The *Gaia*-ESO Survey*: double, triple and quadruple-line spectroscopic binary candidates

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ABSTRACT

Context. The Gaia-ESO Survey (GES) is a large spectroscopic survey that provides a unique opportunity to study the distribution of spectroscopic multiple systems among different populations of the Galaxy.

Aims. We aim at detecting binarity/multiplicity for stars targeted by the GES from the analysis of the cross-correlation functions (CCFs) of the GES spectra with spectral templates.

Methods. We develop a method based on the computation of the CCF successive derivatives to detect multiple peaks and determine their radial velocities, even when the peaks are strongly blended. The parameters of the detection of extrema (DOE) code have been optimized for each GES GIRAFFE and UVES setup to maximize detection. The DOE code therefore allows to automatically detect multiple line spectroscopic binaries (SBn, $n \ge 2$).

Results. We apply this method on the fourth GES internal data release and detect 354 SBn candidates (342 SB2, 11 SB3 and even one SB4), including only nine SBs known in the literature. This implies that about 98% of these SBn candidates are new (because of their faint visual magnitude that can reach V=19). Visual inspection of the SBn candidate spectra reveals that the most probable candidates have indeed a composite spectrum. Among SB2 candidates, an orbital solution could be computed for two previously unknown binaries: CNAME 06404608+0949173 (known as V642 Mon) in NGC 2264 and CNAME 19013257-0027338 in Berkeley 81 (Be 81). A detailed analysis of the unique SB4 (four peaks in the CCF) reveals that CNAME 08414659-5303449 (HD 74438) in the open cluster IC 2391 is a physically bound stellar quadruple system. The SB candidates belonging to stellar clusters are reviewed in detail to discard false detections. We warn against the use of atmospheric parameters for these system components rather than by by SB-specific pipelines.

Conclusions. Our implementation of an automatic detection of spectroscopic binaries within the GES has allowed an efficient discovery of many new multiple systems. With the detection of the SB1 candidates that will be the subject of a forthcoming paper, the study of the statistical and physical properties of the spectroscopic multiple systems will soon be possible for the entire GES sample.

Key words. binaries: spectroscopic - techniques: radial velocities - methods: data analysis - open clusters and associations: general - globular clusters: general

1. Introduction

Binary stars play a fundamental role in astrophysics since they allow direct measurements of masses, radii, and luminosities that put constraints on stellar physics, Galactic archaeology, high-energy physics, etc. Binary systems are found at all evolutionary stages, and after strong interaction, some may end up as double degenerate systems or merged compact objects.

Spectroscopic binaries (SBs) exist in different flavours. On the one hand, SB1 (SB with one observable spectrum) can only be detected from the Doppler shift of the stellar spectral lines. On the other hand, SBn $(n \ge 2)$ are characterized by a composite spectrum made out of n stellar components, and are detected either from the composite nature of the spectrum or from the Doppler shift of the spectral lines. SBs are certainly the binaries that cover the widest range of masses (from brown dwarfs to massive twins) and all ranges of periods (from hours to hundreds of years as observed so far, e.g. Pourbaix 2000). To date, more than 3500 SBs with orbital elements have been catalogued and, among them, about 1126 are SB2 (Pourbaix et al. 2004, and the latest online version of the SB9 catalogue). The Geneva-Copenhagen Survey catalogue (Nordström et al. 2004; Holmberg et al. 2009) contains approximately 4000 SB1, 2100 SB2, and 60 SB3 out of 16700 F and G dwarf stars in the solar neighborhood, most without orbits. In the vast majority of cases, these binaries are not yet confirmed but correspond to an overall binary fraction in the Milky Way of almost 40 %. A census of binary fraction is also available from the Hipparcos catalogue (Frankowski et al. 2007) though the binary fraction per spectral type is probably biased due to selection biases in the Hipparcos entry catalogue. New recent Galactic surveys like APOGEE (Majewski et al. 2015) or LAMOST (Luo et al. 2015) allow new investigations of binarity over large sample of stars (see, e.g., Gao et al. 2014; Troup et al. 2016; Fernandez et al. 2017). For instance, the RAVE survey has led to the detection of 123 SB2 candidates out of 26 000 objects (Matijevič et al. 2010, 2011). We refer the reader to Duchêne & Kraus (2013) for a recent review of the physical properties of multiplicity among stars and more specifically to Raghavan et al. (2010) for a complete volumelimited sample of solar-type stars in the solar neighborhood (distances closer than 25 pc).

The Gaia-ESO Survey (GES) is an on-going ground-based high-resolution spectroscopic survey of 10^5 stellar sources (Gilmore et al. 2012; Randich et al. 2013) covering the main stellar populations (bulge, halo, thin and thick disks) of the Galaxy as well as a large number of open clusters spanning large metallicity and age ranges. All evolutionary stages are encountered within the GES, from pre-main sequence objects to red giants. It aims at complementing the spectroscopy of the Gaia ESA space mission (Wilkinson et al. 2005). The GES uses the FLAMES multi-fibre back end at the high resolution UVES ($R \sim 50\,000$) and moderate resolution GIRAFFE ($R \sim 20\,000$) spectrographs. The visual magnitude of the faintest targets reaches $V \sim 20$. The spectral coverage spans the optical wavelengths (from 4030 to

6950 Å) and the near infrared around the Ca II triplet and the Paschen lines (from 8490 to 8900 Å including the wavelength range of the Radial Velocity Spectrometer of the *Gaia* mission). The median signal-to-noise (S/N) ratio per pixel is similar for UVES and GIRAFFE single exposures (\sim 30) whereas the most frequent values are around 20 and 5 respectively.

The motivation of the present work is to take the advantage of a very large sample to detect automatically SBs with more than one visible component¹ that are not always detected by the GES single-star main analysis pipelines. SBs may be a potential source of error when deriving atmospheric parameters and detailed abundances. This project presents (i) a new method to identify automatically the number of velocity components in each cross-correlation functions (CCFs) using their successive derivatives and (ii) the analysis of about 51 000 stars available within the GES internal data release 4 (iDR4).

In Sect. 2, we describe the iDR4 stellar observations, their associated CCFs and the selection criteria applied to them. The method on which the detection of the velocity components in a CCF relies, its parameters and the formal uncertainty are presented in Sect. 3. In Sect. 4, the set of SBn ($n \ge 2$) detected in iDR4 using this method is discussed, organized according to the stellar populations they belong to.

2. Data selection

2.1. Observations and CCF computation

Our analysis was performed on the iDR4 consisting of $\sim 260\,000$ single exposures (corresponding to $\sim 100\,000$ stacked spectra) of about 51 000 distinct stars observed with the FLAMES instrument feeding the optical spectrographs GIRAFFE (with setups HR3, HR5A, HR6, HR9B, HR10, HR14A, HR15N, HR15, HR21) and UVES (with setups U520 and U580) covering the optical and near-IR wavelength ranges given in Table 1.

The classical definition of a CCF function applied to the stellar spectra is:

$$CCF(h) = \int_{-\infty}^{+\infty} f(x)g(x+h) dx$$
 (1)

where f is a normalised spectrum, g a normalised template spectrum and h is the lag expressed in km s⁻¹. The computation of the CCFs is performed by pipelines at CASU (Cambridge Astronomy Survey Unit²) for GIRAFFE spectra (Lewis et al., in prep.) and at INAF-Arcetri for UVES spectra (Sacco et al. 2014). For UVES CCFs, spectral templates from the library produced by de Laverny et al. (2012), and based on MARCS models (Gustafsson et al. 2008), are used. For GIRAFFE CCFs, spectral templates from the library produced by Munari et al. (2005), and based on Kurucz's models (Kurucz 1993; Castelli & Kurucz 2003), are used. We stress that for a given spectrum, CCFs are calculated for all the templates and the CCF with the highest peak is selected. For UVES spectra, H α and H β are masked in the observations. As illustrated e.g. in Fig. 1, CCFs are characterized by a maximum value (CCF "peak"), a minimum value (lowest point of the CCF "tail") and a full amplitude (maximum - minimum). The constant velocity steps of GIRAFFE and UVES CCFs are 2.75 (mainly) and 0.50 km s^{-1} (for a sampling of 401 and 4000 velocity points), respectively.

^{*} Based on data products from observations made with ESO Telescopes at the La Silla Paranal Observatory under programme ID 188.B-3002. These data products have been processed by the Cambridge Astronomy Survey Unit (CASU) at the Institute of Astronomy, University of Cambridge, and by the FLAMES/UVES reduction team at INAF/Osservatorio Astrofisico di Arcetri. These data have been obtained from the *Gaia*-ESO Survey Data Archive, prepared and hosted by the Wide Field Astronomy Unit, Institute for Astronomy, University of Edinburgh, which is funded by the UK Science and Technology Facilities Council.

Since SB1 systems require a special treatment by analyzing temporal series, their analysis should await the completion of the observations.

http://casu.ast.cam.ac.uk/gaiaeso

Table 1. Setups used in GES and the associated estimated best parameters of the DOE code.

| Instrumental | Spectral | λ range | Main spectral features | THRES0 | THRES2 | SIGMA |
|--------------|------------|-----------------|---|--------|--------|---------------|
| setup | resolution | [nm] | - | [%] | [%] | $[km s^{-1}]$ |
| | | | | | | |
| UVES | | | | | | |
| U520 low | 47 000 | 420 - 520 | G band, H γ , H β | 35 | 8 | 5.0 |
| U520 up | 47 000 | 525 - 620 | Fe I E, Na I D | 35 | 8 | 5.0 |
| U580 low | 47 000 | 480 - 575 | $H\beta$, Mg I b | 35 | 5 | 5.0 |
| U580 up | 47 000 | 585 - 680 | Na I D, H α | 35 | 5 | 5.0 |
| | | | | | | |
| GIRAFFE | | | | | | |
| HR3 | 24 800 | 403 - 420 | ${ m H}\delta$ | 55 | 8 | 3.0 |
| HR5A | 18 470 | 434 - 457 | Нγ | 55 | 8 | 3.0 |
| HR6 | 20350 | 454 - 475 | He I & II, Si III & IV, C III, N II, O II | 55 | 8 | 3.0 |
| HR9B | 25 900 | 514 - 535 | Mg I b, Fe I E | 55 | 8 | 3.0 |
| HR10 | 19800 | 534 - 561 | many weak lines | 55 | 8 | 2.1 |
| HR14A | 17740 | 631 - 670 | $H\alpha$ | 55 | 8 | 3.0 |
| HR15N | 17 000 | 645 - 681 | $H\alpha$, Li I | 55 | 8 | 3.0 |
| HR15 | 19 300 | 660 - 695 | O ₂ A, Li I | 55 | 8 | 3.0 |
| HR21 | 16 200 | 849 - 900 | Ca II triplet, Paschen lines | 55 | 8 | 5.0 |
| | | | • | | | |

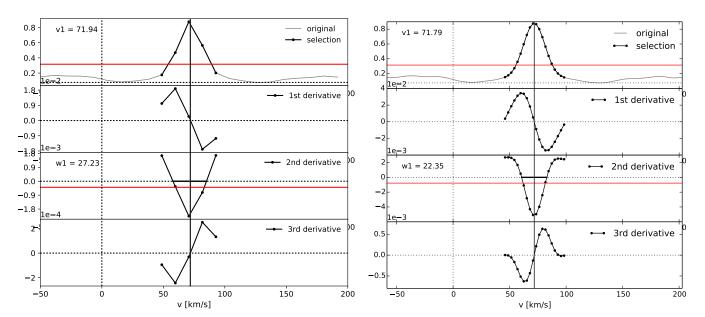


Fig. 1. Simulated CCF at limiting numerical resolution to test the computation of successive derivatives and the detection of the peak (left), and with a more realistic sampling (right). The spectrum used to simulate these CCFs has a radial velocity of 72.0 km s⁻¹ and S/N = 5.

Examples of spectra and CCFs in the setups mentionned above are displayed in Figs. 2 and 3. These figures are built from the solar and Aldebaran spectra. The CCFs are represented over the same velocity range to allow an easy comparison between the various setups. When a lot of weak absorption lines are present (as in setups HR6 and HR10), the CCF peak is narrow and well defined with a width smaller than for setups with strong features like H δ (HR3), H γ (HR5A), the Mg b triplet (HR9B), H α (HR14A and HR15N) and the Ca II triplet (HR21). For HR15, the presence of telluric lines from 685 nm onwards reduces the maximum amplitude of the CCF to a value as low as 0.25, even with a S/N larger than 1000.

For the UVES setups, Aldebaran (α Tau, spectral type K5III) spectra and corresponding CCFs are presented in Fig. 3. Each setup is composed of two spectral chunks. In the present case, the lower chunk comes with $S/N \approx 70$ and the upper one with

S/N > 100. For the setup U520 low, the leftward CCF tail is negative, probably as a result of poor spectrum normalisation due to the co-existence of lots of weak and strong lines. Since the wavelength range of the UVES setups is 2 or 3 times wider than those of GIRAFFE, the UVES setups are well suited to the detection of SBn candidates.

The final GES spectrum of a given object is a stack of all individual exposures, wavelength calibrated, sky substracted and heliocentric radial velocity corrected. This could be a source of confusion in the case of composite spectra where the radial velocity of the different components changes between exposures. Moreover, a double-lined CCF coming from stacked spectra (and mimicking an SB2) can be the result of the SB1 combination taken at different epochs and stacked. To avoid this problem, we performed the binarity detection on the individual exposures (rather than on the stacked ones). This choice avoids spurious

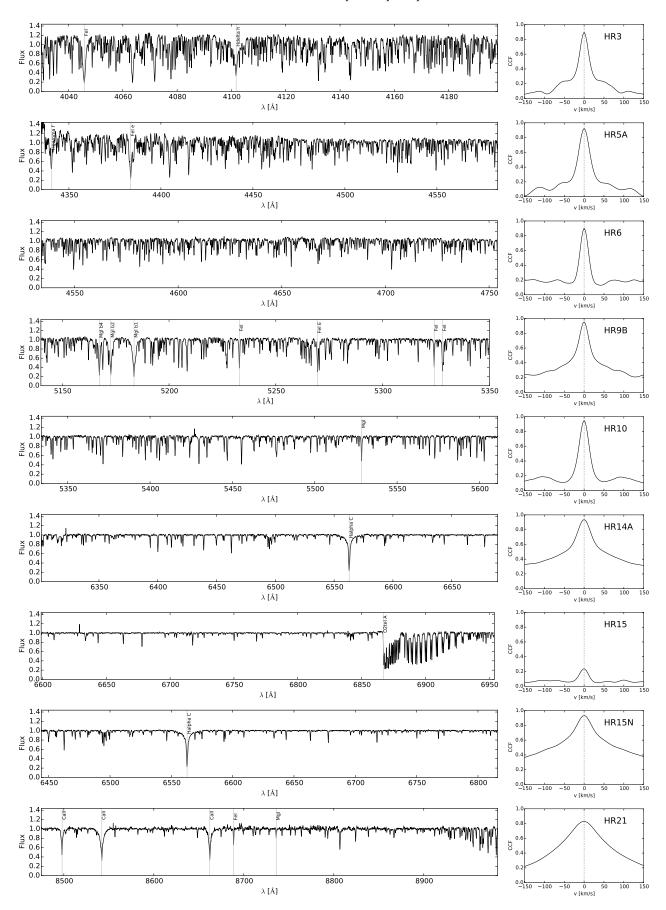


Fig. 2. Solar spectra acquired by GES in GIRAFFE setups with high S/N (> 1000) except for setup HR9B where $S/N \approx 700$. The normalised spectra are shown together with the identification of the main spectral features (left); the associated CCFs are shown on the right panels.

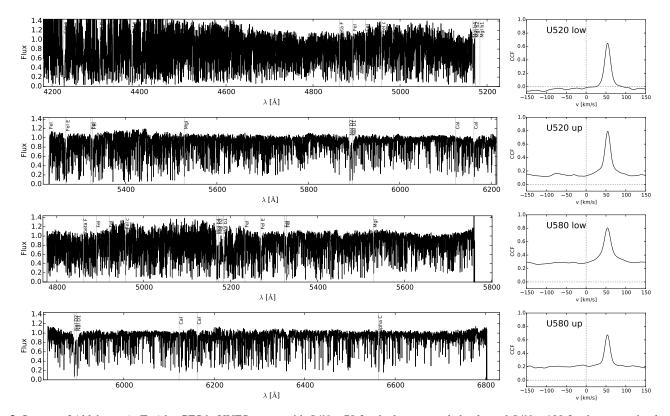


Fig. 3. Spectra of Aldebaran (α Tau) by GES in UVES setups with $S/N \approx 70$ for the low spectral chunks and S/N > 100 for the upper chunks.

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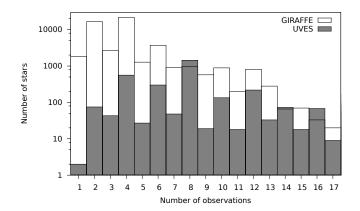


Fig. 4. Number of stars observed as a function of the number of observations per star. A tiny fraction, including benchmark stars, have a number of observations that can reach ~ 100 .

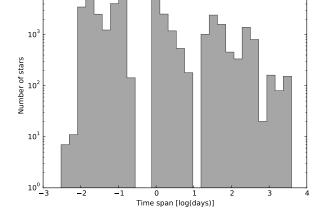


Fig. 5. Histogram of the full time span between observations if more than one is available for a given target.

spectroscopic binary detection, at the expense of using spectra with lower S/N ratios which will be shown not to be detrimental as long as S/N > 5 (see Sect. 3.4).

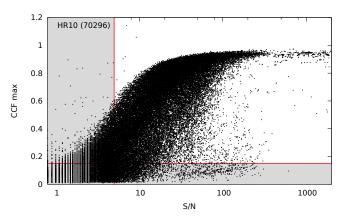
The number of individual observations per target is plotted in Fig. 4. The majority of stars observed with GIRAFFE has 2 or 4 observations because generally observed with HR10 and HR21 setups, whereas there are 4 or 8 observations in the case of UVES due to the presence of two spectral chunks per setup. Moreover, the time span between consecutive observations is very often less than three days, as shown on Fig. 5. Benchmark stars (*i.e.*, a sample of stars with well-determined parameters, to be used as reference; see Heiter et al. 2015a) are the most observed objects, some having more than 100 observations.

2.2. Data selection in iDR4

Our sample has been drawn from the individual spectra database of the GES iDR4³, covering observations until June 2014, to which the following selection criteria were applied:

- S/N larger than 5;
- CCF maximum larger than 0.15;
- CCF minimum larger than -1;
- CCF full amplitude larger than 0.10;
- left CCF continuum right CCF continuum lower than 0.15.

³ GES public data releases may be found at https://www.Gaia-eso.eu/data-products/public-data-releases



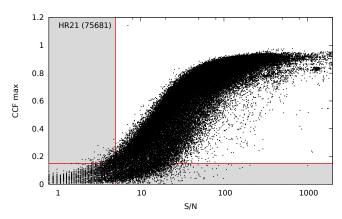


Fig. 6. CCF maximum amplitude versus S/N for HR10 (left panel) and for HR21 (right panel). Solid red lines are the criteria on the S/N (vertical, S/N = 5) and on the lowest value of the CCF maximum (horizontal, 0.15). The shadow area shows the observations excluded from the analysis. In parenthesis is the number of single exposures in each setup.

These criteria were empirically determined thanks to a visual inspection of a representative sample of CCFs. We allow negative values for the CCF minimum to keep CCFs computed on unperfectly normalised spectra (without allowing spectra with a completely wrong normalisation). Criteria on the S/N and on the CCF maximum are presented in Fig. 6 for setups HR10 and HR21 which contain the most numerous observations. This figure clearly shows the impact of the S/N of a spectrum on its associated CCF: the higher the S/N, the higher the CCF maximum. For a given S/N, the interval spanned by the CCF maximum is mainly due to spectrum – template mismatch. For HR10, the over-density located at 30 < S/N < 200 and CCF max < 0.15 is mainly due to NGC 6705 members. In HR21, the clump located at 1000 < S/N < 2000 and 0.80 < CCF max < 0.85 is due to repeated observations of the solar spectrum.

These criteria allow us to avoid detecting spurious (noise-induced) CCF peaks. Over the 260 000 individual science spectra (corresponding to the 100 000 stacked spectra) within the iDR4, 9.3 % have a S/N lower than 5, 1.0 % have a null CCF (data processing issues), 7.8 % have a CCF maximum lower than 0.15, 0.2 % have a CCF minimum lower than -1.0, and 0.02 % have a CCF full amplitude lower than 0.10. We ended up with about 205 000 CCFs (77.7 %), corresponding to \sim 51 000 different stars.

3. Methods

3.1. Detection of extrema (DOE) code

The Detection of extrema (DOE) code has been designed to identify the (local and global) extrema in a given signal even in case these extrema are strongly blended. By using successive derivatives of a function, it is possible to characterize it in a powerful way. Applied on spectral-line profiles for instance, the method makes it possible to identify all contributing blends (Sousa et al. 2007). Here we apply it to the CCFs. The method is inspired from signal-processing techniques (Foster 2013) which convolve the signal (here the CCF) with the derivatives of a Gaussian kernel to smooth and calculate the derivative of the CCF in a single operation. In other words, the first, second and third derivatives of the Gaussian kernel are used to obtain the smoothed derivatives of the CCFs. Indeed, one of the interesting properties of the convolution of two generalized functions is defined as follows:

$$(f' * g)(x) = (f * g')(x)$$
 (2)

where f' and g' are the first derivatives of the generalized functions f and g. Convolving the CCF with the derivative of a Gaussian kernel is equivalent to compute the derivative of the CCF and to convolve (*i.e.*, smooth) it by a Gaussian kernel. We use the routine $gaussian_filter1d$ of the sub-module ndimage of the scipy module (Jones et al. 2001) in Python. The routine calculates first the derivative of the Gaussian kernel before correlating it with the CCF function. The width of the Gaussian kernel controls the amount of smoothing.

A zero in the descending part of the first derivative obviously provides the position of the maximum of the CCF. However, in the case of a CCF composed of two or more peaks, the zeros of the first derivative will only provide the positions of wellseparated peaks, i.e., peaks with a local minimum in between them. Blended peaks might thus be missed. However, this difficulty may be circumvented by using the third derivative, whose zeros occurring in an ascending part provide the positions of all the peaks including the blended ones. Fig. 7 shows that the use of the first derivative only does not allow a satisfactory detection of the CCF components. Indeed, although the CCF in the middle panel clearly exhibits two peaks, the first derivative has only one descending zero-crossing, thus resulting in the detection of one component only. However, the second derivative shows two local minima corresponding to the two CCF velocity components. The position of these two minima can be found by detecting the ascending zero-crossing of the third derivative. By using the third derivative, the different CCF components may thus be identified as regions where the CCF curvature is sufficiently negative (minima of the second derivative, or ascending zeros of the third derivative), separated by a region of larger curvature. To get the velocities of the various components, the CCF third derivative is simply interpolated to find its intersection with the x-axis. Some detection thresholds had to be set to automate the process in order to match the results obtained from an eye inspection of multiple-component CCFs.

The procedure is illustrated on simulated CCFs with or and two peaks (Figs. 1 and 7 respectively). We first test the operation of the DOE code on single peaks at the lowest numerical resolution, *i.e.*, peaks defined with only six velocity points (left panel of Fig. 1). The DOE code applied on a more realistic (more noisy) simulated single-peaked CCF (as shown on the right panel of Fig. 1) also provides satisfactory results, with an accuracy on the radial velocity of the order of 0.20 km s⁻¹. We will show in Sect. 3.4 that the DOE code has a small internal error of 0.25 km s⁻¹.

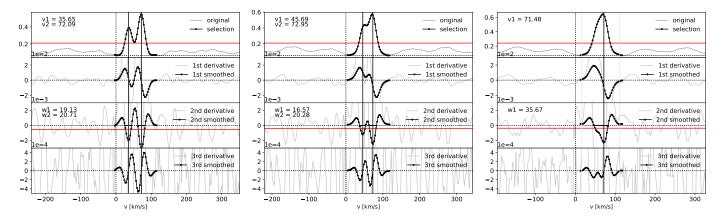


Fig. 7. Simulated noisy double-peak CCF with peaks located at 36.0 km s⁻¹ and 72.0 km s⁻¹ (left), 48.0 km s⁻¹ and 72.0 km s⁻¹ (centre), and 54.0 km s⁻¹ and 72.0 km s⁻¹ (right). Grey lines show derivatives from a simple finite differences method which have the drawback to be very noisy. Instead, black line with dots (in panels below the top one) show the smoothed derivatives computed with Eq. 2. Red lines in top panels show the threshold parameter on the CCF (THRES0) and in the middle-low panels the threshold parameter on the second derivative (THRES2).

The first threshold (THRES0), expressed as a fraction of the full CCF amplitude, defines the considered velocity range: the DOE code is applied only in the region where the CCF is larger than THRES0. The THRES0 threshold is represented by the horizontal red line in the top panels of Fig. 1 and subsequent figures. However, if several well-defined peaks are identified in the CCF, the THRES0 criterion is overridden, and all data points between the CCF peaks are included in the analysis of the derivatives, even though the CCF may be lower than THRES0.

A second threshold, THRES2, is set on the second CCF derivative. The THRES2 parameter is expressed as a fraction of the full amplitude of the CCF second derivative. This negative threshold is represented by the horizontal red line in the "2nd derivative" panel in Fig. 1 (and subsequent figures) such that only minima lower than this threshold are selected for the final peak detection (vertical black lines) whereas second-derivative minima larger than this threshold are not considered to be related to real components (vertical light grey lines in *e.g.* Fig. 9).

The width of the Gaussian kernel for the convolution of the CCF, SIGMA, is the third parameter. It is a smoothing parameter and aims at making the successive derivatives of the CCF less sensitive to the data noise.

The three parameters of DOE (THRESO, THRES2 and SIGMA) have to be set by the user. Their value may have an impact on the number of detected peaks and the radial velocities associated to them. These three parameters need to be adjusted in order to give meaningful results (*i.e.*, matching the efficiency of an eye-detection) on all CCFs, but once fixed for each instrumental setup (see Table 1 and Sect. 3.3), they are kept constant to ensure homogeneous detection efficiency over the whole GES sample.

The parameter values result from a compromise between antagonistic requirements:

- the THRES0 parameter must not be too low to avoid an unrealistically large velocity range, neither too high in order to be able to detect real albeit low secondary peaks;
- the THRES2 parameter must be calibrated on extreme cases (two very close or very separated peaks). The choice of this parameter is important: it ensures that the second derivative (i.e. the curvature) of the CCF is negative enough, therefore corresponding to real components;
- the SIGMA parameter must not be too large, resulting in a too strong smoothing which would endanger the detection of

close peaks, and not too small to reduce the impact of the numerical noise induced by the successive derivatives.

The empirical method used to set these parameters is described in Sect. 3.3.

3.2. Detection of peaks on simulated CCFs

We tested the efficiency of the DOE code on simulated double-peak CCFs. Using the radiative transfer code *turbospectrum* (Plez 2012; de Laverny et al. 2012), the MARCS library of model atmospheres with spherical geometry (Gustafsson et al. 2008) and the GES atomic linelist (Heiter et al. 2015b), we computed the synthetic spectrum of a star with the following stellar parameters: $T_{\rm eff} = 5000\,\rm K$, $\log g = 1.5$, [Fe/H] = 0. and $\xi_{\rm t} = 1.5\,\rm km\,s^{-1}$, between 5330 Å and 5610 Å for a resolution of $R \sim 20\,000$, *i.e.* to reproduce an HR10 spectrum (see Sect. 2.1). Then, we shifted this spectrum so that the radial velocity of this simulated star is $v_{\rm rad,0} = 72\,\rm km\,s^{-1}$.

We also add a Gaussian noise to reproduce spectra with S/N = 20. Then we combine the spectra shifted at different radial velocities to simulate a composite spectrum. Assuming a flux ratio between the two components of 2/3, we set the main peak at a fixed velocity of 72.0 km s^{-1} whereas the position of the second peak is set at either 36.0, 48.0 or 54.0 km s^{-1} . The cross-correlation function between the composite and the initial spectrum is calculated and the CCF is normalised by the maximum value of the mask auto-correlation (auto-correlation of the initial spectrum).

The three simulated CCFs and their derivatives are shown on Fig. 7, the value of SIGMA being 2.1 km s⁻¹. From the first derivative, only one crossing of the *x*-axis leads to the detection of one single peak. From the second derivative, we see clearly two minima in the left and middle panel whereas we see only one minimum in the right panel. This leads to the conclusion that the detection limit between two components is 18 km s⁻¹. This detection limit depends on the typical width of absorption lines in the tested spectrum but also on the SIGMA parameter. However reducing the SIGMA parameter too much could increase false peak detections for bumpy CCFs. A compromise had to be adopted, as described in Sect. 3.3.

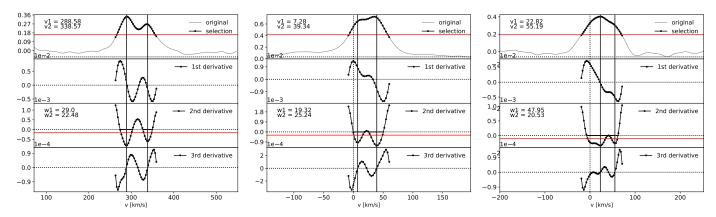


Fig. 8. Examples of iDR4 HR10 double-peak CCFs used to calibrate the parameters of the DOE code. These parameters (THRES0, THRES2 and SIGMA) have been fine-tuned in order to detect multiple components even when they are severely blended as in the case of the rightmost panel.

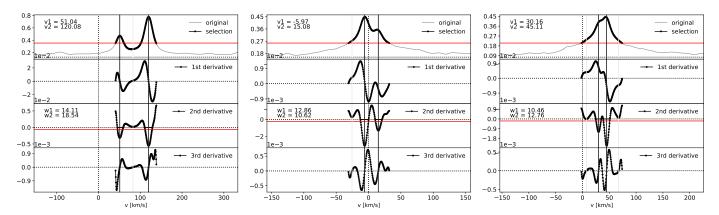


Fig. 9. As Fig. 8 but for the U580 setup.

3.3. Choice of the DOE parameters for the different setups

The three parameters of the DOE code described in Sect. 3.1 have to be adjusted to optimize the CCF components detection. These parameters were adjusted by performing individual calibrations for the different setups (GIRAFFE HR10, HR15N, HR21, and UVES U520 and U580) using examples of single-, double-, and triple-peak CCFs with different separations between the components, and different component widths (i.e. different degree of blending). For the remaining GIRAFFE setups, a standard value of the SIGMA parameter (3 km s⁻¹) was adopted. The adopted values are listed in Table 1. The parameter adjustment aims at obtaining the same detection efficiency on the test CCFs as through eye inspection, especially in the extreme cases (blended CCFs). Figures 8 and 9 illustrate favourable and extreme cases. The value of THRES0 is larger for the GIRAFFE CCFs than for the UVES ones because the correlation noise (i.e., the signal level in the CCF continuum) was observed to be larger in GIRAFFE CCFs.

Depending on the setup resolution along with the number and strength of lines, the minimum separation for peak detection was empirically found to be in the range [20-60] km s⁻¹ for GIRAFFE setups (15 km s⁻¹ for UVES ones). As an example in Sect. 3.2 and Fig. 7, we showed with simulated CCFs that the detection limit is reached for a minimum separation of 18 km s⁻¹ at $R \sim 20\,000$ for slowly rotating stars. The spectrograph resolution and the CCF sampling are not the only relevant parameters here, since the intrinsic line broadening (macroturbulence and stellar rotation) also impacts the CCF width.

DOE includes a procedure to compare the number of valleys in the second derivative with the number of detected peaks. When these numbers are not identical, iteration on the detection occurs after increasing the SIGMA parameter. This procedure prevents false detections since in these situations, the wide CCF often exhibits inflexion points which cause zeros in the third derivative (see left panels of Fig. 10). The number of valleys, defined as regions where the second derivative is continuously negative, is assessed first. For example, in the left "2nd derivative" panel of Fig. 10, one valley is detected. For low values of the SIGMA parameter, the number of detected velocity components is systematically larger than the number of valleys (left panels of Fig. 10). As long as the number of valleys is lower than the number of velocity components detected from the 3rd derivative, the SIGMA parameter is increased by 2 km s⁻¹, until the number of detected velocity components equals the number of valleys. The iterative process is then stopped and the radial velocities of the detected velocity components are identified.

Figure 10 shows an example of this procedure applied on the K1 pre-main sequence object 2MASS J06411542+0946396 (CNAME⁴ 06411542+0946396) member of the cluster NGC 2264 (Fűrész et al. 2006). The DOE run starts with the standard SIGMA value of 5 km s⁻¹. Initially, the DOE code detects three valleys in the second derivative and six velocity

 $^{^4}$ By convention within the GES, the sources are referred to by a 'CNAME' identifier formed from the ICRS (J2000) equatorial coordinates of the sources. For instance, the J2000 coordinates of the source CNAME 08414659-5303449 are $\alpha=8$ h 41 min 46.59 s and $\delta=-53\,^\circ$ 3' 44.9".

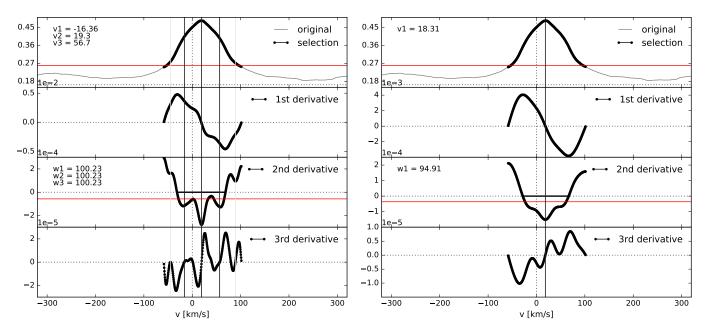


Fig. 10. Special procedure for fast rotators. Left panel: after few iterations three velocity components and one valley are detected. Right panel: after 11 iterations, one velocity component associated to one valley is identified. The associated spectrum has S/N = 65.

components from the third derivative, which are clearly spurious detections. After three iterations, one valley and three velocity components are identified (left panel of Fig. 10). After 11 iterations, SIGMA increases from 5 to 27 km s⁻¹ and the process ends up with one velocity component located at 18.31 km s⁻¹ (right panel of Fig. 10, to be compared with the velocity of 19.86 km s⁻¹ found by Fűrész et al. 2006). The case of CCF multiplicity that can be due to physical processes different from binarity (like pulsating stars, nebular lines in spectra, etc.) is discussed in Sect. 4.7.

3.4. Estimation of the formal uncertainty of the method

In this section, we assess the choice of the SIGMA parameter and its effect on the derived radial velocities and their uncertainty. The uncertainty on the derived radial velocity for single-peak CCF depends mainly on the S/N of the spectrum used to compute the CCF, the normalisation of this spectrum and the mismatch between the spectrum and the mask (spectral type, atomic and molecular profiles, rotational velocity, etc.).

We performed Monte-Carlo simulations to compute singlepeak CCFs from spectra of different S/N ratios but using the same atmospheric parameters defined in Sect. 3.2. We sliced this synthetic spectrum and degraded its resolution in order to match the following settings: GIRAFFE HR10 and HR21, UVES U520 and U580 (up and low). For each S/N level, we computed 251 realisations of our simulated GIRAFFE and UVES spectra by adding a Gaussian noise and computed the corresponding CCFs using a mask made of a noise-free spectrum with a null radial velocity. We finally ran DOE, with different values of SIGMA (from 1 to 15 by step of 1 km s⁻¹). Figures 11 and 12 show the difference $\Delta v_{\rm rad} = v_{\rm rad,doe} - v_{\rm rad,0}$, where $v_{\rm rad,0} = 72.0 \, \rm km \, s^{-1}$, as a function of the DOE parameter SIGMA (right panel) and the 251 CCFs (left panel) along with the noise-free CCF (labeled " $+\infty$ "). We show the results for the lowest S/N (i.e., the most unfavorable cases) for the setups GIRAFFE HR10 and HR21 and UVES U580 (low and up). The mean and standard deviation of $\Delta v_{\rm rad}$

are also superimposed with dark dots and error bars in the right panels.

Comparing the noise-free CCF (blue curve) in the left panels of Figs. 11 and 12 shows striking differences from one setup to the other. This is directly related to the spectral information contained by the spectrum used in the CCF computation. For our simulated star, the HR10 and U580 (low) spectra are more crowded than the HR21 and the U580 (up) spectra. This results in a higher level of the CCF continuum. In addition, in HR21, the large wings of the CCFs are due to the strong Ca II IR triplet that completely dominates this spectral range (see Fig. 2). Figures 11 and 12 also show that the spectral noise tends to shift downward the CCF in comparison to the noise-free CCF because the noisy spectra are less similar to the mask than the noise-free ones. In U580 (Fig. 12), we see that the distance between the noisy CCFs and the reference one is not similar in upper and lower left panels, despite the same S/N. This larger distance in U580 low compared to U580 up could be due to the fact that, for our simulated star, there are more weak lines in the low setup, and therefore, they quickly vanish in the noise when the S/N drops.

The right panels of Figs. 11 and 12 show the effect of SIGMA on the derived radial velocity (uncertainty and/or bias). Our simulations clearly demonstrate that SIGMA has to be chosen in a specific range to ensure reliable results. While our simulated UVES CCFs show that the DOE performance is very stable for any value of SIGMA, our simulated GIRAFFE CCFs show that only a limited range of SIGMA values can ensure reliable velocity measurements. Figure 11 suggests to keep SIGMA between ~ 2 and ~ 8 km s⁻¹ for HR10 and ~ 2 and ~ 7 km s⁻¹ for HR21, in agreement with our empirical calibration on a sub-sample of real GES CCFs (see Table 1). The behavior of DOE, while varying SIGMA, is different for GIRAFFE and UVES CCFs (Figs. 11 and 12). This is not due to the S/N ratio but rather to the sampling of the velocity grid onto which the GIRAFFE and UVES CCFs are computed, i.e. SIGMA is related to the velocity step of the CCFs. Indeed, in Sect. 2.1, we recalled that the sampling frequency of the CCF is lower for GIRAFFE CCFs than for UVES CCFs: as SIGMA increases, a pronounced asymmetry on the

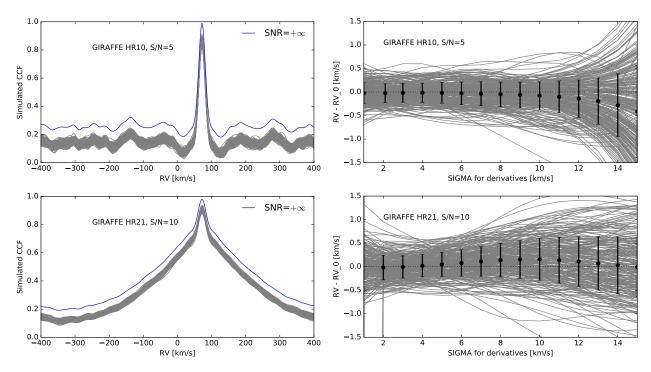


Fig. 11. Estimation of the accuracy of the radial velocities determined by the DOE code on GIRAFFE setups HR10 and HR21 (Ca II triplet region). In each case, 251 simulated CCFs with a S/N ratio as labelled and the blue line representing a noise-free CCF (left panels) were analyzed with DOE varying the value of SIGMA for the calculation of the smoothed successive derivatives and of the radial velocity (right panels).

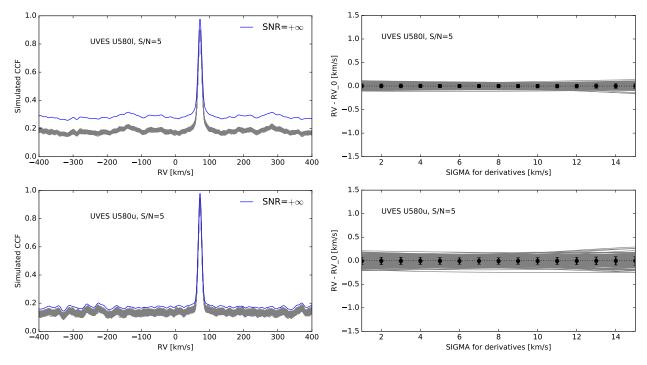
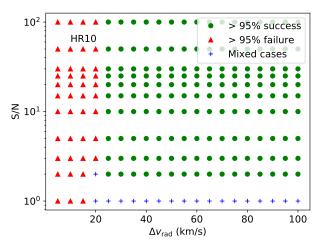


Fig. 12. Same as Fig. 11 for the UVES setups U580 low (H β + Mg I b triplet region) and U580 up (H α + Na I D doublet region).

second derivative appears for GIRAFFE CCFs, resulting in the high scatter displayed by Fig. 11.

Our simulations allow us to quantify the effect of the S/N of the spectra on the method. For U520 and U580, the standard deviation on the radial velocity at the recommended SIGMA goes from 0.05 km s⁻¹ at S/N = 5 to lower than 0.01 km s⁻¹ at S/N = 50. For GIRAFFE HR10, it goes from 0.20 km s⁻¹ at S/N = 5 to 0.02 km s⁻¹

situation is the worst of all the setups with a standard deviation going from 0.25 km s⁻¹ at S/N = 10 to 0.06 km s⁻¹ at S/N = 50. The obvious conclusion is that the UVES setups tend to give more precise results for a given S/N compared to GIRAFFE setups. This is understandable since a single UVES spectrum has a higher resolution and awavelength coverage larger than any GIRAFFE spectrum. For our simulated star, the precision on the radial velocity derived by DOE is up to five times higher for UVES



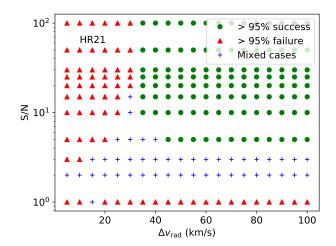


Fig. 13. Assessement of the DOE detection efficiency of the two radial velocity components of simulated SB2 CCFs as a function of the S/N ratio and the radial velocity differences for GIRAFFE HR10 (left panel) and HR21 (right panel) setups.

setups than for GIRAFFE HR10 (this is even worse when compared with HR21).

This first approach of simulated CCFs shows that the method is quite robust with respect to the noise level in the GES spectra. Obviously, the presence of multiple components in the CCF may shift the detected radial velocities especially when the peaks blend one another. In such a case, the inaccuracy on the radial velocity can reach several km s⁻¹ (increasing as the blending degree increases). No quantitative calculations have been performed so far but the middle panel of Fig. 7 shows a good illustration: the main peak is detected at 0.95 km s⁻¹ of its expected position and the second peak at 2.3 km s⁻¹, with a simulated distance of 24 km s⁻¹ between the two peaks. We conclude that the (conservative) random uncertainty on the radial velocity derived by DOE is of the order of ± 0.25 km s⁻¹ while the systematic uncertainty is lower than 0.05 km s⁻¹ for single-peak CCF and may reach a few km s⁻¹ for multi-peak CCF. Other effects, like template mismatch or imperfect normalisation, may have an effect on the uncertainty on the derived radial velocity. We also refer the reader to Jackson et al. (2015) where a discussion on the radial velocity uncertainties may be found, along with their empirical calibrations as a function of S/N, $v \sin i$ and the effective temperature of the source for GIRAFFE HR10, HR15N and HR21 setups. As shown by Sacco et al. (2014) and Jackson et al. (2015), the errors on the GES radial velocities for most of the stars are dominated by the zero-point systematic errors of the wavelength calibration that are not discussed here.

3.5. Detection efficiency as a function of the S/N ratio

Using Monte-Carlo simulations, we assessed the impact of the S/N ratio of GIRAFFE HR10 and HR21 spectra on the detection efficiency of the double-peaked CCF of an SB2. For that purpose we simulated synthetic SB2 spectra (pair of twin stars) varying the S/N (from 1 to 100) and varying the difference in radial velocity of the two components $\Delta v_{\rm rad}$ (from 5 to 100 km s⁻¹). For each pair ($\Delta v_{\rm rad}$, S/N), we computed as above 251 realisations of the spectra and their corresponding CCFs. We then applied DOE with the parameters adapted to each setup (see Table 1).

The maps in Fig. 13 show the detection efficiency in HR10 and HR21. The green dots (respectively the red triangles) indicate $(\Delta v_{\rm rad}, S/N)$ conditions when DOE is able to detect the two

expected peaks in more than 95% of cases (respectively, conditions when DOE failed at detecting the two expected peaks in more than 95% of cases). Blue plusses represent intermediate cases making detection efficiency dependent on the noise: due to the noise, spurious peaks may appear (*i.e.* detection failed) or the two peaks have different height (despite being twin stars) and become discernible to DOE for small $\Delta v_{\rm rad}$ (*i.e.* detection succeeded; *e.g.*, for HR21, at S/N=10 and $\Delta v_{\rm rad}=25~{\rm km~s^{-1}}$).

These simulations demonstrate that even spectra with very low S/N carry sufficient information to reveal the binary nature of the targets. Specifically, in the HR10 setup, double peaks are detected in 95% of cases when $S/N \ge 2$ and $\Delta v_{\rm rad} \ge$ 25 km s⁻¹ while in HR21 setup, they are detected at the same rate when $S/N \ge 5$ and $\Delta v_{\rm rad} \ge 45$ km s⁻¹. Thus, the S/N threshold that we adopted (i.e analysis of CCFs for all spectra with $S/N \ge 5$) protect us from mixed cases, which tend to happen for the lowest levels of S/N ratios. This shows also that the HR10 setup is more suitable to detect SB2 than HR21 because HR21 is located around the IR Ca II triplet whose lines have strong wings that decrease the detection efficiency. In Sect. 4.2, the histogram of the radial velocity separation of the effectively detected SB2 candidates is presented. Observationally, HR10 spectra (respectively, HR21) allow us to detect SB2 with $\Delta v_{\rm rad}$ as low as ~ 25 km s⁻¹ (respectively, ~ 60 km s⁻¹): thus for both setups we are dealing with cases falling in the green dotted area of the maps. Thus, we expect in all cases an SB2 detection efficiency better than 95%.

4. iDR4 results and discussion

The DOE code is included in a specifically designed workflow to handle all the GES single-exposure spectra for all setups. The automated workflow includes three steps: first, the CCFs are selected using the set of criteria described in Sect. 2.2; second, the DOE code is applied to the CCFs to identify the number of peaks and a confidence flag is assigned; third, the CCFs in a given setup are combined per star and a last criterion is applied: for a given star, if more than 75% of the CCFs in at least one setup show 2 peaks (respectively 3 and 4), then the star is classified as SB2 candidate (SB3 and SB4 respectively). This rather restrictive criterion (see Sect. 4.7) was adopted to prevent false positive SB

Table 2. Number of SB2, SB3 and SB4 candidates per confidence flag.

| | Con | fidence | flag | |
|-------------------|-----|---------|------|-------|
| Peculiarity index | A | В | С | Total |
| | | | | |
| SB2 (2020) | 127 | 107 | 108 | 342 |
| SB3 (2030) | 7 | 1 | 3 | 11 |
| SB4 (2040) | 1 | 0 | 0 | 1 |

Notes. A: probable, B: possible, C: tentative

detections (due to spectra normalisation, cosmics, nebular lines, etc.).

After this automatic procedure, a visual inspection is performed to ensure that (i) no false positive detection remains (ii) the confidence flag is relevant. We investigate the CCFs and the spectra of all the SBn candidates one by one. When a clear false detection is encountered, the SB candidate is removed from the list. When an SB was flagged by the automatic process as probable (A) or possible (B), but the visual inspection of the CCF series (all setups considered) casts doubts on this classification, the corresponding spectra for that object are inspected. The choice of the final flag for an object can be downgraded in case other CCFs provide discrepant results. Such a procedure ensures that processes other than binarity moderately contaminate SB candidates flagged C, marginally contaminate SB candidates flagged B and exceptionally contaminate those flagged A. Despite these difficulties, adopting clear classification criteria ensures the best possible consistency throughout the survey.

The SBn candidates reported in the present paper are much fainter on average than those already collected in the Ninth Catalogue of Spectroscopic Binary Orbits (SB9; Pourbaix et al. 2004) (Fig. 14). The average visual magnitude of SB2 within the SB9 catalogue is around $V \sim 8$. For the GES SB2 candidates, the average is $V \sim 15$. The Gaia-ESO program targets both Milky Way field stars and stars in open and globular clusters. We refer the reader to Stonkutė et al. (2016) for the selection function of Milky Way field stars (excluding the bulge stars), to Bragaglia (2012) and Bragaglia et al. (in prep.) for the selection criteria in open clusters, and to Pancino et al. (2017) in globular clusters and calibration open clusters. We emphasize that the targets observed in regions like the bulge, Cha I (Sacco et al. 2017) and γ^2 Vel (Prisinzano et al. 2016) associations, as well as ρ Oph (Rigliaco et al. 2016) molecular cloud are selected on the basis of coordinates and photometry (VISTA and 2MASS), thus providing a rough membership criterion.

The list of the SB2 and SB3 candidates in the Milky Way field is given in Tables A.1 and A.2. The list of SB2 in the bulge, the Cha I, γ^2 Vel and ρ Oph associations and the CoRoT field is given in Table B.1. Finally, the list of SBn in stellar clusters is given in Table C.1. The results (classification and confidence flag) are included in the GES public releases (see footnote 3) using the nomenclature as described in the GES outlier dictionary developed by the GES Working Group 14 (WG 14)⁵.

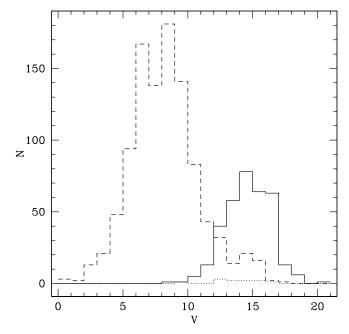


Fig. 14. Magnitude distributions of SB2 systems in the *Ninth Catalogue of Spectroscopic Binary Orbits* (SB9 Orbits; Pourbaix et al. dashed line; 2004, data downloaded in September 2016 from http://sb9.astro.ulb.ac.be, and in the GES (solid line). SB3 systems are shown as the dotted-line histogram.

4.1. The binary classification⁶

The binary classification⁶ has been developed for the GES within WG 14. The following scheme is adopted: the peculiarity flag is built from the juxtaposition of a peculiarity index, and a confidence flag letter. The peculiarity index is defined as 20n0, with $n \ge 2$, where n is the number of distinct velocity components in the CCF. With this peculiarity index, an SB2 is classified as 2020, an SB3 2030, etc. Of course, even though a star is flagged 2020 (*i.e.* SB2), a third component may be present but not visible during the observation or undetectable with the resolution and S/N of the considered exposure.

Moreover, the WG14 dictionary recommends the use of confidence flags (A: probable, B: possible, and C: tentative). Clearly, the closer the CCF peaks are, the less certain the detection is. The criteria to allocate these flags were defined as follows:

- A: the local minimum between peaks is deeper than 50% of the full amplitude of the largest peak;
- B: the local minimum between peaks is higher than 50% of the full amplitude of the largest peak;
- C: no local minimum is detected between peaks but the CCF slope changes.

With these definitions, the SB2 whose CCF is plotted on the left, middle and right panels of Figs. 8 and 9 would be flagged as A, B and C respectively.

For triple-peak CCFs, the same type of criterion is applied to the second local minimum. If this second local minimum is lower than 70% of the full amplitude of the largest peak, then the confidence flag is set to A, else, B. Examples of these two cases are shown on simulated CCFs in Fig. 15. The CCF on the middle panel is classified as 2030B (due to the fact that the leftmost

⁵ The aim of WG 14 is to identify non-standard objects which, if not properly recognised, could lead to erroneous stellar parameters and/or abundances. A dictionary of encountered peculiarities has been created, allowing each node to flag peculiarities in a homogeneous way.

⁶ See note 3

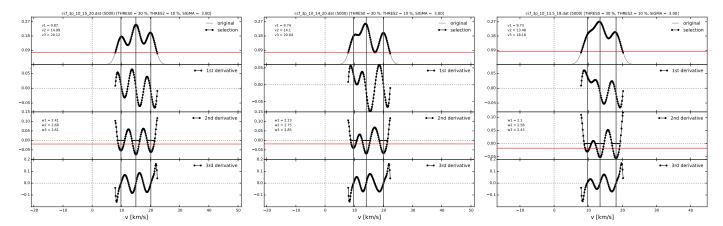


Fig. 15. Triple-peak simulated CCFs with a main peak fixed at 10 km s^{-1} detected with confidence flags A (left; second and third peaks at $15 \text{ and } 20 \text{ km s}^{-1}$), B (middle; second and third peaks at $14 \text{ and } 20 \text{ km s}^{-1}$) and C (right; second and third peaks at $13.5 \text{ and } 18 \text{ km s}^{-1}$).

local minimum is higher than 0.5 times the largest amplitude) but also as 2020A because the middle and leftmost peaks, taken as a whole, are well separated from the rightmost peak.

4.2. iDR4 SB2 candidates

Table 2 presents the breakdown of the detected SBn candidates in terms of confidence flags, whereas Table 3 provides the detailed results of the analysis per field, in terms of automated detection ('DOE' column) and after visual checking ('confirmed' column). A total of 1092 sources were identified as SB2 candidates by the automated procedure described in the previous section, out of which 342 are confirmed after visual inspection, giving a success rate of about 30% similar to that of Matijevič et al. (2010) for the RAVE survey. Typical rejected cases include distorted CCFs caused by negatives fluxes or pulsating stars. Some confidence flags were also changed during the visual inspection phase (see Sect. 4.7). The largest number of stars has been observed with the GIRAFFE setup HR21 because it corresponds to the Gaia wavelength range of the radial velocity spectrometer. However, the rate of SBn detection in this setup is very low because it is dominated by the presence of the Ca II triplet, which is a very strong feature in late-type stars, thus resulting in a broad CCF that can mask possible multiple peaks (Fig. 2, bottom panel). Moreover, emission in the line cores of this triplet induces fake double-peak CCFs because in the templates the lines are always in absorption. Consequently, it is very difficult to identify double peaks due to binarity based on HR21 CCFs (see Sect. 4.7 for more details). This explains why we have only two firm detections among the 31 970 stars observed with this setup only. Hence, this setup is not well-suited to detect stellar multiplicity at least in our situation (see Matijevič et al. 2010: though they could discover 123 SB2 out of 26 000 RAVE targets, they also had to deal with very broadened CCFs and could not detect binaries with $\Delta v_{\rm rad} \leq 50 \ {\rm km \ s^{-1}}$).

The setup with the second largest number of observed objects is HR10. This setup covers the range [535-560] nm with lots of small absorption lines that result in a narrow CCF, suitable for the detection of stellar multiplicity (see Fig. 8). The largest number of probable SB2 candidates is indeed detected with this setup.

To illustrate the fact that some setups are more adapted than others to detect SBn, we show spectra and CCFs in these setups for single stars (the Sun and Arcturus in Figs. 2 and 3) and for an SB2 candidate (NGC 6705 1936 observed in most of the GI-

RAFFE setups where the composite nature of the spectrum is clearly visible in Fig. 16).

Contrary to field stars which are observed in HR10 and HR21 only, cluster stars were observed with many different setups. The number of SB2 candidates in the field is 185 out of 27786 stars (0.67%) whereas in the clusters, it amounts to 127 out of 16468 (0.77%, see Table 3).

There are about 30 SB2 candidates detected with a double-peaked CCF in both GIRAFFE HR10 and HR21. For instance, the field star 02394731-0057248 (magnitude V=13.8) is identified as an SB2 candidate with HR10 and HR21 (see Fig. 17). This new candidate has no entry in the Simbad database.

The histograms of the radial velocity separation of SB2 candidates for GIRAFFE HR10 and HR21 as well as for UVES U580 are shown on Fig. 18 (U520 is not represented due to the small statistics). The smallest measured radial velocity separations are 23.3, 60.9 and 15.2 km s $^{-1}$ for HR10, HR21 and U580, respectively. This is well in line with the detection capabilities of the DOE code as mentionned in Sect. 3.3 (\sim 30 km s $^{-1}$ for GIRAFFE and \sim 15 km s $^{-1}$ for UVES setups). In U580, the high bin value around 72 km s $^{-1}$ is mainly due to the repeated observations of a specific object, the SB4 candidate 08414659-5303449 in IC 2391 (see Sect. 4.5).

Concerning the SB2 candidates in open clusters, not only did we check the cleanliness of the SB2 CCF profile, but we also compared the velocities of the two peaks with the cluster velocity. Assuming that most of the SB2 systems discovered by GES generally have components of about equal masses, then, an SB2 being member of the cluster should have the cluster velocity about midway between the two component velocities. This simple test allows us to assess the likelihood that the SB2 system is a cluster member. This method is applied in full details for the SB2, SB3 and SB4 candidates analyzed in the present section and Sects. 4.4 and 4.5. The results are shown in Table C.1. The numbers of bona fide SB2 candidates retained per cluster after this check are listed in the corresponding column of Table 3. The column labeled 'Member' in Table C.1 evaluates the likelihood of cluster membership based on the component velocities: if the cluster velocity falls in the range encompassed by the component velocities, we assume that the centre of mass of the system moves at the cluster velocity, so that membership is likely. In that case, we put 'y' in the column 'Member'. On the contrary, if the CCF exhibits two well-defined peaks not encompassing the cluster velocity, the star is labeled as SB2 not member of the cluster ('n' in column 'Member'). Another possibility is that one

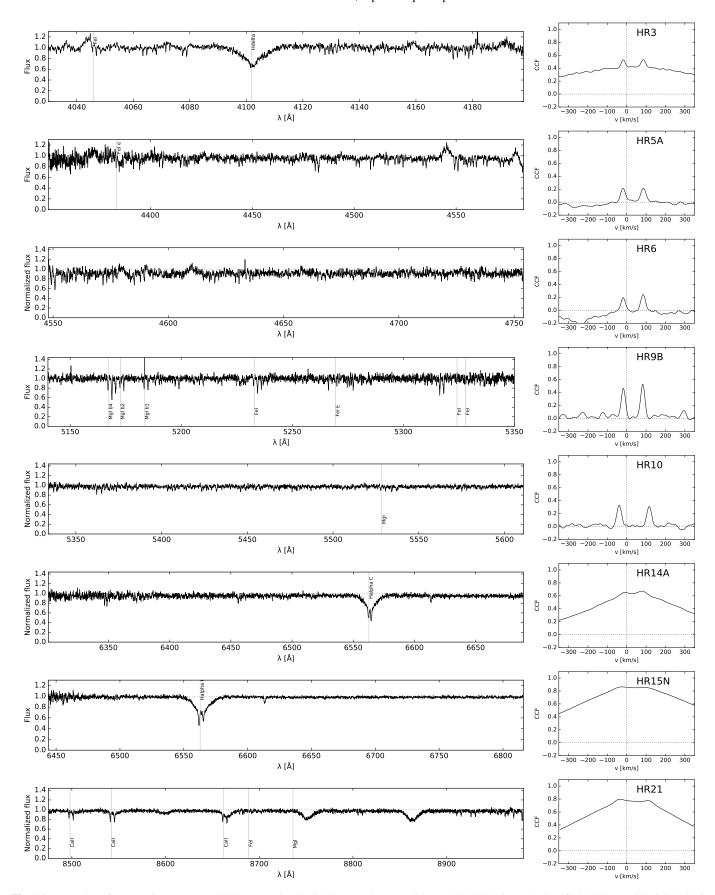


Fig. 16. Examples of composite spectra and CCFs associated with the new SB2 candidate 18503230-0617112 classified 2020A (NGC 6705 1936) with a visual magnitude of V = 13.4 ($B - V \sim 0$). Broad emission lines in HR3, HR5A and HR6 are spill-over from strong Ar lines from a Th-Ar calibration lamp observed along with the target.

Table 3. Distribution of SB2 and SB3 candidates among the different observed fields.

| Field/cluster | log age | v_r | # stars | | # SI | 32 | | | | # SB3 | | | SB2/total | SB3/SB2 |
|----------------|---------|----------------------------------|---------|------|-----------|-----|-----|-----|-----|-----------|-----|-----|-----------|---------|
| , | [yr] | $[\mathrm{km}\ \mathrm{s}^{-1}]$ | | DOE | confirmed | A | В | С | DOE | confirmed | A] | ВС | | [%] |
| | | | | 2.0 | 40.5 | | 4.0 | | | _ | _ | | o | |
| Field | | | 27786 | 263 | 185 | 82 | 48 | 55 | 24 | | 5 | | 0.67 | 3 |
| Bulge | | | 2633 | 6 | 6 | 1 | 3 | 2 | 0 | 0 | | | 0.23 | |
| Cha I | | | 616 | 5 | 2 | _ | 2 | | 1 | 0 | | | 0.49 | |
| Corot | | | 1966 | 13 | 7 | 5 | 2 | _ | 0 | 0 | | | 0.36 | |
| γ^2 Vel | | | 1116 | 28 | 16 | 2 | 7 | 7 | 2 | 0 | | | 1.43 | |
| ho Oph | | | 278 | 2 | 1 | | | 1 | 1 | 0 | | | 0.72 | |
| IC 2391 | 7.74 | 14.49 ± 0.14 | 398 | 4 | 3 | 2 | 1 | | 4 | 0 | | | 0.75 | |
| IC 2602 | 7.48 | 18.12 ± 0.30 | 1784 | 6 | 3 | 1 | 1 | 1 | 3 | 0 | | | 0.17 | |
| IC 4665 | 7.60 | -15.95 ± 1.13 | 559 | 6 | 5 | 2 | 2 | 1 | 1 | 0 | | | 0.89 | |
| M 67 | 9.60 | 33.8 ± 0.5 | 25 | 4 | 4 | 4 | | | 0 | 0 | | | 16.00 | |
| NGC 2243 | 9.60 | 59.5 ± 0.8 | 715 | 38 | 1 | | 1 | | 14 | 0 | | | 0.14 | |
| NGC 2264 | 6.48 | 24.69 ± 0.98 | 1565 | 78 | 4 | 2 | 2 | | 18 | 0 | | | 0.26 | |
| NGC 2451 | 7.8 (A) | 22.70 (A) | 1599 | 18 | 11 | 3 | 5 | 3 | 7 | 1 | 1 | | 0.69 | 9 |
| | 8.9 (B) | 14.00 (B) | | | | | | | | | | | | |
| NGC 2516 | 8.20 | 23.6 ± 1.0 | 726 | 19 | 8 | 1 | 4 | 3 | 10 | 1 | | 1 | 1.10 | 13 |
| NGC 2547 | 7.54 | 15.65 ± 1.26 | 367 | 7 | 1 | 1 | | | 3 | 0 | | | 0.27 | |
| NGC 3293 | 7.00 | -12.00 ± 4.00 | 517 | 158 | 9 | 1 | 5 | 3 | 55 | 0 | | | 1.74 | |
| NGC 3532 | 8.48 | 4.8 ± 1.4 | 94 | 1 | 1 | | 1 | | 0 | 0 | | | 1.06 | |
| NGC 4815 | 8.75 | -29.4 ± 4 | 174 | 11 | 2 | | 1 | 1 | 0 | 0 | | | 1.15 | |
| NGC 6005 | 9.08 | -24.1 ± 1.3 | 531 | 12 | 4 | 2 | 1 | 1 | 8 | 1 | | 1 | 0.75 | 25 |
| NGC 6530 | 6.30 | -4.21 ± 6.35 | 1252 | 95 | 5 | 2 | | 3 | 1 | 0 | | | 0.40 | |
| NGC 6633 | 8.78 | -28.8 ± 1.5 | 1643 | 17 | 15 | 3 | 7 | 5 | 0 | 0 | | | 0.91 | |
| NGC 6705 | 8.47 | 34.9 ± 1.6 | 994 | 108 | 19 | 5 | 3 | 11 | 52 | 1 | 1 | | 1.91 | 5 |
| NGC 6752 | 10.13 | -24.5 ± 1.9 | 728 | 8 | 1 | | 1 | | 0 | 0 | | | 0.14 | |
| NGC 6802 | 8.95 | 11.9 ± 0.9 | 156 | 7 | 2 | 2 | | | 7 | 1 | | 1 | 1.28 | 50 |
| Tr 14 | 6.67 | -15.0 | 858 | 82 | 3 | 2 | 1 | | 19 | 0 | | | 0.35 | |
| Tr 20 | 9.20 | -40.2 ± 1.3 | 1316 | 84 | 19 | 3 | 7 | 9 | 24 | 1 | | 1 | 1.44 | 5 |
| Tr 23 | 8.90 | -61.3 ± 0.9 | 164 | 5 | 1 | 1 | | | 5 | 0 | | | 0.61 | |
| Be 25 | 9.70 | $+134.3 \pm 0.2$ | 38 | 2 | 2 | | 2 | | 1 | 0 | | | 5.26 | |
| Be 81 | 8.93 | 48.3 ± 0.6 | 265 | 5 | 2 | 1 | | 1 | 6 | 0 | | | 0.75 | |
| Total | | | 50863 | 1092 | 342 | 128 | 107 | 107 | 266 | 11 | 7 | 1 3 | 0.68 | 3 |

Notes. The column 'log age' lists the logarithm of the cluster age (in years) from Cantat-Gaudin et al. (2014) (NGC6705), Spina et al. (in prep.) (IC 2391, IC 2602, IC4665, NGC 2243, NGC 2264, NGC 2541, NGC 2547, NGC 3293, NGC 3532, NGC 6530), Bellini et al. (2010) (M 67), Bragaglia & Tosi (2006) (NGC 2243), Sung et al. (2002) (NGC 2516), Friel et al. (2014) (NGC 4815), Jacobson et al. (2016) (NGC 6005, NGC 6633), VandenBerg et al. (2013) (NGC 6705), Tang et al. (submitted) (NGC 6802), Donati et al. (2014) (Tr 20 and Berkeley 81, written Be 81), Overbeek et al. (2016) (Tr 23), and Carraro et al. (2007) (Be 25). The column v_r lists the radial velocity; for the clusters with ages larger than 100 Myr see Jacobson et al. (2016, only UVES targets) excepted for M 67 (Casamiquela et al. 2016), NGC 2243 (Smiljanic et al. 2016); Friel et al. (2014) (NGC 4815), Harris (1996) (NGC 6752). For the young clusters, see Dias et al. (2002) (IC 2391, IC 2602, IC 4665, NGC 2264, NGC2451, NGC 2547, NGC 3293, NGC 6530), and Carraro et al. (2007) (Be 25). The column '# stars' lists the number of stars in that particular field/cluster observed by the GES. The columns 'DOE' give the number of SB detected automatically, whereas the column 'confirmed' represents the number of SB kept after eye inspection of CCFs and associated spectra. The columns labeled 'A', 'B' and 'C' list the number of confirmed systems by confidence flag (probable, possible and tentative respectively). No SB2 or SB3 candidates have been found yet with the DOE code for the following clusters within the GES: Be 44 (93), M 15 (109), M 2 (110), NGC 104 (1138), NGC 1851 (127), NGC 1904 (113), NGC 2808 (112), NGC 362 (304), NGC 4372 (120), NGC 4833 (102) and NGC 5927 (124), where the numbers in parenthesis give the number of stars observed in each cluster.

component has a velocity close to that of the cluster, and the second velocity is offset. In that case, the SB2 nature is questionable and the star is more probably a pulsating star (responsible for the secondary peak or bump) belonging to the cluster ('y' in column 'Member'). The list of individual radial velocities will be given in a forthcoming paper, based on iDR5 data. More extended remarks for each cluster are provided in Appendix C.

4.3. Orbital elements of two confirmed SB2 in clusters

With the data collected so far, we were able to confirm the binary nature of two SB2 candidates in clusters by deriving reliable orbital solutions for the systems 06404608+0949173 (NGC 2264 92) and 19013257-0027338 (Berkeley 81, written Be 81).

The first system 06404608+0949173 (magnitude $V \sim 12$) is a *bona fide* SB2 for which 24 spectra are available (20 GIRAFFE HR15N and 4 UVES U580), and an orbit can be computed, as shown on Fig. 19. Observations where only one velocity component is detected are not used to calculate the orbital solution

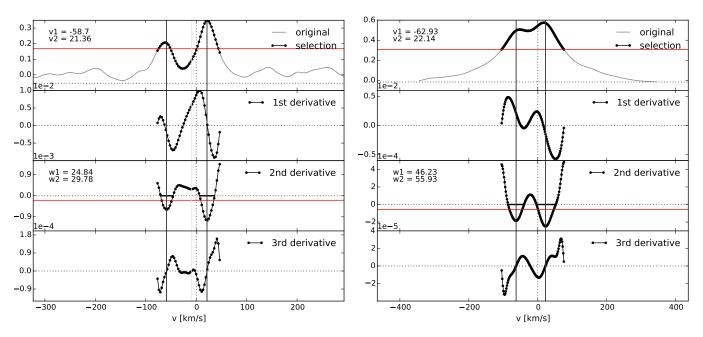


Fig. 17. Example of identification of a new SB2 candidate 02394731-0057248 not reported in Simbad. Left panel: GIRAFFE HR10 setup ($S/N \sim 10$). Right panel: GIRAFFE HR21 setup ($S/N \sim 140$).

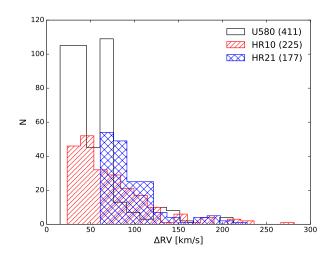


Fig. 18. Histograms of the radial velocity separation of SB2 candidates for GIRAFFE HR10, HR21 and for UVES U580 single exposures. The numbers in parenthesis are the numbers of single exposures where two peaks were identified.

because these velocities are not accurate (Fig. 19), since the two velocity components are blended. The orbital elements are listed in Table 4. The short period of 2.9637 ± 0.0002 d implies that neither of the components can be a giant which is consistent with the classification of the system as K0 IV (Walker 1956). The centre-of-mass velocity of the system (14.6 km s⁻¹) is close to the cluster velocity (17.7 km s⁻¹), as it should. The mass ratio is $M_B/M_A = 1.10$. Classified as FK Com in the GCVS (=V642 Mon), this source is chromospherically active with X-ray emission (ROSAT and XMM). This system thus adds to the two SB2 systems with available orbits (VSB 111 and VSB 126) already known in NGC 2264 (Karnath et al. 2013).

The second system 19013257-0027338 (magnitude $V \sim 17$) is a confirmed SB2 (2020 A) for which 18 spectra are available (8 GIRAFFE HR15N and 10 GIRAFFE HR9B). This source is

not listed in the Simbad database. The orbital elements are given in Table 4 and the orbit is displayed in Fig. 20. Strangely enough, a good SB2 solution for this system could only be obtained by adding an extra parameter to the orbital elements, namely an offset, between the systemic velocities derived from component A and from component B (see the ΔV_B term in Eq. (2) of Pourbaix & Boffin (2016)). In most cases, this offset is null but there could be situations where it is not, like in the presence of gravitational redshifts or convective blueshifts that are different for components A and B (Pourbaix & Boffin 2016). Alternatively, if the spectrum of one of the components forms in an expanding wind (as in a Wolf-Rayet star), it would lead as well to such an offset. However, what is puzzling in the considered case is the large value of the offset (24.8 ± 1.2) for which we could not find any convincing explanation. Indeed, no Wolf-Rayet stars are known in the Be 81 cluster according to the Simbad database. This very diffuse cluster of intermediate age lies towards the Galactic centre (Hayes & Friel 2014; Donati et al. 2014).

4.4. SB3 candidates

Tables 2 and 3 show that, in total, 11 SB3 candidates (7 probable: flag A, 1 possible: flag B, and 3 tentative: flag C) have been detected. Among those, five SB3 are found in the field (Fig. 21 and Table A.2) and six in clusters (Fig. 22 and within the Table C.1). A total of 266 targets were initially labeled as SB3 candidates by the DOE code while only 11 were kept after visual inspection, giving a success rate of about 4 % (compared to 30 % for SB2 detection). The SB3 candidates are essentially detected in UVES setups and in GIRAFFE setups HR9B and HR10. SB3 candidates in the stellar clusters have been examined on a case by case basis, and the results are reported below.

NGC 2451. The CCF of 07470917-3859003 exhibits three clear peaks (the CCF is classified as 2030A), at 25.0, 96.1, and 136.6 km s^{-1} . The first velocity is compatible with member-

Table 4. Orbital elements for 06404608+0949173 in NGC 2264, and 19013257-0027338 in Be 81.

| CNAME | 06404608+0949173 | 19013257-0027338 |
|---------------------------------------|-------------------------|-----------------------|
| | | |
| P(d) | 2.9637 ± 0.0002 | 15.528 ± 0.002 |
| e | 0.092 ± 0.006 | 0.170 ± 0.006 |
| ω (°) | 56.8 ± 3.9 | 265.7 ± 3.9 |
| T_0 -2 400 000 (d) | 56072.4085 ± 0.0351 | 56470.531 ± 0.140 |
| $V_0 ({\rm km \ s^{-1}})$ | 14.32 ± 0.55 | 34.51 ± 0.66 |
| ΔV_B | 0.00 (adopted) | 24.8 ± 1.2 |
| $K_A ({\rm km \ s^{-1}})$ | 106.3 ± 0.7 | 86.0 ± 0.9 |
| $K_B (\mathrm{km \ s}^{-1})$ | 117.0 ± 0.6 | 97.0 ± 0.9 |
| $\sigma_A(O-C)$ (km s ⁻¹) | 20.2 | 6.1 |
| $\sigma_B(O-C)$ (km s ⁻¹) | 9.3 | 6.8 |
| $a_A \sin i$ (Gm) | 4.315 ± 0.030 | 18.1 ± 0.2 |
| M_A/M_B | 1.10 | 1.13 |
| N | 16 | 18 |

Notes. The orbital elements are the orbital period P, the eccentricity e, the argument of the periastron ω from the ascending node, the time of passage at periastron T_0 , the velocity of the centre-of-mass V_0 , the primary and secondary velocity amplitudes K_A and K_B , the projected primary semi-major axis on the plane of the sky $a_A \sin i$ and the primary to the secondary mass ratio M_A/M_B . $\sigma_A(O-C)$ and $\sigma_B(O-C)$ are the standard deviation of the residuals (observed – calculated) of components A and B. N is the number of avalaible CCFs on which two velocity components are identified. For the meaning of ΔV_B see Eq. (2) of (Pourbaix & Boffin 2016).

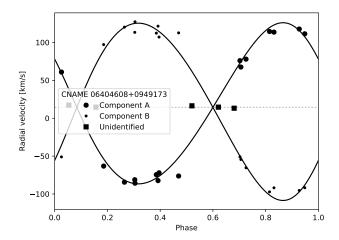


Fig. 19. The SB2 orbit of 06404608 + 0949173 in NGC 2264. Component A is represented by large circles and component B by small circles. Squares represent the single radial velocity obtained when only one peak is visible in the CCF; these are not used to calculate the orbital solution, due to their larger uncertainties. The error on radial velocities amounts to ± 0.25 km s⁻¹. Horizontal dotted line is V_0 .

ship in NGC 2451A. The DSS⁷ image reveals the presence of a slightly fainter star about 12" south (a larger distance than the 1.2" size of the fibre, so no contamination is possible). Given the fact that the two fainter peaks are not located symmetrically with respect to the cluster velocity, it is doubtful that the system could be an SB3 system in case of membership to NGC 2451.

NGC 2516. NGC 2516 45 (system 07575737-6044162) is a star classified as A2 V (Hartoog 1976) with V = 9.9. The iDR4 recommended parameters ($T_{\rm eff} = 8500$ K, $\log g = 4.1$ and solar metallicity) suggest that it could be a δ Scu star. Its CCF is most likely associated with a fast rotator with a superimposed

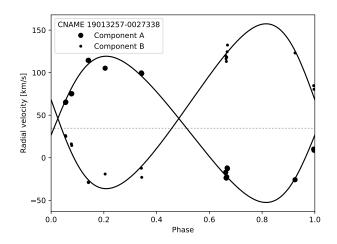


Fig. 20. The SB2 orbit of 19013257-0027338 in Berkeley 81. Component A is represented by large circles and component B by small circles. The error on radial velocities amounts to ± 0.25 km s⁻¹. Horizontal dotted line is V_0 .

sharper central peak. The SB3 nature of this candidate is therefore doubtful and a follow-up of this source should be performed before drawin any firm conclusion.

NGC 6705. In total, the DOE routine finds 52 SB3 candidates in NGC 6705, one of the largest number of SB3 among all the targeted clusters (Table 3). After a first-pass analysis we discarded all of them but one. NGC 6705 1147 (system 18510286-0615250). The velocities corresponding to the three peaks observed in the CCF are listed in Table 5. They exhibit clear temporal variations. The cluster velocity is 29.5 km s⁻¹ (Cantat-Gaudin et al. 2014). This velocity is close to that of the middle (C, *i.e.*, faintest) peak in the CCF. That central peak is not varying as much as the most extreme peaks, and moreover, the shape of the C peak is not as sharp as are the A and B peaks. Considering the fact that the cluster NGC 6705 is a dense one, we believe that this third peak is from background contamination. We therefore

⁷ Digitized Sky Survey: https://archive.stsci.edu/cgi-bin/ dss_form

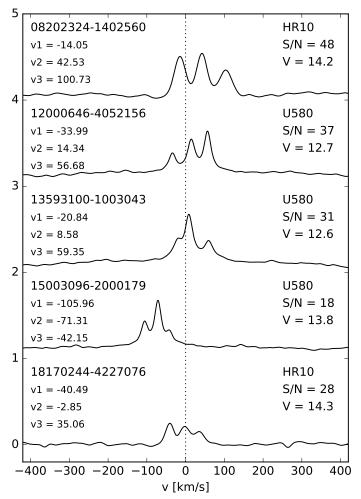


Fig. 21. The CCFs of the five SB3 candidates (flagged 2030 A) in the field. Velocities of the components are given in km $\rm s^{-1}$.

conclude that the detection of NGC 6705 1147 as SB3 is spurious, and should be downgraded to SB2. The SB2 analysis is presented in Table 5 where we computed the mass ratio, adopting 34 km s⁻¹ (Table 3) as the centre-of-mass (cluster) velocity. The observed velocity variations are consistent at all times with a mass ratio of the order of 1.32.

NGC 6005. The CCF of 15553867-5724434 (classified as 2030B) shows three peaks, at -81.6, -14.4 and 32.7 km s⁻¹, to be compared with -25.2 km s⁻¹ for the cluster velocity (Carlberg 2014). The spectra are at the minimum required S/N. These data are compatible with 15553867-5724434 being an SB3, member of NGC 6005.

NGC 6802. The CCF of 19302315+2013406 (classified as 2030C) shows three distinct peaks, at -22.4, 22.0 and 65.5 km s⁻¹, to be compared with 12.4 km s⁻¹ for the cluster velocity (Hayes & Friel 2014). These data are compatible with 19302315+2013406 being an SB3, member of NGC 6802.

Trumpler 20. The CCF of 12391904-6035311 (classified as 2030C) shows three distinct peaks, at -85.78, -44.4 and 14.8 km s⁻¹, to be compared with -40.8 km s⁻¹ for the cluster velocity (Kharchenko et al. 2005). These data are compatible with 12391904-6035311 being an SB3, member of Trumpler 20. An extended analysis of the GES data for this cluster may be found in Donati et al. (2014).

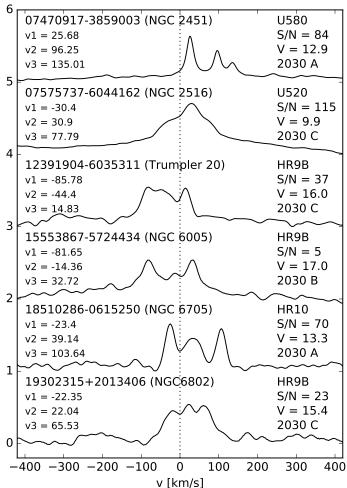


Fig. 22. The CCFs of the six SB3 candidates in the stellar clusters. Velocities of the components are given in km $\rm s^{-1}$. The vertical scale of the CCFs has been magnified for clarity.

4.5. The unique SB4 candidate HD 74438

We have detected one SB4 candidate: the A2V star HD 74438 (CNAME 08414659-5303449, with V = 7.58) belonging to the open cluster IC 2391 (Platais et al. 2007).

The star has been observed 45 times within 2.5 h on February 18, 2014, with the U520 and U580 setups. Its peculiarity was already noticed by Platais et al. (2007), since it lies 0.9 mag above the main sequence in a color-magnitude diagram, and therefore was already suspected to be a triple system (since the maximum deviation for a binary system with two components of equal brightness would amount to $2.5 \times \log 2 = 0.75$ mag). It is nevertheless considered a bona fide member of the cluster by Platais et al. (2007). Therefore, one may consider that the centre-ofmass velocity for the system is identical to the cluster velocity, namely 14.8 ± 1 km s⁻¹ (Platais et al. 2007). A typical example of the CCF of HD 74438 is presented on Fig. 23, with its four distinct CCF peaks clearly apparent. The velocities of the peaks at different times over the night of February 18, 2014 are collected in Table 6. In this Table, we first notice that the velocities of components A and B (which correspond to the highest peaks) vary slowly and oppositely to each other. Their amplitude of variations is similar. If we compute the velocity variations with respect to the cluster velocity (which should correspond to the center-of-mass velocity of the AB pair, neglecting the gravitational influence of components C and D – columns $\Delta v_r(A)$ and

Table 5. Velocities of the three peaks (A, B, C) in the CCF of NGC 6705 1147. The columns labeled Δ list the differential velocity with respect to the centre-of-mass (*i.e.*, cluster) velocity, adopted as 34 km s⁻¹.

| JD - 2 456 000 | Setup | $v_r(A)$ | $v_r(B)$ | $v_r(C)$ | $\Delta v_r(A)$ | $\Delta v_r(B)$ | M_A/M_B |
|----------------|-------|----------|----------|----------|-----------------|-----------------|-----------|
| 77.409 | HR3 | 79.62 | -24.70 | 33.83 | 45.62 | 58.70 | 1.29 |
| 99.268 | HR3 | 95.35 | -47.33 | 29.87 | 61.35 | 81.33 | 1.33 |
| 99.280 | HR5A | 95.38 | -45.73 | 23.68 | 61.38 | 79.73 | 1.30 |
| 99.295 | HR6 | 93.65 | -44.84 | 35.92 | 59.65 | 78.84 | 1.32 |
| 99.298 | HR9B | 94.83 | -46.62 | 40.28 | 60.84 | 80.62 | 1.33 |
| 103.110 | HR10 | -26.78 | 106.91 | 39.14 | 60.78 | 72.91 | 1.20 |
| 442.394 | HR10 | 75.38 | -18.75 | 40.61 | 41.38 | 52.75 | 1.27 |
| 442.400 | HR10 | 72.20 | -20.23 | 26.72 | 38.20 | 54.23 | 1.42 |
| 442.406 | HR10 | 75.41 | -22.23 | 33.44 | 41.41 | 56.23 | 1.36 |

Table 6. Velocities of the four peaks (A, B, C, D) in the CCF of HD 74438 over the night of February 18, 2014 obtained with the U580 setup. The columns labeled Δ list the differential velocity with respect to the centre-of-mass (*i.e.*, cluster) velocity.

| JD - 2 456 707 | $v_r(A)$ | $v_r(B)$ | $v_r(C)$ | $v_r(D)$ | $\Delta v_r(A)$ | $\Delta v_r(B)$ | $\Delta v_r(C)$ | $\Delta v_r(D)$ | M_A/M_B | M_D/M_C |
|----------------|----------|----------|----------|----------|-----------------|-----------------|-----------------|-----------------|-----------|-----------|
| 0.028 | 50.61 | -21.40 | -44.25 | 67.92 | 35.81 | 36.20 | 59.05 | 53.12 | 1.01 | 1.11 |
| 0.030 | 50.67 | -21.14 | -44.53 | 68.18 | 35.87 | 35.94 | 59.33 | 53.38 | 1.00 | 1.11 |
| 0.113 | 51.18 | -22.18 | -52.08 | 74.07 | 36.38 | 36.98 | 66.88 | 59.27 | 1.02 | 1.13 |
| 0.120 | 51.08 | -22.40 | -52.31 | 74.55 | 36.28 | 37.20 | 67.11 | 59.75 | 1.02 | 1.12 |

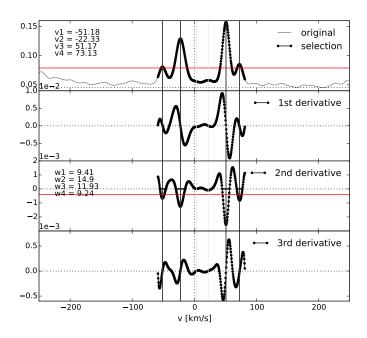


Fig. 23. The CCF of the A2V star HD 74438, obtained on JD 2456707.102 with the setup U580. The four peaks are clearly visible.

 $\Delta v_r(B)$ in Table 6), we note that these variations obey a simple property: their ratio is almost constant. In a simple binary system, this property is expected since the ratio $\Delta v_r(B)/\Delta v_r(A)$ equals the mass ratio M_A/M_B . Here we find $M_A/M_B \sim 1.01$. Thus, the brightest components in the system, which correspond to the most prominent peaks A and B, are close to twins since their masses differ by 1% only. We observe that the pair CD obeys the same property: $\Delta v_r(C)/\Delta v_r(D)$ is almost constant, even though the amplitude of variations is larger than that of the AB pair. Again, assuming no perturbations from the AB pair, we get $M_D/M_C = \Delta v_r(C)/\Delta v_r(D) \sim 1.12$. It seems therefore that the observed variations do make sense and give credit for a physical nature of the ABCD system as a double pair AB/CD. We could nevertheless expect some perturbations of one pair on the other,

at least in the form of a trend of the center-of-mass velocities of each pair, if pair CD orbits around pair AB. The available observations do not span a time interval long enough to check that possibility.

Assuming that the ratio of the CCF amplitudes roughly scales with the luminosity ratio⁸, and adopting a ratio of 3 between the peak amplitudes of A and D (see Fig. 23), we get a magnitude difference between components A and D equal to $\Delta m = 2.5 \log 3 = 1.2$ mag. Consequently, the observed visual magnitude $m_V = 7.58$ is mainly due to the pair AB. With the parallax of the system $\pi = 5.716 \pm 0.298$ mas provided by Gaia DR1 (Gaia Collaboration et al. 2016), the distance of this system is 175 ± 9 pc. The absolute magnitude of AB pair is then $M_V(AB) = 1.36$. Assuming similar masses, we have $M_V(A) = M_V(B) = 2.12$. This corresponds to a spectral type A7 and to masses of $M_A = M_B = 1.8 \text{ M}_{\odot}$ if on the main sequence (luminosity class V). The absolute magnitudes of the components C and D are consequently $M_V(C) = M_V(D) = 3.31$ corresponding to a spectral type F1 which correspond to a mass of about 1.5 M_☉. Inserting these values in the defining relation for the orbital velocity semi-amplitude (expressed in km s⁻¹):

$$K_i = 212.9 \left(\frac{M_i}{P(d)}\right)^{1/3} \frac{q}{(1+q)^{2/3}} \frac{\sin i}{(1-e^2)^{1/2}},$$
(3)

it is possible to derive an upper limit to the orbital period. Indeed, for the AB pair, we adopt e=0, q=1, $M_A=1.8~{\rm M_{\odot}}$, and $K_A>36~{\rm km~s^{-1}}$ (Table 6), and obtain an upper limit on the orbital period of the AB pair, $P({\rm d})<93~{\rm sin^3}~i$. The same method applied on the CD pair (with $M_D=1.5~{\rm M_{\odot}}, e=0, q=1.1$, and $K_D>60~{\rm km~s^{-1}}$) yields $P({\rm d})<20~{\rm sin^3}~i$, in agreement with the fast variation observed in Table 6 for the C and D velocities.

An even more constraining limitation on the orbital period may be derived from the fast variations exhibited by the D component over the 2.2 h time span covered by the observations (Table 6). We first assume that 74.55 km s⁻¹ corresponds to the maximum orbital velocity, from which we derive a semi-amplitude

⁸ If the spectral types of the components are very different, spectral mismatch may invalidate this hypothesis, but this is unlikely given the SB2 nature of the source which implies a luminosity ratio close to one and hence similar spectral types.

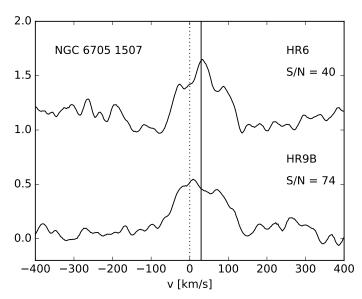


Fig. 24. The CCFs of star 1507 in the cluster NGC 6705, with its triple-peak CCF, most probably caused by pseudo-absorptions (caused by pulsation) superimposed on a rapid-rotator profile. The vertical plain line shows the cluster velocity.

 $K_D = 59.75 \text{ km s}^{-1}$, corresponding to $\omega t_1 = \pi/2$. It is then possible to find $\omega = 2\pi/P$, and hence P, by assuming a sinusoidal velocity variation (in a circular orbit), reaching a velocity of 67.9 km s⁻¹ at time $t_2 < t_1$, such that $\omega t_2 = \arcsin\frac{67.9-14.8}{K_D} = 1.093$. From this, we derive $\omega t_1 - \omega t_2 = \pi/2 - 1.093 = 0.477 = 2\pi/P \times (t_1 - t_2) = 2\pi/P \times 2.2$ h, or P = 29 h as tentative period of the CD pair.

To conclude, we note that the above arguments allow us as well to estimate the deviation of HD 74438 in the color - magnitude diagram, for a system consisting of components with fluxes $F_A = F_B$, and $F_D = F_C = 1/3F_A$. The magnitude excess amounts to $2.5 \log(2 + 2/3) = 1.1$ mag, not far from the 0.9 mag reported by Platais et al. (2007). The velocities of the components would definitely be worth monitoring over a few hundred days.

4.6. Multiplicity flagging by other GES working groups

It is worth mentioning that different nodes within the GES WGs have identified/detected spectroscopic systems for restricted subsamples of iDR4 data. Because we wanted to rely on a homogeneous detection process, we did not include the SBn detected by other WG in the present analysis. This detailed comparison will be performed for the next data release.

WG 12, focusing on pre-main sequence stars in clusters, detected 176 SB2 (A: 168, B:2, C: 6), one SB3 and two SB4. The intersection with our list amounts to 66. In particular, the two SB4 detected by WG12 are classified as SB2 in our final list; we re-checked that only two peaks are visible on the CCFs computed from single exposures. WG 12 developed a specific method to remove nebular contamination by masking the nebular lines in HR15N spectra for the clusters NGC 2264, NGC 6530 and Tr14. Indeed, these nebular lines can produce a double-peaked CCF that can be misclassified as an SB2 candidate; see Klutsch et al. (in prep.) for more details.

WG 13, dedicated to OBA-star spectrum analyses, identified about 30 SB2 in clusters (NGC 2547, NGC 3293, NGC 6705 and Tr 14). They detected one SB3 candidate (system 10344470-5805229 in NGC 3293) that we have rejected. Indeed, the three

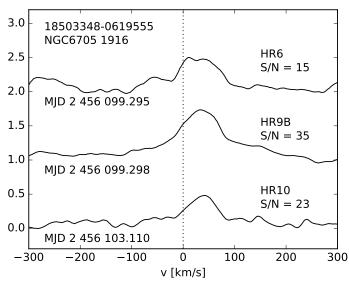


Fig. 25. Example of CCFs of a δ Scu type star that can mimic an SB2 or even an SB3.

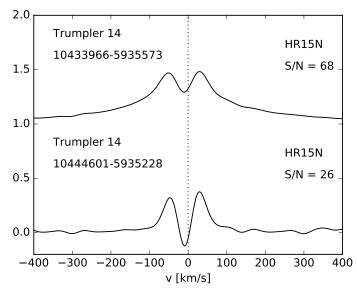


Fig. 26. Example of CCFs in HR15N that mimic SB2 but are due to emission in $H\alpha$ produced by nebular lines in the young cluster Trumpler 14.

peaks were detected by our method only in two CCFs and only in the HR5A setup, whereas 10 CCFs of the same object displayed only one or two peaks in various other setups (HR3, HR6, HR9B and HR14A). This SB3 detection was therefore considered as not reliable enough considering our rejection criteria (discussed at the beginning of Sect. 4). However, we did not even select this object as an SB2 because the velocity difference between the 2 peaks is too large (> 290 km s⁻¹), indicating possible spurious peak(s).

In summary, the GES working groups, which are very focused, will inevitably reach higher detection rates for specific types of objects, but their methods do not apply to the whole GES survey. The method presented here, on the contrary, aims at providing homogeneous information for the whole survey, using all (GIRAFFE and UVES) individual spectra.

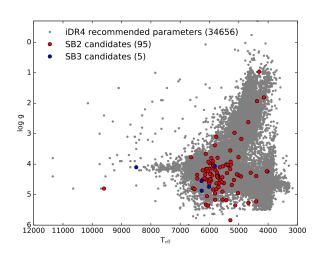


Fig. 27. $\log g - T_{\rm eff}$ diagram of iDR4 stars with recommended atmospheric parameters. Among them rhe SB2 (red circles) and SB3 (blue circles) candidates are displayed.

4.7. Multiple peak CCFs unrelated to binarity

Double- and triple-component CCFs may sometimes be mimicked by physical processes unrelated to binarity. To clearly establish the binary nature of field stars, multiple observations covering a complete orbital cycle are mandatory in order to derive the orbital elements that fit best the radial velocities. In the case of stars belonging to associations and clusters containing hot and cold gas, the situation is worse: emission lines, which are not masked prior to the CCF computations, may produce troughs in the CCFs that could be interpreted as multiple peaks. Moreover, hot and pulsating stars like δ Scu stars, or young hot stars with discs, may also produce bumps in the CCFs. It is beyond the scope of the present paper to study the specific signatures of such processes on the CCFs, which also depend on the considered setup. However, we provide below some examples of multiple peak CCFs probably unrelated to binarity. Besides, in order to remove some spectral signatures degrading the CCFs (emission lines, very strong lines, etc.), we plan to recompute consistently all GIRAFFE and UVES CCFs in a forthcoming paper.

For instance, NGC 6705 1507 (system 18505296-0617402) is classified as A0 (Cantat-Gaudin et al. 2014) and shows three peaks in its CCF (originally classified as 2030C; Fig. 24) for the setting HR6, at -25.1, 33.8, and 86.9 km s⁻¹. The central, highest peak is close to the cluster velocity, and the other two are almost symmetrically located from the central peak, at $\pm 50 \,\mathrm{km \, s^{-1}}$. The very edge of the CCF has a steep slope which is reminiscent of a fast rotator. Indeed, the full base width of the CCF is about 180 km s⁻¹, a value typical for the rotation velocities of A stars. Moreover, a spectrum in the HR9B setting, taken on the same night, confirms the above analysis, which makes us conclude that the triple-peak CCF of star 1507 in the cluster NGC 6705 is most probably caused by pseudo-absorptions superimposed on a rapid-rotator profile. A similar situation is encountered for the 2 other SB3 candidates 18510403-0616023 and 18511155-0606094. These three objects have been discarded from the final list.

An example of a star automatically classified as an SB2 with flag C and very likely to be rather a δ Scu star, *i.e.* a hot rapid rotator with pulsation and no emission in H α , is 18503348-0619555 (NGC 6705 1916, V=13.7). This star has recommended parameters of $T_{\rm eff}=7821$ K and $\log g=3.96$, compati-

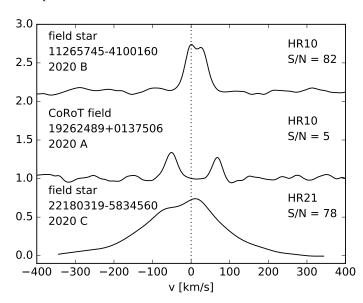


Fig. 28. Three giant SB2 candidates.

ble with a δ Scu-type star. The CCF in different setups at different epochs are shown on Fig. 25. The first CCF has 2 components (SB2), one broader than the other. The asymmetry of the second CCF could potentially lead the DOE code to identify 3 components (SB3). The last CCF is less ambiguous though it can be seen as an SB2 with close radial velocities. This SB2 candidate has been removed from the final list of SBn candidates.

In Trumpler 14, spectra are strongly contaminated by nebular lines around $H\alpha$. This may result from a reduction issue (inadequate sky subtraction in a nebular background). The nebular lines in emission, located at the cluster velocity, superimpose on the absorption lines of the star, also at the cluster velocity. Because the nebular lines in emission are narrower than the stellar ones in absorption, it results in a CCF with two clear peaks; sometimes the minimum between the two peaks gets even lower than the CCF continuum. Such false SB2 candidates could be unmasked (see Fig. 26 for the two examples 10433966-5935573 and 10444601-5935228) because in that cluster we found too many stars with radial velocities around -40 and 20 km s^{-1} , *i.e.* symmetrical with respect to the cluster velocity ($\sim -10 \text{ km s}^{-1}$). They can be explained by an emission at the cluster velocity obliterating the H α line resulting in a central absorption splitting the CCF (an emission line corresponds to absorption in the CCF.)

4.8. Distribution in the ($\log g$, $T_{\rm eff}$) plane

The GES consortium provides recommended atmospheric parameters ($T_{\rm eff}$, log g and [Fe/H]) for 63% of stars from the iDR4. They result from a delicate merging of atmospheric parameters obtained by different WGs using different methods, but all with the same model atmospheres and linelists. Among them, we identified a hundred of our confirmed SBn candidates, representing 30% of our detected SBn).

They are shown in the $\log g - T_{\rm eff}$ plane (see Fig. 27). This figure reveals a sudden drop in the number of stars surveyed above 7000 K. This threshold corresponds to the transition between A and F stars, the latter being surveyed in a systematic way by the GES, the former being included only if they belong to specific clusters. For SBn, the atmospheric parameters provided by the GES pipeline are uncertain (or even wrong, as we show below) because (i) composite spectra cannot be fitted with

Table 7. List of the nine known SB2 systems confirmed by GES.

| Name | GES field | CNAME | V | Catalogue | Reference |
|--|-----------|------------------|-------|-----------------|--------------------------|
| 2MASS J06435849-0100515 CoRoT 102715243 | CoRoT | 06435847-0100516 | 13.05 | | Loeillet et al. (2008) |
| CD-52 2472, IC 2391 56 | IC 2391 | 08385566-5257516 | 10.06 | WEBDA | Mermilliod et al. (2009) |
| NGC 2682 117 | M 67 | 08511868+1147026 | 12.59 | SB9, WEBDA | Mathieu et al. (1990) |
| NGC 2682 119 | M 67 | 08511901+1150056 | 12.53 | SB9, WDS, WEBDA | Mathieu et al. (1990) |
| NGC 2682 ES 4004 | M 67 | 08512291+1148493 | 12.69 | SB9, WDS, WEBDA | Mathieu et al. (1990) |
| NGC 2682 165 | M 67 | 08512940+1154139 | 12.83 | WDS | Gavras et al. (2010) |
| PU Car | Cha I | 11085326-7519374 | 12.17 | WDS | Köhler et al. (2008) |
| 2MASS J18505933-0622051 | NGC 6705 | 18505933-0622051 | 17.06 | | Koo et al. (2007) |
| CoRoT 101129018 | CoRoT | 19263739+0152562 | 13.60 | | Cabrera et al. (2009) |
| | | | | | , |

Note:

SB9: Ninth catalogue of spectroscopic binary orbits (Pourbaix et al. 2004);

WDS: Washington visual Double Star catalogue (Mason et al. 2016);

WEBDA: A site Devoted to Stellar Clusters in the Galaxy and the Magellanic Clouds: http://webda.physics.muni.cz

single synthetic spectra, and (ii) spectra fitted by the automated pipelines are not the individual exposures but rather the stacked ones. Despite these shortcomings, the $\log g - T_{\rm eff}$ diagram nevertheless allows us to identify systems of interest.

The two SB2 and SB3 systems on the warm end of the $\log g - T_{\rm eff}$ diagram (with $T_{\rm eff} > 8000$ K) are worth discussing. Their CNAMEs are 18280622+0642252 (NGC 6633 110, BD+06 3793, A3V), classified as 2020A, and 07575737-6044162 (NGC 2516 45, CD-60 1959, A2V), classified as 2030C.

The system 18280622+0642252 shows two peaks of equal heights at $-70~\rm km~s^{-1}$ and $38~\rm km~s^{-1}$. The former peak is particularly broad, and is probably associated with a rapidly rotating star. Since the cluster velocity ($-25.4~\rm km~s^{-1}$) lies in between the two peaks, and the double-peak CCF is very well-defined, we confirm the SB2 flag from the DOE routine.

The system 07575737-6044162 exhibits a broad CCF most likely associated with a fast rotator. It has a sharp central peak. It may perhaps be an SB2, but certainly not an SB3 (see Fig. 22).

The three giant SB2 candidates (19262489+0137506, 22180319-5834560 and 11265745-4100160) appearing in the $\log g - T_{\rm eff}$ diagram (with $\log g < 2$) are surprising, since they should have a mass ratio very close to 1. Their CCFs are displayed on Fig. 28. To our knowledge, there are only few SB2 systems known so far involving two giant stars: (i) HD 172481 (more precisely an F2Ia post-AGB star and an M giant; (Reyniers & Van Winckel 2001; Jorissen et al. 2009); (ii) HD 187669 (a double-line eclipsing binary; Hełminiak et al. 2015a); (iii) TYC 6861-523-1 / ASAS J182510-2435.5 (Ratajczak et al. 2013); (iv) KIC 09246715 (a double-lined spectroscopic and eclipsing binary; Hełminiak et al. 2015b).

The system 19262489+0137506 (a CoRoT target with $T_{\rm eff}$ = 4300 K, $\log g = 1.0$), classified as 2020A, has indeed two peaks well separated by 117 km s⁻¹, of almost equal intensities, implying a rather short period for a pair of giants (Fig. 28, middle). Adopting K = 117/2 km s⁻¹, q = 1, $\sin i = 1$, e = 0, and $M_1 = 1$ M_{\odot}, Eq. 3 predicts a period of the order of 7.5 d for the associated binary. This is rather short considering the giant nature of the two components. For instance, the minimum orbital period in the large sample of binaries with a K giant component in open clusters (Mermilliod et al. 2007) is just above 25 d. The situation is even worse for the sample of field M giants from Jorissen et al. (2009) where the shortest orbital period is above

200 d. This trend of course reflects the increase of the stellar radius along the giant branch. Independently, the spectral type of the system was estimated to be M2III from broad-band photometry (Exo-Dat, Deleuil et al. 2009). In any case, this system is worth a follow-up investigation, especially looking for signs of mass-transfer activity (like possible $H\alpha$ emission in its spectrum, but the 2 spectra available in HR15 are too noisy to see any such sign of activity).

The system 22180319-5834560, classified as 2020C (and $T_{\rm eff}=4100~{\rm K}$, $\log g=1.8$), exhibits a very broad CCF coming from the strong Ca II triplet in the HR21 setup, with two bumps responsible for the SB2 classification (Fig. 28, bottom). Observations in HR10 one day later does not show any sign of binarity. Inspection of the HR21 spectra reveals that the bumps observed in the CCF may be due to emission in the Ca II triplet line cores, making the SB nature doubtful.

The system 11265745-4100160 (V=13), classified as 2020B (with $T_{\rm eff}=4400$ K, $\log g=1.9$, top CCF of Figure 28), exhibits two close velocity components in HR10 (separated by about 32 km s⁻¹) but not visible in HR21. The validity of the atmospheric parameters may have been disturbed by the SB2 nature of the star.

4.9. Comparison with other catalogues

To estimate the proportion of new SBn candidates, we cross-checked our 352 distinct candidates with published online catalogues of stars. The intersection with the Simbad database (Wenger et al. 2000) provides 96 matches. Among them one is classified as double or multiple star (WDS J08513+1150, CNAME 08511901+1150056 belonging to M67), four as spectroscopic binary stars: 2MASS J06435849-0100515 (CNAME 06435847-0100516) in the Corot field, CD-52 2472 (CNAME 08385566-5257516) in the cluster IC2391, 2MASS J08512291+1148493 (CNAME 08512291+1148493) in M67 and NGC 2682 165 (CNAME 08512940+1154139) also in M67. Two are classified as eclipsing binary stars: 2MASS J18505933-0622051 (CNAME 18505933-0622051) in NGC 6705 and CoRoT 101129018 (CNAME 19263739+0152562). All these previously known binaries have been attributed by our DOE code a "A" confidence

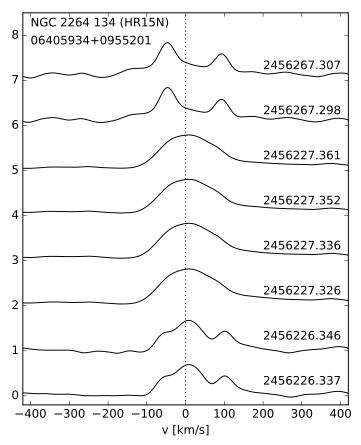


Fig. 29. iDR4 CCFs of the pre-main sequence star NGC 2264 134 (06405934+0955201). Known as SB2 in WEBDA, this star shows clear evidence to be an SB3 candidate.

We cross-matched our detections with various other catalogues, using the X-Match and the Vizier Search online tools from the CDS⁹ by uploading the J2000 coordinates built from the CNAME of our SB candidates. For each catalogue, we set the matching area within a radius of 3 arcsec.

The comparison with the *Ninth Catalogue of Spectroscopic Binary Orbits* (Pourbaix et al. 2004, SB9) leads to three systems in common, namely 08511868+1147026, 08511901+1150056, and 08512291+1148493, which are members of the M67 cluster (NGC 2682) with a visual magnitude of about 12.5.

The comparison with the *Washington visual Double Star* catalogue (WDS, Mason et al. 2016) leads to an intersection of two systems, namely WDS J08513+1150 in M 67 and WDS J11088-7519 in Cha I (CNAME 08511901+1150056 and 11085326-7519374 respectively).

Cross-matches with the Geneva-Copenhagen Survey of the solar neighborhood III (Holmberg et al. 2009), with the bibliographic catalogue of stellar radial velocities (Malaroda et al. 2006), with the RAVE catalogue of SB2 candidates (Matijevič et al. 2010) and with the Multiple Star Catalogue (MSC) (Tokovinin 1997) resulted in empty intersections. We stress that the limiting magnitudes of all these catalogues are much brighter than that of the GES ($V \sim 19$), therefore we expected a small intersection.

As far as the WEBDA cluster database is concerned, four of our SBn candidates are known in WEBDA, with available orbital parameters (see Table 7). We also found that two SB2

known in WEBDA are observed in iDR4 but were discarded by the workflow. M67 111 has been observed (08511799+1145541) but the second peak is too low to be automatically detected. The same issue occurs with NGC 2264 134 (06405934+0955201), known to be an SB2 in WEBDA and known to be a pre-main sequence star. It has been observed eight times and seems to be an SB3 candidate because four CCFs have one peak, two CCFs have two peaks and two CCFs have three peaks (see Fig. 29).

For the sake of completeness, we also checked whether the DOE algorithm did retrieve the known SBn candidates from the Geneva-Copenhagen Survey and from SB9. It turns out that only one SB2 (08511799+1145541 in M67) present in SB9 was not found by DOE. The reason thereof is the following: 10 observations in U580 were performed but the second peak is only visible and detected in two of them. Because only stars with more than 75% of multiple peaks detection in a given setup were flagged as SB2 candidates, 08511799+1145541 was rejected. This shows that the 75% criterion, chosen to be conservative, might be too restrictive in some cases, although it prevents many false positive detections.

Previously known SB2 systems flagged as such by the GES are listed in Table 7. We stress the fact that the analysis of the GES data provides a substantial number of new SB2 and SB3 candidates because SB detection was performed on a huge data sample ($\sim 50\,000$ stars) characterized by a faint limiting magnitude with respect to previous surveys. The new SB2, SB3 and SB4 candidates clearly deserve more observations in order to derive their orbital elements.

5. Conclusion

We present a method aiming at identifying multiple-lined spectroscopic binaries (SBn, $n \ge 2$) based on the successive derivatives of the CCFs. A list of SBn among the GES iDR4, both in the Galactic field and in the stellar clusters, is presented. In addition, orbital solutions for binary systems belonging to the open clusters NGC 2264 and Be 81 have been calculated.

The detection method has been tested on all the setups of the GIRAFFE and UVES spectrographs available within the GES. It turns out that UVES U580 and GIRAFFE HR10 are the most appropriate setups to detect multiplicity with velocity differences as low as 15 km s⁻¹ and 23 km s⁻¹, respectively. Simulations show that the DOE algorithm reliably derives radial velocities (with a formal error of the order of 0.20 km s⁻¹ at a typical S/N of 10 for GIRAFFE and lower than 0.01 km s⁻¹ at S/N = 50 for UVES setups; for multi-component CCFs, the formal error will be slightly increased and, in addition, the systematic error may reach a few km s⁻¹ at the detection limit).

The detection method leads to a number of false positive detections in stellar clusters. Using physical properties of the clusters and combining information from the spectra and CCFs of different setups, we discussed and discarded a fraction of candidates. A confusing SB2-like signature could be imprinted to the CCF by pulsations in δ Scuti variable stars, by H α emission in circumstellar discs or interstellar absorption by cold clouds along the line of sight. In such cases, spurious peaks or bumps appear in the CCF.

We discovered 340 SB2, 11 SB3 and one SB4 out of 51 000 stars with more than 205 000 single exposures. The most confident binary candidates ('A' flag) most often show very clear composite spectra. Incidentally, we warn against the use of the GES recommended atmospheric parameters for these SBn candidates. Indeed, one third of SBn candidates do have GES recommended

⁹ http://cdsxmatch.u-strasbg.fr/xmatch, http://vizier.u-strasbg.fr

parameters, but the the presence of multiple components in spectral lines can potentially lead to erroneous parameters.

The frequency of SBn ($n \ge 2$) found by our method in the GES iDR4 sample is 0.7 %. Most of the SBn candidates are new because they belong to a sample of stars much fainter than what was covered by previous catalogues. If we extrapolate this percentage of 0.7% SBn binaries to the final GES pool of 10^5 stars, we expect to reach about 1 000 new SBn systems in the upcoming data releases because the number of observed stars will increase by a factor of two and because we plan to further fine-tune our detection criteria. Indeed the aim of the present analysis was to detect binaries, minimizing the number of "false positive" detections (*i.e.* stars wrongly classified as SBn). The method presented in this paper can be readily applied to the ESA *Gaia* mission spectra.

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Appendix A: SB2 and SB3 candidates in the field

 $\textbf{Table A.1.} \ \, \text{List of SB2 candidates in the field ordered by right ascension}.$

| CNAME | | | | | | | | | |
|---|------------------|-------|--------|-------|-------|-----------|----------|----------|-------|
| 00195847-5423227 2020A 4 HR10 56532_287 93_29 153_47 14_20 0020200-5436167 2020A 4 HR10 56532_308 285_74 330_48 15_30 00301156-5001500 2020A 2 4 U580 56266.085 17.67 47.52 13_90 00301274-0334401 2020B 4 HR21 56468_397 -48.62 24_97 15_40 00503283-4955302 2020B 4 HR10 56268_134 -21_03 32_27 14_90 00503283-4955302 2020B 4 HR121 56204_172 18.82 130_23_14.80 01000070-0100143 2020C 4 HR21 56204_172 18.82 130_23_14.80 01012693_5420463 2020C 4 HR21 56204_172 -97_34 -33_48 14_50 01012693_5420463 2020C 4 HR21 56204_172 -97_34 -33_48 14_50 01012693_5420463 2020C 4 HR21 56204_172 -97_34 -33_48 14_50 01120304_5435209 2020B 4 HR21 56204_266 -22_60 68_63 15_20 01200304_5435209 2020B 4 HR21 56204_266 -22_60 68_63 15_20 01200392-0102102 2020C 4 HR21 56204_266 -22_60 68_63 15_20 0130909_54303014 2020A 4 HR10 5658_390 4040 83_81 14_20 013993831_4688457 2020B 4 HR10 5658_8390 4040 83_81 14_20 013933831_4688457 2020B 4 HR10 5658_8390 4040 83_81 14_20 01405323_556575 2020B 4 HR10 5658_8390 4040 83_81 14_20 015852747-5401493 2020B 4 HR10 5658_390 12_55 13_50 015852747-5401493 2020B 4 HR10 5658_390 12_55 13_50 015852747-5401493 2020B 4 HR10 5658_390 12_55 13_50 01585747-5401493 2020B 4 HR10 5658_27 12_55 51_88 13_10 01585747-5401493 2020B 4 HR10 5657_227 -7_69 54_71 14_00 2020058_510250 2020C 4 HR21 5658_2227 -7_69 54_71 14_00 2020058_510250 2020C 4 HR21 5658_223_207 -23_45 24_67 15_00 2020058_510250 2020C 4 HR21 5658_223_207 -23_45 24_67 15_00 202005449-0055403 2020C 4 HR10 5627_2126 -38_68_31 16_00 2021058_69_012610 2020C 4 HR21 5658_223_207 -23_45 24_67 15_00 2020058_510250 2020C 4 HR10 56578_216 13_53 94_34 14_50 202005445-0053438 2020C 4 HR10 56578_216 13_53 94_34 14_50 202005445-005448 2020A 4 HR10 56578_216 13_53 94_34 14_50 202005445-005448 2020A 4 HR10 56578_216 13_55 90_58_11_40 0331610-5601321 2020C 4 HR21 5658_223_46 -50_58_100_14 19_0 0331610-5601321 2020A 4 HR10 5622_186_6 33_99 97_59_6 15_10 0331793-00444478_8199 2020A 4 HR10 5620_33_46 -50_58_8 100_14 19_0 0331610-5601321 2020A 4 HR10 | CNAME | flag | # exp. | # sp. | setup | MJD | $v_r(1)$ | $v_r(2)$ | V |
| 00195847-5423227 2020A 4 HR10 56532_287 93_29 153_47 14_20 0020200-5436167 2020A 4 HR10 56532_308 285_74 330_48 15_30 00301156-5001500 2020A 2 4 U580 56266.085 17.67 47.52 13_90 00301274-0334401 2020B 4 HR21 56468_397 -48.62 24_97 15_40 00503283-4955302 2020B 4 HR10 56268_134 -21_03 32_27 14_90 00503283-4955302 2020B 4 HR121 56204_172 18.82 130_23_14.80 01000070-0100143 2020C 4 HR21 56204_172 18.82 130_23_14.80 01012693_5420463 2020C 4 HR21 56204_172 -97_34 -33_48 14_50 01012693_5420463 2020C 4 HR21 56204_172 -97_34 -33_48 14_50 01012693_5420463 2020C 4 HR21 56204_172 -97_34 -33_48 14_50 01120304_5435209 2020B 4 HR21 56204_266 -22_60 68_63 15_20 01200304_5435209 2020B 4 HR21 56204_266 -22_60 68_63 15_20 01200392-0102102 2020C 4 HR21 56204_266 -22_60 68_63 15_20 0130909_54303014 2020A 4 HR10 5658_390 4040 83_81 14_20 013993831_4688457 2020B 4 HR10 5658_8390 4040 83_81 14_20 013933831_4688457 2020B 4 HR10 5658_8390 4040 83_81 14_20 01405323_556575 2020B 4 HR10 5658_8390 4040 83_81 14_20 015852747-5401493 2020B 4 HR10 5658_390 12_55 13_50 015852747-5401493 2020B 4 HR10 5658_390 12_55 13_50 015852747-5401493 2020B 4 HR10 5658_390 12_55 13_50 01585747-5401493 2020B 4 HR10 5658_27 12_55 51_88 13_10 01585747-5401493 2020B 4 HR10 5657_227 -7_69 54_71 14_00 2020058_510250 2020C 4 HR21 5658_2227 -7_69 54_71 14_00 2020058_510250 2020C 4 HR21 5658_223_207 -23_45 24_67 15_00 2020058_510250 2020C 4 HR21 5658_223_207 -23_45 24_67 15_00 202005449-0055403 2020C 4 HR10 5627_2126 -38_68_31 16_00 2021058_69_012610 2020C 4 HR21 5658_223_207 -23_45 24_67 15_00 2020058_510250 2020C 4 HR10 56578_216 13_53 94_34 14_50 202005445-0053438 2020C 4 HR10 56578_216 13_53 94_34 14_50 202005445-005448 2020A 4 HR10 56578_216 13_53 94_34 14_50 202005445-005448 2020A 4 HR10 56578_216 13_55 90_58_11_40 0331610-5601321 2020C 4 HR21 5658_223_46 -50_58_100_14 19_0 0331610-5601321 2020A 4 HR10 5622_186_6 33_99 97_59_6 15_10 0331793-00444478_8199 2020A 4 HR10 5620_33_46 -50_58_8 100_14 19_0 0331610-5601321 2020A 4 HR10 | 00040663-0101512 | 2020B | 6 | 6 | HR21 | 56205 162 | -65 45 | 66 95 | 16 10 |
| 00020150-5436167 2020A | | | | | | | | | |
| 00301156-5001500 2020A 2 4 US80 56266.085 17.67 47.52 13.90 00301274.0334401 2020C 4 4 HR21 56468.397 -48.62 24.97 15.40 00324599-4354509 2020B 4 8 US80 56198.130 -5.84 15.63 12.90 00503283-4955302 2020B 4 4 HR121 56264.172 18.82 130.23 14.80 0100070-0100143 2020C 4 4 HR21 56204.172 18.82 130.23 14.80 0100070-0100143 2020C 4 4 HR21 56204.172 -97.34 -33.48 14.50 01012693-5420463 2020C 4 4 HR21 56204.172 -97.34 -33.48 14.50 01012693-5420463 2020C 4 4 HR21 56204.266 -22.60 68.63 15.20 01200304-5435209 2020B 4 HR21 56204.266 -22.60 68.63 15.20 01200304-5435209 2020B 4 HR21 56204.266 -22.60 68.63 15.50 01202092-0102102 2020C 4 HR10 56580.192 -16.04 74.55 13.50 01300825-5009146 2020A 4 HR10 56580.192 -16.04 74.55 13.50 01390790-5403014 2020A 4 HR10 56580.192 -16.04 74.55 13.50 01393331-4648457 2020B 4 HR10 56548.390 40.40 83.81 14.20 01393831-4648457 2020B 4 HR10 56548.390 40.40 83.81 14.20 01393831-6458510 2020C 4 HR10 56597.248 24.46 60.55 13.50 0158259-04658510 2020C 4 HR10 56597.248 24.46 60.55 13.50 0158259-04658510 2020C 4 HR10 56597.124 36.60 0200045-5352567 2020B 4 HR10 56580.217 -65.75 40.52 14.00 0200277-6455438 2020C 4 HR10 56597.124 36.60 02002074-655438 2020C 4 HR10 56224.275 -62.19 111.35 13.50 02005449-0055403 2020C 4 HR10 56224.275 -62.19 111.35 13.50 02005449-0055403 2020C 4 HR10 56223.207 -23.45 24.67 15.00 02105468-5012361 2020C 5 5 HR21 56352.333 -23.84 42.38 15.00 02105468-5012361 2020C 4 HR10 56578.216 13.53 94.34 14.50 02105468-5012361 2020C 4 HR10 56252.186 37.94 64.65 14.70 02105436-50103481 2020C 5 5 HR21 56352.333 -23.84 42.38 15.00 02195436-50103481 2020C 4 HR10 56578.216 13.55 9 15.40 15.70 0317599-0034528 2020B 4 HR10 56224.275 -62.19 111.53 13.50 020959-5004269 2020A 4 HR10 5625.186 37.94 64.65 14.70 0315199-0034546 2020A 4 HR10 5625.186 37.94 64.65 14.70 0315799-0034528 2020B 4 HR10 56208.238 -64.68 98.89 15.70 0315799-0034528 2020B 4 HR10 56208.238 -64.68 98.89 15.90 03374095-2723284 2020A 4 HR10 56208.338 -63.89 15.40 15.70 03384566-4710178 2020B 4 HR10 HR21 56500.31 -7.88 21.61 13.5 | | | | | | | | | |
| 00301724-0334401 2020C 4 4 HR21 56468.397 -48.62 24.97 15.40 00324599-3435409 2020B 4 8 USS0 5698.130 -5.84 15.63 12.90 00503283-4955302 2020B 4 4 HR10 56268.134 -21.03 32.27 14.90 01000070-0100143 2020C 4 4 HR21 56204.172 -97.34 -33.48 14.50 01194076-0047374 2020C 4 4 HR21 56530.337 -92.63 -23.25 15.30 01202092-0102102 2020C 4 4 HR21 56552.310 -10.28 80.61 15.60 01300825-5009146 2020A 4 4 HR10 56580.192 -16.04 74.55 13.50 01393831-4648457 2020B 4 HR10 56580.192 -16.04 74.55 13.50 0158279-74655438 2020B 4 HR10 56579.248 24.46 60.55 13.50 | | | | | | | | | |
| 00324599-4354509 2020B 4 8 U580 56198.130 -5.84 15.63 12.90 00503234994355302 2020A 4 4 HR21 56204.172 -97.34 -33.48 14.50 01000070-0100143 2020C 4 4 HR21 56204.172 -97.34 -33.48 14.50 010102693-5420463 2020C 4 4 HR21 56204.172 -97.34 -33.48 14.50 01012693-5420463 2020C 4 4 HR21 56204.266 -22.60 68.63 15.60 012020304-4535209 2020B 4 4 HR21 56204.266 -22.60 68.63 15.60 012020302-0102102 2020C 4 4 HR21 56204.284 -56.79 16.26 15.60 01202092-0102102 2020C 4 4 HR21 56204.284 -56.79 16.26 15.60 01202093-5509146 2020A 4 4 HR10 56558.0192 -16.04 74.55 13.50 01390730-5403014 2020A 4 4 HR10 56588.0192 -16.04 74.55 13.50 01390730-5403014 2020A 4 4 HR10 56548.390 40.40 83.81 14.20 01393831-4648457 2020B 4 4 HR10 56548.390 40.40 83.81 14.20 01393831-4648457 2020B 4 HR10 56548.390 12.59 51.88 13.10 01585747-5401493 2020B 4 HR10 56548.390 12.59 51.88 13.10 01585747-5401493 2020C 4 BUS80 56207.122 5.97 26.61 28.0 2020C044-0455438 2020C 4 HR10 56592.97 -7.69 54.71 14.00 2020270455438 2020B 4 HR10 56592.97 -7.69 54.71 14.00 2020270455438 2020B 4 HR10 56292.3207 -23.45 24.67 15.00 20205449-0055403 2020A 4 HR21 56531.288 -20.25 86.83 16.00 20205449-0055403 2020A 4 HR10 56223.207 -23.45 24.67 15.00 20205449-0055403 2020A 4 HR10 5623.207 -23.45 24.67 15.00 20205449-0055403 2020A 4 HR10 5623.207 -23.45 24.67 15.00 20205449-0055403 2020A 4 HR10 56578.216 13.53 94.34 14.50 20205449-0055403 2020A 4 HR10 5623.207 -23.45 24.67 15.00 20205449-0055403 2020A 4 HR10 5623.207 -23.45 24.67 15.00 20205449-0055403 2020A 4 HR10 56251.288 -20.25 86.83 16.00 20290765-0104381 2020C 4 HR21 56558.216 13.53 94.34 14.00 20305849-0055403 2020A 4 HR10 56225.186 37.94 42.88 15.00 20305849-4055403 2020A 4 HR10 56225.186 37.94 42.83 15.00 20305849-4055403 2020A 4 HR10 56251.88 70 23.45 24.67 15.90 20305269-5010152 2020C 4 HR10 56205.30 57.82 16 -11.85 70.20 13.15 10.00 14.00 20305269-5010152 2020C 4 HR10 56205.30 57.82 16 -11.85 70.90 14.00 20305269-5010152 2020C 4 HR10 56205.30 57.92 15.40 14.00 50334966-4710178 2020B 4 HR10 56205.30 57.92 15.40 14.00 503349 | | | | | | | | | |
| 00503283-4955302 2020B 4 4 HR10 \$6268.134 -21.03 32.27 14.90 00591557-1005576 2020B 4 4 HR21 \$56204.172 18.82 130.23 14.80 01012603-5420463 2020C 4 4 HR21 \$56204.172 -97.34 -33.48 14.50 01120092-1002102 2020C 4 4 HR21 \$56520.337 -92.63 -23.25 15.30 0120092-0102102 2020C 4 4 HR21 \$56520.310 -10.28 80.61 15.60 01300825-5009146 2020A 4 4 HR10 \$56580.192 -16.04 74.55 13.50 01405323-5356575 2020B 4 4 HR10 \$56580.192 -16.04 74.55 13.50 01582747-5401493 2020B 4 4 HR10 \$56580.217 -65.75 40.52 14.00 01582747-75401493 2020B 4 4 HR10 \$56580.217 -65.7 | | | | | | | | | |
| 00591557-0105576 2020C 4 4 HR21 56204.172 -97.34 -33.48 14.50 01002093-5420463 2020C 4 4 HR21 565204.172 -97.34 -33.48 14.50 01194076-0047374 2020C 4 4 HR21 56520.337 -92.63 -23.25 15.30 01202092-0102102 2020B 4 HR21 56552.310 -10.28 80.61 15.60 01300825-5090146 2020A 4 4 HR10 56580.192 -16.04 74.55 13.50 01390790-5403014 2020A 4 4 HR10 56584.390 40.40 83.81 14.20 01405323-5356575 2020B 4 4 HR10 56584.390 12.59 51.88 13.10 0158290-04688510 2020C 4 4 HR10 56580.217 -65.75 40.52 14.00 0200383-3539 2020C 4 HR10 56524.275 -62.79 5.476 12.80 | | | | | | | | | |
| 011012693-5420463 2020C 4 4 HR21 565204.266 -22.60 68.63 15.20 011204076-0047374 2020C 4 HR21 56204.266 -22.60 68.63 15.20 011200304-5435209 2020B 4 HR21 56524.284 -56.79 16.26 15.60 01202092-0102102 2020C 4 HR21 56524.284 -56.79 16.26 15.60 01202092-0102102 2020A 4 HR21 56524.284 -56.79 16.26 15.60 01300825-5009146 2020A 4 HR10 56588.192 -16.04 74.55 13.50 01390790-5403014 2020A 4 HR10 56548.390 40.40 83.81 14.20 01393831-4464857 2020B 4 HR10 56548.390 12.59 51.88 13.10 01585747-5401493 2020B 4 HR10 56548.390 12.59 51.88 13.10 01585747-5401493 2020B 4 HR10 56548.390 12.59 51.88 13.10 01585747-5401493 2020C 4 HR10 56592.277 -65.75 40.52 140.50 20000945-5352567 2020A 4 HR10 56592.277 -65.75 40.52 140.50 20000945-5352567 2020A 4 HR10 56207.124 56.00 57.34 140.50 20005449-0055403 2020C 4 HR10 56207.144 56.02 73.89 14.10 20205449-0055403 2020A 4 HR10 56223.207 -23.45 24.67 15.00 2015686-5012361 2020C 4 HR21 56224.275 -62.19 111.35 13.50 20205449-0055403 2020A 4 HR10 56223.207 -23.45 24.67 15.00 2029076-5012361 2020C 4 HR21 56523.233 -23.84 42.38 15.00 2029076-5012361 2020C 4 HR21 56523.233 -23.84 42.38 15.00 2029076-5012361 2020C 4 HR21 56532.333 -23.84 42.38 15.00 2029076-50138506 2020B 4 HR10 56578.216 13.53 94.34 14.50 20290759-5004269 2020A 4 HR10 56578.216 13.53 94.34 14.50 20290759-5004269 2020A 4 HR10 56578.216 13.53 94.34 14.50 20290759-5004269 2020A 4 HR10 56578.216 -11.88 72.23 14.30 202097439731-0057248 2020A 4 HR10 56578.216 -11.88 72.23 13.30 202097439731-0057248 2020A 4 HR10 56252.186 37.94 64.65 14.70 20303818102-0034548 2020A 4 HR10 56275.186 -11.88 72.23 14.30 2030345-66-4710178 2020B 4 HR10 56207.312 288.73 337.53 16.30 203175934-0024337 2020C 4 HR10 56207.312 288.73 337.53 16.30 203175934-0024337 2020A 4 HR10 5607.312 288.73 337.53 16.30 203444-603493 2020B 4 HR10 5607.312 288.73 337.53 16.30 203444-603418 2020B 4 HR | | 2020B | 4 | 4 | HR21 | | | | 14.80 |
| 01194076-0047374 2020C | 01000070-0100143 | 2020C | 4 | 4 | HR21 | 56204.172 | -97.34 | -33.48 | 14.50 |
| 01200304-5435209 2020B 4 4 HR21 56552.310 -10.28 80.61 15.60 01202092-0102102 2020C 4 4 HR21 56204.284 -56.79 16.26 15.80 01300825-5009146 2020A 4 4 HR10 56580.192 -16.04 74.55 13.50 01390790-5403014 2020A 4 4 HR10 56584.390 40.40 83.81 14.20 01393831-4648457 2020B 4 4 HR10 56548.390 12.59 51.88 13.10 01585747-5401493 2020B 4 4 HR10 56548.390 12.59 51.88 13.10 01585747-5401493 2020B 4 4 HR10 56580.127 -65.75 40.52 14.00 01592290-46688510 2020C 4 8 U580 56207.122 5.97 26.76 12.80 2000945-5352567 2020A 4 4 HR10 56578.297 -7.69 54.71 14.00 2002707-4655438 2020B 4 4 HR10 56207.144 36.62 73.89 14.10 2020S383-0053539 2020C 4 HR21 56224.275 -62.19 111.35 13.50 2005449-0055403 2020A 4 4 HR10 5623.207 -23.45 24.67 15.00 20195865-5012361 2020C 4 HR21 56224.275 -62.19 111.35 13.50 20205449-0055403 2020B 4 4 HR10 56373.33 -23.84 42.38 15.00 22290765-0318506 2020B 4 4 HR21 56226.222 6.73 81.89 15.70 22290595-5004269 2020A 4 HR10 56578.216 13.53 94.34 14.50 22290595-5004269 2020A 4 HR10 56578.216 13.53 94.34 14.50 20394731-0057248 2020A 4 HR10 T6578.216 13.53 94.34 14.50 20394731-0057248 2020A 4 HR10 T6578.216 -11.88 72.23 14.30 20394731-0057248 2020A 4 HR10 T6578.216 -11.88 72.23 14.30 20394731-0057248 2020A 4 HR10 T6578.216 -11.88 72.23 14.30 20394731-0057248 2020A 4 HR10 T6525.186 -113.51 0.00 14.00 2303828-4656379 2020B 4 HR10 T65225.186 -113.51 0.00 14.00 2303828-4656379 2020B 4 HR10 T6525.186 -113.51 0.00 14.00 2303828-4656379 2020B 4 HR10 T6525.186 -113.51 0.00 14.00 2303828-4666379 2020B 4 HR10 T6525.386 74.99 17.44 15.50 03334956-4710178 2020A 4 HR10 T6525.386 74.99 17.44 15.50 03349456-4710178 2020A 4 HR10 T65205.338 -7.49 17.49 17.49 17.29 13.20 03349456-4710178 2020A 4 HR10 T6509.23 -7.60 2035 8.89 12.90 03349566-4710178 2020A 4 HR10 T6509.23 -7.60 2035 8.89 12.90 03394566-4710178 2020A 4 HR10 T6509.23 -7.60 2035 8.89 12.90 03394566-4710178 2020A 4 HR10 T6509.23 -7.60 2020A 4 | 01012693-5420463 | 2020C | 4 | 4 | HR21 | 56530.337 | -92.63 | -23.25 | 15.30 |
| 01202092-0102102 2020C | 01194076-0047374 | 2020C | 4 | 4 | HR21 | 56204.266 | -22.60 | 68.63 | 15.20 |
| 01390825-5009146 | 01200304-5435209 | 2020B | 4 | 4 | HR21 | 56552.310 | -10.28 | 80.61 | 15.60 |
| 01390790-5403014 2020A | 01202092-0102102 | 2020C | 4 | 4 | HR21 | 56204.284 | -56.79 | 16.26 | 15.80 |
| 01393831-4648457 2020B | 01300825-5009146 | 2020A | 4 | 4 | HR10 | 56580.192 | -16.04 | 74.55 | 13.50 |
| 01405323-5356575 2020B | 01390790-5403014 | 2020A | 4 | 4 | HR10 | 56548.390 | 40.40 | 83.81 | 14.20 |
| 01585747-5401493 2020B 4 4 HR21 56580.217 -65.75 40.52 14.00 01592290-4658510 2020C 4 8 U580 56207.122 5.97 26.76 12.80 2000945-5352567 2020A 4 4 HR10 56579.297 -7.69 54.71 14.00 20002707-4655438 2020B 4 4 HR10 56207.144 36.62 73.89 14.10 20005449-0055403 2020A 4 4 HR10 56223.207 -23.45 24.67 15.00 20105686-5012361 2020C 4 4 HR21 56531.288 -20.25 86.83 16.00 2194365-0104381 2020C 5 5 HR21 56532.333 -23.84 42.38 15.00 2290765-0318506 2020B 4 4 HR10 56223.207 6.73 81.89 15.70 2290959-5004269 2020A 4 HR10 56578.216 13.53 94.34 14.50 20394731-0057248 2020A 4 HR10 56578.216 13.53 94.34 14.50 20394731-0057248 2020C 4 HR21 56526.222 6.73 81.89 15.70 2039459-5004269 2020A 4 HR10 56578.216 13.53 94.34 14.50 20394731-0057248 2020A 4 HR10 56578.216 -11.88 72.23 14.30 20394731-0057248 2020A 4 HR10 FR10 56578.216 13.53 94.34 14.50 20394731-0057248 2020A 4 HR10 FR10 56578.216 -11.88 72.23 14.30 20394731-0057248 2020A 4 HR10 FR10 56310.061 -15.11 41.25 15.90 20315192-0034528 2020B 6 HR10 56310.061 -15.11 41.25 15.90 203175192-0034528 2020B 4 HR10 56225.186 37.94 64.65 14.70 203175192-0034528 2020B 4 HR10 56225.186 -113.51 0.00 14.00 2030828-4656379 2020B 4 HR10 56225.186 -113.51 0.00 14.00 2030828-4656379 2020B 4 HR10 56225.186 -113.51 0.00 14.00 2030828-4656379 2020B 4 HR10 56208.238 67.49 115.44 15.60 203341845-2722333 2020A 4 HR10 56208.238 67.49 115.44 15.60 203381845-2722333 2020A 4 HR10 56208.238 67.99 11.54 15.60 203381845-2722333 2020A 4 HR10 56194.274 -90.52 27.62 14.50 203394566-4710178 2020B 4 HR10 56194.274 -90.52 27.62 14.50 20345481-6040332 2020B 4 HR10 56194.274 -90.52 27.62 14.50 2040440492-4609391 2020A 4 HR10 FR10 FR10 FR10 FR10 FR10 FR10 FR10 F | 01393831-4648457 | 2020B | 4 | 4 | HR10 | 56197.248 | 24.46 | 60.55 | 13.50 |
| 01592290-4688510 2020C 4 8 U\$80 56207.122 5.97 26.76 12.80 02000707-4655438 2020B 4 4 HR10 56507.297 -7.69 54.71 14.00 02002707-4655438 2020C 4 4 HR10 56204.275 -62.19 111.35 13.50 02005449-0055403 2020A 4 4 HR10 56223.207 -23.45 24.67 15.00 02195686-5012361 2020C 4 4 HR21 56531.288 -20.25 86.83 16.00 02194365-0104381 2020C 5 5 HR21 56532.333 -23.84 42.38 15.00 02290765-0318506 2020B 4 4 HR10 56578.216 13.53 94.34 14.50 0239059-5004269 2020A 4 4 HR10 56578.216 13.53 94.34 14.50 02394731-0057248 2020A 4 4 HR10 HR21 56576.204 -58.59 15.40 15 | 01405323-5356575 | 2020B | 4 | 4 | HR10 | | | | |
| 02000945-5352567 2020A 4 HR10 56579.297 -7.69 54.71 14.00 02002707-4655438 2020B 4 HR10 56207.144 36.62 73.89 14.10 020055493 2020C 4 HR21 56224.275 -62.19 111.35 13.50 02105686-5012361 2020C 4 HR21 56531.288 -20.25 86.83 16.00 02194365-0104381 2020C 5 5 HR21 56532.333 -23.84 42.38 15.00 02290765-0318506 2020B 4 HR21 56226.222 6.73 81.89 15.70 02290959-5004269 2020A 4 HR10 56578.216 13.53 94.34 14.50 02305230-4956149 2020A 4 HR10 18758.216 11.88 72.23 14.30 02304731-0057248 2020A 4 HR10 HR21 56578.216 13.53 94.34 14.50 031309980-5007403 2020B 6 6 HR10 <td>01585747-5401493</td> <td></td> <td>4</td> <td>4</td> <td></td> <td>56580.217</td> <td></td> <td>40.52</td> <td></td> | 01585747-5401493 | | 4 | 4 | | 56580.217 | | 40.52 | |
| 02002707-4655438 2020B 4 4 HR10 56207.144 36.62 73.89 14.10 02005484-0055339 2020C 4 4 HR10 56224.275 -62.19 111.35 13.50 02005449-0055403 2020A 4 4 HR21 56531.288 -20.25 86.83 16.00 02194365-0104381 2020C 5 5 HR21 56532.333 -23.84 42.38 15.00 02290765-0318506 2020B 4 4 HR21 56526.222 6.73 81.89 15.70 02290765-0318506 2020A 4 4 HR10 56578.216 -11.88 72.23 14.30 02394731-0057248 2020A 4 4 HR10 HR21 56172.267 -58.70 21.36 13.80 02503269-5010152 2020C 4 4 HR21 56576.204 -58.59 15.40 15.70 03175934-0024337 2020B 6 6 HR10 56310.061 -15.11 41.25 | 01592290-4658510 | 2020C | | 8 | | | | | |
| 02003583-0053539 2020C 4 4 HR21 56224.275 -62.19 111.35 13.50 02005449-0055403 2020A 4 4 HR10 56223.207 -23.45 24.67 15.00 02195686-5012361 2020C 4 4 HR21 56531.288 -20.25 86.83 16.00 02194365-0104381 2020C 5 5 HR21 56532.333 -23.84 42.38 15.00 02290959-5004269 2020A 4 4 HR10 56578.216 -11.88 72.23 14.30 02302503-4956149 2020A 4 4 HR10 56578.216 -11.88 72.23 14.30 02304731-0057248 2020A 4 4 HR10 56576.204 -58.59 15.40 15.70 03103980-5007403 2020B 6 6 HR10 56310.061 -15.11 41.25 15.90 03175192-0034528 2020B 4 4 HR10 56225.186 37.94 | | | | | | | | | |
| 02005449-0055403 2020A 4 4 HR10 56223.207 -23.45 24.67 15.00 02105686-5012361 2020C 4 4 HR21 56531.288 -20.25 86.83 16.00 02290765-0318506 2020B 4 4 HR21 56532.333 -23.84 42.38 15.00 02290959-5004269 2020A 4 4 HR10 56578.216 13.53 94.34 14.50 02302503-4956149 2020A 4 4 HR10 56578.216 -11.88 72.23 14.30 02503269-5010152 2020C 4 4 HR10 HR21 56172.267 -58.70 21.36 13.80 02503269-5010152 2020C 4 4 HR10 56310.061 -15.11 41.25 15.70 03175192-0034528 2020B 6 6 HR10 56225.186 37.94 64.65 14.70 03175192-034546 2020A 4 HR21 56226.132 -9.62 86.60 <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> | | | | | | | | | |
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| 02194365-0104381 2020C 5 5 HR21 56532.333 -23.84 42.38 15.00 02290765-0318506 2020B 4 4 HR10 56526.222 6.73 81.89 15.70 02302503-4956149 2020A 4 4 HR10 56578.216 -11.88 72.23 14.30 02304731-0057248 2020A 4 4 HR10 56578.216 -58.70 21.36 13.80 02503269-5010152 2020C 4 4 HR10 56176.204 -58.59 15.40 15.70 03103980-5007403 2020B 6 6 HR10 56310.061 -15.11 41.25 15.90 03175192-0034528 2020B 4 4 HR10 56225.186 37.94 64.65 15.10 03181102-0034546 2020A 4 4 HR10 56225.186 37.94 64.65 15.10 03201610-5601321 2020B 4 4 HR10 56197.296 -2.25 40.37 14.90 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> | | | | | | | | | |
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| 02290959-5004269 2020A 4 4 HR10 56578.216 13.53 94.34 14.50 02302503-4956149 2020A 4 4 HR10 56578.216 -11.88 72.23 14.30 02394731-0057248 2020A 4 4 HR10 HR21 56172.267 -58.70 21.36 13.80 02503269-5010152 2020C 4 4 HR21 56576.204 -58.59 15.40 15.70 03103980-5007403 2020B 6 6 HR10 56310.061 -15.11 41.25 15.90 03175192-0034528 2020B 4 4 HR21 56226.132 -9.62 86.60 15.10 03181102-0034546 2020A 4 4 HR10 56197.296 -2.25 40.37 14.90 03201610-5601321 2020B 4 4 HR10 56197.296 -2.25 40.37 14.90 03394566-4710178 2020B 4 4 HR10 56208.238 -46.86 98.89 12.90 03394566-4710178 | | | | | | | | | |
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| 02394731-0057248 2020A 4 4 HR10 HR21 56172.267 -58.70 21.36 13.80 02503269-5010152 2020C 4 4 HR21 56576.204 -58.59 15.40 15.70 03103980-5007403 2020B 6 6 HR10 56320.618 37.94 64.65 14.70 03175192-0034528 2020B 4 4 HR21 56225.186 37.94 64.65 14.70 03175934-0024337 2020C 4 4 HR10 56225.186 -113.51 0.00 14.00 03200828-4656379 2020B 4 4 HR10 56197.296 -2.25 40.37 14.90 03201610-5601321 2020B 4 4 HR10 56280.238 67.49 115.44 15.60 03374095-2723384 2020A 4 4 HR10 HR21 56208.238 67.49 115.44 15.60 03381845-2722333 2020A 4 4 HR10 HR21 56208.238 -4. | | | | | | | | | |
| 02503269-5010152 2020C 4 4 HR21 56576.204 -58.59 15.40 15.70 03103980-5007403 2020B 6 6 HR10 56310.061 -15.11 41.25 15.90 03175192-0034528 2020B 4 4 HR10 56225.186 37.94 64.65 14.70 03181102-0034546 2020A 4 4 HR10 56225.186 -113.51 0.00 14.00 03201610-5601321 2020B 4 4 HR10 56197.296 -2.25 40.37 14.90 03374095-2723284 2020A 4 4 HR10 56208.238 67.49 115.44 15.60 03381845-2722333 2020A 4 4 HR10 56208.238 67.49 115.44 15.60 03401027+0002559 2020A 4 4 HR10 48.288.73 337.53 16.30 03595053-4701073 2020A 4 4 HR10 56194.274 39.19 75.96 | | | | | | | | | |
| 03103980-5007403 2020B 6 6 HR10 56310.061 -15.11 41.25 15.90 03175192-0034528 2020B 4 4 HR10 56225.186 37.94 64.65 14.70 03175934-0024337 2020C 4 4 HR21 56226.132 -9.62 86.60 15.10 03181102-0034546 2020A 4 4 HR10 56225.186 -113.51 0.00 14.00 03200828-4656379 2020B 4 4 HR10 56197.296 -2.25 40.37 14.90 03201610-5601321 2020B 4 8 U580 56580.261 -7.88 21.61 13.50 03374095-2723284 2020A 4 4 HR10 56208.238 67.49 115.44 15.60 03394566-4710178 2020B 4 4 HR10 56207.312 288.73 337.53 16.30 03401027+0002559 2020A 4 4 HR10 56194.274 39.19 | | | | | | | | | |
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| 04202910-0019338 2020A 4 8 U580 55998.026 -50.58 100.14 11.90 04301327-5001191 2020A 6 12 U580 56264.244 118.87 167.53 13.10 04404692-4609391 2020A 4 4 HR10 HR21 56577.238 59.05 141.04 15.30 04410121-5004008 2020A 4 4 HR10 56223.304 -16.92 51.75 14.10 04434718-0040232 2020B 4 4 HR10 HR21 56551.345 98.00 136.04 14.40 05291006-6028494 2020B 4 4 HR10 HR21 56709.111 -21.19 71.29 13.20 05294654-6025081 2020A 4 4 HR10 56709.019 32.19 75.21 15.10 05313822-6021421 2020A 4 4 HR10 56709.019 57.18 116.23 16.00 05402480-4726342 2020B 4 4 HR10 56711.024 <t< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<> | | | | | | | | | |
| 04301327-5001191 2020A 6 12 U580 56264.244 118.87 167.53 13.10 04404692-4609391 2020A 4 4 HR10 HR21 56577.238 59.05 141.04 15.30 04410121-5004008 2020A 4 4 HR10 56223.304 -16.92 51.75 14.10 04434718-0040232 2020B 4 4 HR10 HR21 56551.345 98.00 136.04 14.40 05291006-6028494 2020B 4 4 HR21 56709.111 -21.19 71.29 13.20 05294654-6025081 2020A 4 4 HR10 56709.019 32.19 75.21 15.10 05313822-6021421 2020A 4 4 HR10 56709.019 57.18 116.23 16.00 05402480-4726342 2020B 4 8 U580 56711.024 50.09 71.43 12.50 055043344-4738199 2020B 4 4 HR21 56606.315 3.28 | | | | | | | | | |
| 04404692-4609391 2020A 4 4 HR10 HR21 56577.238 59.05 141.04 15.30 04410121-5004008 2020A 4 4 HR10 56223.304 -16.92 51.75 14.10 04434718-0040232 2020B 4 4 HR10 HR21 56551.345 98.00 136.04 14.40 05291006-6028494 2020B 4 4 HR10 56709.111 -21.19 71.29 13.20 05294654-6025081 2020A 4 4 HR10 56709.019 32.19 75.21 15.10 05313822-6021421 2020A 4 4 HR10 56709.019 57.18 116.23 16.00 05402480-4726342 2020B 4 8 U580 56711.024 50.09 71.43 12.50 05403344-4738199 2020B 4 4 HR10 56711.113 75.79 118.51 15.80 05562593-6029184 2020A 4 4 HR21 56606.315 3.28 <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> | | | | | | | | | |
| 04410121-5004008 2020A 4 4 HR10 56223.304 -16.92 51.75 14.10 04434718-0040232 2020B 4 4 HR10 HR21 56551.345 98.00 136.04 14.40 05291006-6028494 2020B 4 4 HR10 56709.111 -21.19 71.29 13.20 05294654-6025081 2020A 4 4 HR10 56709.019 32.19 75.21 15.10 05313822-6021421 2020A 4 4 HR10 56709.019 57.18 116.23 16.00 05402480-4726342 2020B 4 8 U580 56711.024 50.09 71.43 12.50 05403344-4738199 2020B 4 4 HR10 56711.113 75.79 118.51 15.80 05554481-6034418 2020C 4 4 HR21 56606.315 3.28 110.72 14.70 05562593-6029184 2020A 4 4 HR10 56006.315 -12.42 | | | | | | | | | |
| 04434718-0040232 2020B 4 4 HR10 HR21 56551.345 98.00 136.04 14.40 05291006-6028494 2020B 4 4 HR21 56709.111 -21.19 71.29 13.20 05294654-6025081 2020A 4 4 HR10 56709.019 32.19 75.21 15.10 05313822-6021421 2020A 4 4 HR10 56709.019 57.18 116.23 16.00 05402480-4726342 2020B 4 8 U580 56711.024 50.09 71.43 12.50 05403344-4738199 2020B 4 4 HR10 56711.113 75.79 118.51 15.80 05554481-6034418 2020C 4 4 HR21 56606.315 3.28 110.72 14.70 05562593-6029184 2020A 4 8 U580 56606.315 -12.42 34.22 13.10 07554475-0908077 2020A 4 4 HR10 56001.042 79.69 125.36 14.90 07555317-0848462 2020C 4 4 | | | | | | | | | |
| 05291006-6028494 2020B 4 4 HR21 56709.111 -21.19 71.29 13.20 05294654-6025081 2020A 4 4 HR10 56709.019 32.19 75.21 15.10 05313822-6021421 2020A 4 4 HR10 56709.019 57.18 116.23 16.00 05402480-4726342 2020B 4 8 U580 56711.024 50.09 71.43 12.50 05403344-4738199 2020B 4 4 HR10 56711.113 75.79 118.51 15.80 05554481-6034418 2020C 4 4 HR21 56606.315 3.28 110.72 14.70 05562593-6029184 2020A 4 8 U580 56606.315 -12.42 34.22 13.10 07554475-0908077 2020A 4 4 HR10 56001.042 79.69 125.36 14.90 07555317-0848462 2020C 4 4 HR21 56000.076 47.50 119.55 15.10 | | | | | | | | | |
| 05294654-6025081 2020A 4 4 HR10 56709.019 32.19 75.21 15.10 05313822-6021421 2020A 4 4 HR10 56709.019 57.18 116.23 16.00 05402480-4726342 2020B 4 8 U580 56711.024 50.09 71.43 12.50 05403344-4738199 2020B 4 4 HR10 56711.113 75.79 118.51 15.80 05554481-6034418 2020C 4 4 HR21 56606.315 3.28 110.72 14.70 05562593-6029184 2020A 4 8 U580 56606.315 -12.42 34.22 13.10 07554475-0908077 2020A 4 4 HR10 56001.042 79.69 125.36 14.90 07555317-0848462 2020C 4 4 HR21 56000.076 47.50 119.55 15.10 | | | | | | | | | |
| 05313822-6021421 2020A 4 4 HR10 56709.019 57.18 116.23 16.00 05402480-4726342 2020B 4 8 U580 56711.024 50.09 71.43 12.50 05403344-4738199 2020B 4 4 HR10 56711.113 75.79 118.51 15.80 055554481-6034418 2020C 4 4 HR21 56606.315 3.28 110.72 14.70 05562593-6029184 2020A 4 8 U580 56606.315 -12.42 34.22 13.10 07554475-0908077 2020A 4 4 HR10 56001.042 79.69 125.36 14.90 07555317-0848462 2020C 4 4 HR21 56000.076 47.50 119.55 15.10 | | | | | | | | | |
| 05402480-4726342 2020B 4 8 U580 56711.024 50.09 71.43 12.50 05403344-4738199 2020B 4 4 HR10 56711.113 75.79 118.51 15.80 055554481-6034418 2020C 4 4 HR21 56606.315 3.28 110.72 14.70 05562593-6029184 2020A 4 8 U580 56606.315 -12.42 34.22 13.10 07554475-0908077 2020A 4 4 HR10 56001.042 79.69 125.36 14.90 07555317-0848462 2020C 4 4 HR21 56000.076 47.50 119.55 15.10 | | | | | | | | | |
| 05403344-4738199 2020B 4 4 HR10 56711.113 75.79 118.51 15.80 05554481-6034418 2020C 4 4 HR21 56606.315 3.28 110.72 14.70 05562593-6029184 2020A 4 8 U580 56606.315 -12.42 34.22 13.10 07554475-0908077 2020A 4 4 HR10 56001.042 79.69 125.36 14.90 07555317-0848462 2020C 4 4 HR21 56000.076 47.50 119.55 15.10 | | | | | | | | | |
| 05554481-6034418 2020C 4 4 HR21 56606.315 3.28 110.72 14.70 05562593-6029184 2020A 4 8 U580 56606.315 -12.42 34.22 13.10 07554475-0908077 2020A 4 4 HR10 56001.042 79.69 125.36 14.90 07555317-0848462 2020C 4 4 HR21 56000.076 47.50 119.55 15.10 | | | | | | | | | |
| 05562593-6029184 2020A 4 8 U580 56606.315 -12.42 34.22 13.10 07554475-0908077 2020A 4 4 HR10 56001.042 79.69 125.36 14.90 07555317-0848462 2020C 4 4 HR21 56000.076 47.50 119.55 15.10 | | | | | | | | | |
| 07554475-0908077 2020A 4 4 HR10 56001.042 79.69 125.36 14.90 07555317-0848462 2020C 4 4 HR21 56000.076 47.50 119.55 15.10 | | | | | | | | | |
| 07555317-0848462 2020C 4 4 HR21 56000.076 47.50 119.55 15.10 | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

Table A.1. Continued.

| CNAME | flag | # exp. | # sp. | setup | MJD | $v_r(1)$ | $v_r(2)$ | V |
|------------------|----------------|--------|--------|--------------|-----------|------------------|----------|----------------|
| 08191969-1412025 | 2020B | 4 | 4 | HR10 | 56758.012 | 47.82 | 83.86 | 14.00 |
| 08194766-1411293 | 2020B | 4 | 4 | HR10 | 56758.012 | 15.96 | 48.53 | 16.00 |
| 08231542-0535165 | 2020B | 4 | 8 | U580 | 56314.137 | -5.39 | 11.91 | 12.90 |
| 08231783-0523549 | 2020B | 4 | 4 | HR21 | 56341.085 | -33.50 | 31.74 | 16.40 |
| 08233762-0536506 | 2020A | 4 | 8 | U580 | 56314.137 | 12.10 | 44.00 | 13.10 |
| 08395189-0756213 | 2020A 2020B | 4 | 4 | HR10 | 56378.103 | -21.55 | 15.86 | 15.10 |
| 08395720-0756505 | 2020B 2020C | 4 | 4 | HR10 | 56378.103 | 73.20 | 104.50 | 13.50 |
| 08403017-1409445 | 2020A | 4 | 4 | HR10 | 56678.207 | 50.72 | 91.12 | 14.40 |
| 08582336-1403021 | 2020A 2020B | 4 | 4 | HR10 | 56679.175 | 68.05 | 98.08 | 16.60 |
| 09193694-1751496 | 2020B | 4 | 4 | HR10 | 56706.273 | 37.38 | 82.60 | 14.40 |
| 09382162-1758544 | 2020B 2020C | 4 | 4 | HR21 | 56708.237 | 64.53 | 133.81 | 14.70 |
| 09391804-1755456 | 2020B | 4 | 4 | HR21 | 56708.237 | -26.58 | 93.47 | 16.60 |
| 09393263-0505599 | 2020B | 5 | 5 | HR10 | 56793.997 | -33.37 | 20.06 | 14.90 |
| 09594300-4054056 | 2020B | 4 | 4 | HR10 | 55928.261 | 57.16 | 84.96 | 13.90 |
| 09594650-4059014 | 2020A | 4 | 4 | HR10 HR21 | 55928.261 | -43.94 | 45.55 | 14.20 |
| 10004160-4053496 | 2020A 2020A | 4 | 4 | HR10 | 55928.282 | -56.40 | 0.72 | 13.80 |
| 10075849-0753079 | 2020A 2020C | 4 | 4 | HR21 | 56346.187 | -3.44 | 101.75 | 16.90 |
| 10090938-4121350 | 2020B | 4 | 4 | HR10 | 56343.190 | 9.68 | 47.54 | 17.13 |
| 10090938-4121330 | 2020B 2020A | 4 | 4 | HR10 | 56343.190 | 41.90 | 89.08 | 16.89 |
| 10091241-4132470 | 2020A 2020A | 4 | 4 | HR10 HR21 | 56343.190 | -44.60 | 55.97 | 16.23 |
| 10092032-4138283 | 2020A 2020A | 4 | 8 | U580 | 56343.190 | 5.54 | 59.52 | 13.80 |
| 10224640-3541044 | 2020A 2020A | 4 | 8 | U580 | 56677.262 | -14.88 | 28.50 | 13.60 |
| 10232266-3541019 | 2020A 2020A | 4 | 8 | U580 | 56679.316 | 22.99 | 55.67 | 13.70 |
| 10232300-3531571 | 2020A 2020C | 4 | 6 4 | HR21 | 56677.333 | -33.71 | 41.65 | 14.40 |
| 10394014-4108011 | 2020C 2020A | 4 | 4 | HR10 | 56376.050 | -33.71 -32.14 | 16.59 | 15.70 |
| 10403618-4104492 | 2020A 2020A | 4 | 4 | HR10 HR21 | 56376.050 | -56.89 | 58.35 | 16.00 |
| 11001645-4102232 | 2020A 2020C | 5 | 5 | HR10 HR21 | 55972.231 | -30.89 7.28 | 39.34 | 14.90 |
| 11010640-1322020 | 2020C 2020C | 4 | 4 | HR10 | 56343.284 | 1.09 | 33.20 | 18.60 |
| 11010040-1322020 | 2020C 2020B | 4 | 4 | HR10 | 56816.953 | 16.00 | 53.28 | 14.70 |
| 11230355-3455286 | 2020B 2020A | 4 | 4 | HR10 | 56798.975 | -10.70 | 69.68 | |
| 11265745-4100160 | 2020A 2020B | 4 | 4 | HR10 | 56376.096 | -3.01 | 29.55 | 13.40 13.00 |
| 11315400-4359284 | 2020B 2020C | 4 | 4 | HR21 | 56378.058 | -5.01 -61.47 | 80.43 | 14.40 |
| 11513400-4339284 | 2020C 2020C | 4 | 4 | HR21 | 55998.260 | -01.47 -18.04 | 99.27 | 16.70 |
| 12000916-4101004 | 2020C 2020A | 4 | 8 | U580 | 55998.260 | -13.04 -47.51 | 18.99 | 12.30 |
| 12000910-4101004 | 2020A 2020A | 4 | 4 | HR10 | 56798.028 | 11.64 | 73.11 | 16.40 |
| 12001709-3711439 | 2020A 2020A | 4 | 8 | U580 | 56798.028 | -0.76 | 41.61 | 13.80 |
| 12111883-4109109 | 2020A 2020A | 4 | 6 4 | HR10 HR21 | 56099.020 | -0.76 21.79 | 97.94 | 14.20 |
| 12113870-4103193 | 2020A 2020C | 4 | 4 | HR10 HR21 | 56099.020 | -141.40 | -3.08 | 14.20 |
| 12121230-4104498 | 2020C 2020C | - | - | HR10 | 56099.020 | -6.21 | 33.32 | 16.80 |
| | | 4 | 4 | | | | | 16.50 |
| 12194390-3652280 | 2020A 2020C | 4 4 | 4 | HR10 HR21 | 56799.021 | -17.48 | 37.19 | |
| 12270079-4054566 | | 4 | 4 8 | U580 | 56026.160 | -11.18 -13.10 | 70.95 | 14.80 |
| 12273877-4056402 | 2020C | | | HR10 | 56026.160 | | 5.17 | 13.00 |
| 12431359-1304540 | 2020B | 4 | 4 | | 56075.090 | 80.54 | 117.97 | 16.50 |
| 12432209-4053149 | 2020A | 4 | 4 | HR10 | 56446.016 | -43.16 | 3.42 | 14.70 |
| 12435905-0553086 | 2020A | 4 | 4 | HR10 | 56445.971 | 11.28 | 65.36 | 15.20 |
| 12562790-4516555 | 2020C | 6 | 6 | HR21 | 56468.068 | -33.48 | 29.84 | 14.80 |
| 13201190-0859503 | 2020A | 4 | 4 | HR10 HR21 | 56444.062 | -63.29 | 15.57 | 15.90 |
| 13203450-1302162 | 2020C | 4 | 4 | HR10 | 56444.108 | 18.37 | 50.90 | 14.30 |
| 13272650-4059266 | 2020A | 4 | 4 | HR10 HR21 | 56074.137 | -52.36 | 45.90 | 14.40 |
| 13285153-4107423 | 2020A | 4 | 4 | HR10 | 56074.137 | -122.48 | -77.71 | 15.10 |
| 14001419-4054092 | 2020B | 4 | 4 | HR10 | 56002.306 | -101.41 | -61.30 | 15.70 |
| 14091400-3404548 | 2020A | 4 | 4 | HR10 HR21 | 56758.198 | -12.18 | 98.40 | 15.70 |
| 14194570-1451154 | 2020C | 4 | 4 | HR21 | 56756.274 | -55.20 | 28.19 | 16.50 |
| 14222902-4402086 | 2020A | 4 | 8 | U580 | 56469.067 | -73.83 | -39.67 | 13.00 |
| 14271982-0854407 | 2020B | 4 | 4 | HR10 | 56443.065 | -54.04 | -9.21 | 14.50 |
| 14402357-4009161 | 2020A | 4 | 4 | HR10 HR21 | 56471.007 | -51.42 | 6.26 | 13.40 |
| 14591899-2001019 | 2020C | 4 | 4 | HR21 | 56754.372 | -71.26 | 5.85 | 16.60 |
| 15001595-2001152 | 2020A | 4 | 4 | HR10 | 56754.264 | -24.52 | 13.59 | 17.10 |
| 15003201-1456355 | 2020A | 4 | 4 | HR10 HR21 | 56755.236 | -124.58 | -53.53 | 15.60 |
| 15095102-1507425 | 2020A | 4 | 4 | HR10 | 56756.227 | -91.84 | -34.22 | 14.30 |

Table A.1. Continued.

| CNAME | flag | # exp. | # sp. | setup | MJD | $v_r(1)$ | $v_r(2)$ | |
|-------------------|-------|--------|-------|-----------|-----------|----------|----------|-------|
| 4.500.5550.000000 | | | | <u> </u> | | | | 10.10 |
| 15095773-2000080 | 2020B | 4 | 8 | U580 | 56757.241 | -26.65 | 3.27 | 13.40 |
| 15103048-1508193 | 2020A | 4 | 4 | HR10 | 56756.248 | -6.32 | 40.67 | 14.50 |
| 15104140-1502572 | 2020A | 4 | 4 | HR10 HR21 | 56756.227 | -110.74 | -16.23 | 14.00 |
| 15104535-4054419 | 2020B | 4 | 4 | HR10 | 56445.093 | -63.55 | -12.87 | 14.70 |
| 15105813-4048090 | 2020A | 4 | 4 | HR10 HR21 | 56445.093 | -55.76 | 58.10 | 13.70 |
| 15112349-4052387 | 2020A | 4 | 4 | HR10 | 56445.093 | -131.32 | -48.91 | 15.70 |
| 15122047-4054438 | 2020B | 4 | 4 | HR21 | 56446.197 | -50.78 | 65.82 | 14.80 |
| 15161563-4125518 | 2020C | 4 | 4 | HR21 | 56444.196 | 2.50 | 67.81 | 15.00 |
| 15164593-4122457 | 2020C | 4 | 4 | HR21 | 56444.196 | -81.86 | -14.62 | 14.20 |
| 15291504-1953570 | 2020C | 4 | 4 | HR21 | 56817.237 | 20.76 | 83.47 | 16.80 |
| 15300257-4303505 | 2020C | 4 | 4 | HR21 | 56375.273 | -59.09 | 12.07 | 12.70 |
| 15305329-1956301 | 2020C | 4 | 4 | HR21 | 56817.219 | -82.63 | 24.67 | 14.20 |
| 15305481-4130573 | 2020B | 2 | 2 | HR21 | 56854.987 | -96.73 | 92.52 | 13.30 |
| 15420717-4407146 | 2020A | 4 | 4 | HR10 | 56377.359 | -17.37 | 78.24 | 14.80 |
| 15490519-1359089 | 2020A | 4 | 4 | HR10 HR21 | 56798.207 | -39.28 | 67.37 | 15.30 |
| 15492053-0742483 | 2020A | 4 | 4 | HR10 HR21 | 56853.980 | -16.69 | 66.03 | 14.40 |
| 15495562-0724391 | 2020C | 4 | 4 | HR21 | 56853.148 | -172.12 | -97.63 | 16.50 |
| 15502613-0740084 | 2020A | 4 | 4 | HR10 | 56854.001 | -189.77 | -132.55 | 15.40 |
| 15504227-1937508 | 2020C | 4 | 4 | HR21 | 56852.040 | 44.81 | 118.81 | 14.60 |
| 15545953-4106578 | 2020A | 4 | 4 | HR10 | 56024.218 | -158.01 | 21.97 | 16.70 |
| 16035830-4547485 | 2020C | 4 | 4 | HR21 | 56377.316 | -92.54 | -6.58 | 14.50 |
| 17005619-0511542 | 2020C | 4 | 4 | HR21 | 56024.333 | -63.21 | 7.58 | 14.70 |
| 17334015-4253407 | 2020A | 7 | 7 | HR10 | 56024.378 | -11.27 | 72.68 | 15.40 |
| 17592273-4232176 | 2020C | 4 | 4 | HR21 | 56795.221 | -21.63 | 55.54 | 17.40 |
| 18103653-4455176 | 2020B | 4 | 8 | U580 | 56798.409 | 12.57 | 34.07 | 13.10 |
| 18134362-4221083 | 2020C | 6 | 6 | HR21 | 56821.118 | -102.95 | -15.45 | 14.50 |
| 18135851-4226346 | 2020B | 6 | 12 | U580 | 56856.988 | -33.65 | -6.38 | 12.90 |
| 18162528-4239594 | 2020A | 2 | 2 | HR10 | 56821.258 | -166.42 | 61.92 | 14.10 |
| 18180629-4457294 | 2020B | 2 | 2 | HR21 | 56853.175 | -99.34 | 28.14 | 14.10 |
| 18201282-4708422 | 2020C | 4 | 4 | HR10 | 56446.173 | -39.74 | 32.80 | 16.40 |
| 18203927-4655397 | 2020A | 4 | 4 | HR10 HR21 | 56446.151 | -59.02 | 45.27 | 15.30 |
| 18402582-4709250 | 2020C | 4 | 4 | HR10 | 56498.087 | -77.50 | -54.20 | 17.00 |
| 18410111-4238337 | 2020A | 4 | 4 | HR10 HR21 | 56854.225 | -132.94 | 96.51 | 14.20 |
| 18490733-3954253 | 2020A | 4 | 4 | HR10 HR21 | 56821.304 | -52.98 | 11.59 | 14.10 |
| 18590483-4711187 | 2020C | 2 | 2 | HR21 | 56852.228 | -3.62 | 78.82 | 16.50 |
| 18591414-4710472 | 2020C | 2 | 2 | HR21 | 56852.228 | -126.16 | -6.03 | 16.60 |
| 19000942-4231227 | 2020A | 4 | 8 | U580 | 56796.289 | 64.26 | 118.21 | 13.20 |
| 20183934-5400476 | 2020C | 4 | 4 | HR21 | 56795.348 | -18.21 | 53.56 | 14.50 |
| 20192137-4706271 | 2020B | 4 | 8 | U580 | 56169.233 | -40.37 | -17.80 | 12.80 |
| 20194866-4651252 | 2020B | 4 | 4 | HR21 | 56173.176 | -108.88 | 42.10 | 14.60 |
| 20593297-4655410 | 2020A | 5 | 5 | HR10 HR21 | 56819.391 | -89.93 | 7.19 | 16.10 |
| 20594465-0044334 | 2020B | 4 | 4 | HR10 | 56855.317 | -36.30 | -3.47 | 15.00 |
| 21100126-0156012 | 2020A | 2 | 2 | HR10 | 56075.346 | -15.57 | 57.46 | 15.90 |
| 21101784-0205349 | 2020A | 4 | 8 | U580 | 56075.346 | -51.08 | 14.05 | 13.70 |
| 21201559-4807298 | 2020C | 2 | 2 | HR21 | 56170.281 | -207.13 | -126.88 | 17.10 |
| 21392385-5501257 | 2020A | 4 | 4 | HR10 | 56852.300 | -113.35 | -54.44 | 16.20 |
| 21402535-0055041 | 2020B | 4 | 8 | U580 | 56855.364 | -35.24 | -9.49 | 12.70 |
| 21523327-0321571 | 2020A | 4 | 4 | HR10 HR21 | 56101.381 | -131.22 | -18.06 | 12.70 |
| 21523611-0327136 | 2020A | 4 | 4 | HR10 HR21 | 56101.381 | -54.42 | 27.90 | 16.10 |
| 21594936-4747133 | 2020A | 7 | 7 | HR10 HR21 | 56468.343 | -80.96 | 24.33 | 14.80 |
| 21595211-4745562 | 2020C | 7 | 7 | HR21 | 56103.390 | -58.88 | 9.37 | 15.70 |
| 22003339-4803527 | 2020A | 7 | 7 | HR10 | 56468.343 | -40.29 | 80.29 | 12.90 |
| 22180319-5834560 | 2020C | 4 | 4 | HR21 | 56853.375 | -71.53 | 15.23 | 14.60 |
| 22184292-5454411 | 2020C | 4 | 4 | HR21 | 56634.025 | -66.04 | 18.99 | 15.10 |
| 22184686-5506505 | 2020A | 4 | 4 | HR10 | 56607.047 | 60.95 | 122.54 | 14.20 |
| 22291350-0507554 | 2020B | 4 | 4 | HR10 | 56502.314 | -25.08 | 26.66 | 14.40 |
| 22293255-5016362 | 2020C | 4 | 4 | HR21 | 56635.034 | -41.36 | 40.10 | 14.60 |
| 22494111-0506006 | 2020A | 4 | 4 | HR10 | 56548.228 | -105.68 | -26.75 | 15.80 |
| 22495134-5544411 | 2020B | 4 | 4 | HR10 | 56576.109 | -11.74 | 32.94 | 14.10 |
| 22593725-0052333 | 2020A | 4 | 8 | U580 | 56501.304 | -65.70 | -26.62 | 13.90 |

Table A.1. Continued.

| CNAME | flag | # exp. | # sp. | setup | MJD | $v_r(1)$ | $v_r(2)$ | \overline{V} |
|------------------|-------|--------|-------|-------|-----------|----------|----------|----------------|
| | | - | - | | | , | , | |
| 23291894-5018404 | 2020A | 4 | 4 | HR10 | 56503.371 | 31.27 | 75.99 | 16.10 |
| 23303304-0504082 | 2020C | 4 | 4 | HR21 | 56225.047 | -26.68 | 51.21 | 15.30 |
| 23354061-4305405 | 2020A | 4 | 4 | HR10 | 56857.312 | 69.50 | 112.65 | 15.30 |
| 23394097-0056031 | 2020C | 4 | 4 | HR21 | 56224.096 | -32.62 | 28.29 | 15.90 |
| 23481930-5617480 | 2020B | 4 | 4 | HR10 | 56547.261 | 42.89 | 80.65 | 15.10 |
| 23501242-0503050 | 2020B | 4 | 4 | HR21 | 56267.025 | -62.12 | 58.52 | 15.70 |
| 23501961-5012563 | 2020A | 4 | 8 | U580 | 56602.084 | -70.46 | 70.20 | 12.20 |
| 23572607-4802051 | 2020C | 4 | 4 | HR21 | 56206.128 | -27.59 | 46.31 | 15.30 |
| | | | | | | | | |

Notes. The column 'CNAME' is the GES name (constructed from the J2000 coordinates), 'flag' is the final flag after eye inspection, '# exp.' the number of exposures available for that star, '# sp.' is the number of available spectra (larger than the number of exposures in the case of UVES data which provide two spectra per exposure), 'setup' is the spectrograph setup, 'MJD' is the modified Julian Date of the unique observation listed, $v_r(1)$ and $v_r(2)$ are the velocities of the two components in km s⁻¹. The last column gives the visual magnitude of the source.

Table A.2. List of SB3 candidates in the field ordered by right ascension.

| CNAME | flag | # exp. | # sp. | setup | MJD | $v_r(1)$ | $v_r(2)$ | $v_{r}(3)$ | V |
|------------------|--------|--------|-------|--------|-----------|----------|----------|------------|-------|
| 000000011100500 | 2020.4 | 4 | | IID 10 | 56550.013 | 1407 | 10.50 | 100.72 | 14.20 |
| 08202324-1402560 | 2030A | 4 | 4 | HR10 | 56758.012 | -14.05 | 42.53 | 100.73 | 14.20 |
| 12000646-4052156 | 2030A | 4 | 8 | U580 | 55998.324 | -33.99 | 14.34 | 56.68 | 12.70 |
| 13593100-1003043 | 2030A | 6 | 12 | U580 | 55999.277 | -16.50 | 11.43 | 52.05 | 12.60 |
| 15003096-2000179 | 2030A | 4 | 8 | U580 | 56754.264 | -105.96 | -71.31 | -42.15 | 13.80 |
| 18170244-4227076 | 2030A | 2 | 2 | HR10 | 56821.258 | -39.69 | -1.83 | 32.40 | 14.30 |
| | | | | | | | | | |

Appendix B: SB2 candidates in selected fields

Table B.1. List of SB2 candidates in selected fields a ordered by right ascension.

| CNAME | flag | # exp. | # sp. | setup | MJD | $v_r(1)$ | $v_r(2)$ | V |
|------------------|----------------|---------|-------|-----------------|---------------------|------------------|----------|-------------|
| D 1 | | | | | | | | |
| Bulge | 20200 | 2 | 2 | IIDA1 | 5.6010. 0 06 | 77.01 | 0.70 | 15.26 |
| 17542544-3750568 | 2020C | 2 | 2 | HR21 | 56819.206 | -77.81 | 9.78 | 15.36 |
| 17571482-4147030 | 2020B | 2 | 4 | U580 | 56173.006 | -11.07 | 30.13 | 11.57 |
| 17581333-3434348 | 2020B | 3 | 3 | HR21 | 56817.269 | -32.77 | 54.95 | 15.46 |
| 18041571-3000506 | 2020A | 2 | 2 | HR21 | 55724.240 | -51.90 | 145.50 | 16.31 |
| 18175005-3247501 | 2020C | 2 | 2 | HR21 | 56207.979 | -17.67 | 75.84 | 15.10 |
| 18380149-2820437 | 2020B | 2 | 2 | HR21 | 56758.359 | -128.80 | -42.25 | 14.18 |
| Cha I | | | | | | | | |
| 11085326-7519374 | 2020D | 2 | 4 | 11500 | 56047.002 | 22.15 | £1.70 | 10 17 |
| | 2020B | 2 | | U580 | 56047.093 | -33.15 | 51.72 | 12.17 |
| 11120384-7650542 | 2020B | 2 | 2 | HR15N | 56025.156 | 11.90 | 60.79 | 14.16 |
| CoRoT | | | | | | | | |
| 06435847-0100516 | 2020A | 18 | 18 | HR10 HR15N | 55999.997 | -40.34 | 54.97 | 13.05 |
| 19235724+0138241 | 2020A 2020A | 6 | 6 | HR10 HR15N HR21 | 56470.289 | 7.22 | 103.61 | 14.40 |
| 19243943+0048136 | 2020A 2020C | 18 | 18 | HR15N | 56171.039 | -52.08 | 65.68 | 15.11^{b} |
| 19243943+0048136 | 2020C 2020C | 18 6 | | HR15N | 56756.414 | -32.08 -47.86 | -1.75 | |
| | | | 6 | | | | | 12.69 |
| 19261871+0030211 | 2020A | 6 | 6 | HR10 HR21 | 56473.199 | 13.50 | 90.26 | 14.86 |
| 19262489+0137506 | 2020A | 6 | 6 | HR10 | 56816.215 | -50.50 | 67.49 | 14.90 |
| 19263739+0152562 | 2020A | 6 | 6 | HR10 | 56473.166 | -60.25 | 221.28 | 13.60 |
| γ^2 Vel | | | | | | | | |
| | 2020 4 | 2 | 4 | 11500 | 55072 105 | 25.20 | 20.17 | 11 42 |
| 08072516-4712522 | 2020A | 2 | 4 | U580 | 55972.105 | -25.30 | 20.17 | 11.43 |
| 08073722-4705053 | 2020C | 2 | 4 | U580 | 55929.251 | 54.85 | 83.85 | 11.83 |
| 08074628-4700347 | 2020B | 2 | 2 | HR15N | 55929.251 | -11.60 | 56.77 | 13.37 |
| 08082580-4716381 | 2020C | 2 | 2 | HR15N | 55928.190 | -0.20 | 61.00 | 16.21 |
| 08091392-4715498 | 2020C | 2 | 2 | HR15N | 55928.146 | 15.65 | 107.03 | 16.93 |
| 08091937-4719385 | 2020C | 2 | 2 | HR15N | 55972.080 | -67.47 | 92.02 | 12.75 |
| 08093154-4724289 | 2020C | 2 | 2 | HR15N | 55928.146 | 17.43 | 107.48 | 17.47 |
| 08093589-4718525 | 2020B | 2 | 6 | HR15N U580 | 55972.080 | -4.47 | 40.48 | 12.79 |
| 08094221-4719527 | 2020C | 2 | 6 | HR15N | 55972.080 | -29.17 | 49.90 | 12.40 |
| 08094864-4702207 | 2020B | 2 | 2 | HR15N | 55927.156 | -4.09 | 52.59 | 16.52 |
| 08095076-4745311 | 2020C | 2 | 2 | HR15N | 55972.155 | -44.06 | 1.17 | 12.90 |
| 08095692-4717476 | 2020B | 2 | 2 | HR15N | 55972.080 | -33.39 | 48.57 | 13.35 |
| 08103996-4714428 | 2020B | 2 | 8 | HR15N U580 | 55972.056 | -36.24 | 60.15 | 12.06 |
| 08111009-4718006 | 2020B | 2 | 2 | HR15N | 55928.099 | 11.41 | 65.79 | 16.36 |
| 08115305-4654115 | 2020A | 2 | 6 | U580 HR15N | 55927.111 | 0.52 | 53.30 | 12.93 |
| 08115892-4715140 | 2020B | 2 | 2 | HR15N | 55928.099 | -4.87 | 60.44 | 16.95 |
| | | | | | | | | |
| ho Oph | | | | | | | | |
| 16244913-2447469 | 2020C | 2 | 2 | HR15N | 56103.158 | -10.40 | 47.36 | 15.68 |
| | | | | | | | | |

Notes.

(a) See text for references about target selection and membership assessement in those fields.

(b) The visual magnitude of this star was wrongly assessed by CASU. The closest star resolved in Simbad is at a distance of 42.88 arcsec and corresponds to CoRoT 100791478.

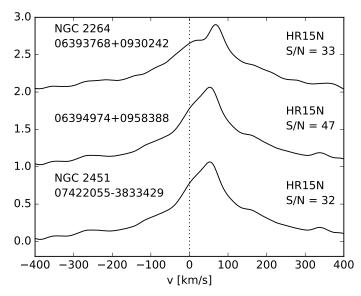


Fig. C.1. Two examples of stars in NGC 2264 and one in NGC 2451 flagged as SB2 by the DOE procedure but discarded from the final list.

Appendix C: SB2, SB3 and SB4 candidates in stellar clusters

IC 2391. This open cluster includes the unique SB4 candidate 08414659-5303449 in the current iDR4 GES data. At some epochs, the two weakest components are hardly visible, that is why we classified this source with both 2020A and 2040A flags (see Fig. 23). This SB4 candidate is analyzed in detail in Sect. 4.5.

IC 2602. All the three systems are consistent with cluster membership. System 10403116-6416249 seems to be a pair of rapidly rotating stars.

IC 4665. System 17452506+0540233 has a broad CCF with a secondary bump in its tail, but the velocities are not centred on the cluster velocity.

M67. All four SB2s are confirmed through visual inspection, having composite spectra and having membership confirmed.

NGC 2243. Only one clear SB2 candidate with a composite spectrum is retained. Two other candidates (06292559-3116070 and 06294409-3116276) are not retained, since the major peak of the CCF is at the cluster velocity, with a secondary bump offset by -60 km s^{-1} and -100 km s^{-1} , respectively.

NGC 2264. The DOE procedure has flagged a lot of stars as SB2 in this (and in all other) young clusters. Many of these stars have broad CCFs with a secondary bump, as illustrated in Fig. C.1. As the centre of this very broad CCF is close to the cluster velocity, these stars are thought to be both rapidly rotating and pulsating (δ Scu variables), and this combination is responsible for the peculiar and specific CCFs observed in young clusters, whose turn-off is located higher up on the main sequence to allow the presence of δ Scu stars. Not all of them are A stars though, and therefore we suggest the alternative hypothesis that this peculiar CCF profile is related to the disk still surrounding these young stars. In that case, the CCFs offer an interesting diagnostic to study/detect these disks (see Rebull et al. 2002). 06405650+0911389 (HD 261905) has its main peak at the cluster velocity, and a clearly defined, well-separated second peak at a velocity of 71.9 km s⁻¹. Although the field is not especially crowded, the DSS image¹⁰ reveals that the stellar image might be not perfectly round, and seems contaminated by a nearby source. 06421531+0942581 has a secondary peak close to the cluster velocity, but the main peak is totally offset (99 km s⁻¹). That peak might be due to a somewhat brighter star (NGC 2264 SBL 560) located about 4 arcsec west of the target (probably not a member, given its largely offset velocity).

NGC 2451. The situation for this cluster is quite special since there are in fact two different clusters, located at different distances, superimposed at the same location on the sky (Dias et al. 2002). These authors report a velocity of ± 2.7 km s⁻¹ for the nearest NGC 2451A cluster and 14.0 km s⁻¹ for the farthest NGC 2451B cluster. 07401559-3735416, a genuine SB2 system, cannot be a member of NGC 2451. On JD 2456634, the CCF exhibits peaks at 21 and 62 km s⁻¹, while at JD 2456638 and JD 2456677, the peaks are located around ± 2.0 km s⁻¹, implying a centre-of-mass velocity of the order of 40 km s⁻¹, significantly offset with respect to the velocities of NGC 2451A and NGC 2451B. 07422055-3833429 bears similarities with the cases discussed in relation with NGC 2264, namely a very broad CCF (base width of about 400 km s⁻¹), a main peak at 105 km s⁻¹, well offset with respect to the cluster velocity, and another bump at 20 km s⁻¹, close to the cluster velocity. The spectrum seems to show H α emission. This star has been discarded from the final list.

NGC 2516. 07593671-6021483 is probably a genuine SB2, with the peaks (22 and 50 km s⁻¹) centred on the cluster velocity (23.6 km s⁻¹). 07594121-6109251 has a broad (base width 100 km s⁻¹) CCF, with two bumps (-23 and -5 km s⁻¹) not centred on the cluster velocity and is maybe contaminated by nebular absorption lines.

NGC 2547. 08081564-4908244 is a genuine SB2, but probably not a member of NGC 2547, since the component velocities (52 and

¹⁰ http://archive.stsci.edu/dss

 122 km s^{-1}) do not encompass the cluster velocity (15.7 km s⁻¹).

NGC 3293. 10361099-5814310 classified as 2020C is probably a δ Scu star (the recommended parameters are $T_{\rm eff}$ = 8985 K, log g = 4.01) and shows emission in H α . Rather than SB2 systems, 10353288-5813498 and 10353397-5813178 are rapidly rotating (and probably pulsating) stars (because their CCFs are distorted). They are pre-main sequence star candidates (Delgado et al. 2007).

NGC 3532. The source 11085927-5849560 is identified for the first time as an SB2 candidate.

NGC 6005. Three SB2 candidates have only been observed with the HR9B setup (around the Mg I b triplet) where it is difficult to assess if the spectra are composite or not. 15555518-5725349 shows a broad CCF due to H α in HR15N with a main peak at -69 km s^{-1} , and a bump at -27 km s^{-1} , close to the cluster velocity.

NGC 6530. Numerous spurious detections of SB candidates are due to the presence of nebular lines in emission in HR15. Also, there are thin and deep absorption lines around 6678, 6715 and 6730 Å. Nebular lines are present around 6717 and 6730 Å in HR15 and have led to some reduction issues since negative fluxes are observed at these wavelengths in some stars (18044420-2415380, 18045889-2415261, 18043887-2427164). Their associated CCFs are then not reliable and have been discarded from the final list. There is strong and deep $H\alpha$ absorption in several stars. Surprisingly, many discarded SB2 components have velocities close to -60 km s^{-1} . This raises the question of the presence of another possible velocity component for that cluster.

NGC 6633. 18280622+0642252 (NGC 6633 110, V = 10.1, A3) is an interesting case of a fast rotator which could be a δ Scu-type star according to the iDR4 recommended parameters ($T_{\text{eff}} = 9600 \text{ K}$, $\log g = 4.80$ and solar metallicity). Only the upper grating of U580 is available showing very thin and deep absorption lines superimposed on the less deep and rotationally broadened Na I D doublet probably caused by nebular line contamination.

NGC 6705. The composite spectra and the associated CCFs of one of the five SB2 A candidates are presented in Fig. 16. This is an illustration of a very favorable case because 18503230-0617112 (NGC 6705 1936) has been observed in eight setups and shows a two-component CCF in all of them. 18511434-0617090 has four observations with the HR15N (H α) setup. In all cases, the main peak is around 33 km s⁻¹, close thus to the cluster velocity, whereas the CCF exhibits a secondary bump around -50 km s⁻¹. But the contrast of that bump is variable, suggesting that its origin may be related to stellar variability (but $B - V \sim 1$, suggesting that the star is a red giant, and H α variability is not expected; Cantat-Gaudin et al. 2014). On the contrary, if the system were an SB2, its kinematics is not compatible with membership in the cluster.

NGC 6752. 19105940-5957059 is the star A13 in Moni Bidin et al. (2006) which has not been detected as binary. The CCFs show clearly the presence of two peaks (flagged 2020 B). 23 observations covering more than 1500 days are available, but we unsuccessfully tried to fit an orbit. Indeed the radial velocities of the components stay constant within few km s⁻¹. Moreover the star is located in a very dense region of this globular cluster and we conclude that this is an "optical" SB2.

NGC 6802. Two SB2 and one SB3 candidates have been found in this cluster.

Trumpler 14. A large number of false SB2 detections were identified due to the presence of very strong nebular lines and reduction issues in HR15N where spectra have H α with negative flux and core emission (see Sect. 4.7 and figures within for discussion). Nebular emission in Trumpler 14 and more generally in the Carina nebula is investigated in details by Damiani et al. (2016).

Trumpler 20. 12384378-6037077 has one component located at the cluster velocity. The unique CCF of 12393764-6038190 could either be indicative of a rapidly rotating star, with some asymmetries in the line profile or of a cluster member (-36 km s^{-1}) blended with a non-member (-77 km s^{-1}). The same remark holds true for 12393362-6041446. The secondary peak of 12391767-6036083 is probably from a non-member. The main peak in the CCF of 12391992-6029552 at -3.4 km s^{-1} is probably from a non-member.

Trumpler 23. The radial velocity of this cluster has just been assessed to $-61.3 \pm 1.9 \text{ km s}^{-1}$ within the GES consortium (Overbeek et al., submitted). Therefore the SB2 candidate 16004521-5332044 may be considered as a member of this cluster.

Table C.1. SB2, SB3 and SB4 candidates in clusters ordered by increasing identifier. The column 'CNAME' is the GES name (constructed from the J2000 coordinates), 'flag' is the final flag after eye inspection, '# exp.' the number of exposures available for that star, '# sp.' is the number of available spectra (larger than the number of exposures in the case of UVES data which provide two spectra per exposure), 'setup' is the spectrograph setup, 'MJD' is the modified Julian Date of the unique observation listed, v_r is the cluster velocity, $v_r(1)$ and $v_r(2)$ are the velocities of the two components. The 'Member' column states whether the SB candidate belongs to the cluster or not (see Sect. 4.2). The last column 'Remark' contains additional information after detailed inspection of their spectra and CCFs: CS: composite spectrum, 1RRC/2RRC: one or two rapidly-rotating component(s), PULS: pulsating star, δ Scu: probable δ Scu type star, $H\alpha$ e: $H\alpha$ with emission, NaDe: Na I D with emission, NLC: nebular line contamination, ILC: interstellar line contamination, XR: X-ray source, ORB: orbit calculated, ST: see text for additional information. The "?" character is indicative of some uncertainty in the preceeding characterisation.

| Cluster | log age | | | | | v_r (| (km s ⁻¹) | | | |
|--------------------------------------|----------------|--------|--------|----------------|------------------------|-----------------------|-----------------------|------------|--------|-----------------------|
| CNAME | flag | # exp. | # sp. | setup | MJD | $v_r(1)$ | $v_r(2)$ | SB2/3/4 | Member | Remark |
| | | | | | | (km s ⁻¹) | (km s ⁻¹) | | | |
| IC 2391 | 7.74 | | | | | 14.4 | 19 ± 0.14 | | | |
| 08385566-5257516 | 2020B | 4 | 8 | U580 | 56705.032 | -14.84 | 44.91 | SB2 | у | CS |
| 08393881-5310071 | 2020A | 6 | 12 | U580 | 56705.032 | -23.25 | 39.12 | SB2 | y | CS, 1RRC |
| 08414659-5303449 | 2020A | 45 | 90 | U520 | 56707.028 | -21.64 | 50.75 | SB2 | y | CS |
| 08414659-5303449 | 2040A | 45 | 90 | U520 U580 | 56707.028 | -21.64 | 50.75 | SB4 | у | CS, ST |
| IC 2602 | 7.48 | | | | | 18.1 | 12 ± 0.30 | | | |
| 10403116-6416249 | 2020C | 1 | 1 | HR15N | 53827.129 | -67.55 | 98.63 | SB2 | y | CS |
| 10450829-6422416 | 2020A | 1 | 1 | HR15N | 53839.031 | -69.80 | 66.01 | SB2 | y | CS |
| 10460575-6420184 | 2020B | 2 | 4 | U580 | 56711.229 | -18.14 | 22.87 | SB2 | У | CS, 1RRC |
| IC 4665 | 7.60 | | | | | | 95 ± 1.13 | | | |
| 17450496+0541287 | | | 6 | HR15N | | -109.77 | 46.17 | SB2 | У | CS, H α e |
| 17452506+0540233 | | 2 | 2 | HR15N | 56471.099 | 7.72 | 87.39 | SB2 | n | CS? |
| 17453692+0542424 | | | 4 | U580 | 56471.099 | -49.75 | 18.17 | SB2 | У | CS |
| 17455717+0601224 | | 2 | 2 | HR15N | 56471.233 | -43.74 | 53.34 | SB2 | У | CS |
| 17472992+0607069 | 2020B | 2 | 2 | HR15N | 56473.072 | -64.42 | 8.52 | SB2 | У | CS |
| M 67 | 9.60 | | | | | 33 | $.8 \pm 0.5$ | | | |
| 08511868+1147026 | 2020A | 3 | 6 | U5801 | 54866.304 | -12.47 | 88.80 | SB2 | У | CS, XR |
| 08511901+1150056 | | | 8 | U580l | 54866.221 | -28.00 | 97.99 | SB2 | y | CS |
| 08512291+1148493 | | | 8 | U5801 | 54866.221 | 15.78 | 53.47 | SB2 | У | CS |
| 08512940+1154139 | 2020A | 5 | 10 | U5801 | 54853.182 | 15.99 | 49.90 | SB2 | У | CS |
| NGC 2243 | 9.60 | | | | | 59 | $.5 \pm 0.8$ | | | |
| 06290412-3114343 | 2020B | 4 | 4 | HR15N | 56603.226 | 19.78 | 118.51 | SB2 | У | CS |
| NGC 2264 | 6.48 | | | | | 24 6 | 69 ± 0.98 | | | |
| 06404608+0949173 | | 22 | 24 | HR15N U580 | 55915 177 | -88.21 | 102.35 | SB2 | y | CS, 2RRC, ORB, XR, ST |
| 06413150+0954548 | | 22 | 24 | HR15N U580 | | -24.07 | 58.82 | SB2 | y | CS, NLC? |
| 06413207+1001049 | | 4 | 6 | U580 | 56267.205 | 77.74 | 133.75 | SB2 | n | CS, 1RRC |
| 06414775+0952023 | | | 10 | HR15N U580 | | -52.95 | 84.71 | SB2 | у | CS, NaDe |
| | | | | | | | | | | |
| NGC 2451 | 7.8 (A) | | | | | | .70 (A) | | | |
| 07271224 2021467 | 8.9 (B) | 4 | 4 | IID 15N | 56624212 | | 00 (B) | CDA | | CS |
| 07371334-3831467 07382664-3839208 | 2020B 2020B | 4 | 4 4 | HR15N | 56634.212 56634.212 | -16.05 0.71 | 46.59 57.57 | SB2 SB2 | У | CS |
| 07384076-3743189 | 2020B 2020C | | 4 | HR15N HR15N | 56677.217 | -6.51 | 61.72 | SB2? | У | |
| 07401559-3735416 | 2020C 2020A | | 12 | U580 | 56634.259 | 21.18 | 61.77 | SB2? | y n | CS, ST |
| 07405697-3721458 | 2020A | | 4 | U580l | 56677.309 | 101.60 | 146.85 | SB2 | n | CS, S1 |
| 07403097-3721438 | 2020A 2020C | 2 | 2 | HR15N | 56635.182 | 49.04 | 118.40 | SB2? | n | Co |
| 07431451-3810155 | 2020C | 2 | 2 | HR15N | 56635.226 | -11.94 | 47.02 | SB2: | y | |
| 07454636-3809168 | 2020C | 2 | 2 | HR15N | 56679.221 | -34.99 | 46.81 | SB2 | y y | |
| 07455390-3812406 | 2020B | 4 | 8 | U580 | 56637.222 | -2.21 | 31.73 | SB2 | y | CS |
| 07455995-3854469 | 2020B | 2 | 2 | HR15N | 56679.290 | -23.86 | 68.51 | SB2 | y | CS |
| 07463487-3905202 | 2020A | | 2 | HR15N | 56679.290 | -10.76 | 75.22 | SB2 | y | CS |
| 07470917-3859003 | 2030A | 2 | 4 | U580 | 56637.287 | | 96.07,136.62 | SB3 | у | CS |
| | | | | | | | | | • | |

 Table C.1. Continued.

| Cluster CNAME | log age flag | # exn | # sn | set-up | MJD | v_r (ki $v_r(1)$ | $m s^{-1}$) | SB2/3/4 | Member | Remark |
|-------------------------------------|-----------------|--------|-------|---------------------|------------------------|----------------------|----------------------|------------|----------|-------------------------------|
| CIVINE | nag | п схр. | п sp. | - set-up | WIJD | (km s^{-1}) | (km s^{-1}) | 3D2/3/4 | Wichiber | Remark |
| NGC 2516 | 8.20 | | | | | 23.6 | ± 1.0 | | | |
| 07540665-6043081 | 2020A | 2 | 2 | HR15N | 56342.032 | -40.52 | 63.01 | SB2 | у | CS, H α e |
| 07551150-6028375 | 2020C | 2 | 2 | HR15N | 56374.017 | -4.99 | 54.22 | SB2 | у | CS |
| 07563381-6046027 | 2020B | 2 | 2 | HR15N | 56375.037 | -3.54 | 50.50 | SB2 | y | CS |
| 07575737-6044162 | 2030C | 2 | 4 | U520 | 56375.037 | -30.40 | 30.90, 77.79 | SB3 | y | ST |
| 07593411-6042583 | 2020B | 4 | 4 | HR15N | 56375.037 | -39.31 | 61.19 | SB2 | y | CS |
| 07593671-6021483 | 2020B | 2 | 4 | U580 | 56376.004 | 21.84 | 49.71 | SB2 | y | CS |
| 07594121-6109251 | 2020C | 3 | 4 | U580 | 56374.128 | -23.26 | -5.11 | SB2 | n | CS?, NLC? |
| 07594744-6049228 | 2020B | 4 | 4 | HR15N | 56375.011 | -1.23 | 48.64 | SB2 | у | CS., NEC. |
| 7595659-6049283 | 2020D | | 2 | HR15N | 56375.078 | -9.56 | 49.97 | SB2 | y Y | CS |
| NGC 2547 | 7.54 | | | | | 15.65 | ± 1.26 | | | |
| 08081564-4908244 | 2020A | 4 | 6 | U580 HR15N | 56310.201 | 51.01 | 119.87 | SB2 | n | CS, ST |
| | | | | | | | | | | |
| NGC 3293 10343408-5814431 | 7.00 2020A | 12 | 12 | HR3 HR5A HR9B HR14A | 55072 322 | -12.00 -9.65 | 0 ± 4.00 51.10 | SB2 | n | CS?, Hαe |
| | | | | | | | | | n | , |
| 0345341-5812222 | 2020C | 12 | 12 | HR9B | 56024.110 | -21.54 | 39.34 | SB2 | У | $H\alpha e$? |
| 10350728-5810574 | 2020B | 9 | 9 | HR6 | 56024.034 | -18.58 | 151.33 | SB2 | У | 2RRC? |
| 0361099-5814310 | 2020C | 9 | 9 | HR6 HR14A | 56000.121 | -78.31 | 41.59 | SB2? | У | δ Scu? H α e ST |
| 10361385-5819052 | 2020B | 12 | 12 | HR5A HR14A | 55972.322 | -70.47 | 34.69 | SB2 | У | CS?, 1RRC |
| 10361494-5814170 | 2020B | 7 | 7 | HR6 HR14A | 55999.147 | -54.32 | 20.01 | SB2 | y | $H\alpha e$ |
| 10361791-5814296 | 2020C | 12 | 12 | HR14A | 55972.322 | -46.06 | 57.26 | SB2 | у | |
| 10362294-5825333 | 2020B | 7 | 7 | HR3 | 55998.113 | -40.41 | 39.06 | SB2 | y | CS? |
| 10362842-5805112 | 2020B | 7 | 7 | HR3 HR5A HR6 | 55998.218 | -40.13 | 29.55 | SB2 | y | CS |
| | | | | | | | | | | |
| NGC 3532 | 8.48 | 0 | 10 | 11500 | 56440.052 | | ± 1.4 | CD2 | | CC |
| 11085927-5849560 | 2020B | 9 | 18 | U580 | 56440.953 | -11.12 | 28.73 | SB2 | У | CS |
| NGC 4815 | 8.75 | | | | | | $.4 \pm 4$ | | | |
| 12573865-6454061 | 2020B | 12 | 12 | HR9B | 56025.203 | -103.71 | 37.33 | SB2 | У | noisy |
| 12572682-6456300 | 2020C | 10 | 10 | HR15N | 56028.203 | -89.49 | -2.06 | SB2 | У | $H\alpha e$? |
| NGC 6005 | 9.08 | | | | | 24.1 | 1 ± 1.3 | | | |
| | | 4 | 4 | HDOD | 56705 065 | | | CD 20 | 0 | · CT |
| 15553867-5724434 | 2030B | | 4 | HR9B | 56795.265 | | -14.4, 32.7 | SB3? | y? | noisy, ST |
| 15554550-5728087 | 2020B | 4 | 4 | HR9B | 56795.265 | -63.56 | 3.69 | SB2 | У | CS? |
| 15554669-5725386 | 2020A | 2 | 2 | HR9B | 56794.295 | -50.27 | 0.40 | SB2 | У | CS? |
| 15555518-5725349 | 2020C | 6 | 6 | HR15N | 56816.147 | -68.85 | -26.73 | SB2? | n? | noisy, ST |
| 15561896-5725399 | 2020A | 2 | 2 | HR9B | 56794.295 | -104.43 | -28.40 | SB2 | n | CS? |
| NGC 6530 | 6.30 | | | | | 4.21 | ± 6.35 | | | |
| NGC 0530 18040734-2422217 | 0.30 2020C | 1 | 1 | HR15 | 52787.320 | -4.21 -40.0 9 | ± 0.33 | SB2 | у | |
| 18040988-2425323 | 2020A | | 1 | HR15 | 52787.390 | -62.7 6 | 50.74 | SB2 | | CS, NLC |
| 18045495-2423096 | 2020A 2020C | | | | 52787.390 | -61.2 8 | | SB2? | y | CS, NLC |
| | | | 3 | HR15 | | | 0.50 | | y? | CC |
| 8045528-2412512 8052912-2428104 | 2020A 2020C | | 2 2 | HR15N HR15N | 56173.078 56502.262 | -105.5 2 $-14.1 3$ | 6.67 56.55 | SB2 SB2 | y n | CS $H\alpha e$ |
| 2 120101 | 20200 | - | - | Incisit | 30302.202 | 15 | 30.33 | 552 | | |
| NGC6633 | 8.78 | | | | | | 3 ± 1.5 | | | |
| 18263193+0637329 | 2020B | 2 | 2 | HR15N | 56444.288 | -72.17 | 78.21 | SB2 | у | $H\alpha e$ |
| 18263896+0630410 | 2020B | 2 | 2 | HR15N | 56445.184 | -74.59 | -1.45 | SB2 | y | NLC? |
| 18264081+0632435 | | 2 | 2 | HR15N | 56445.184 | 4.85 | 58.63 | SB2 | n | CS |
| 18265864+0640458 | | 2 | 2 | HR15N | 56444.288 | -89.10 | -0.78 | SB2 | у | CS |
| 8270724+0638394 | | | 2 | HR15N | 56445.184 | -49.28 | 42.61 | SB2 | y | CS |
| 8271075+0627061 | | | 4 | HR15N | 56442.297 | 2.20 | 58.00 | SB2 | n n | |
| 8272122+0637268 | | | 5 | HR9B HR15N | 56444.273 | -45.42 | 59.67 | SB2 | | CS |
| | | | | | | | | | У | |
| 8272783+0644321 | | | 2 | HR15N | 56444.309 | -34.67 | 37.55 | SB2 | У | CS |
| 8274341+0641115 | | | 5 | HR9B | 54279.258 | -80.28 | -31.25 | SB2 | n | 4886 ·· |
| 8280622+0642252 | | | 4 | U520u | 56444.342 | -55.62 | 39.20 | SB2 | У | 1RRC, PULS, IL |
| 8280970+0638061 | | 3 | 3 | HR15N | 56444.333 | -66.95 | 28.70 | SB2 | y | CS |
| 8281038+0647407 | 2020B | 2 | 4 | U580 | 56854.131 | -38.61 | -13.44 | SB2 | y | CS |
| 8282150+0645278 | | 2 | 2 | HR15N | 56446.241 | -8.46 | 103.81 | SB2 | n | $H\alpha e$? |
| 8282354+0646402 | | 3 | 3 | HR15N | 56444.333 | -104.96 | 30.15 | SB2 | у | CS |
| | | | | | | | | | | |

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 Table C.1. Continued.

| Cluster CNAME | log age flag | | # sp. | set-up | MJD | $v_r(1)$ | | SB2/3/4 | Member | Remark |
|--------------------------------------|-----------------|--------|----------|--|------------------------|-----------------|-----------------------|-------------|--------|---|
| | | | | | | $(km s^{-1})$ | (km s ⁻¹) | | | |
| NGC 6705 | 8.47 | | | | | 34. | $.9 \pm 1.6$ | | | |
| 18503230-0617112 | 2020A | 12 | 12 | HR6 HR9B HR10 HR21 | 56103.110 | -38.24 | 117.09 | SB2 | у | CS |
| 18503690-0621100 | | | 2 | HR15N | 56102.120 | -29.51 | 83.84 | SB2 | у | CS |
| 18503840-0617048 | 2020C | | 7 | HR10 HR15N HR21 | 56443.382 | -18.97 | 85.47 | SB2 | y | CS |
| 18504649-0611443 | 2020C | | 2 | HR15N | 56101.333 | -42.77 | 37.24 | SB2 | y? | CS |
| 18505726-0609408 | 2020C | | 2 | HR15N | 56102.120 | -14.52 | 104.31 | SB2 | У | CC |
| 18505561-0614552 18505933-0622051 | 2020B 2020C | 2 | 2 4 | HR15N HR15N | 56101.243 56077.363 | -10.39 -2.32 | 80.95 144.85 | SB2 SB2 | У | CS $H\alpha e$? |
| 18510072-0609118 | 2020C | 2 | 2 | HR15N | 56101.333 | -2.32 -12.01 | 60.80 | SB2 SB2 | У | CS |
| 18510223-0614547 | 2020C | | 10 | HR3 HR6 HR9B HR10 | 56099.365 | -8.13 | 69.14 | SB2 | y y | CS, 1RRC |
| 10010220 0011017 | | 10 | | HR14A | 200771202 | 0.10 | 0,11. | 552 | J | 05, 11410 |
| 18510286-0615250 | 2020A | 12 | 12 | HR3 HR6 HR9B HR10 HR21 | 56442.400 | -19.65 | 71.55 | SB2 | у | CS |
| 18510286-0615250 | 2030A | 12 | 12 | HR3 HR6 HR9B HR10 HR21 | 56099.311 | -44.37 | 40.28, 93.39 | SB3 | у | CS, ST |
| 18510401-0615387 | 2020C | | 2 | HR15N | 56075.275 | -7.77 | 62.68 | SB2 | y | noisy |
| 18510405-0617156 | 2020C | | 2 | HR15N | 56075.255 | -59.09 | 42.95 | SB2 | У | H α e? |
| 18510456-0617121 | 2020A | 12 | 12 | HR3 HR6 HR9B HR10 | 56103.110 | -7.76 | 81.62 | SB2 | У | CS |
| 18510462-0616124 | 2020B | 10 | 10 | HR14A HR15N HR21 HR3 HR6 HR9B HR14A | 56000 265 | -3.64 | 91.28 | SB2 | ** | |
| 18511134-0616106 | 2020B 2020A | | 12 | HR3 HR6 HR9B HR10 | 56103.110 | 2.11 | 71.07 | SB2 SB2 | y y | CS |
| 10311134-0010100 | 202011 | 12 | 12 | HR14A HR21 | 30103.110 | 2.11 | 71.07 | SDZ | y | Cb |
| 18511220-0617467 | 2020B | 2 | 2 | HR15N | 56101.288 | -3.56 | 78.60 | SB2 | y | CS |
| 18511434-0617090 | 2020C | 4 | 4 | HR15N | 56075.300 | -51.22 | 33.12 | ? | y | $H\alpha e$?, ST |
| 18512166-0624074 | 2020C | | 4 | HR15N | 56075.300 | 7.39 | 53.69 | SB2 | у | |
| 18513193-0612518 | 2020C | 2 | 2 | HR15N | 56077.363 | -2.33 | 96.69 | SB2 | У | $H\alpha e$? |
| NGC 6752 | 10.13 | | | | | 2/ | 4.5 ± 1.9 | | | |
| 19105940-5957059 | 2020B | 54 | 108 | U580 | 54624.335 | -39.76 | +.5 ± 1.9 -18.25 | SB2 | у | |
| NGC 6802 | 8.95 | | | | | 11 | $.9 \pm 0.9$ | | • | |
| 19302315+2013406 | | 4 | 4 | HR9B | 56794.388 | -22.35 | 22.04, 65.53 | SB3 | V | |
| 19303540+2016178 | | | 4 | HR9B | 56794.388 | -10.52 | 34.61 | SB2 | y y | CS |
| 19304355+2016530 | | | 6 | HR9B | 56797.303 | -60.71 | 86.93 | SB2 | y | |
| | | | | | | | | | | |
| Trumpler 14 | 6.67 | 1.5 | 1.5 | IID (| 56445.006 | | -15.0 | CD2 | | |
| 10434299-5953132 | | 15 | 15 | HR6 | 56445.026 56442.090 | | 113.84 | SB2 | У | CC 1DDC II |
| 10442462-5930359 10443037-5937267 | 2020A | | 19 19 | HR5A HR6 HR14A HR6 HR14A | 56442.090 | | 94.25 161.46 | SB2 SB2 | У | CS, 1RRC, H α e CS, 2RRC, H α e |
| 10443037-3937207 | 2020A | 19 | 19 | TIKU TIKT4A | 30442.094 | -120.43 | 101.40 | 302 | У | CS, 2KKC, Hae |
| Trumpler 20 | 9.20 | | | | | | 0.2 ± 1.3 | | | |
| 12382369-6041067 | 2020C | | 1 | HR9B | 54962.018 | -58.36 | -8.07 | SB2 | У | noisy |
| 12382945-6036007 | 2020A | | 1 | HR9B | 54960.122 | -72.68 | 13.06 | SB2 | У | |
| 12383365-6031092 | | 1 | 1 | HR9B | 54929.059 | -53.14 | 36.44 | SB2 | У | CS? |
| 12384378-6037077 | | 1 | 1 | HR9B | 54959.979 | -40.24 | 24.74 | SB2 | n | CS |
| 12384744-6036400 | 2020B | 1 1 | 1 | HR9B | 54960.028 54960.075 | -43.73 | 9.52 -4.50 | SB2 SB2? | n | |
| 12385726-6038597 12390677-6042208 | | 1 | 1 1 | HR9B HR9B | 54959.979 | -63.54 -21.45 | -4.30 19.41 | SB2? | y | |
| 12390898-6037473 | | 7 | 7 | HR9B HR15N | 56002.184 | | 41.80 | SB2 | n y | CS? |
| 12391247-6037429 | | 1 | 1 | HR9B | 54962.068 | -67.29 | -3.30 | SB2 | y y | CD. |
| 12391904-6035311 | | 1 | 1 | HR9B | 54960.075 | -85.78 | 14.83 | SB2 | y | |
| 12391904-6035311 | | 1 | 1 | HR9B | 54960.075 | | -44.40, 14.83 | SB3 | y | |
| 12393449-6039575 | 2020B | 1 | 1 | HR9B | 54962.068 | -60.30 | -7.33 | SB2 | y | |
| 12393764-6038190 | 2020C | | 1 | HR9B | 54960.075 | -77.26 | -36.00 | SB2 | y | 1RRC?, ST |
| 12391767-6036083 | | 1 | 1 | HR9B | 54962.068 | -42.12 | -4.61 | SB2 | у | ST |
| 12391992-6029552 | | 1 | 1 | HR9B | 54962.068 | -49.20 | -3.38 | SB2 | У | ST |
| 12394909-6040513 | 2020A | | 7 | HR9B HR15N | 56002.184 | -69.73 | -12.26 | SB2 | У | |
| 12401228-6034325 | | 12 | 12 | HR15N | 56377.231 | -65.37 | -2.61 | SB2 | У | |
| 12402686-6036013 12403561-6044331 | | 1 | 1 | HR9B | 54962.018 | -67.57 | -11.38 | SB2 | У | maiar |
| | 2020C | 1 | 1 | HR9B | 54962.018 | -60.11 | -26.56 | SB2 | y | noisy |

A&A proofs: manuscript no. sb

 Table C.1. Continued.

| Cluster CNAME | log age flag | # exp. | # sp. | set-up | MJD | v_r (kr $v_r(1)$ (km s ⁻¹) | $v_r(2) \ (\text{km s}^{-1})$ | SB2/3/4 | Member | Remark |
|---|------------------------|----------|----------|---------------------|------------------------|--|-------------------------------|-------------|--------|----------------|
| Trumpler 23 16004521-5332044 | 8.90 2020A | 4 | 4 | HR9B | 56551.985 | -61.3 -137.87 | ± 1.9 26.29 | SB2 | у | 2RRC |
| Berkeley 25 06413639-1628236 06414138-1624323 | | 20 20 | 20 20 | HR9B HR9B | 56576.317 56576.297 | 134.3 -6.62 -10.52 | ± 0.2 27.00 28.45 | SB2 SB2 | n n | noisy noisy |
| Berkeley 81 19013140-0028066 19013257-0027338 | 8.93 2020C 2020A | 8 24 | 8 24 | HR15N HR9B HR15N | 56170.005 56170.005 | 48.3 -11.28 -18.49 | ± 0.6 76.17 118.26 | SB2? SB2 | y y | ORB |