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THE PROGRAMME "ACCURATE MASSES FOR SB2 COMPONENTS"*

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Abstract. A selection of spectroscopic binaries (SBs) are observed since 4 years with the T193/Sophie spectrograph, in order to improve their orbital elements. Our aim is to derive accurate stellar masses when the astrometric measurements of Gaia will be available. The last progresses of the programme are presented.

Keywords: binaries: spectroscopic

1 Introduction

An observation program is on going since 2010 at the OHP observatory with the T193/Sophie, in order to improve the orbital elements of a selection of 200 known spectroscopic binaries (SBs) (Halbwachs & Arenou 2009; Halbwachs et al 2014). Our long-term goal is the derivation of accurate stellar masses from the orbital elements of the double-lined spectroscopic binaries (SB2s), taking into account the astrometric measurement of the Gaia satellite. We present the status of this programme after 4 years of observations during which 727 spectra were obtained.

2 Selection of the double-lined binaries

After rejection of a few stars known as multiple systems, the initial selection contained 200 stars: 49 SB2s and 151 single-lined spectroscopic binaries (SB1s). Thanks to the Sophie spectrograph, it was possible to detect an additional component for 25 SB1s. Among these stars, 20 were confirmed as SB2s, and 5 appeared to be multiple systems in reality (Halbwachs et al 2014). Therefore, the present list of targets consists in 69 SB2s, plus 7 stars with uncertain status. The number of observations made for each category of stars is presented in Fig.1. A few discarded stars received a number of spectra much larger than the others; these stars are usually multiple systems which were erroneously considered as new SB2s when an additional component was discovered. The "SB1s still to observe" are SB1s with a cross-correlation function (CCF) exhibiting a dip too wide to allow the detection of the secondary component when they were observed. These stars must be observed again at the phase corresponding to the maximum difference between the radial velocities (RVs) of the components. However, they are low-priority targets, since it will probably not be possible to obtain enough measurements of the secondary RV to derive accurately the masses of the components.

* BASED ON OBSERVATIONS PERFORMED AT THE HAUTE-PROVENCE OBSERVATORY

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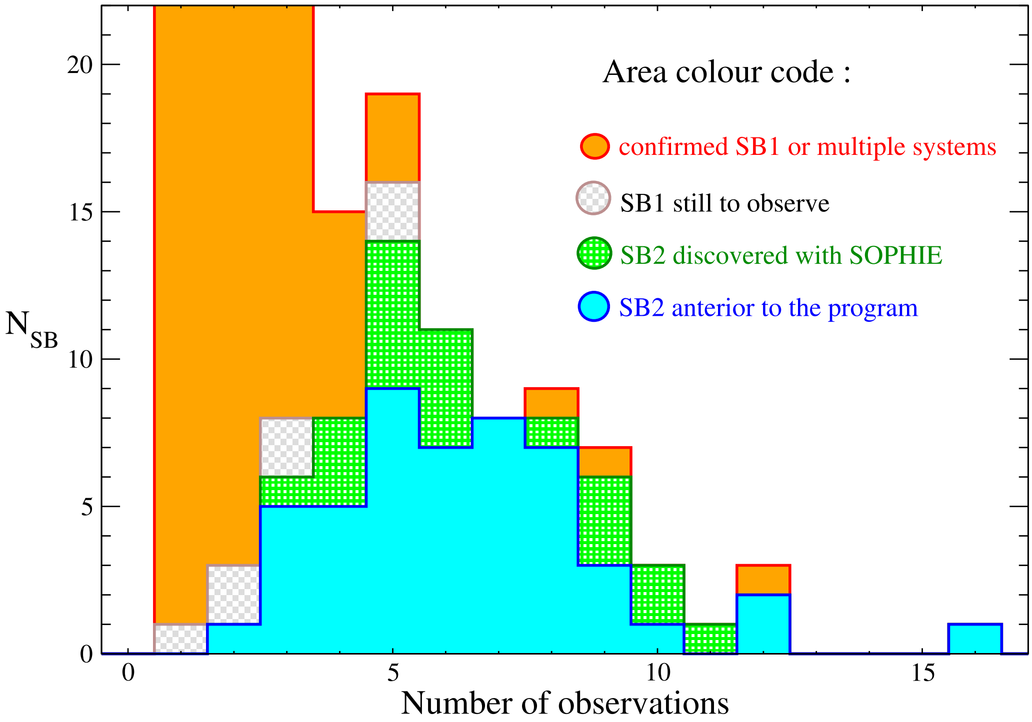

Fig. 1. Histogram of the programme stars according to the numbers of spectra they received, after semester 2013B.

3 Computability of accurate SB orbits

The elements of the spectroscopic orbits were already derived from our Sophie observations for a few SB2s (Halbwachs et al 2012, 2013), but they are not considered as definitive. An SB1 orbital solution consists in 6 parameters: the RV of the barycentre, V_0, the period, P, the eccentricity, e, the periastron epoch, T_0, the periastron longitude, ω, and the semi-amplitude of RV, K_1. Therefore, 7 measurements are a minimum to derive the elements of a SB1 orbit and their uncertainties. For a SB2, the semi-amplitude of the secondary RVs, K_2, is still added to the parameters, and a systematic shift between the RVs of both components must also be added; at the same time, an observation may provide 2 RV measurements, one for each component. With the reasonable assumption that the RV of the primary component may always be measured, it is then sufficient to have 6 observations with 3 measurements of the secondary RV to derive an SB2 orbit with uncertainties: the 6 measurements of the primary RV provide the six elements of the primary orbit, and the 3 measurements of the secondary count for the mass ratio, i.e. for K_2, for the shift between the RV, and for the uncertainties.

However, the minimum of 6 spectra is realistic only when the RV measurements are obtained with reliable estimations of the uncertainties. Otherwise, it is necessary to verify the uncertainties for each component, i.e. to derive separately the SB1 orbital elements of each component. A minimum of 7 spectra, with the secondary RV estimated for each of them, is then required, in order to derive the χ^2 and the F_2 estimator of the goodness-of-fit of the SB1 orbital solution of each component (Stuart & Ord 1994):

$$F_2 = \sqrt{\frac{9\nu}{2}} \left(\sqrt[3]{\frac{\chi^2}{\nu}} + \frac{2}{9\nu} - 1 \right) \tag{3.1}$$

where ν is the number of degrees of freedom. When the uncertainties used in the derivation of χ^2 are realistic, F_2 obeys the normal distribution $\mathcal{N}(0,1)$; therefore, it is usually between -2 and 2. If F_2 is abnormally large, the uncertainties of the RVs must be increased.

With only 7 spectra, the correction of the uncertainties is a bit hazardous, since we have only one degree of freedom. It comes from Eq. 3.1 that, for a target value of F_2, χ^2 is given by the equation:

$$\chi^2(F_2) = \nu \left(1 + \frac{F_2}{\sqrt{4.5\nu}} - \frac{1}{4.5\nu} \right)^3 \tag{3.2}$$

Therefore, when $\nu = 1$, $F_2 = 0$ if $\chi^2 = 0.47$, and $F_2 = 1$ if $\chi^2 = 1.95$. Since the correction to apply to the uncertainties is $\sqrt{\frac{\chi^2(F)}{\chi^2(0)}} = 2.04$, the relative uncertainty of the corrected errors is a bit more than 100 %. This is quite large, and it is necessary to increase the number of measurements to have a reliable correction. With 5 degrees of freedom, i.e. with 11 RV measurements, the accuracy of the uncertainties is 35 %, which is much more acceptable. So we consider that an orbit is reliable if it is derived from a minimum of 11 RV measurements of the secondary component.

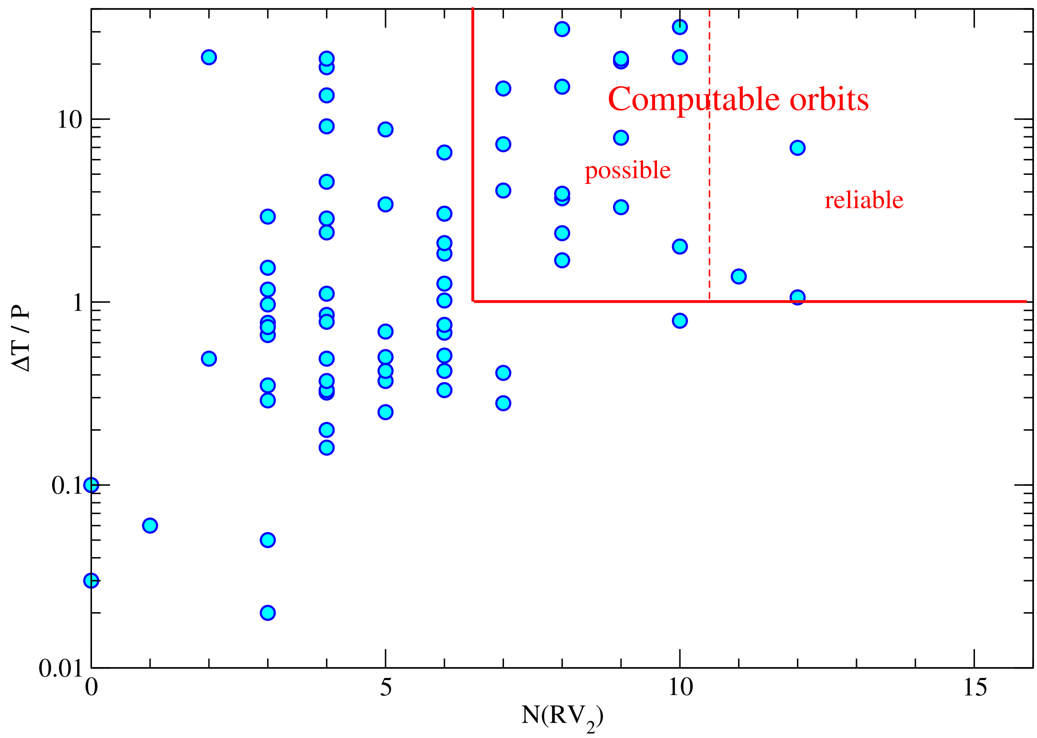

Fig. 2. The number of covered periods vs the number of detections of the secondary dip of the SB2, after semester 2013B.

In addition to the number of measurements, another condition is that the observations must cover a complete orbital period. In Fig. 2, all the SB2s are plotted in a "period coverage vs number of secondary measurements" diagram. It appears that only 3 stars seem to satisfy the conditions to have a reliable orbit, but, in reality, 2 of them received several observations during the same night. Therefore, only one SB2 may be considered as satisfactorily observed. More observations are requested for all the others. It is worth noticing that the calculation used to select the SBs for which accurate masses should be obtained was based on simulations assuming observations distributed over 7 years. The low number of SBs with a derivable orbit after 4 years is not abnormal.

4 Future prospects

4.1 Addition of SBs brighter than 6 mag

At the end of 2013, it appeared that the stars brighter than 6 mag would also receive astrometric measurements from Gaia, when $V > 2$ mag. Ninety-one bright stars, including 16 SB2s, were then added. Except for one star observed with the VLTI (Sect.4.2, hereafter), these stars will be observed with a low priority, during spare time or when the weather conditions are too bad for the faint stars. However, due to bad weather conditions during the two last missions, five candidate new SB2s were already found among these stars.

4.2 *Derivation of masses from VLTI measurements*

Observing time has been obtained at the VLTI in order to observe 3 SB2s of our programme, including one star from the bright supplement. It will then be possible to derive masses before the end of the Gaia mission, and to validate the masses that we will obtain from Gaia.

5 Conclusions

Our programme is nicely going on. The number of SB2s with a derivable orbit is still small, but it should grow fast during the next years. Accurate masses for a total of around 180 components should be obtained at the end of the Gaia mission if the observations with the T193/Sophie are continued at the same rate.

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