BD +13 331: Triple system or SB2 with a Cepheid component ?

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INTRODUCTION

Griffin, Yoss and Miller (1994) derived a single-lined spectroscopic binary (SB1) orbit for BD +13 331 = HD 12871, based on 48 radial velocity (RV) measurements. They demonstrated that this star is a binary system with a period of 3.75 years and a mass function of 0.369 solar masses. As they assumed that the primary component is a solar-type star, they concluded that the system probably includes at least one third component.

Despite this assumption of high multiplicity, BD +13 331 was included in a selection of SBs for which the masses of the components could be determined with a high precision from Gaia astrometric measurements if a double-lined SB (SB2) orbit was available at that time (Halbwachs et al., 2014). This selection was drawn from the online SB9 catalogue (https://sb9.astro.ulb.ac.be/, Pourbaix et al., 2004), and the observations began as early as 2010 using the T193 telescope of the Haute Provence observatory (OHP), equipped with the Sophie spectrograph.

DETECTION OF THE SECONDARY COMPONENT, AND FIRST DOUBTS

A secondary dip was detected in the cross-correlation function (CCF) of the first spectrum recorded for BD +13 331, using a K0 template (Fig. 1). Consequently, the star was retained in the target catalogue and has been observed regularly since 2010.

The first difficulties arose when there were enough observations to calculate an SB2 orbit: the residuals were so large that it was necessary to a add noise of 8 km/s to obtain a solution with a goodness-of-fit index F_2=0. It was therefore assumed that the secondary component was itself an SB1-type binary star.

At the same time, the minimum masses of the two components of the 3.75-year SB2 orbit were of the order of 9 and 4 solar masses respectively, which ruled out the possibility that the primary was a solar-type star.

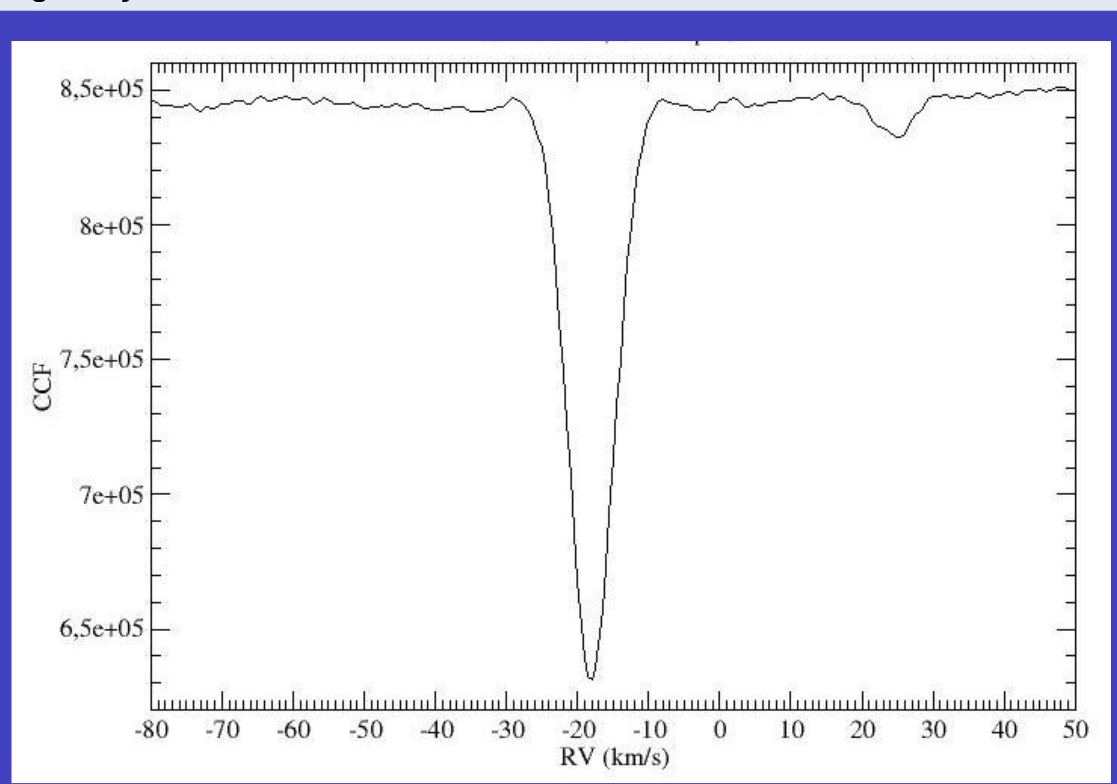

Fig. 1. Cross-correlation function (CCF) of the first record of the spectrum of BD +13 331 with a K0 template. The secondary dip is clearly visible around RV=+25 km/s.

Finally, attempts to calculate a triple system solution proved fruitless, as the period of the secondary remained undetermined.

SEARCH FOR THE PERIOD OF THE ORBIT OF THE SECONDARY COMPONENT

By early 2023, we had made 19 observations of BD +13 331, but no period emerged from the periodogram of the residual RVs of the secondary component. It was therefore decided to observe the star intensively during the maximum separation of the RVs of the components of the long-period orbit, in autumn 2023 and in autumn 2025. Thanks to the observation service mode, 11 spectra were obtained in 2023, revealing that the RV of the secondary component varied with a period of approximately 5 weeks (Fig. 2). Seven more spectra were obtained in 2025, making it possible to determine the period accurately .

Fig. 2 shows a periodogram of the residuals from the secondary RV following the calculation of the SB2 3.75-year orbit . Two peaks stand out clearly: one around 73.3 days, and one around the second harmonic, i.e. 36.6 days.

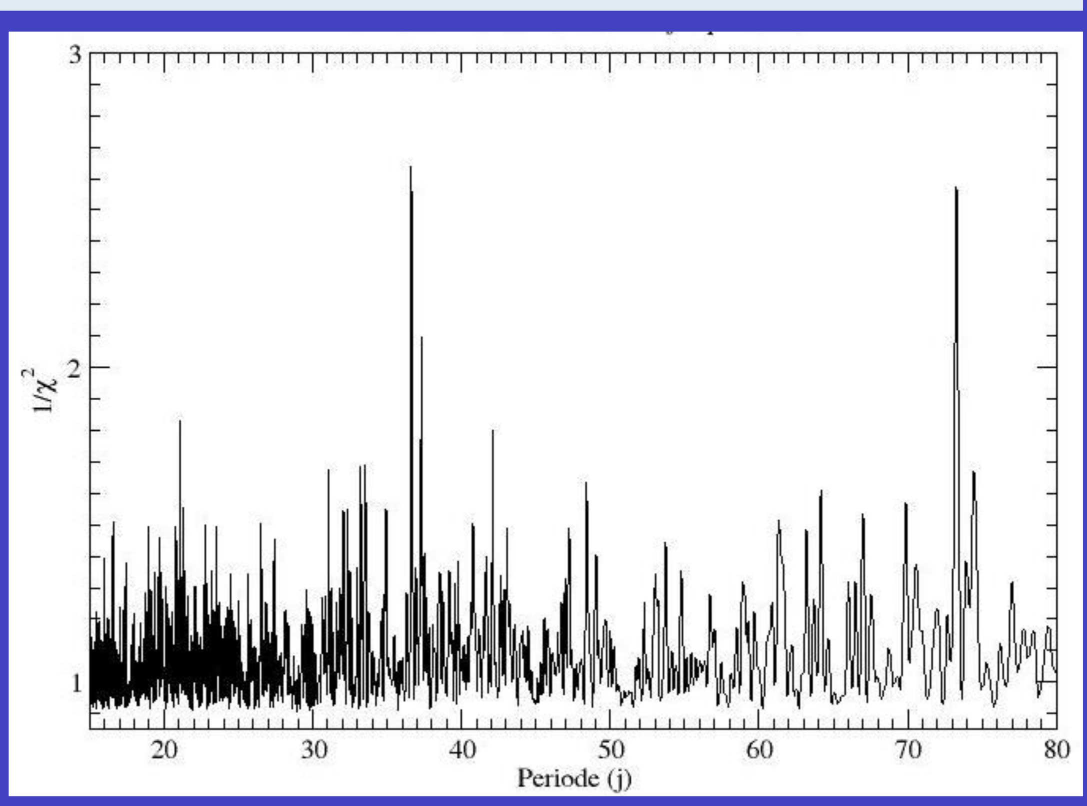

Fig. 2. Periodogram of the residuals of the RV of the secondary component, after subtracting the orbital motion with a period of 3.75 years. The periods indicated by the two main peaks are 36.6 and 73.3 days respectively.

Furthermore, the CCFs from two observations revealed a third dip with a velocity of approximately -5 km/s, which corresponds to the barycentric radial velocity (Fig. 3).

At this stage, BD +13 331 could therefore be a quintuple system, comprising a binary with a period of 3.75 years, the secondary component of which is a resonant triple system with a companion having a period of 36.6 days and another with a period of 73.3 days, the whole being further accompanied by a distant component.

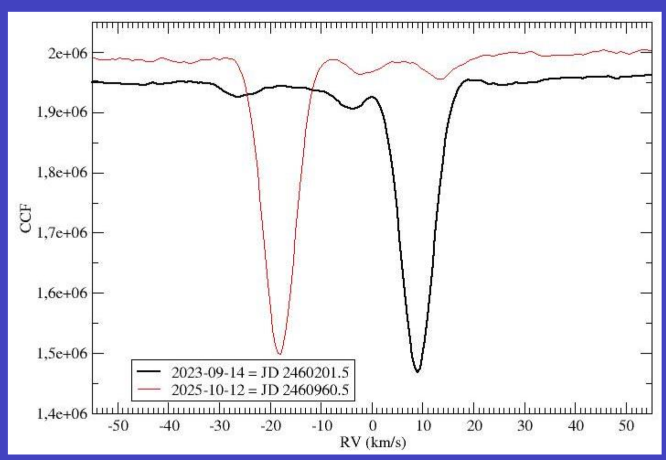

Fig. 3. The two CCF exhibiting 3 dips. The third dip is at around -5 km/s.

AN SB1 ORBIT FOR THE SECONDARY COMPONENT

It was only possible to calculate a three-component solution including an SB1 orbit by discarding all the secondary RVs prior to JD 2460000, as well as that of JD 60960.5. This is because these measurements showed excessive dispersion relative to the solution. The orbital elements obtained in this way are presented in Table 1, and the resulting physical quantities are shown in Table 2.

Table 1. Orbital elements of the 3-component solution.

Orbital elements	SB2 orbit	SB1 orbit
P (days)	1374.98 ± 0.47	36.584 ± 0.032
e	0.1797 ± 0.0023	0.38 ± 0.11
T_0 (JD-2400000)	57138.5 ± 3.6	60205.15 ± 0.91
V_γ (km/s)	-4.533 ± 0.026	-
ω (°)	272.98 ± 0.87	356.0 ± 9.2
K1 (km/s)	13.911 ± 0.024	11.6 ± 1.8
K2 (km/s)	30.60 ± 0.62	-
σ_{O-C} (km/s), N_{mes}	0.087 , 38	1.3 , 18

Table 2. Properties of the triple system derived from the orbital elements in Table 1.

Physical quantities	SB2 orbit	SB1 orbit
a_1 sin i (Gm)	258.75 ± 0.37	5.41 ± 0.64
a_2 sin i (Gm)	569.2 ± 11.6	-
$\mathcal{M}_1 \sin^3 i$ or $f_\mathcal{M}$ ($\mathcal{M}_\odot$)	8.23 ± 0.40	0.00471
$\mathcal{M}_2 \sin^3 i$ ($\mathcal{M}_\odot$)	3.74 ± 0.11	-

The orbits are shown in Fig. 4. The variations in the residuals of the secondary RV, once removing the 36-day signal, in panels (d) and (e), are consistent with a fluctuation with a period of 73.3 days and an amplitude of 5 km/s. The secondary component could therefore have two companions, with periods of 36.6 and 73.3 days, at least if such a configuration is stable.

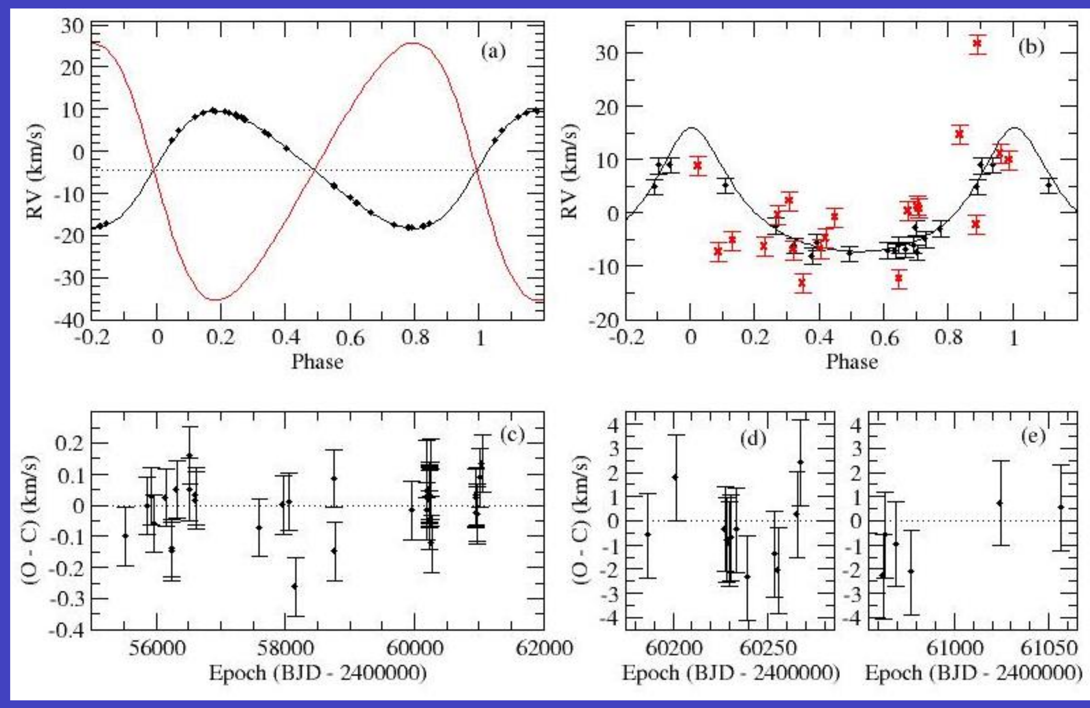

Fig 4. Orbits of the 3-component solution presented in Tables 1 and 2: (a) SB2 orbit with a period of 3.75 years; only the 38 primary RVs are shown. (b) SB1 orbit showing the RV variations of the secondary component, after subtracting the SB2 orbit; the solution was calculated solely from the black points; the red points correspond to measurements obtained before JD 2460000, or at JD 2460960.5; (c) residuals of the 38 primary RVs; (d-e) residuals of the 18 secondary RVs.

THE PULSATION HYPOTHESIS

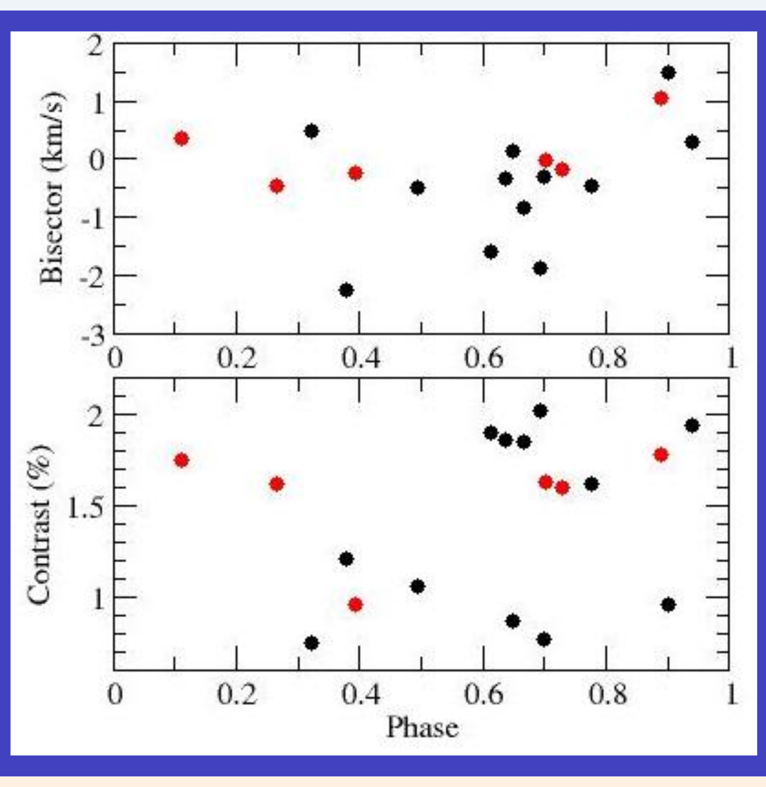

Fig. 5. The bisector span and the relative depth of the secondary correlation dips for the 18 observations selected after JD 2460000. The observations of 2024 are in black, and that of 2025 are in red.

The complex behaviour of the secondary component's RVs can be explained not by invoking additional components, but assuming that the star is a pulsating variable star: Given a minimum mass of 3.74 $\mathcal{M}_\odot$ (see Table 2), it could be a Cepheid or an SRd-type star. This would explain the RV curves in Fig. 4b, 4d and 4e, the periodicity of the residuals, as well as the humps and the period variations of the star.

The main objection, however, is that pulsating stars are photometrically variable, which has not been observed for BD +13 331. However, the luminosity of the primary component, with as mass greater than 8.23 $\mathcal{M}_\odot$, is probably much higher than that of the secondary, which could explain why luminosity variations have not been detected.

It is well kown that the shape of the correlation dip of Cepheid stars varies in phase with radial velocity (see, e.g., Netzel et al. 2024, 2025), which could be used to characterise a pulsating variable.The most relevant parameters are the bisector span, and the relative depth, or contrast. The variations of these parameters with the 36.584-day period are shown in Fig. 5 for the 18 secondary dips selected after JD 2460000.

Although highly uncertain due to the low contrast, these parameters do indeed show fluctuations in phase with the RV. It should be noted that these fluctuations are smoother in the most recent observations than in those from 2024.

CONCLUSION

We have observed the secondary correlation dip of BD +13 331, and we have shown that the RVs variations obtained after JD 2460000 may be reproduced with a multiple star model. However, the bisector span and the contrast of the correlation dip are varying in phase with the RV, indicating that the secondary component of BD +13 331 is not a binary, but a massive pulsating star, such as a Cepheid or an SRd-type star.

Furthermore, we have detected a third component, which could be a distant companion, as its radial velocity is close to that of the barycentre of the system formed by the other two.

References

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