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NEW SB2 ORBITAL ELEMENTS FOR ACCURATE MASSES WITH GAIA: HD 9312, HD 9313 AND HD 183255*

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Abstract. We are observing a selection of about 70 double-lined binaries (SB2) with the T193/Sophie in order to improve their orbital elements. Our goal is to obtain the masses of the components with a 1 % accuracy when the astrometric observations of Gaia are available.

In the course of this program, it appeared that the orbital elements of some known SB2 were too uncertain for deriving ephemerides sufficiently reliable for planning the observations. We present new elements for a selection of three SB2 which have already received at least 4 new RV measurements per component star: HD 9312, HD 9313 and HD 183255.

Keywords: binaries: spectroscopic, stars: individual: HD 9312, HD 9313, HD 183255

1 Introduction

Gaia will provide the opportunity to derive stellar masses with errors around 1 %, by combining Gaia astrometry with accurate SB2 orbital elements. For that purpose, a large observation program is on going at the OHP observatory with the T193/Sophie, in order to improve the orbital elements of known SB (Halbwachs & Arenou 2009).

We expect to derive accurate orbital elements for about 70 SB2. The orbits published in the past are used to compute ephemerides in order to optimize the selection of the targets during the observation runs. However, some of these orbits are too obsolete for that purpose, and they were revised on the basis of our first observations.

We present hereafter three revised orbits obtained from ancient observations and from at least 4 Sophie spectra, providing at least 4 radial velocity (RV) measurements per component. This condition enable us to derive the elements of the spectroscopic orbit from the new measurements alone. This calculation is used to adjust the weights of the new and of the ancient measurements, as explained in section 3 hereafter. Each object is briefly discussed in section 4. Section 5 is the conclusion.

2 The observations and the RV measurements

The spectra of the three stars were taken between April 2010 and April 2012, using the 193 cm telescope of the Haute-Provence observatory and the Sophie spectrograph in high resolution mode. Since our stars are all rather bright (the faintest is HD 183255, a 8-mag star), an exposure shorter than 20 minutes was sufficient to reach a signal-to-noise ratio as large as 100.

The Sophie pipeline produces several reduction files, including the cross-correlation function (CCF) of the spectrum with a mask. Plots of the CCF of HD 9312 and of HD 9313 showing the peaks of the two components are presented in Halbwachs et al. (2011). The radial velocities of the SB2 components were obtained fitting the CCF with two normal distributions. The results are summarized in Table 1 hereafter. It is worth noticing that the uncertainties derived from the Gaussian fitting, σ_{V_1} and σ_{V_2}, are widely underestimated since the CCF is not exactly represented by two normal distributions subtracted from a linear background, as assumed: in reality, each correlation peak is flanked by two side lobes due to differences between the mask and the actual spectra, and the background is not perfectly linear. The uncertainties will then be revised in the next section.

* BASED ON OBSERVATIONS PERFORMED AT THE HAUTE-PROVENCE OBSERVATORY

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Table 1. The RV measurements obtained from Sophie spectra of HD 9312, HD 9313 and HD 183255. σ_V is the uncertainty derived fitting the CCF with two normal distributions, and $\acute{\sigma_V}$ is the uncertainty eventually assumed in the calculation of the SB2 solution when the ancient measurements are also taken into account.

HD 9312 = HIP 7143

Epoch (BJD)	V_1 (km/s)	σ_{V_1}	$\acute{\sigma_{V_1}}$	V_2 (km/s)	σ_{V_2}	$\acute{\sigma_{V_2}}$
2455440.59494	-28.4985	0.0029	2.383	39.851	0.024	2.383
2455532.30387	30.0514	0.0015	2.383	-37.061	0.013	2.383
2455783.60406	17.5097	0.0036	2.383	-20.195	0.032	2.383
2455864.40548	30.5953	0.0032	2.383	-37.646	0.026	2.383

HD 9313 = HIP 7134

Epoch (BJD)	V_1 (km/s)	σ_{V_1}	$\acute{\sigma_{V_1}}$	V_2 (km/s)	σ_{V_2}	$\acute{\sigma_{V_2}}$
2455440.58846	10.5593	0.0017	0.348	-50.003	0.039	0.350
2455783.59352	-16.9401	0.0111	0.348	-12.129	0.213	0.408
2455864.39349	-8.2810	0.0072	0.348	-24.197	0.105	0.364
2455933.24111	-1.1507	0.0074	0.348	-33.223	0.146	0.378

HD 183255 = HIP 95575

Epoch (BJD)	V_1 (km/s)	σ_{V_1}	$\acute{\sigma_{V_1}}$	V_2 (km/s)	σ_{V_2}	$\acute{\sigma_{V_2}}$
2455306.60517	-78.7361	0.0019	0.869	-51.451	0.005	0.869
2455440.38547	-70.4586	0.0026	0.869	-58.466	0.007	0.869
2455693.56575	-60.8733	0.0059	0.869	-68.567	0.015	0.869
2455784.41810	-74.8302	0.0080	0.869	-52.909	0.021	0.869
2456034.59835	-57.7317	0.0081	0.869	-71.990	0.021	0.869

3 Calculation of the new orbital elements

The orbital elements are revised adding the Sophie RV measurements to the ancient ones. However, the relative weights of the measurements must be carefully adjusted for that calculation. This is done as follows:

- The orbital elements are derived from the ancient measurements alone, assigning to each RV measurement the weight $w_i = 1/\sigma^2_{V_i}$. The F_2 estimator of the goodness-of-fit is then derived (Stuart & Ord 1994); when it is null or very close to zero, the solution is accepted. The same noise is quadratically added to all the uncertainties, and the calculation is repeated otherwise.

- The same process is applied to the Sophie measurements. However, since the number of degrees of freedom is small, the nominal value of F_2 is not zero, but is computed by simulations. New uncertainties, usually much larger than the original ones, are thus obtained.

- All the RV measurements are considered together, with weights derived from the new uncertainties. A systematic shift between the Sophie measurements and the ancient ones, D_0, is added to the unknowns of the solution. Again, the calculation is repeated until $F_2 \approx 0$. The final uncertainties, $\acute{\sigma_{V_i}}$, are thus obtained. These uncertainties are listed in table 1 for the Sophie measurements. The uncertainties of the ancient measurements are the quadratic sum of the original values and of the supplement, $\sigma_{V\,Sup}$, which are listed in table 2 with the orbital elements. The ancient and the new orbits are shown in Fig. 1 for comparison, with the measurements folded in phase.

Table 2. The revised orbital elements of HD 9312, HD 9313 and HD 183255. $\sigma_{V\ Sup}$ is the uncertainty quadratically added to that of the ancient measurements in the calculation process. ΔT is the time span covered by all the observations; the number in parenthesis refers to the ancient observations alone.

Elements	HD 9312	HD 9313	HD 183255
N_{meas} (Ancient+Sophie)	35 + 4×2	68 + 4×2	32 + 5×2
$\sigma_{V\ Sup}$ (km/s)	3.272	0.307	0.581
ΔT (days) (ancient orbit)	27801 (1611)	16121 (2515)	9404 (1545)
Period (days)	36.51836 ± 0.00068	53.51155 ± 0.00022	166.8349 ± 0.0170
T_0 (BJD−2 400 000)	54094.16 ± 1.39	39810.78 ± 0.10	47744.60 ± 3.66
e	0.109 ± 0.042	0.39819 ± 0.00502	0.1393 ± 0.0136
ω (deg)	200.2 ± 13.5	279.60 ± 0.80	58.8 ± 8.4
V_γ (km/s)	-4.05 ± 1.06	-14.811 ± 0.116	-64.438 ± 0.145
K_1 (km/s)	31.00 ± 1.28	24.395 ± 0.162	13.810 ± 0.315
K_2 (km/s)	43.85 ± 2.50	33.75 ± 0.38	16.517 ± 0.588
D_0 (km/s)	5.51 ± 1.38	-0.023 ± 0.198	-0.522 ± 0.320
$a_1 \sin i$ (Gm)	15.47 ± 0.61	16.465 ± 0.109	31.37 ± 0.73
$a_2 \sin i$ (Gm)	21.89 ± 1.18	22.78 ± 0.27	37.53 ± 1.35
$\mathcal{M}_1 \sin^3 i$ ($\mathcal{M}_\odot$)	0.913 ± 0.120	0.4882 ± 0.0123	0.255 ± 0.022
$\mathcal{M}_2 \sin^3 i$ ($\mathcal{M}_\odot$)	0.645 ± 0.071	0.3529 ± 0.0061	0.213 ± 0.015
σ_{o-c} km/s (ancient/Sophie/all)	5.94/1.45/5.37	0.936/0.211/0.888	1.009/0.794/0.954

4 Notes to individual stars

- HD 9312 = HIP 7143. Ancient SB1 orbit of Heard (1940), who didn't provide uncertainties for individual RV measurement; the estimated "probable error" of 5.2 km/s (erroneously written as 3.2 in the publication) is assumed for each ancient measurement at the beginning of the calculation process; when $\sigma_{V\ Sup} = 3.272$ is quadratically added, one obtains $\sigma_{RV} = 6.145$ km/s for every ancient measurements. The detection of the secondary spectrum is reported in Halbwachs et al. (2011). The very large uncertainties eventually assigned to the Sophie measurements (table 1) is surprising for a G5-type star with narrow CCF–peaks, and suggest that the system could be triple in reality. This should be clarify with future observations.

- HD 9313 = HIP 7134. Ancient SB1 orbit of Griffin & Emerson (1975), who assigned the same weight to all measurements; the r.m.s. residual 0.9 km/s is used as uncertainty for each ancient measurement at the beginning of the calculation process. The detection of the secondary spectrum is reported in Halbwachs et al. (2011).

- HD 183255 = HIP 95575 = GJ 1237. Ancient SB2 orbit of Tokovinin (1991), who assigned to the primary component 10 measurements which obviously refer to blended spectra; the Julian days of these measurements are $2,400,000 +$ 47007, 47012, 47022 (2 measurements), 47055, 47059, 48082, 48089, 48166 and 48175. These measurements were assumed to be linear combinations of the RV of both components, using the method described in Halbwachs, Mayor & Udry (2012); we derive the relative contribution of the primary velocity to the velocity of the blend: $C_0 = 0.797 \pm 0.032$.

5 Concluding remarks

We have presented new orbital elements for 3 SB2, including two systems which previously had only SB1 orbits. In addition to the detection of the secondary components, the orbital elements were improved thanks to the extension of the time span of the observation by a factor larger than 6, and thanks to the accuracy of the few

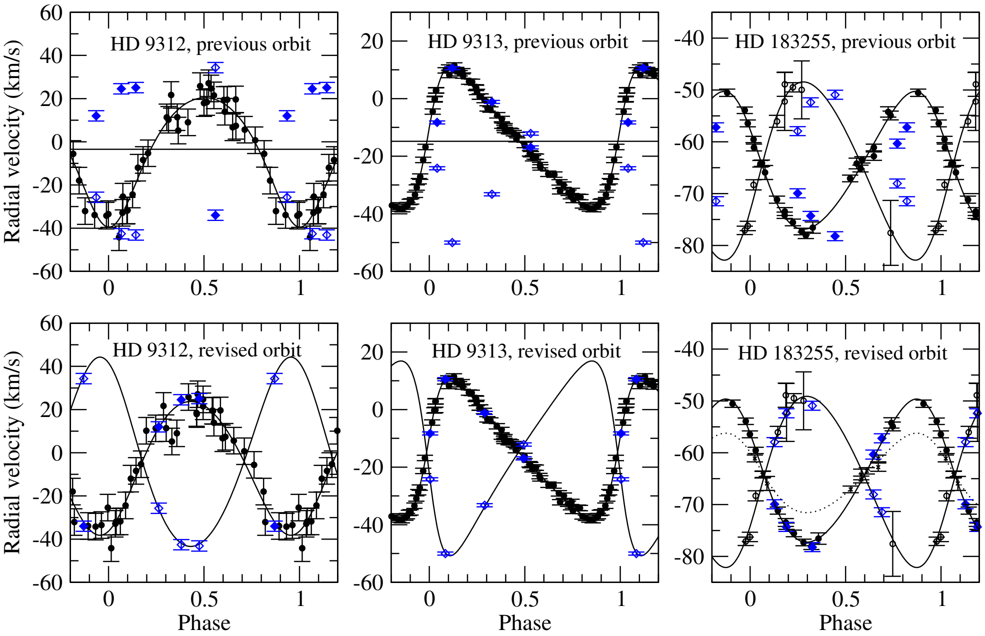

Fig. 1. The ancient (**up**) and the revised (**down**) orbits, folded in phase. The black circles refer to the ancient RV measurements, and the blue diamonds are preliminary estimations of the RV obtained from Sophie. The filled and open symbols refer to the primary and to the secondary components, respectively. The asterisks (HD 183255, revised orbit, dotted line) refer to ancient blended measurements used to derive C_0 (explanations in the notes).

additional Sophie measurements: it comes from the last line of table 2 that σ_{o-c} is respectively 4, 3, and 1.3 times smaller for the Sophie measurements than for the ancient ones.

The uncertainties of $\mathcal{M}_{1,2} \sin^3 i$ are all larger than 1 %, and are then larger than our expectation for the end of the programme. However, these orbits are preliminary, and the final ones should be better for two reasons: the calculation of the orbit will be improved by using a method more elaborated than fitting the CCF, such as TODMOR (Zucker et al. 2003; Tal-Or et al. 2011) or a method based on Markov chains (Salomon et al. 2012), and the number of Sophie spectra should be tripled. The targeted 1 % uncertainties should then be reached at the end of the programme.

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