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Contribution to the search for binaries among Am stars – III. HD 7119: a double-lined spectroscopic binary and a triple system

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ABSTRACT

Radial velocity observations of HD 7119 with the CORAVEL instrument at Observatoire de Haute-Provence are reported. Known as an Am/δ Del metallic-line star, HD 7119 was included in our spectroscopic survey of Am-type stars, the purpose of which was to determine the frequency of binaries in this stellar family. This object is found to be a double-lined spectroscopic binary with a variable value of V_0, the systematic velocity of the centre of gravity of the pair. The variation of this parameter is interpreted in terms of the orbital motion of an unseen third body with a much longer period. The orbital elements were derived for both the short- and the long-period orbits. These orbits can be considered to be well determined since these observations were performed on a regular basis over the 1992–1998 period, covering more than 320 orbital cycles for the short-period ($P = 6.76$ d) and 1.3 cycle for the long-period orbit ($P \sim 1700$ d). As deduced from the ratio of the correlation dip areas, the magnitude difference of the components of the short-period system is 0.7 mag. Combined with the *Hipparcos* data, this value leads to visual absolute magnitudes of 0.5 and 1.2 for the primary and secondary components, respectively. Such magnitudes are consistent with evolved δ Del-type stars. The third body could be a cool dwarf star with a minimum mass of 0.5 $M_{\odot}$, located at $\sim$0.016 arcsec of the main system. Consequently, it cannot be the visual companion detected by Couteau with a separation of 3.35 arcsec. If this latter visual component were a physical component (rather than an optical one), HD 7119 would be a quadruple system.

Key words: binaries: spectroscopic – stars: fundamental parameters – stars: individual: HD 7119.

1 INTRODUCTION

We present a study of the radial velocity of HD 7119 (HIP 5588) based on spectroscopic observations performed over the period 1992–1998 with the CORAVEL instrument (Baranne, Mayor & Poncet 1979). This instrument was mounted at the Cassegrain focus of the Swiss 1-m telescope of Observatoire de Haute-Provence (OHP).

This work is part of an extensive programme to study the frequency of binaries among the family of hot stars with metallic lines of Am type. Started in the early 1990s, this programme is concerned with a large sample of Am-type stars mainly from the 'Third catalogue of Am stars with known spectral types' (Hauck 1986). The full description of this sample and the first results were presented in Ginestet & Carquillat (1998, hereafter Paper I) and North et al. (1998).

In his catalogue, Hauck selected Bertaud (1970)'s classification for HD 7119, i.e. A5 for the Ca II K line, and F2 for the metallic lines (nothing was mentioned concerning the hydrogen lines). HD 7119 was first reported as Am by Bidelman (1964) from objective-prism observations, and then re-classified as δ Del by Cowley & Cowley (1965), using Morgan's classification spectrograph. In a more recent paper, Bossi et al. (1983) reported a private communication where M. Jaschek confirmed Cowley's δ Del classification. More recently still, a new classification was established with the Marly spectrograph at OHP (IIaO plates with a dispersion of 80 Å mm^{-1}) by Grenier et al. (1999), who gives Am (A4 A8 F4). This last classification is close to Bertaud's. However, Grenier et al. note that the absolute magnitude of HD 7119 derived from the *Hipparcos* parallax leads to a much too large luminosity compared with the proposed spectral type. This apparent discrepancy vanishes when considering the δ Del type previously attributed to this object.

Bossi et al. have detected a possible photometric variability of HD 7119 in the visible domain, which may be caused by pulsations. For these authors, evolved stars with metallic lines of δ Del type

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could also be pulsating variables, whereas this seems to be out of the question for dwarf stars of Am type.

In the present work, we reveal the (to our knowledge, previously unknown) double-lined spectroscopic binary nature of HD 7119. Previous spectroscopic observations, also performed at OHP (Fehrenbach et al. 1997; Grenier et al. 1999), did not reveal the binary nature of this object. This lack of detection is probably a consequence of an insufficient spectroscopic dispersion (80 Å mm^{-1} in both cases, which limits the resolution at $\sim$110 km s^{-1}). We find that the short-period system, with a period close to 7 d, exhibits a variation of the velocity V_0 of its centre of gravity with a period of 4.7 yr. As HD 7119 is also known as a visual binary (Cou 147 AB, Couteau 1968) we investigate whether the third 'spectroscopic' body corresponds to the visual component detected by Couteau at Nice Observatory.

2 OBSERVATIONS AND DERIVATION OF ORBITAL ELEMENTS

60 radial velocity (RV) measurements were performed with CORAVEL and were used for the determination of the orbital elements of the system. These observations (Table 1) were obtained over 6 years (1992 November–1998 October), which correspond to 320 orbital cycles. CORAVEL is a spectrophotometer that allows radial velocity measurements by performing a cross-correlation of the stellar spectrum with a physical mask placed in the focal plane of the spectrograph (Baranne et al. 1979). Gaussian functions are then fitted to the cross-correlation dips to derive radial velocities. Fig. 1 shows an example of the correlation dips observed for the primary and secondary components of HD 7119. Given the width of these dips, the minimum RV separation of two components is $\sim$20 km s^{-1}. Five measurements had to be discarded because the correlation dips were blended. The mean internal error is 0.7 km s^{-1} for the primary RV and 0.9 km s^{-1} for the secondary RV.

The orbital elements were first computed with the least-squares program BS1 (Nadal et al. 1979), revised by J.-L. Prieur. During a first test on the primary RV, it appeared that most residuals $(O-C)_{01}$ were too large, and not randomly distributed (column 5 of Table 1 and Fig. 2). Their standard deviation was $\sigma(O-C)_{01} = 1.7$ km s^{-1}, which was more than twice the mean error of the RV measurements. The presence of a perturbing third body, with a much larger period was thus very likely.

A new program (BS3) was then developed by J.-L. Prieur to simultaneously fit the orbit of the two visible components and that of the invisible third component. To obtain the initial values of the orbital parameters for the long-period system, we proceeded with the same method as for HD 83270-1 (Ginestet, Carquillat & Pédoussaut 1991). We split the 60 RV measurements into 12 small 'observation groups' (separated by blank lines in Table 1) for which the variation of the velocity V_0 of the centre of gravity of the short-period system could be neglected. The variation versus time of the residuals obtained in these groups could be interpreted as a Keplerian motion caused by the presence of a third body. We obtained a first estimation of the elements of the long-period orbit by applying the least-squares program BS1 to these residuals.

These values were then used as initial values by the least-squares program BS3, which fitted the two orbits simultaneously. For that computation, weights of 1.0 and 0.5 were used for the primary and secondary RV measurements, respectively. The residuals obtained in that case (Table 2 and Fig. 2) are very close to the mean standard deviation of the measurement errors for both components and do not exhibit any long-term variation. The two orbits are displayed in Figs 3 and 4 and the corresponding elements with their errors are given in Table 2.

The eccentricity of the two visible components is very small and the orbit is nearly circular, which is not surprising, given the short period of 6.76 d. This small value for the eccentricity is nevertheless significant with regard to its error value. The presence of a third body may have contributed to the small eccentricity in a system that was already circularized (Mazeh 1990).

The orbit of the third body was first assumed to be circular, on the basis of the distribution of the residuals (Fig. 4). When two further parameters were added (eccentricity and omega for the long-period orbit) to the model, the residuals remained at the same level and the eccentricity derived was very small, equal to zero within the errors.

3 DISCUSSION

3.1 Physical parameters of the short-period system

The ratio of the correlation dip areas given by CORAVEL for the primary and secondary components allows an evaluation of the magnitude difference (Lucke & Mayor 1980). For HD 7119, this ratio is 1.93, which leads to $\Delta m_V = 0.715$, if we assume that the two stars have similar temperatures.

The mass–luminosity relation for main-sequence stars with $M_{bol} < 7.5$, as given by Schmidt-Kaler (1982), is $\log M/M_{\odot} = 0.46 - 0.10 M_{bol}$, i.e. in the case of a binary system $\log M_1/M_2 = 0.10 \Delta M_{bol}$. For HD 7119, let us assume that the effective temperatures of both components are similar and thus $\Delta M_V \approx \Delta M_{bol}$. The mass ratio is derived directly from orbital data with $M_1/M_2 = K_2/K_1$. From Table 2 we obtain $M_1/M_2 = 1.102 \pm 0.003$ and $\Delta M_V = 0.42 \pm 0.03$ mag, which is smaller than the value derived from the correlation dips. This is an indication that the two stars are not at the same stage of evolution. In particular, the primary is more luminous than a dwarf star with a similar mass.

In the *Hipparcos* catalogue (ESA 1997), we find the following values: $V = 7.57$, $B - V = 0.34$, $\pi = 3.38 \pm 0.93$ mas. HD 7119 would then be at a distance $d = 300$ (+110, −70) pc. Its global absolute magnitude would be $M_V = 0.035 \pm 0.60$, assuming an interstellar absorption of 0.18 mag (Lucke 1978). If we neglect the contribution of the invisible third body, this would lead to $M_{V1} = 0.50 \pm 0.60$ and $M_{V2} = 1.20 \pm 0.60$ for the absolute magnitudes of the primary and the secondary, respectively. If both stars are hot late stars with metallic lines, which is very likely when considering the global index $B - V$, these values correspond to the magnitudes of giant stars (Schmidt-Kaler 1982). The two visible components are then two δ Del stars.

Obviously, the lack of knowledge of the orbital inclination i forbids a direct determination of the component masses. To estimate these values, we can use Schaller et al. (1992)'s theoretical Hertzsprung–Russell diagram with evolution tracks, and the isochrones given by Meynet, Mermilliod & Maeder (1993), as in Carquillat, Ginestet & Prieur (2001) for the system HD 98880. For HD 7119, we estimated $T_{eff} \approx 7500$ K, on the basis of a dereddened colour index $B - V = 0.28$, and the luminosity of each component by applying a bolometric correction of −0.1, to the absolute magnitudes found previously. Taking into account the uncertainties on these values, the two stars were plotted on the same isochrone with the constraint of a mass ratio equal to $K_2/K_1 = 1.10$, as observed. The corresponding mass values are $M_1 = 2.2 \pm 0.3$ $M_{\odot}$ and $M_2 = 2.0 \pm 0.3$ $M_{\odot}$, with an age of $\sim 8 \times 10^8$ yr.

The radii can be estimated using the well-known relation $\log R/R_{\odot} = 0.5 \log L/L_{\odot} - 2 \log T + 7.54$ with $\log L = 1.9$

Table 1. Radial velocities RV of HD 7119. The indices 1 and 2 refer to the primary and secondary components, respectively. The residuals $(O-C)_{01}$ for the preliminary orbit of the primary are given in column 5. The final residuals obtained when assuming the presence of a third invisible component are given in columns 6 and 7.

Date	JD 240 0000+	RV_1 (km s^{-1})	RV_2 (km s^{-1})	$(O-C)_{01}$ (km s^{-1})	$(O-C)_1$ (km s^{-1})	$(O-C)_2$ (km s^{-1})
13-11-1992	48940.473	−21.6	+7.0	+1.8	+0.5	−0.6
9-12-1992	48966.422	+19.3	−39.0	+1.2	−0.2	−0.8
10-12-1992	48967.430	−18.2	+4.2	+1.8	+0.6	+0.2
12-12-1992	48969.281	−46.2	+32.4	+1.4	+0.2	−2.0
12-12-1992	48969.488	−42.4	+29.9	+1.6	+0.6	−0.8
13-12-1992	48970.309	−18.6	+5.2	+1.1	+0.2	+1.2
15-12-1992	48972.281	+35.4	−56.5	+2.3	−0.3	−0.5
12-01-1993	49000.324	+16.1	−33.4	+1.1	−0.3	+1.3
14-01-1993	49002.355	−47.3	+35.7	+2.0	+0.3	−0.1
25-11-1993	49137.398	+31.7	−56.2	+0.1	−0.3	−0.3
26-11-1993	49138.383	+5.2	−26.5	−0.2	+0.6	−0.7
27-11-1993	49319.375	−33.3	+15.5	−0.9	−0.5	+0.1
28-12-1993	49320.363	−50.9	+36.6	−0.2	+0.1	+1.1
29-12-1993	49321.371	−38.4	+23.5	−1.2	−0.2	+2.1
1-12-1993	49323.340	+29.3	−52.5	+1.6	+0.9	−0.4
3-12-1993	49324.504	+24.5	−48.6	−1.2	−1.0	+0.3
15-10-1994	49640.535	+8.2	−37.1	−3.1	−0.1	−0.6
15-10-1994	49641.465	+30.3	−60.4	−2.0	+0.5	+0.1
16-10-1994	49642.473	+17.5	−46.3	−3.6	+0.1	+0.5
18-10-1994	49644.414	−48.6	+24.8	−3.5	+0.1	−1.1
19-10-1994	49644.617	−52.3	+28.3	−3.9	−0.4	−1.2
10-02-1996	50124.316	−44.2	+23.0	−2.7	+0.2	+0.2
11-02-1996	50125.312	−53.4	+31.3	−3.7	−0.7	−0.8
13-02-1996	50127.312	+8.5	−34.0	−1.0	+1.5	−0.3
30-08-1996	50325.566	+14.5	−38.5	−1.0	+0.0	−1.0
31-08-1996	50326.613	−25.6	+7.6	−1.1	−0.1	+1.0
1-09-1996	50327.570	−49.5	+31.6	−0.6	−0.0	−1.4
26-11-1996	50414.406	−20.2	+3.8	+0.3	+0.5	+0.6
27-11-1996	50415.426	−48.4	+34.6	−0.1	−0.4	+1.3
28-11-1996	50416.406	−45.5	+30.9	−0.6	−0.3	+0.7
30-11-1996	50418.430	+21.9	−43.4	+0.7	−0.4	+0.7
1-12-1996	50419.363	+33.4	−57.0	+0.6	−0.6	−0.1
2-12-1996	50419.504	+34.3	–	+2.5	+1.6	–
2-12-1996	50420.383	+10.9	−33.4	+0.7	+1.0	−3.0
3-12-1996	50420.535	+5.7	−22.2	+1.2	+1.5	+1.9
3-12-1996	50421.328	−27.4	+10.4	−1.0	−1.0	+0.7
3-12-1996	50421.426	−30.8	+13.8	−1.0	−0.3	+0.4
28-01-1997	50477.352	−43.1	+26.8	−0.0	−1.1	−2.0
30-01-1997	50479.359	+23.8	−46.4	+0.6	−0.5	−0.5
16-10-1977	50738.395	+2.3	−20.4	+0.5	−0.1	−0.6
17-10-1997	50739.387	−34.0	+21.8	+1.3	+0.0	+1.3
18-10-1997	50739.520	−37.6	+24.7	+1.5	−0.2	+0.1
18-10-1997	50740.305	−49.4	+35.9	+1.4	−0.2	−1.5
18-10-1997	50740.477	−49.3	–	+1.3	−0.0	–
19-10-1977	50740.703	−47.6	–	+1.2	+0.0	–
19-10-1977	50741.375	−33.2	+21.2	+1.5	+0.7	+0.7
19-10-1997	50741.484	−30.3	+17.2	+1.1	+0.2	+0.4
24-10-1997	50746.426	−40.5	+28.4	+2.2	+0.6	−0.1
20-01-1998	50834.379	−42.1	+29.4	+1.8	+0.6	+0.0
21-01-1998	50835.336	−47.6	+34.2	+1.5	+0.7	−1.3
22-01-1998	50836.340	−24.8	+9.3	+0.1	−0.4	+0.0
23-01-1998	50837.289	+11.7	−31.5	+1.6	+0.1	−1.0
24-01-1998	50838.324	+34.2	−57.2	+1.4	−0.8	−1.0
20-10-1998	51106.500	−38.0	+18.4	−3.4	−1.3	+1.0
20-10-1998	51107.473	+0.9	−19.0	+0.8	+2.2	+2.6
21-10-1998	51107.641	+5.2	−29.6	−1.1	+0.1	−0.9
21-10-1998	51108.348	+26.2	−51.7	−0.9	−0.5	+0.8
21-10-1988	51108.469	+29.0	−55.1	−0.3	−0.0	−0.1
22-10-1998	51109.316	+28.2	−55.6	−1.9	−0.9	−0.5
22-10-1998	51109.488	+25.3	−51.4	−1.6	−0.4	−0.0

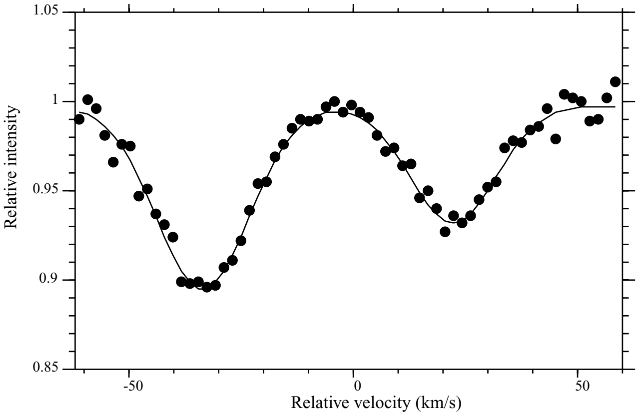

Figure 1. Typical CORAVEL cross-correlation dip obtained for HD 7119.

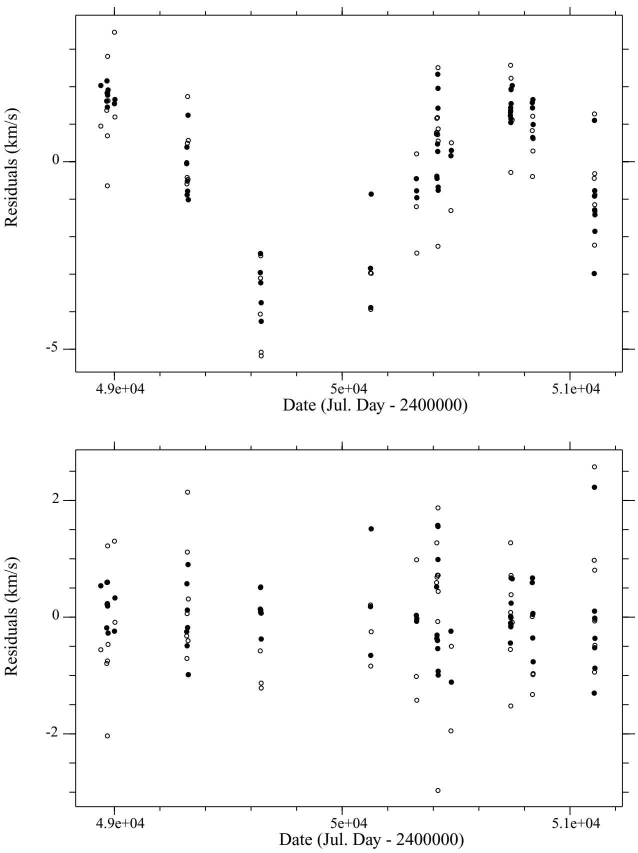

Figure 2. HD 7119: residuals obtained when assuming two components only (top) and three components (bottom).

$-\,0.4M_{\mathrm{bol}}$. This leads to $R_1 = 4.6^{+1.4}_{-1.1}\ \mathrm{R}_{\odot}$ and $R_2 = 3.3^{+1.1}_{-0.8}\ \mathrm{R}_{\odot}$. If we are dealing with late Am-type stars, as proposed in this section, these radii are compatible with those of evolved stars (Schmidt-Kaler 1982).

The value of $M_1 \sin^3 i$ found in Table 2 then leads to $i = 29.5^{\circ} \pm 2.0^{\circ}$, and to a separation of the components of $a = a_1 + a_2 = 17.0 \pm 1.0$ Gm, i.e. $24.0 \pm 1.5\ \mathrm{R}_{\odot}$. Given the estimated radii of 3–5 $\mathrm{R}_{\odot}$, the system appears detached.

3.2 Rotation–revolution synchronism

When considering the short period of the main pair, one may expect that their rotation is synchronized with their orbital motion. In order to check this hypothesis, we applied the test from Kitamura & Kondo (1978) on each component. This test assumes that synchronism is indeed verified and then estimates the value of the component radius corresponding to the observed rotation velocity and orbital period (i.e. $R/\mathrm{R}_{\odot} = V_{\mathrm{e}} \times P/50.6$, where V_{e} is the equatorial rotation velocity in km s^{-1} and P is the orbital period in days). When the values found for each component are compatible with typical radii of stars with similar spectral types, it is likely that there is indeed synchronism. Let us note that this test assumes that the orbital and equatorial planes of both stars are coplanar. This assumption is needed since the rotation velocity is only measured via the projected velocity $v \sin i$.

As shown by Benz & Mayor (1981, 1984), the projected velocity can be derived from the analysis of the CORAVEL correlation dips. For HD 7119, the values of $v \sin i$ for the primary and secondary are, respectively, 12.8 ± 0.2 and 7.8 ± 0.4 km s^{-1}. With the assumptions already mentioned (synchronism and coplanarity) these values lead to radii of 3.5 and 2.1 $\mathrm{R}_{\odot}$ for the primary and secondary, respectively. These values are smaller than the estimated values from the physical parameters (cf. Section 3.1), but they are still in reasonable agreement, given the rather large uncertainties. For instance, a small deviation from coplanarity with an inclination of the rotation axes of $i = 22^{\circ}$ (instead of $i = 29^{\circ}$ for the orbital axes) would lead to $R_1 = 4.5\ \mathrm{R}_{\odot}$ and $R_2 = 2.8\ \mathrm{R}_{\odot}$, in very good agreement with the theoretical values. We thus conclude that synchronism is plausible for both components.

Table 2. Orbital elements of HD 7119. Orbit 1: final elements for the short-period system. Orbit 2: elements corresponding to the orbital motion of the centre of gravity of the short-period system relative to the centre of gravity of the triple system.

Elements		Orbit 1		Orbit 2	
P	d	6.761 504	±0.000 027	1687.	±26
T^a	JD 2400000+	48 945.35	±0.09	50 684.4	±12.
ω	(deg)	7.7	±5.0		
e		0.028	±0.003	0.	±0.04
K_1	km s^{-1}	42.48	±0.13	3.00	±0.15
K_2	km s^{-1}	46.81	±0.19		
V_0	km s^{-1}	Variable		−10.94	±0.11
$a_1 \sin i$	Gm	3.945	±0.012	69.61	±3.64
$a_2 \sin i$	Gm	4.350	±0.018		
$M_1 \sin^3 i$	$\mathrm{M}_{\odot}$	0.262	±0.002		
$M_2 \sin^3 i$	$\mathrm{M}_{\odot}$	0.237	±0.002		
f(m)	$\mathrm{M}_{\odot}$			0.0047	±0.0008
$\sigma(O-C)_1$	km s^{-1}	0.68			
$\sigma(O-C)_2$	km s^{-1}	1.04			

$^a T$: periastron passage for orbit 1; ascending node passage for orbit 2.

3.3 Hypotheses on the third body

Let $f(m) = (M_1 + M_2) \sin^3 i\, g(\mu)$ be the mass function of the long-period orbit (orbit 2 of Table 2), with $\mu = M_3/(M_1 + M_2)$, $g(\mu) = \mu^3/(1+\mu)^2$, where M_3 is the mass of the third body.

With the values found in Section 3.1, the total mass of the short-period system is $M_1 + M_2 = 4.2\ \mathrm{M}_{\odot}$. As the mass function is $f(m) = 0.0047\ \mathrm{M}_{\odot}$ (Table 2), the mass ratio is $\mu \geqslant 0.11$, i.e. $M_3 \geqslant 0.47\ \mathrm{M}_{\odot}$. This boundary value (assuming $i = 90^{\circ}$ for orbit 2) corresponds to the mass of a cool dwarf with a spectrum close to M2 (Schmidt-Kaler 1982). As an alternative, if we assume that the orbital plane of the short-period pair and that of the third body are coplanar ($i \sim 30^{\circ}$), we obtain $\mu = 0.24$ and $M_3 = 1.0\ \mathrm{M}_{\odot}$. In

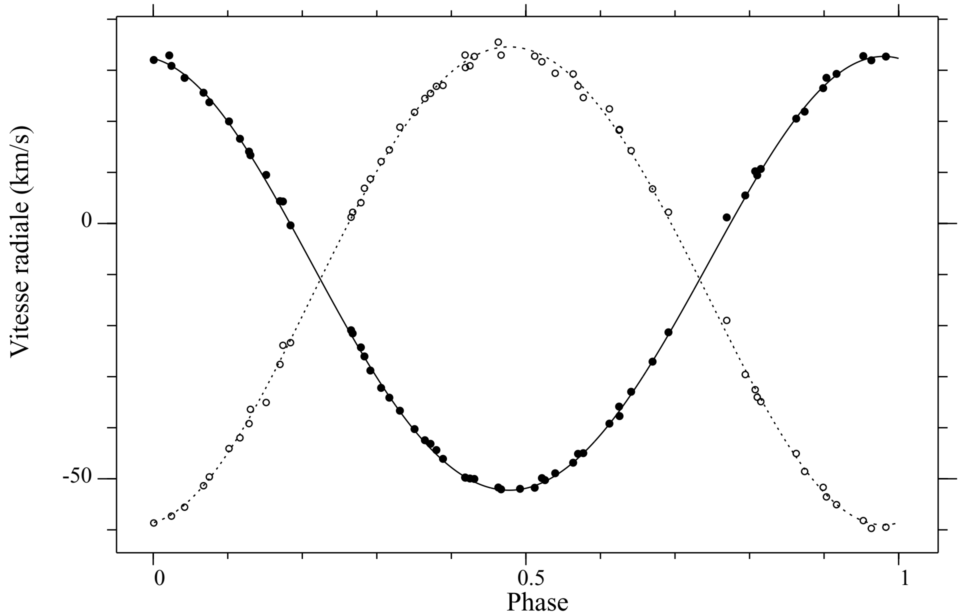

Figure 3. HD 7119: radial velocity curves of the two components of the short-period system, computed with the final elements. Filled circles, primary component; open circles, secondary component. The origin of the phases corresponds to the periastron passage.

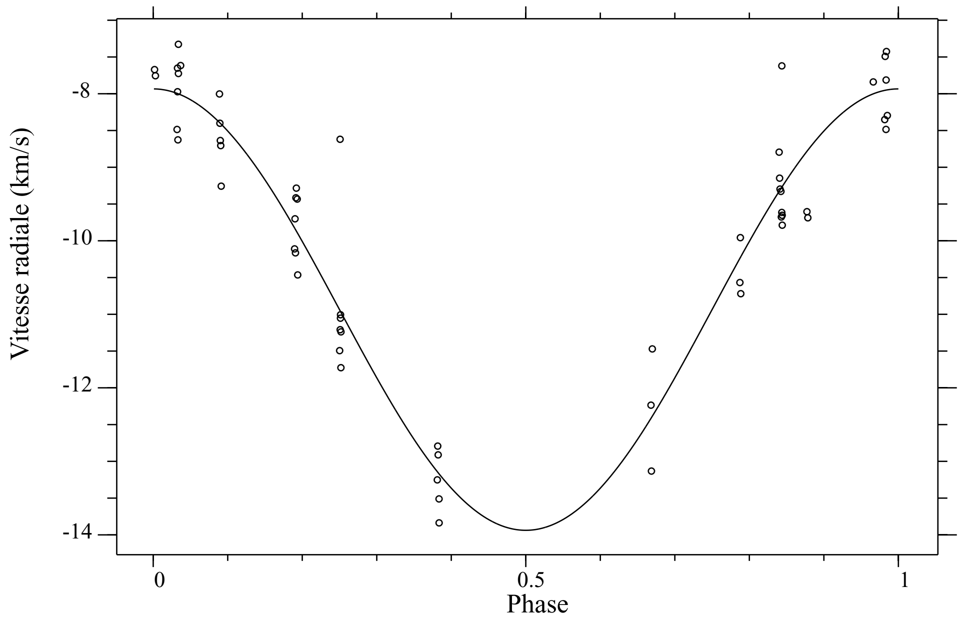

Figure 4. HD 7119: radial velocity curve of the centre of gravity of the short period system (fit obtained simultaneously with that of Fig. 1). The origin of the phases corresponds to the ascending node passage.

that case, the third body could be a dwarf star of solar type, and would also be invisible because of a too large brightness difference ($\Delta m_V \sim 5$ mag).

Using the value $a_1 \sin i = 69.61$ Gm for the long-period orbit (Table 2), the separation a' of the third body may thus be approximated by $a' \approx a_1 \sin i (1 + 1/\mu)/\sin i$. For $i = 90°$ and $30°$, we obtain $a' = 702$ Gm (4.7 au) and $a' = 724$ Gm (4.8 au), respectively. At the expected distance of 300 pc, this corresponds to an angular separation of 0.016 arcsec.

In the introduction we mentioned that HD 7119 was known as a visual binary (Cou 147), since Couteau's discovery in 1967 with the 50-cm refractor of Nice Observatory (Couteau 1968). The visual companion was recently confirmed by a new observation in 1992 by Thorel (1996). Although the magnitude difference of ∼5 mag reported by Thorel is close to that of the third 'spectroscopic' body that we found, the separation of 3.35 arcsec of the visual companion is considerably larger than the estimation we have just done (0.016 arcsec). Note that the visual companion could also be an optical one, since the position parameters (θ, ρ) did not change significantly between the two observations of 1967 and 1992. On the other hand, if the visual companion really is a physical companion, HD 7119 is a quadruple system.

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