SB1, single-lined spectroscopic binaries, is a different story. Such spectroscopic binaries do not exhibit more than one stellar component in their spectra. However, their radial velocities vary with time. Merle et al. (*submitted*) used the radial velocities (and their associated uncertainties) computed by Van der Swaelmen et al. (*in prep.*) to detect variabilities in the time series of radial velocities. To discriminate between random changes and astrophysical changes of the radial velocity, we computed the χ^2 given in Eq. 1.1. The F2 quantity given in Eq. 1.2 should then follow a normal distribution if the variations in the radial velocities are explained only by normally-distributed random errors. The departure from normality (the right heavy tail in Fig. 2) points at objects with an astrophysical change of their radial velocity. We then used the Gaia DR2 photometry to exclude photometric variables from the sample of variables. Some of our results are discussed in Sec. 2.2.

$$\chi^2_{N-1} = \sum_{i=1}^{N} \left(\frac{v_i - \bar{v}}{e_i} \right)^2 \tag{1.1}$$

$$F2(\chi^2, N) = \sqrt{\frac{9(N-1)}{2}} \left[\left(\frac{\chi^2}{N-1} \right)^{1/3} + \frac{2}{9(N-1)} - 1 \right] \tag{1.2}$$

2 Results

2.1 Mass-ratio distribution of SB2

We identify (Van der Swaelmen et al. *in prep.*) more than 300 SB2 in the Gaia-ESO iDR5. Only few of them were previously known since the Gaia-ESO survey targets fainter objects than other catalogues like RAVE (Matijevič et al. 2010) or MSC (Tokovinin 1997). When the Gaia-ESO SB2 have been observed at different epochs, we could determine their mass-ratio by computing the slope of the relation $v_{\mathrm{secondary}}$ vs v_{primary}. Left panel of Fig. 3 shows an example of such a linear regression. We could apply this procedure to only 10 % of our SB2 and right panel of Fig. 3 shows the distribution of their mass-ratio q. We note that it is biased towards $q = 1$: it is explained by the fact that SB2 exhibit two stellar components in their spectra, which means that they have similar spectral type and therefore, similar masses (they are co-eval). The Gaia DR2 photometry allows us to go further into the characterisation of our SB2 and shows that they lie on the main-sequence.

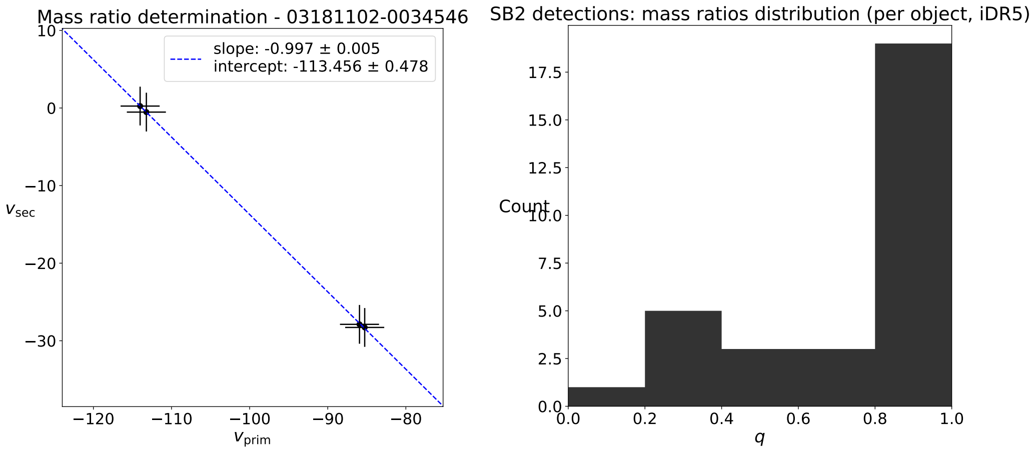

Fig. 3. Left: determination of the mass-ratio using the slope of the relation $v_{\mathrm{secondary}}$ vs v_{primary}. **Right**: mass-ratio distribution for about 10 % of the SB2 detected in the fifth internal data release of the Gaia-ESO survey.

2.2 Metallicity-dependence of the SB1 fraction

We identify (Merle et al. *submitted*) more than 600 (resp., 800) SB1 in the Gaia-ESO iDR5 at the 5σ (resp., 3σ) confidence level. Figure 4 shows an example of SB1 for which we could determine its orbital elements. The

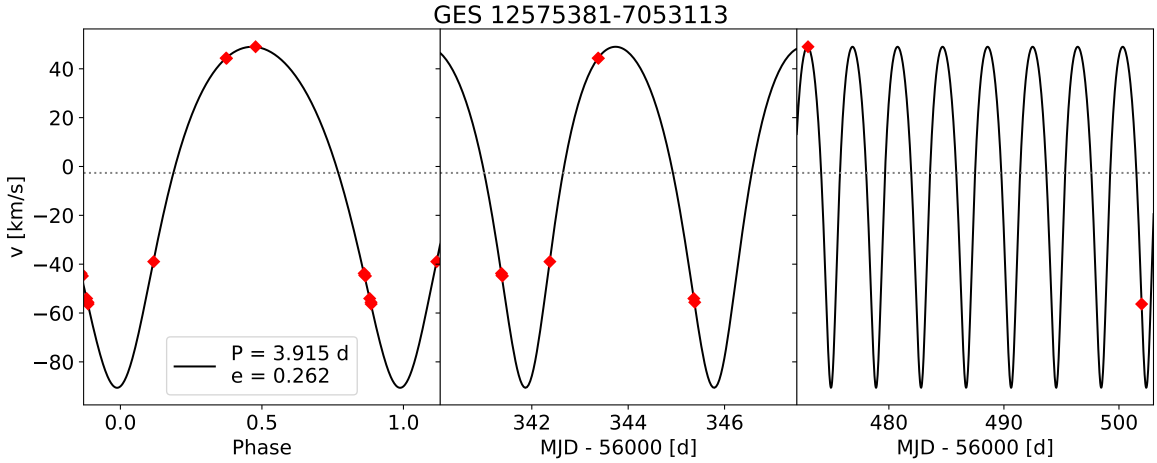

Fig. 4. One of the few SB1 for which we could fit an orbit. The period and eccentricity are indicated in the legend. Red dots stand for the measured radial velocities. The left panel shows the evolution of the radial velocity with respect to the phase while the middle and right panels show the time evolution.

period is $P \sim 4\,\mathrm{d}$ and the eccentricity is $e \sim 0.26$. Using the Gaia-ESO metallicities and after correcting for detection biases, we could estimate the evolution of the SB1 fraction as a function of the metallicity. Figure 5 shows our results as well as literature trends. We note that the SB1 fraction is anti-correlated with the metallicity and our trend is in good agreement with previous studies. Such a relation may have fundamental consequences for the formation scenarios of binary stars (e.g., Moe et al. 2019).

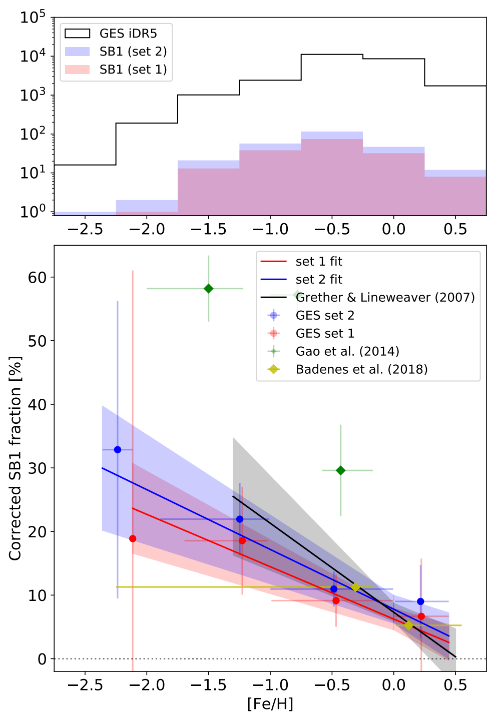

Fig. 5. Top panel: the metallicity distribution of the full Gaia-ESO sample (black line) and of the SB1 sample at the 3σ (set 2, blue) and 5σ (set 1, red) confidence levels. Notice the vertical logarithmic axis. **Bottom panel**: SB1 fraction vs. metallicity. Literature data (Grether & Lineweaver 2007; Gao et al. 2014; Badenes et al. 2018) are also shown.

3 Conclusion

Though the Gaia-ESO survey is designed for the study of the chemo-dynamical evolution of the Milky Way, it can also be successfully used to hunt for new spectroscopic binaries. We discovered few hundreds of SB1 and SB2, a handful of SB3 and one SB4. Combining the Gaia-ESO survey with the Gaia DR2 allowed us to go further into the characterisation of our spectroscopic binaries.

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