Contribution to the search for binaries among Am stars - VIII. New spectroscopic orbits of eight systems and statistical study of a sample of 91 Am stars

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Contribution to the search for binaries among Am stars. VIII. New spectroscopic orbits of 8 systems and statistical study of a sample of 91 Am stars.

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ABSTRACT

This paper is the last of a series devoted to the study of Am stars, with the monitoring of radial velocities of a sample of 91 objects during more than twenty years. The purpose was to determine which stars were members of spectroscopic binaries (SBs) and study in detail those systems in order to obtain observational constraints on the origin of the Am phenomenon.

In the first part, we present the results of a detailed study of eight Am stars (HD 32893, 60489, 109762, 111057, 113697, 204918, 219675 and BD+44°4512) observed at Haute-Provence and Cambridge observatories with CORAVEL instruments. We find that these objects are single-lined SBs whose orbital elements are determined for the first time. HD 32893 is found to be a triple spectroscopic system whose third body might be detected by speckle interferometry. Physical parameters are inferred for the primaries of those SBs. We then investigate the influence of tidal interaction and find that it has already led to the synchronism of the primaries and to the circularisation of the orbits of four of those systems.

In the second part of this paper, we present the main results of our whole programme and derive some statistical properties of Am stars. We give the recapitulating table of the orbital parameters found for the SBs of our whole sample and the list of those for which no evidence for radial velocity variations could be found during our monitoring. Our study shows that at least 64% of Am stars are members of SBs. This rate is significantly greater than that of normal stars. Although some SBs may have been not detected, this study shows that a substantial fraction of Am stars do not belong to SBs: they are either isolated stars or members of wide binary systems.

We then present some statistical properties of the orbital parameters of the SBs whose primary is an Am star, on an extended sample obtained by adding 29 Am SB orbits published by other authors. The corresponding e vs $\log P$ diagram shows a cutoff between the circular and the eccentric systems at $P \approx 5.6 \pm 0.5$ d, which indicates that a typical age of 0.5–1 $\times 10^9$ yr for the Am stars, which is in agreement with the values found in our previous detailed studies. A Monte-Carlo analysis shows that the distribution of the mass function values $f(m)$ is compatible with a power-law distribution $N(m) \propto m^{-\alpha}$ of the masses m of the companions with $\alpha = 0.3 \pm 0.2$ or with a Gaussian distribution centered on 0.8±0.5 $M_{\odot}$, which indicates that the companions of Am SBs are mostly dwarf stars of type G-K-M.

Key words: Binaries: spectroscopic — Stars: fundamental parameters, mass function

1 INTRODUCTION

Am stars are chemically peculiar hot stars of type A whose spectra show an over-abundance of heavy elements and an under-abundance of calcium. It is now generally admitted that such anomalies are the consequence of chemical element segregation in the outer layers of those stars.

Observational studies (Abt 1961, 1965, Abt & Levy 1985) have shown that most Am stars belonged to close binary systems and that all Am stars have small rotational velocities, with $v \sin i < 100$ km.s^{-1}, smaller than the normal A stars. Abt (1961) first suggested that tidal interaction with the companion could be at the origin of the Am phenomenon, through the spin-orbit synchronism which reduces the axial rotation of the stars. Nevertheless Abt & Levy (1985) found that there existed isolated Am stars and that another process had to be invoked to explain their small rotational velocities.

According to the model proposed by Michaud (1980) and Michaud et al. (1983), small rotational velocities are required to allow helium to settle gravitationally rather quickly after the star has reached the main sequence (a few 10^6 yr only), producing the vanishing of the HeII convection zone existing in A stars that blocks the diffusion of the chemical elements from the deep layers. After this disappearance, the diffusion can proceed higher in the star, at the bottom of the H-HeI convection zone, where Ca is in the Ar configuration (i.e. CaII) and so has a small g_{rad}, causing an under-abundance of Ca that is observed in the spectra of the Am stars. This model is also called "superficial model", since the separation of chemical elements occurs close to the surface of the star and implies that only a small proportion of the star would have anomalous abundances during the main sequence ($\sim 10^{-10}\ M_\star$).

A modified version of this model called "evolution model" was recently proposed by Richer et al. (2000) and Michaud et al. (2005) in which the separation of elements occurs deeper in the star, at a radius where Ca is in the Ne configuration (i.e. CaX), which also corresponds to a small value of g_{rad}(Ca), causing Ca under-abundances. In this case, anomalous abundances would affect a larger fraction of the stellar mass while the star is on the main sequence ($\sim 10^{-5}\ M_\star$), and thus would survive after the turn-off. Thus, contrarily to the superficial model, the evolution model would naturally explain the existence of evolved Am stars, similar to *o* Leo found by Griffin (2002).

Note that hydrodynamical codes based on those two models tend to produce too large abundance anomalies, when only atomic diffusion is considered. There is a need of introducing a competing process whose nature has been a matter of debate in the last thirty years. A possibility would be to improve the treatment of turbulence with the introduction of anisotropy in the vertical transport as suggested by a recent work by Talon et al. (2006) who manages to reproduce observed Am spectra with a self-consistent model.

This paper is the eighth and last paper of a series (see Table 1) devoted to the search for and the consequent study of spectroscopic binaries (SBs) in a sample of 91 Am stars, mainly constituted from the Third Catalogue of Am Stars with Known Spectral Types (Hauck 1986). Our main purpose was to bring some observational arguments about the implication of binaries in Am phenomenon. To do so, we wanted to:

(i) search for all the SBs in this sample and derive the rate of Am stars belonging to SBs,
(ii) monitor the radial velocities of SBs found in the sample and determine their orbital parameters and physical properties of the stellar components,
(iii) study the importance of tidal interaction in those systems, that may lead to the circularisation of the orbits and to the spin-orbit synchronization.

Table 1. Presentation of the papers of this series.

Name	Reference
Paper I	Ginestet & Carquillat, 1998
Paper II	Carquillat, Ginestet & Prieur, 2001
Paper III	Carquillat et al., 2002
Paper IV	Ginestet et al., 2003
Paper V	Carquillat et al., 2003
Paper VI	Carquillat et al., 2004
Paper VII	Prieur, Carquillat & Imbert, 2006

Although this programme was initiated with conventional spectrographs in the years 1980, most of observations were done after 1992 with the CORAVEL instrument mounted at the Cassegrain focus of the 1-m Swiss telescope at the *Observatoire de Haute-Provence* (OHP). After 2000, many measurements were also obtained with the CORAVEL instrument mounted on the coudé focus of the 91-cm telescope at the Cambridge Observatories, thanks to the collaboration of R.F. Griffin. When we started this study, none of the 91 stars of our sample had known SB orbital elements. Most of the orbits were then determined and published by our team (J.-M. Carquillat, N. Ginestet, A. Pédoussaut and J.-L. Prieur) or in collaboration with colleagues of Marseille (France), Cambridge (U.K.) and Geneva (Swiss).

Because this paper is the last of this series, it is articulated in two folds: we first present the last detailed study of eight new SBs and then give the final results derived from our observational programme.

The first part concerns the study of HD 32893, 60489, 109762, 111057, 113697, 204918, 219675 and BD+44°4512. All those stars appeared as single-lined spectroscopic binaries (SB1) with CORAVEL, but our observations revealed that the first one, HD 32893, was in fact a triple spectroscopic system. In Section 2, we present our observations and the orbital elements we derived, for the first time to our knowledge, for those eight systems. In Section 3, we give some useful information that we found in the literature about the studied stars. In Section 4, like for the previous papers of the series, we derive some physical parameters of the primary components and examine their evolutionary status. We also estimate the minimum masses and separations of the unseen companions. In Section 5, we examine the occurrence of tidal effects for the studied systems in terms of rotation-revolution synchronism of the primaries.

The second part starts in Section 6, with the final results of the RV survey of our sample of 91 stars and some related statistics about the frequency of Am belonging to SBs. In Section 6.2, we present the properties of the orbital systems of an extended SB sample of Am stars with 89 orbits and derive some constraints on the distribution of the masses of companions.

2 OBSERVATIONS AND DERIVATION OF ORBITAL ELEMENTS

Most of the observations concerning the eight objects were performed at OHP, but additional observations were also carried out by R.F Griffin who kindly observed some stars of our programme with his own CORAVEL in Cambridge. CORAVEL is a spectrophotometer that allows measurements of heliocentric RVs by performing a cross-correlation of the stellar spectrum with a physical mask placed in the focal plane of the spectrograph (Baranne, Mayor & Poncet 1979). This instrument was initially conceived to study the stars cooler than the spectral type F4 but it was also found fit for use for slow-rotating ($v \sin i < 40$ km.s^{-1}) hotter stars when they exhibit metallic lines in their spectrum, like the Am stars. The precision of the RVs depends upon $v \sin i$, the projected rotational velocity of the star. The mean rms error varies from about 0.5 km.s^{-1} for the slowest rotators to about 1.5 km.s^{-1} for the maximum limit value of $v \sin i \approx 40$ km.s^{-1}.

The RVs obtained at OHP and in Cambridge were reduced to the system of the Geneva Observatory RV data base (Udry, Mayor & Queloz 1999). For HD 60489, we also used 4 RVs obtained with the AURELIE spectrograph at OHP by Künzli & North (1998) that were reduced to this system by applying an offset of +1 km.s^{-1}. The resulting RV measures of the eight new SBs are given in Tables 2 to 9[1]. Those from Cambridge are marked with ^{C} in col. 3 and those from the AURELIE spectrograph with ^{Aur}.

The spectroscopic orbital elements given in Table 10 were obtained from the observed RVs using a fully automatic sequence of programmes described in Paper VII. All the RVs obtained with CORAVEL (OHP and Cambridge) were weighted unity; those from the AURELIE spectrograph were weighted 1/4. For HD 32893, our usual least-squares programme "BS1", that fits orbital parameters to SB1 data (Nadal et al 1979), led to $O - C$ residuals much larger than the value expected from the RV errors, and not randomly distributed with time. This gave us a hint of the presence of an unseen third body in the system and the analysis of the residuals allowed us to estimate its period. The RVs were then successfully re-processed with our programme "BS4", that performs a least-squares minimization of the orbital elements of a triple hierarchical spectroscopic system to SB1 data (see Paper IV).

The computed RV curves for those eight systems are given in Figs. 1 and 2, and the $O - C$ residuals in Tables 2 to 9. For BD +44°4512, the bad repartition in phase of the observations is due to the value of the orbital period which is nearly equal to an integer number of days ($P = 5.002$ d).

Table 2. Radial velocities and $(O-C)$ residuals for HD 32893. In cols. 2 and 3, cycles (s) and (l) refer to the short and long period systems, respectively.

Date (JD) 2400000+	Cycle (s)	Cycle (l)	RV_O km.s^{-1}	$RV_{(O-C)}$ km.s^{-1}
50746.570	−0.34	−0.38	−10.6	−0.1
50838.512	41.92	−0.29	59.1	−0.4
50839.426	42.34	−0.29	−12.5	−0.1
50839.516	42.38	−0.29	−22.0	0.1
51106.520	165.11	−0.06	49.1	−0.3
51106.633	165.17	−0.06	37.1	0.2
51106.711	165.20	−0.06	26.4	−0.3
51107.441	165.54	−0.06	−36.0	0.7
51107.578	165.60	−0.06	−28.1	0.4
51108.434	165.99	−0.06	61.2	−0.3
51108.637	166.09	−0.06	53.8	−0.5
51109.441	166.46	−0.06	−36.0	0.4
51109.664	166.56	−0.06	−34.3	0.5
51110.438	166.91	−0.06	54.9	0.5
51110.672	167.02	−0.05	60.2	−0.7
51111.430	167.37	−0.05	−21.8	1.0
51185.570	201.45	0.01	−43.6	0.4
51186.234	201.75	0.01	5.5	0.3
51186.414	201.84	0.01	29.8	−0.1
51186.605	201.93	0.01	48.0	−0.4
53010.449	1040.26	1.62	12.5	−0.5
53010.598	1040.33	1.62	−7.4	0.1
53011.344	1040.67	1.62	−9.2	−0.5
53011.449	1040.72	1.62	4.4	−1.1
53011.578	1040.78	1.62	24.8	0.9
53012.336	1041.13	1.62	51.3	0.6
53012.441	1041.17	1.62	39.0	0.5
53014.359	1042.06	1.62	62.8	0.4
53014.469	1042.11	1.62	55.9	1.1
53087.281	1075.57	1.68	−28.9	0.3
53088.301	1076.04	1.68	64.2	0.8
53089.328	1076.51	1.69	−34.0	0.3
53091.312	1077.43	1.69	−28.9	0.4
53258.637	1154.34	1.83	−11.5	0.2
53259.633	1154.80	1.84	28.1	−0.5
53339.422	1191.47	1.91	−36.5	−0.8
53343.645	1193.41	1.91	−30.3	−1.1
53344.508	1193.81	1.91	30.9	−0.2
53345.469	1194.25	1.91	11.8	−1.2
53445.328	1240.15	2.00	25.5	0.2
53447.344	1241.08	2.00	40.2	−0.2
53625.648	1323.04	2.16	63.9	0.2
53626.629	1323.49	2.16	−35.2	−0.7
53627.621	1323.94	2.16	61.4	−0.3
53704.617	1359.33	2.23	−9.9	−0.4
53705.531	1359.75	2.23	17.1	0.5
53746.457	1378.57	2.26	−30.5	−0.4

3 NOTES ON INDIVIDUAL SYSTEMS

In this section we report the origin of the Am classification of those eight stars and some complementary information.

HD 32893 (HIP 24108). The Am classification originates from Abt (1985). The star is ADS 3723 A, the primary component of a wide visual pair. According to the CCDM catalogue (Dommanget & Nys 1994), the visual secondary is a faint star of tenth magnitude at ≈ 12 ″ of the A component. It is a new spectroscopic triple system (see Sect. 2).

HD 60489 (HIP 36869, HR 2904). This star was classified Am by Bertaud & Floquet (1967) and A7 III by Cowley & Jaschek (1969). Künzli & North (1998) found it is an evolved metallic-line star and detected some light variations.

HD 109762. Two references for its Am nature are quoted in

[1] Tables 2, 3, 4, 5, 6, 7, 8, 9 and 15 are displayed in a truncated form here. They can be found in integrality in the web publication version.

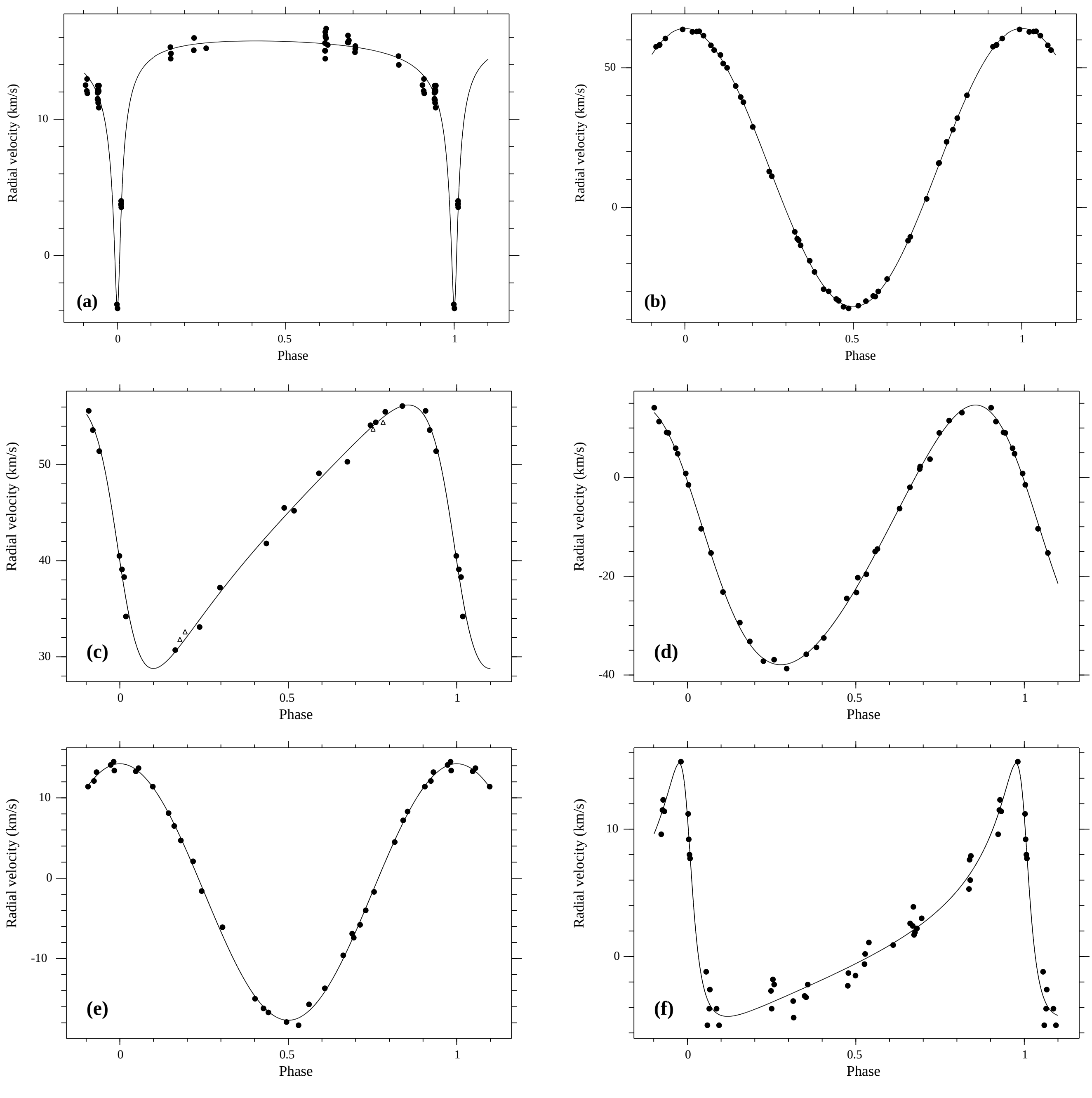

Figure 1. RV curves (solid lines) computed with the orbital elements of Table 10: (a) HD 32893 (long-period outer system), (b) HD 32893 (short-period inner system), (c) HD 60489, (d) HD 109762, (e) HD 111057 and (f) HD 113697. For HD 32893 (a) and HD 111057 that have a circular orbit, the ascending node was taken as the origin of the phases. For the other systems, the origin of the phases corresponds to the periastron passage. The CORAVEL measures are displayed with black dots. For HD 60489, the few AURELIE measures are reported with open triangles.

Hauck (1986)'s catalogue: Slettebak, Bahner & Stock (1961) and Slettebak, Wright & Graham (1968). Hill et al. (1976) confirmed its classification as Am and first noted the variability of its RV. This star was not observed by Hipparcos.

HD 111057 (HIP 62341). The Am classification originates from Hill et al. (1976) and was confirmed by Bidelman (1988).

HD 113697 (HIP 63806). Hynek (1938) listed this star with "composite spectrum", but this was contradicted by our spectroscopic study in the near infrared region that led to a classification as Am (Ginestet et al. 1997). Our result is in agreement with the Henry Draper's Catalogue where this star is classified as A3 with a mention in the notes of the presence in the spectrum of *"several solar lines (too) strong for class A3"*. Grenier et al. (1999) gave the classification A5 III but this luminosity class is not in agreement with the visual absolute magnitude ($M_V = 2.4 \pm 0.3$) obtained from the trigonometric parallax (ESA 1997). This value of M_V

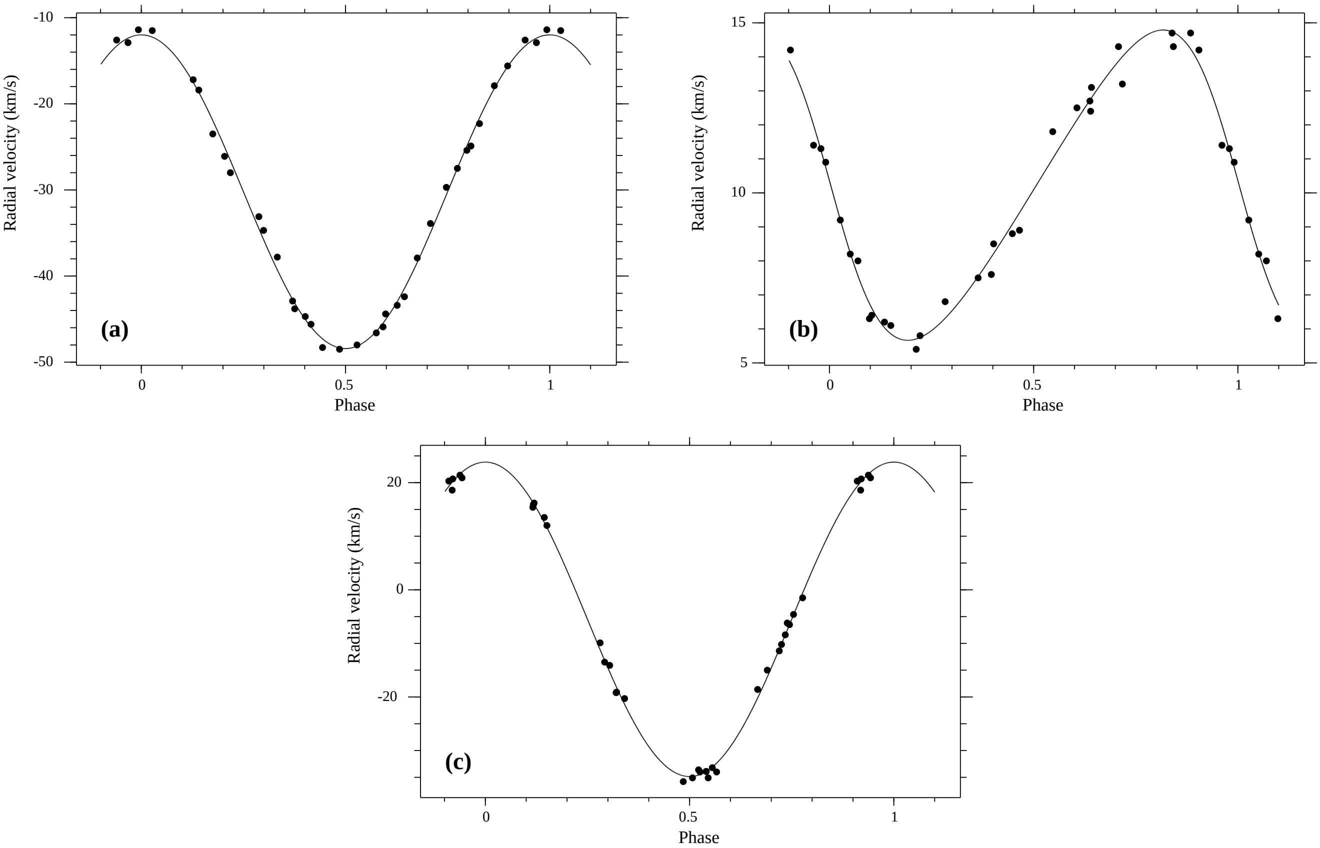

Figure 2. RV curves computed with the orbital elements of Table 10: (a) HD 204918, (b) HD 219675 and (c) BD +44°4512 The origin of the phases corresponds to the periastron passage.

Table 3. Radial velocities and $(O-C)$ residuals for HD 60489.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O-C)$ km s^{-1}
49663.62	−12.25	53.7^{Aur}	−0.3
49665.65	−12.22	54.4^{Aur}	−0.5
49692.61	−11.82	31.8^{Aur}	0.7
49693.65	−11.81	32.6^{Aur}	0.8
50478.50	−0.26	54.1	0.3
50479.56	−0.24	54.4	0.1
50481.48	−0.21	55.5	0.4
50745.64	3.68	50.3	−1.2
50835.56	5.00	40.5	0.2
50836.51	5.01	38.3	1.2
51108.67	9.02	34.2	−1.8
51186.57	10.16	30.7	0.2
52936.65	35.92	53.6	−0.4
53010.48	37.01	39.1	0.6
53343.52	41.91	55.6	0.7
53345.64	41.94	51.4	−0.6
53447.31	43.44	41.8	−0.7
53705.64	47.24	33.1	−0.8
53746.53	47.84	56.1	0.0
54185.40	54.30	37.2^{C}	0.5
54198.35	54.49	45.5^{C}	0.9
54200.34	54.52	45.2^{C}	−0.5
54205.36	54.59	49.1^{C}	0.7

corresponds to that of a dwarf A star, which is the typical luminosity class of the Am stars.

HD 204918 (HIP 106184). The Am classification quoted in Hauck (1986)'s catalogue originates from Abt (1984).

HD 219675 (HIP 115011). The Am classification originates from Abt (1985). This new SB belongs to the close visual binary ADS 16650 AB, for which Scardia et al. (2002) computed an orbit with $P = 173.7$ yr and $a = 0.41''$. According to Fabricius & Makarov (2000), we have $\Delta m_V \approx 2$ for this visual pair. Therefore, HD 219675 is a true physical triple system.

BD+44°4512 The Am classification of this faint star listed in Hauck (1986)'s catalogue originates from Floquet (1975). This star was not observed by Hipparcos.

4 PHYSICAL PARAMETERS

Like for the previous papers of the series we now derive some physical parameters of those systems (reported in Table 11) using the orbital parameters we have found, Strömgren photometry and other available data found in the literature.

4.1 Color excess and M_V deduced from Strömgren photometry

The Strömgren photometric indices β, $b-y$, m_1 and c_1, found in Hauck & Mermilliod (1998)'s catalogue for the studied objects are displayed in cols. 2, 3, 5 and 7 of Table 12,

Table 4. Radial velocities and $(O-C)$ residuals for HD 109762.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O-C)$ km s^{-1}
50837.60	−0.37	−6.3	−0.2
50839.64	−0.31	1.7	0.0
50976.43	3.69	2.2	0.4
50977.43	3.72	3.7	−1.6
50978.37	3.75	9.0	0.7
50979.37	3.78	11.5	0.4
53011.70	63.23	−37.2	−0.5
53088.53	65.47	−24.5	1.0
53089.51	65.50	−23.3	−1.0
53089.65	65.51	−20.3	1.6
53090.52	65.53	−19.6	−0.8
53091.41	65.56	−15.0	0.5
53091.64	65.56	−14.5	0.2
53144.34	67.11	−23.2	−0.7
53343.74	72.94	9.1	−0.4
53344.66	72.97	5.9	0.3
53345.68	73.00	0.8	0.6
53445.53	75.92	11.3	−0.7
53446.48	75.94	9.0	0.2
53447.42	75.97	4.8	0.2
53448.51	76.00	−1.5	−0.1
53795.59	86.16	-29.4^C	1.0
53796.60	86.19	-33.2^C	0.5
53834.53	87.29	-38.7^C	−0.9
53836.52	87.35	-35.8^C	−0.1
53837.55	87.38	-34.4^C	−0.6
53867.44	88.26	-36.9^C	0.8
53872.49	88.41	-32.5^C	−0.4
53886.50	88.81	13.1^C	−0.5
53889.46	88.90	14.1^C	1.0
53915.41	89.66	-2.0^C	0.0
53928.41	90.04	-10.4^C	−1.1
53929.41	90.07	-15.3^C	0.2

Table 5. Radial velocities and $(O-C)$ residuals for HD 111057.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O-C)$ km s^{-1}
53087.52	−1.09	11.4	−0.1
53088.50	−0.84	6.5	−0.2
53089.52	−0.57	−16.2	−0.2
53090.55	−0.31	−7.4	−0.2
53091.46	−0.07	13.2	0.4
53091.66	−0.02	14.5	0.4
53444.64	91.71	−5.8	−0.4
53445.45	91.92	12.1	−0.3
53445.64	91.97	14.1	0.1
53446.44	92.18	4.7	−0.3
53446.68	92.24	−1.6	−0.6
53447.44	92.44	−16.7	−0.1
53447.65	92.49	−17.9	−0.2
53448.40	92.69	−6.9	0.7
53448.65	92.75	−1.7	−0.5
53704.73	159.30	−6.1	1.0
53705.72	159.56	−15.7	0.8
53746.73	170.22	2.1	0.6
53883.38	205.73	−4.0	−0.3
53884.36	205.98	13.4	−0.8
54114.74	265.85	8.3^C	0.3
54134.72	271.05	13.3^C	−0.2
54137.68	271.82	4.5^C	−0.2
54138.60	272.06	13.7^C	0.4
54146.64	274.14	8.1^C	0.0
54186.61	284.53	-18.3^C	−0.9
54192.64	286.10	11.4^C	0.1
54194.60	286.61	-13.7^C	0.4
54195.50	286.84	7.2^C	0.3
54201.50	288.40	-15.0^C	−0.3
54202.51	288.66	-9.6^C	0.4

respectively. Unfortunately, no Strömgren photometry data was found for BD +44°4512.

When β was available, the de-reddened indices $(b-y)_0$, $(m_1)_0$, $(c_1)_0$ and $(\delta m_1)_0$ were computed with Crawford (1975, 1979)'s formulae. The colour-excess was then derived with the relation $E_{B-V} = E_{b-y}/0.73$ (Crawford 1975). When β was not known, E_{B-V} was derived from Lucke (1978)'s opacity maps and the distance deduced from the parallax. Then the same relation allowed to retrieve E_{b-y} which we could use to correct the Strömgren indices for reddening effects. The values obtained for E_{b-y}, $(m_1)_0$, $(c_1)_0$ and $(\delta m_1)_0$ are reported in cols. 4, 6, 8 and 9 of Table 12, respectively.

The values derived for E_{B-V} (line 5 of of Table 11) were also used to correct the apparent visual magnitudes m_V (line 3) for the interstellar absorption $A_V \approx 3\,E_{B-V}$. When the Hipparcos parallaxes were available (line 7) those corrected magnitudes allowed the computation of the absolute magnitudes M_V (line 9).

For HD 109762, which has not been observed by Hipparcos, we estimated its absolute magnitude from the Strömgren photometry using the relation derived by North et al. (1997) for a sample of stars of types A and Am observed by Hipparcos:

$$M_V = 12.6 - 3.7\,\beta - 8.3\,(\delta c_1)_0 + 6.5\,(\delta m_1)_0 + 7.2\,10^{-6}\,(v \sin i)^2.$$

With the formulae of Crawford (1975), we obtained $(\delta c_1)_0 = 0.05$, which led to $M_V = 1.71$.

4.2 $T_{\rm eff}$, $\log g$ and [Fe/H] from Strömgren photometry

When β was known, the effective temperature $T_{\rm eff}$ and the gravity $\log g$ (lines 11 and 13 of Table 11) were estimated from the grid of $(c_1)_0$ versus β given by Moon & Dworetsky (1985). In the other cases, those parameters were obtained from the Relyea & Kurucz (1978) grids of $(c_1)_0$ versus $(b-y)_0$.

The metallicity [Fe/H] (Table 11, line 14) was derived from the δm_1 values, using Cayrel's calibration as reported by Crawford (1975, Fig. 17 of this paper). The positives values we found are in agreement with the metallic-lined nature of the stars. Note that the value [Fe/H] = 0.86 obtained for HD 219675 is probably slightly overestimated, because of the presence of a close cooler visual companion only two magnitudes fainter.

Table 6. Radial velocities and $(O-C)$ residuals for HD 113697.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O-C)$ km s^{-1}
46486.61	−0.39	0.9	−0.1
47283.49	1.09	−4.1	0.3
47287.52	1.09	−5.4	−0.8
47601.54	1.68	1.9	−0.3
47604.61	1.68	2.2	−0.1
47964.55	2.35	−3.1	−0.6
47969.61	2.36	−2.2	0.1
48673.64	3.66	2.6	0.7
49140.45	4.53	−0.6	−0.4
49141.43	4.53	0.2	0.4
49147.43	4.54	1.1	1.1
49426.65	5.06	−1.2	1.9
49428.57	5.06	−5.4	−2.0
49431.56	5.06	−4.1	−0.4
49432.55	5.07	−2.6	1.2
50126.70	6.35	−3.2	−0.8
50193.55	6.48	−2.3	−1.4
50194.52	6.48	−1.3	−0.5
50477.64	7.00	11.2	1.0
50478.59	7.00	9.2	−0.3
50479.74	7.01	8.0	−0.7
50480.68	7.01	7.7	−0.3
50610.44	7.25	−2.7	0.9
50611.49	7.25	−4.1	−0.5
50613.46	7.25	−1.8	1.8
50615.48	7.26	−2.2	1.3
50837.61	7.67	2.4	0.4
50838.60	7.67	3.9	1.8
50839.71	7.67	1.7	−0.4
50974.44	7.92	9.6	−1.6
50976.44	7.93	11.5	0.0
50977.48	7.93	12.3	0.7
50979.43	7.93	11.4	−0.5
51186.71	8.32	−4.8	−2.0
53011.68	11.70	3.0	0.4
53087.55	11.84	5.3	−1.1
53088.51	11.84	7.6	1.2
53089.53	11.84	6.0	−0.5
53090.60	11.84	7.9	1.3
53345.70	12.31	−3.5	−0.6
53445.55	12.50	−1.5	−0.9
53705.73	12.98	15.3	0.3

Table 7. Radial velocities and $(O-C)$ residuals for HD 204918.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O-C)$ km s^{-1}
53260.39	−0.41	−45.9	−0.4
53261.47	−0.19	−24.9	−1.1
53262.41	−0.01	−11.4	0.6
53343.30	16.03	−11.5	0.8
53344.27	16.22	−28.0	−1.4
53345.26	16.42	−45.6	0.3
53624.41	71.75	−29.7	0.9
53625.38	71.94	−12.6	0.7
53626.32	72.13	−17.2	0.3
53626.57	72.18	−23.5	−1.6
53627.36	72.33	−37.8	1.5
53627.58	72.38	−43.8	−0.7
53628.35	72.53	−48.0	0.1
53628.59	72.58	−46.6	−0.2
53703.23	87.37	−42.9	−0.2
53703.38	87.40	−44.7	0.3
53704.38	87.60	−44.4	0.7
53705.26	87.77	−27.5	0.0
53705.38	87.80	−25.4	−0.5
53706.24	87.97	−12.9	−0.5
53746.24	95.90	−15.6	0.1
53748.21	96.29	−33.1	1.4
53749.21	96.49	−48.5	−0.2
54013.46	148.86	-17.9^C	0.3
54033.46	152.83	-22.3^C	−0.7
54040.40	154.20	-26.1^C	−1.1
54065.30	159.14	-18.4^C	0.3
54073.21	160.71	-33.9^C	1.1
54086.29	163.30	-34.7^C	1.1
54098.27	165.68	-37.9^C	0.5
54112.24	168.44	-48.3^C	−1.0
54123.25	170.63	-43.4^C	−0.4
54123.34	170.64	-42.4^C	−1.0

4.3 Influence of the unseen companions

The eight systems studied here have small mass functions, i.e. $f(m) < 0.063$ M$_\odot$ (see Table 10), which indicates that the companions have probably small masses. Indeed, if we assume that M_1, i and M_{V1} are equal to their statistically most likely values, $M_1 \approx 2$ M$_\odot$, $i \approx 60°$ and $M_{V1} \approx 1.7$ (cf. North 1997), we find $M_2 \lesssim 0.9$ M$_\odot$. This corresponds to a companion with spectral type cooler than G5 V and $\Delta m_V \gtrsim 3.4$ (Schmidt-Kaler 1982). So we may approximate, with only a minor error, the photometric indices of the primary components by the global values. The physical parameters derived from the global Strömgren indices in Sect. 4.1 and 4.2 can thus be affected to the Am primaries only.

For a given system, the visual absolute magnitude M_{V1} of the primary component lies between two limits, a minimum value corresponding to the global magnitude M_V of the system and a maximum value $M_{V1,\,\max}$, corresponding to $\Delta m_V = 2$ (which is the average limit of detection of the secondary with CORAVEL). We will adopt $M_{V1} = (M_V + M_{V1,\,\max})/2$, which is reported in line 10 of Table 11. For the triple system HD 219675 we applied a double correction, taking also into account the presence of the close visual component (see Section 3).

4.4 Evolutionary status, masses and radii

From the values of M_{V1} and the bolometric corrections tabulated by Flower (1996) we obtained the luminosity $L_1/\mathrm{L}_\odot$ given in line 12 of Table 11. The stars could be then plotted on the theoretical HR diagram of Schaller et al. (1992) for solar metallicity (Fig. 3). Like the other Am stars studied in the previous papers of the series, they are scattered within the whole width of the main sequence. This fact was also pointed out by Domingo & Figueras (1999) and is inconsistent with an older study of Gómez et al (1981) who found that the Am stars were located about 1 mag. above the main sequence.

We then derived the theoretical masses (line 15 of Table 11) and ages (line 21) of the Am primaries using the isochrones from Meynet, Mermilliod & Maeder (1993) also

Table 8. Radial velocities and $(O-C)$ residuals for HD 219675.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O-C)$ km s^{-1}
49640.42	−0.36	12.7	0.0
49641.39	−0.36	12.4	−0.4
49642.45	−0.36	13.1	0.3
50416.38	1.10	6.3	−0.4
50419.37	1.10	6.4	−0.2
50477.28	1.21	5.4	−0.3
50482.25	1.22	5.8	0.1
50611.63	1.47	8.9	−0.5
50740.45	1.71	14.3	0.4
50745.47	1.72	13.2	−0.8
50834.24	1.88	14.7	0.5
50975.62	2.15	6.1	0.2
51106.41	2.40	7.6	−0.5
51109.41	2.40	8.5	0.3
51186.29	2.55	11.8	0.8
52937.45	5.84	14.3	−0.4
53010.30	5.98	11.3	0.0
53259.37	6.45	8.8	−0.3
53343.37	6.61	12.5	0.4
53624.44	7.13	6.2	0.2
53703.31	7.28	6.8	0.5
53746.25	7.36	7.5	0.0
53998.58	7.84	14.7^C	0.0
54033.46	7.90	14.2^C	0.4
54063.48	7.96	11.4^C	−0.6
54079.34	7.99	10.9^C	0.1
54098.33	8.03	9.2^C	0.0
54111.27	8.05	8.2^C	0.0
54121.27	8.07	8.0^C	0.4

displayed in Fig. 3. The values found for masses are close to 2 $M_\odot$, which is in agreement to what we assumed in Section 4.3. The isochrones indicate ages lying between 0.5 and 1 giga-years, except perhaps HD 111057 that may be younger.

Finally, using the Stefan radiation law: $\log(R/R_\odot) = -0.2M_{\rm bol} - 2\log T_{\rm eff} + 8.47$ (Schmidt-Kaler 1982), we computed the theoretical radii of those stars (line 16). The rather large values we found for HD 60489 and HD 219675 are consistent with the evolved character of the primary components of those systems.

In the case of BD +44°4512 for which very few data were known, we simply assumed that $M_1 \approx 2$ $M_\odot$ and $R_1 \approx 2.5$ $R_\odot$, which are typical values for Am stars.

4.5 Minimum masses and separations of the spectroscopic companions

The mass function of a spectroscopic binary can be defined as:

$$f(m) = M_1 \sin^3 i\, \mu^3/(1+\mu)^2 \qquad (1)$$

where $\mu = M_2/M_1$ is the mass ratio of the components (1 = primary, 2 = secondary). When using for each system the mass M_1 quoted in line 15 of Table 11, the relation (1) gives, with $i = 90°$, the minimum value of μ, from which we can derive $M_{2,\,\rm min}$, the minimum value of the mass of the companion (line 17 of Table 11).

Table 9. Radial velocities and $(O-C)$ residuals for BD +44°4512.

Date (JD) 2400000+	Cycle	RV km s^{-1}	$(O-C)$ km s^{-1}
50479.27	−0.66	−20.3	1.1
50480.27	−0.46	−33.9	0.0
50481.26	−0.26	−6.2	1.3
50482.28	−0.06	20.9	−1.1
50740.40	51.55	−35.1	−1.4
50741.55	51.78	−1.5	−0.9
50745.50	52.57	−34.0	−1.6
50746.45	52.75	−4.6	0.1
50835.32	70.52	−33.6	1.0
50836.31	70.72	−11.4	−0.3
50837.31	70.92	20.7	0.5
50838.29	71.12	15.4	−0.9
51106.45	124.73	−10.2	−0.1
51107.42	124.92	18.6	−1.5
51108.42	125.12	16.2	0.2
51108.58	125.15	12.0	0.4
51109.29	125.29	−13.5	−0.3
51109.43	125.32	−19.2	−1.2
51110.45	125.53	−34.0	0.5
51186.31	140.69	−15.0	1.3
53011.32	505.54	−33.9	0.0
53012.29	505.73	−8.4	0.0
53014.34	506.14	13.5	0.9
53261.50	555.56	−33.2	−0.1
53262.45	555.74	−6.5	0.0
53343.31	571.91	20.3	1.0
53343.45	571.94	21.4	−0.2
53344.35	572.12	15.9	−0.3
53345.37	572.32	−19.1	−0.9
53626.41	628.51	−35.1	−0.3
53705.32	644.28	−9.9	1.3
53705.43	644.30	−14.1	1.2
53746.35	652.48	−35.8	−1.1
53747.26	652.67	−18.6	1.6

The mean linear separation a between the two components of a binary system is:

$$a = a_1(1+1/\mu) = a_1 \sin i(1+1/\mu)/\sin i \qquad (2)$$

where a_1 is the semi-major axis of the orbit of the primary relative to the centre of mass of the system. The value of $a_1 \sin i$ can be derived from the orbital elements (col. 8 of Table 10), but unfortunately the inclination i is unknown. The relations (1) and (2) can lead to an estimate of the separation a, provided that an assumption is made on the value of i. According to Carquillat et al. (1982) the values obtained in this way have a very small dependency on the value assumed for i. For the eight SBs of our small sample we computed the values of a for $20° < i < 90°$ (range of 94% likelihood) with the constraint that $\mu < 1$, which sometimes reduced this range. The mean values and the corresponding ranges of uncertainties are given in Table 11 (lines 18 and 19).

The third body of the triple system of HD 32893 was also considered and we estimated its minimum mass $M_{3,\,\rm min}$ and its distance a' from the short-period system. In the formulae (1) and (2) we replaced M_1 with $(M_1 + M_2)$, the total mass of the short-period system, and we set $\mu =$

Table 10. Orbital elements of the 8 new SB. T_0: periastron passage epoch for eccentric orbits, ascending node passage epoch for circular orbits. Column 1, HD 32893: (s) short-period system, (l) long-period system.

HD/BD	P (d)	T_0 (JD) 2400000+	ω (°)	e	K_1 (km.s^{-1})	V_0 (km.s^{-1})	$a_1 \sin i$ (Gm)	$f(m)$ ($M_\odot$)	$\sigma_{(O-C)}$ (km.s^{-1})
32893 (s)	2.175561	50747.305	—	0.0	49.84	var.	1.491	0.0280	0.55
	±0.000002	± 0.002			±0.13		0.004	± 0.0002	
" (l)	1136.7	51173.2	185.0	0.848	9.76	14.21	81.0	0.0164	
	±1.5	±2.0	±2.7	±0.010	±0.27	±0.13	±4.8	±0.0029	
60489	67.9501	50495.89	100.6	0.422	13.71	43.56	11.62	0.0136	0.74
	±0.0088	±0.55	±4.8	±0.021	±0.43	±0.22	±0.50	±0.0017	
109762	34.1863	50850.25	65.5	0.135	26.29	−13.11	12.24	0.0627	0.71
	±0.0021	±0.35	±3.4	±0.009	±0.24	±0.18	±0.13	±0.0019	
111057	3.848018	53091.727	—	0.0	15.96	−1.72	0.8446	0.00162	0.45
	±0.000048	±0.009			±0.12	±0.09	±0.0066	±0.00004	
113697	539.9	46696.8	54.4	0.675	9.93	1.32	54.4	0.0220	0.97
	±1.4	±9.7	±3.1	±0.034	±0.52	±0.18	±5.3	±0.0063	
204918	5.04496	53262.446	—	0.0	18.21	−30.21	1.263	0.00316	0.79
	± 0.00017	±0.019			±0.22	±0.15	±0.015	±0.00011	
219675	531.40	49833.	88.3	0.197	4.56	10.20	32.7	0.00494	0.38
	±0.84	±15.	±8.9	±0.024	±0.13	±0.09	±1.1	±0.00049	
+44° 4512	5.002094	50482.563	—	0.0	29.34	−5.51	2.018	0.01312	0.90
	±0.000025	±0.009			±0.24	±0.17	±0.017	±0.00032	

Table 11. Physical parameters derived from Strömgren indices, parallaxes, orbital elements and theoretical data. The indices 1 and 2 refer to the primary (Am) or the secondary stars, respectively.

(1)	HD (BD)	32893	60489	109762	111057	113697	204918	219675	+44°4512
(2)	HIP	24108	28432	—	62341	63806	106184	115011	—
(3)	V	6.74	6.55	8.58	8.46	8.47	6.77	6.73	10.19
(4)	$B-V$	0.30	0.23	0.27	0.23	0.34	0.31	0.37	0.32
(5)	E_{B-V}	0.03	0.01	0.00	0.00	0.00	0.04	0.00	—
(6)	$v \sin i$ (km.s^{-1})	10.0	24.0	20.5	10.6	23.8	11.4	21.3	18.9
		±1.0	±2.4	±1.5	±1.3	±2.4	±1.6	±2.1	±1.0
(7)	π (mas)	11.63	6.98	—	5.72	6.07	8.15	6.23	—
		±0.88	±0.83		±1.07	±0.95	±0.60	±1.31	
(8)	d (pc)	86	143	—	175	165	123	161	—
(9)	M_V	1.98	0.74	—	2.25	2.39	1.21	0.70	—
		±0.16	±0.26		±0.41	±0.34	±0.16	±0.46	
(10)	M_{V_1}	2.06	0.82	1.71	2.33	2.47	1.29	0.94	—
		±0.17	±0.26	±0.36	±0.41	±0.34	±0.17	±0.46	
(11)	$T_{\mathrm{eff}\,1}$ (K)	7900	7650	7500	7950	7200	7700	7200	—
		±100	±100	±100	±100	±100	±100	±100	
(12)	$\log(L_1/L_\odot)$	1.064	1.560	1.200	0.956	0.900	1.372	1.512	—
		±0.068	±0.104	±0.144	±0.164	±0.136	±0.068	±0.184	
(13)	$\log g_1$ (cgs)	4.3	3.6	4.1	4.2	4.0	4.1	3.7	—
(14)	$[Fe/H]_1$ (dex)	0.42	0.18	0.49	0.62	0.12	0.45	0.86	—
(15)	M_1 ($M_\odot$)	1.80	2.20	1.85	1.70	1.60	2.00	2.15	≈2
		±0.05	±0.10	±0.15	±0.10	±0.10	±0.05	±0.15	
(16)	R_1 ($R_\odot$)	1.8	3.4	2.3	1.6	1.8	2.7	3.6	≈2.5
		±0.2	±0.5	±0.4	±0.3	±0.3	±0.3	±0.9	
(17)	$M_{2\min}$ ($M_\odot$)	0.5	0.5	0.8	0.2	0.5	0.3	0.3	0.4
(18)	a ($R_\odot$)	10.0	103.1	64.3	13.1	381	16.8	388	17.6
		±0.8	±6.8	±4.0	±0.4	±28	±1.0	±20	±1.3
(19)	a (au)		0.48	0.30		1.8		1.8	
			±0.03	±0.02		±0.1		±0.1	
(20)	Synchronism?	Likely	No	No	Likely	No	Likely	No	Likely
(21)	log [age (yr)]	$8.80^{+0.05}_{-0.10}$	$8.88^{+0.04}_{-0.04}$	$9.00^{+0.02}_{-0.04}$	< 8.82	$9.05^{+0.05}_{-0.25}$	$8.93^{+0.02}_{-0.02}$	$8.93^{+0.07}_{-0.03}$	—

Table 12. Strömgren photometry (subscript 0 refers to de-reddened indices).

HD	β	$b-y$	E_{b-y}	m_1	$(m_1)_0$	c_1	$(c_1)_0$	$(\delta m_1)_0$
32893	—	0.169	0.02	0.220	0.23	0.752	0.75	−0.02
60489	2.800	0.135	0.01	0.199	0.20	0.969	0.97	0.00
109762	2.778	0.164	0.00	0.224	0.22	0.791	0.79	−0.03
111057	2.828	0.125	0.00	0.249	0.25	0.836	0.84	−0.04
113697	2.745	0.196	0.00	0.175	0.18	0.724	0.72	0.01
204918	—	0.195	0.03	0.215	0.23	0.776	0.77	−0.03
219675	—	0.218	0.00	0.248	0.25	0.701	0.70	−0.07

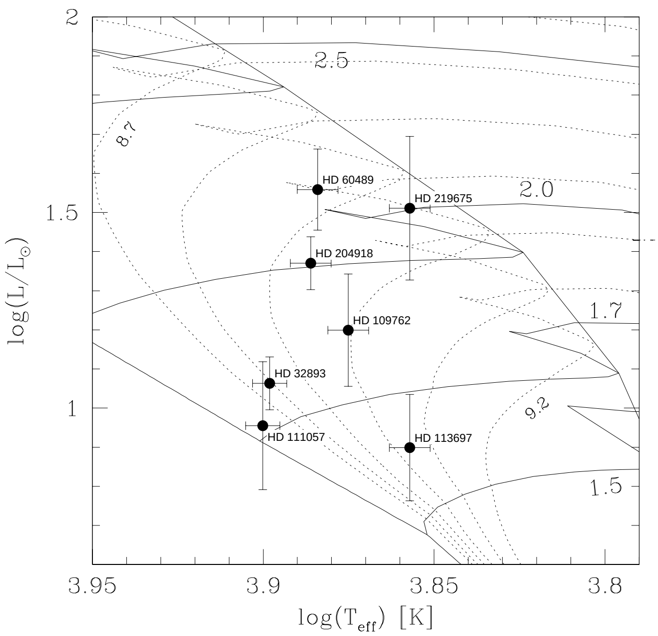

Figure 3. Location of the primary components of the eight new SB1s in the theoretical HR diagram computed by Schaller et al. (1992) for $Z = 0.02$, with the isochrones (dotted lines) given by Meynet et al. (1993), for log age[years] varying from 8.7 to 9.2 by steps of 0.1. The solid lines correspond to the evolution tracks for mass values of 1.5, 1.7, 2.0 and 2.5 M$_\odot$.

$M3/(M1+M2)$. The value of $M_{3\,\rm min}$ corresponds to the case when $i = 90°$ with $(M_1 + M_2)_{\rm min} = 1.8 + 0.5 = 2.3$ M$_\odot$ (see Table 11, col. 2, lines 15 and 17). We thus found: $M_{3\,\rm min} = 0.5\ M_\odot$, which is similar to what we obtained for $M_{2\,\rm min}$. The maximum value corresponds to a mass ratio unity for the short-period system, i.e. $(M_1 + M_2)_{\rm max} = 3.6$ M$_\odot$. For a', we computed the mean of the two values obtained for a' when using the minimum and maximum values for M_1+M_2, and found $a' = 3.5 \pm 0.5$ au. At 86 pc, which is the distance derived from the Hipparcos parallax, this value corresponds to an angular separation of 0.041 ± 0.009 ″(taking also into account the error on the parallax). According to the high eccentricity of the orbit ($e \approx 0.85$), a separation near 0.075″could be reached at the apastron. Hence the third companion could be detected by speckle interferometry with a 2-meter class telescope, provided it is not too faint (i.e. $\Delta m_V < 3$ mag).

5 ROTATION-REVOLUTION SYNCHRONISM

In this section we test the occurrence for the studied systems of rotation-revolution synchronism that is the consequence of gravitational tidal effects. More details about this procedure can be found in Papers VI and VII.

For a circular orbit, the orbital period P of the system, the radius R of the considered component ant its equatorial rotational velocity v verify the relation $v = R/P$ when synchronism is reached. Using the following units: P in days, R in solar radii and v in km.s^{-1}, this relation becomes:

$$v = 50.6(R/\mathrm{R}_\odot)/P. \quad (3)$$

Practically, we only have access to the projected equatorial velocity $v \sin i$. The relation (3) implies that:

$$v \sin i < 50.6\ (R/\mathrm{R}_\odot)/P \quad (4)$$

This inequality constitutes a test for synchronism.

For the systems formed with highly eccentric orbits the evolution is much slower. Hut (1981) has shown that such systems reach first a state close to synchronism, called *"pseudo-synchronism"* before the orbit is circularised. The test of pseudo-synchronism uses also the inequality (4) with a small change: P is replaced by the pseudo-period P_{ps} defined as:

$$P_{\rm ps} = P\ \frac{(1 + 3\,e^2 + \frac{3}{8}\,e^4)\,(1 - e^2)^{3/2}}{1 + \frac{15}{2}\,e^2 + \frac{45}{8}\,e^4 + \frac{5}{16}\,e^6} \quad (5)$$

We derived the values of $v \sin i$ for our eight systems from the width of the correlation dips obtained with CORAVEL (reported in Table 11, line 6) using the calibration given by Benz & Mayor (1981). We thus applied the test (4) to the primary components of HD 32893, 111057, 204918 and BD +44°4512 which have circular orbits, and found that those velocities were compatible with the values of R_1 reported in line 16 of Table 11. For the four other systems, HD 60489, 106762, 113697 and 219675 with an eccentric orbit, we found that P_{ps} are 31.1, 30.8, 94.4 and 430 d, respectively, which lead to negatives tests: the primaries still rotate too fast. Those results, reported in line 20 of Table 11, are in agreement with what we have obtained in our series of papers: the Am primary stars belonging to SB systems with short periods ($P \lesssim 10$ d) and circular orbits verify the synchronism tests, whereas most of the primaries of the other systems with longer periods and eccentric orbits rotate too fast.

6 FINAL RESULTS OF OUR RV SURVEY OF 91 AM STARS

In this section we present the final results of the RV survey of our sample of 91 Am stars, whose full list can be found in Tables 13 and 14.

6.1 Presentation of the data

When we started this study in the mid-1980's, none of the stars belonging to our sample had known SB orbital elements. We are now able to present in Table 13 the orbital elements of 53 double or multiple spectroscopic systems from this sample. The references of the corresponding papers are indicated in the last column. Most of the data come from this series of papers (see Table 1), but additional references were used for:

- HD 66068/9, 83270/1, 177390/1: for historical reasons, the orbits of those objects were published in our series of papers devoted to composite-spectrum stars, because those Am objects were misclassified;
- HD 43478, 51565 A and B, 67911, 73045, 73174, 96391: their orbits were published in collaboration with colleagues of Cambridge or Geneva;
- HD 105680, 140122 A and B, 208132: their orbits were published by other authors before the end of our investigation.

Table 14 contains the RV data we have collected about the remaining 38 stars. When the RVs can be considered as constant, the average value and its estimated error is given in col. 7. Otherwise the mention "var" indicates it is variable. For each object, we give the number N of observations in col. 5 and the range of epochs concerned in col 6. When N is small or RVs are variable, we give the individual measures separately (Table 15). This is indicated with an asterisk in col. 5.

The analysis of this data have led to the following conclusions:

- 31 stars have not shown significant RV variations during our observing runs.
- 3 stars (HD 40602, 101393 and 151235) were found as having a variable RV but with an insufficient number of observations for deriving an orbit;
- 3 stars (HD 104957, 112431 and 154392) do not show significant RV variations but the small number of observations precludes us from deriving any conclusion;
- one star (HD 200407) is perhaps variable in RV, but here also more observations are needed for confirmation.

6.2 Rate of Am stars belonging to SB systems

Among our sample of 91 Am stars observed with CORAVEL, 58 objects have been identified as SBs: the 55 entries of Table 13 and three other stars (HD 40602, 101393 and 151235) recognized as having a variable RV (see Table 14). This number of SBs corresponds to a rate of 64%, which is significantly larger than the rate of 47$\pm$3% found by Jaschek & Gómez (1970) for a sample of 295 normal A-type stars. Note that they find that the rate of SBs is constant along the main sequence with a total value of 47 ± 5% for their whole sample of 746 normal main sequence stars.

We reach the same conclusion when comparing with the investigation of Duquennoy & Mayor (1991) who studied a sample of 164 nearby solar-type stars and concluded that "only about one third of the G-dwarf primaries may be real single stars". Since their estimation also included visual binaries, we should now consider, for comparison, the total number of binaries in our sample. When adding the 12 visual binaries that have not been detected as SBs of Table 14 to the 58 SBs that we have found, it appears that 70 Am stars at least are binaries. We conclude that at least 77% of the Am stars of our sample belong to binary systems. This is again larger than the proportion of 2/3 found by Duquennoy & Mayor (1991).

As for the distribution between double-lined (SB2) and single-lined (SB1) among the 58 SBs in the sample, we count only 12 SB2s (21% of the SBs, or 13% of the sample). Note that this value should be considered as a minimum estimate since the detection as SB1 or SB2 strongly depends upon the used instrument. For example, HD 67911 and HD 126031 are quoted as SB2s (Table 13) because of the contribution to our observations of the ELODIE spectrometer (Baranne et al. 1996) mounted on a 2-m telescope, which permitted the detection of the secondary.

In Table 16 we give, for the SB2s of our sample, the values obtained for the mass ratio $\mu = M_2/M_1$ of the two components (col. 2) and the estimates i_0 of the inclinations of those systems (col. 3), derived when assuming that $M_2 = 2 \pm 0.4$ M$_\odot$. In the notes, EB indicates that the system is an eclipsing binary and in this case, we give the more accurate value found for its inclination i and the mass M_1 derived for the primary star. The values of i_0 show that a necessary condition for detecting SBs seems to be $i \gtrsim 10°$.

There are 60 orbits reported in Table 13, although the number of concerned Am stars is only of 53. This is explained by the presence of multiple systems in our sample: 5 triple spectroscopic systems (HD 7119, 32893, 73174, 83270/1 and 100054 B) and 2 quadruple systems that both include 2 SBs (HD 51565/6 and 140122). Note also that 5 other SBs belong to close visual pairs (with $\rho < 1''$): HD 61250, 151746, 155714, 195692 and 219675.

In Table 14, we see that 31 Am stars seemed to have a constant RV, which represents 34% of our sample. We find a similar proportion in the other sample of 60 bright Am stars studied by Abt & Levy (1985). This rate should be considered as a maximum value of the fraction of the single stars present in those samples, because some SBs may have not been detected, either because they have a long period and a very eccentric orbit, or because their inclination is too small with $i \lesssim 10°$. The latter possibility has nevertheless a negligible influence on the observed rate since the probability to see a system near "pole-on" with $i < 10°$ is only 1.5 %.

Note that 12 stars among those 31 objects belong to visual binary systems (see Table 14, col. 8).

7 STATISTICS ON A SAMPLE OF 89 SB ORBITS OF AM STARS

In this section we examine some properties of the orbital elements of the SBs whose primary is an Am star. To improve the validity of those statistics, we have added to our sample

Table 13. Orbital elements obtained of our list of Am stars (begin.). T_0: periastron passage for elliptic orbits, ascending node passage for circular orbits. For triple spectroscopic systems, (l) and (s) in col. 1 indicate long and short period systems, respectively.

HD (BD)	P (days)	T_0 (JD) 2400000+	ω (°)	e	K_1 K_2 (km.s^{-1})	V_0 (km.s^{-1})	$a_1 \sin i$ $a_2 \sin i$ (Gm)	$M_1 \sin^3 i$ $M_2 \sin^3 i$ (M$_\odot$)	$f(m)$ (M$_\odot$)	$v_1 \sin i$ $v_2 \sin i$ (km.s^{-1})	References Notes
341	6.24268	48941.63	299.1	0.010	32.46	−3.19	2.79		0.0221	11.7	Paper V
3970	39.5743	48945.06	148.6	0.521	18.17	0.52	8.44		0.015	29.1	Paper VII
7119 (s)	6.761504	48945.35	7.7	0.028	42.48	var	3.945	0.262	0.054	12.8	Paper III
					46.81		4.350	0.237		7.8	SB2
” (l)	1867	50684.4	—	0.0	3.00	−10.94	69.61		0.0047	—	sp. triple system
19342	42.6301	49323.630	—	0.0	26.80	6.16	15.71		0.0853	9.9	Paper VI
19910	15.41418	49325.46	67.2	0.059	45.77	11.64	9.68		0.1526	14.1	Paper VI
32893 (s)	2.175561	50747.305	—	0.0	49.84	var.	1.491		0.0280	10.0	This paper
” (l)	1136.7	51173.2	185.0	0.848	9.76	14.21	81.0		0.0164	—	sp. triple system
35035	1025.21	49357.9	14.0	0.613	15.59	43.51	173.7		0.199	22.1	Paper VII
36360	216.54	49129.1	116.1	0.112	12.37	13.90	36.60		0.0417	20.0	Paper VI
41724/5	2.887679	46337.619	—	0.0	71.7	10.9	2.85		0.111	25.0	Carquillat et al. 1988
43478	5.464086	47000.176	—	0.0	86.48	−6.63	6.498	1.777	0.367	28.1	North et al. 1998a
					95.03		7.14	1.617		20.6	V406 Aur. EB
51565/6 A	6.766301	47995.05	280.8	0.027	44.76	−11.20	4.163		0.06293	14.0	Griffin et al. 1997
51565/6 B	4.48131	48160.45	11.0	0.0	16.54	−13.18	1.019		0.00212	—	quadruple system
55822	5.12294	48673.60	70.6	0.122	40.20	30.87	2.81		0.0338	21.0	Paper V
60489	67.9606	50495.07	94.6	0.400	13.35	43.30	11.43		0.0129	24.0	This paper
61250	2.23024	48939.29	—	0.0	25.37	−5.43	0.78		0.00378	25.2	Paper V
66068/9	7.747993	47600.690	341.1	0.418	56.07	−21.06	5.425	0.776	0.106	27.3	Carquillat et al. 1994
					75.06		7.265	0.580		9.1	
67317	4.43324	49321.05	—	0.0	33.23	6.37	2.03		0.0169	12.6	Paper V
67911	12.50736	49998.763	—	0.0	40.01	−1.15	6.881	0.896	0.083	11.7	Carrier et al. 2002a
					63.90		10.992	0.561		3.9	CQ Lyn. δ Sct var
73174 (s)	5.97012	49996.23	—	0.009	41.73	var	3.410		0.0444	7.3	Debernardi et al. 2000
” (l)	2878	45931	203.8	0.417	4.60	35.56	165.6		0.0221	—	sp. triple system
73045	435.57	49722.0	28.8	0.320	11.89	35.20	68.01		0.0662	14.1	Debernardi et al. 2000
81976	5.655750	49785.941	341.4	0.061	61.68	19.85	4.788	0.5875	0.137	14.7	Paper II
					63.84		4.956	0.5676		14.4	
83270 (s)	5.821433	45343.878	—	0.0	44.24	var	3.54		0.0523	—	Ginestet et al. 1991
” (l)	635.4	45464.5	135.4	0.149	9.37	10.84	80.9		0.0524	—	sp. triple system
93946	3.55527	53091.29	220.5	0.014	48.02	3.36	2.347		0.0409	25.3	Paper VII
93991	3.20858	48675.01	—	0.0	16.46	−15.33	0.73		0.00149	26.2	Paper V
96391	4.915427	45234.242	—	0.0	84.69	−1.67	5.724	1.408	0.310	23.5	North et al. 1998a
					90.19		6.10	1.322		18.0	
98880	14.20783	48682.883	—	0.0	42.47	2.40	8.298	0.6091	0.113	10.6	Paper II
					49.16		9.604	0.5262		9.2	
100054B (s)	12.79430	49781.19	137.0	0.028	18.69	var	3.29		0.0087	5.6	Paper IV
” (l)	874.2	49377.0	172.0	0.097	5.30	−13.52	63.4		0.013	—	sp. triple system
102925	16.43718	49798.439	—	0.0	26.62	−0.89	6.02		0.0322	8.0	Paper VI
105680	70.0795	45991.19	192.6	0.380	30.75	−5.13	27.42		0.1676	13.9	Carrier et al. 2002b
109762	34.1863	50850.25	65.5	0.135	26.29	−13.11	12.24		0.0627	20.5	This paper
111057	3.848157	53091.716	—	0.0	15.83	−1.72	0.8374		0.00158	10.6	This paper
113697	539.9	46696.8	54.4	0.675	9.93	1.32	54.4		0.0220	23.8	This paper
125273	7.482664	48665.660	355.3	0.071	49.82	−17.42	5.113	0.412	0.095	11.0	Paper I
					51.75		5.311	0.396		10.7	
126031	3.782624	50480.328	—	0.0	82.23	−28.37	4.277	1.600	0.218	24.4	Paper VI
					110.10		5.727	1.195		—	DV Boo. EB
127263	14.23834	50488.062	248.6	0.319	24.87	−14.07	4.62		0.01936	11.0	Paper VI
138406	25.8513	49792.55	9.8	0.213	10.75	−6.68	3.73		0.00311	6.6	Paper VI
140122A	10.880	52015.0	345	0.10	13.5	0.7	2.00	0.030	0.0027	13.5	Fekel 2004
					21.6		3.21	0.018		—	
140122B	15.770	52537.5	283	0.29	7.0	3.1	1.6		0.0007	—	quadruple system
151604	19.69858	53063.355	296.1	0.566	71.39	−14.35	15.94	1.724	0.417	11.0	To be published
					72.55		16.20	1.696		11.5	V916 Her. EB
151746	4.83737	52826.205	—	0.0	31.78	−14.02	2.114		0.0161	13.1	Paper VII
153286	3458.18	49051.3	185.3	0.367	5.67	−11.41	251.0		0.053	7.3	Paper VII
155714	3.334772	49144.192	—	0.0	6.28	−43.63	0.288		0.000086	17.4	Paper VI
162950	10.04288	49153.90	257.9	0.205	11.87	7.03	1.60		0.00164	8.8	Paper V

Table 13. Orbital elements obtained for our list of Am stars. T_0: periastron passage for elliptic orbits, ascending node passage for circular orbits (cont.).

HD (BD)	P (days)	T_0 (JD) 2400000+	ω (°)	e	K_1 K_2 (km.s^{-1})	V_0 (km.s^{-1})	$a_1 \sin i$ $a_2 \sin i$ (Gm)	$M_1 \sin^3 i$ $M_2 \sin^3 i$ (M$_\odot$)	$f(m)$ (M$_\odot$)	$v_1 \sin i$ $v_2 \sin i$	References Notes
177390/1	8.00802	46335.165	—	0.0	27.8	−19.9	3.06	0.085	0.018	8.0	Carquillat et al. 1988
					30.3		3.34	0.078		9.0	
187258	25.8048	49628.91	165.9	0.370	17.36	−34.76	5.72		0.011	11.4	Paper IV
195692	11.292249	48138.102	—	0.0	39.92	−25.49	6.20		0.0746	9.6	Paper VI
199360	1.9986874	49640.743	—	0.0	11.74	4.90	0.323		0.000336	13.5	Paper VI
204751	59.6993	52475.31	320.9	0.867	19.78	−24.44	8.08		0.0059	27.3	Paper VII
204918	5.04496	53262.446	—	0.0	18.21	−30.21	1.263		0.00316	11.4	This paper
208132	8.30344	50039.24	72.9	0.194	21.80	7.61	2.442		0.00843	14.0	Griffin 2003
219675	531.40	49833.	88.3	0.197	4.56	10.20	32.7		0.00494	21.3	This paper
224002	19.8059	49657.33	109.0	0.107	32.21	−19.48	8.72		0.068	38.8	Paper VII
224890	9.54640	48971.19	85.6	0.214	10.89	−8.02	1.40		0.00119	11.9	Paper V
225137	4.33346	49326.559	—	0.0	56.42	0.94	3.36		0.0808	19.1	Paper V
BD+44°4512	5.002094	50482.563	—	0.0	29.34	−5.51	2.018		0.01312	18.9	This paper

Table 14. Other stars of the whole Am sample. For the stars with an asterisk in Col. 5, individual RVs are displayed in Table 15.

HD	HIP	V	$B-V$	N	Epoch	RV (km.s^{-1})	Notes
1714	1722	8.50	0.35	9	1993...2005	5.6±0.4	
1732	1748	7.75	0.33	10	1992...2005	5.3±0.6	
5128	4212	6.27	0.19	12	1992...2005	−2.4±0.6	ADS 735 A
13929	10690	7.45	0.25	12	1992...2006	−3.0±0.5	
15385	11578	6.19	0.16	10	1992...2005	22.0±0.7	
16763	12540	6.99	0.27	14	1992...2005	24.5±1.0	ADS 2050 AB
16932	—	8.2	—	11	1997...2005	5.9±0.5	
18460	14013	8.44	0.36	10	1994...2005	−11.3±0.3	
21437	16143	6.72	0.45	9	1993...2005	−9.1±0.3	ADS 2546 AB
29193	21465	7.35	0.32	10	1993...2005	4.3±0.4	ADS 3329 AB
40602	28432	7.90	0.37	11	1992...2004	var	Now studied by R. Griffin
56820	35735	6.36	0.28	15	1992...2005	5.0±1.1	ADS 5995 AB. Wide dip.
62257	37898	7.54	0.19	8	2004...2006	13.2±0.5	
76461	43976	6.99	0.27	9	1993...2005	33.9±1.0	Wide dip
90931	51457	6.86	0.32	11	1992...2005	0.5±0.7	
95190	53727	7.24	0.25	10	1997...2006	1.1±0.5	ADS 8003 AB
101393	56940	9.05	0.29	9*	2004...2006	var	
104957	58937	8.87	0.26	4*	2005...2007	−17.3±0.8?	
105601	59271	7.38	0.29	10	1992...2005	−59.8±0.9	High proper−motion star
105702	59309	5.72	0.35	10	1992...2005	−6.2±0.7	11 Vir
105967	59451	6.93	0.15	9	1997...2006	−1.8±0.5	
109764	61579	6.59	0.25	8	1995...2005	−1.4±0.2	
109782	61584	7.67	0.40	10	1992...2005	−4.1±0.5	ADS 8611 AB
110248	61851	7.65	0.30	10	1992...2005	−9.1±0.5	Variable star
112431	63135	8.93	0.21	4*	2005...2007	−5.0±0.4?	
124587/8	69523	6.80	0.34	10	1992...2005	−8.3±0.9	ADS 9174 AB. Wide dip
144999	79010	7.74	0.23	8	2003...2006	−25.2±0.4	ADS 9930 AB
151235	81929	8.97	0.28	4*	2005	var	Wide dip
154392	83445	8.65	0.25	4*	2005...2007	−52.1±1.3?	Wide dip
158116	85327	7.68	0.29	9	1993...2005	−24.5±0.5	ADS 10553 A
158251	85434	7.24	0.28	10	1993...2006	−15.2±0.7	ADS 10560 AB
188593	—	8.52	0.28	8	1994...2005	−25.9±0.5	
190145	98357	7.56	0.26	8	2003...2005	−16.4±0.7	
190401	98728	7.00	0.35	8	1994...2005	−29.3±1.0	
200407	103779	6.74	0.31	7*	2004...2005	var ?	ADS 14560 AB. Wide dip.
201033	104051	8.04	0.26	8	1994...2005	−25.2±0.3	
222770	117010	7.63	0.30	11	1992...2006	−11.8±0.4	
223247	117360	8.13	0.30	17	1992...2006	−3.8±1.0	Wide dip

Table 15. Individual RVs for HD 101393, 104957, 112431, 151235, 154392 and 200407.

HD	Date (JD) 2400000+	RV (km.s^{-1})	σ_{RV} (km.s^{-1})
101393	53088.47	10.4	0.5
"	53089.44	10.8	0.9
"	53090.53	11.8	0.8
"	53091.43	10.7	0.5
"	53343.73	11.9	0.5
"	53446.47	8.6	0.4
"	53447.56	8.4	0.5
"	53704.72	4.6	0.8
"	53747.54	5.8	0.5
104957	53447.63	−16.4	0.4
"	53448.52	−17.1	0.4
"	53746.70	−18.2	0.7
"	54134.74	−17.5	0.5
112431	53446.53	−5.3	0.4
"	53447.57	−5.2	0.5
"	53448.60	−4.5	0.9
"	54134.73	−5.1	0.5
151235	53447.62	−36.5	0.7
"	53448.63	−33.0	0.8
"	53627.31	−0.7	0.9
"	53628.30	−4.9	1.0
154392	53446.61	−51.6	0.6
"	53447.69	−53.1	0.7
"	53626.31	−50.4	0.8
"	54209.58	−53.1	0.7
200407	53260.41	−5.0	0.8
"	53261.47	−6.0	0.5
"	53262.42	−6.3	0.4
"	53344.26	−4.3	0.5
"	53345.27	−3.7	0.4
"	53626.34	−3.7	0.5
"	53706.29	−3.0	0.5

Table 16. SB2s of our program Am stars: mass ratio $\mu = M_2/M_1$ in col. 1 and inclination estimates i_0 in col. 2, assuming that $M_2 = 2 \pm 0.4$ M$_\odot$.

HD	μ	i_0 (degrees)	Notes
7119	0.905	31^{+2}_{-2}	
43478	0.910	74^{+16}_{-9}	EB: i=79°, $M_1 = 1.88$ M$_\odot$
66068/9	0.747	47^{+5}_{-4}	
67911	0.626	50^{+6}_{-4}	
81976	0.966	42^{+4}_{-3}	
96391	0.939	63^{+10}_{-6}	
98880	0.864	42^{+4}_{-3}	
125273	0.961	36^{+4}_{-2}	
126031	0.747	68^{+22}_{-7}	EB: i=83°, $M_1 = 1.64$ M$_\odot$
140122A	0.60	14^{+1}_{-1}	
151604	0.984	72^{+18}_{-8}	EB: still in study
177390	0.92	20^{+2}_{-1}	

some Am stars studied by Abt & Levy (1985). From their initial sample of 35 Am stars in SB systems (table 3 of their paper), we have selected 29 objects for which the quality of the orbit was good enough, and discarded the stars for which the orbital elements were qualified by the authors of "uncertain" or "marginal". In this way our sample of 60 orbits (Table 13) could be extended to 89 SB orbits involving 82 Am stars. In what follows, this set will be called "extended SB sample".

7.1 Distribution of the orbital periods

The histogram of the periods P smaller than 100 d is plotted in Fig. 4a with a step of 2 d and the histogram of $\log P$ of the extended SB sample in Fig. 4b. Both distributions show a well-marked peak at $P \approx 5$ d. Note also that most of those binary stars have a small period: 2/3 of the sample systems have a period smaller than 20 d. This result is in agreement with those of past investigations (Abt 1961, Ginestet et al. 1982): the Am binaries are mostly encountered in tight SBs. This puts to light the key role played by tidal effects through the spin-orbit synchronism that reduces the axial rotation of the stars in such systems which in turn triggers the formation of Am-stars, according to the generally admitted theory (see Sect. 1). Indeed, in his pioneering comparative study of normal and Am stars, Abt (1965) found two main differences concerning the equatorial velocities and orbital periods: normal A stars rotate more quickly, with $v \sin i$ in the range 50-250 km.s^{-1} and belong to long-period systems, with $P > 100$ d. This absence (or strong deficit) of A stars in systems with $P < 100$ d was confirmed by subsequent studies (Abt & Bidelman 1969, Ginestet et al. 1982), who showed that the domain with 2.5 d $< P <$ 100 d mutually excludes A and Am binaries.

Another feature of the Am stars clearly visible in our sample (see Table 13, col. 2) is the lack of systems with very short periods (i.e., less than 1.3 d). This property is also the consequence of the same phenomenon. Indeed, assuming for instance $R = 2.5$ R$_\odot$ for the radius of the star and $i = 90°$, a period shorter then 1.3 d implies that $v \sin i > 100$ km.s^{-1} which corresponds to the generally admitted superior limit for producing an Am star (Abt & Levy 1985).

In the long-period side of the distribution, we note 12 orbits (13 % of the sample) with $\log P > 2.5$ (i.e. $P \gtrsim 300$ d). Five of those are the long-period orbits of triple spectroscopic systems, but the others are not tightly bound to another star. Hence it appears, as previously pointed out by Abt (1965) and Ginestet et al. (1982) that some Am stars (i.e. 7 in our sample) also belong to long-period SBs, like normal A-type stars.

7.2 $\log P/e$ diagram

The e vs $\log P$ diagram plotted in Fig. 5 presents the general features of those of other star families, but it differs by the value of the critical period, $P_c = 5.6 \pm 0.5$ d, that separates the domains of eccentric and circular orbits. For comparison, other studies have found shorter values, with $P_c \approx 3.2$ d for Ap binaries (North et al. 1998b) and only $P_c \approx 0.6$ d for normal A stars (Gerbaldi, Floquet & Hauck 1985), whereas a longer value of about 11 d was found by Duquenoy & Mayor (1991) for nearby G dwarfs.

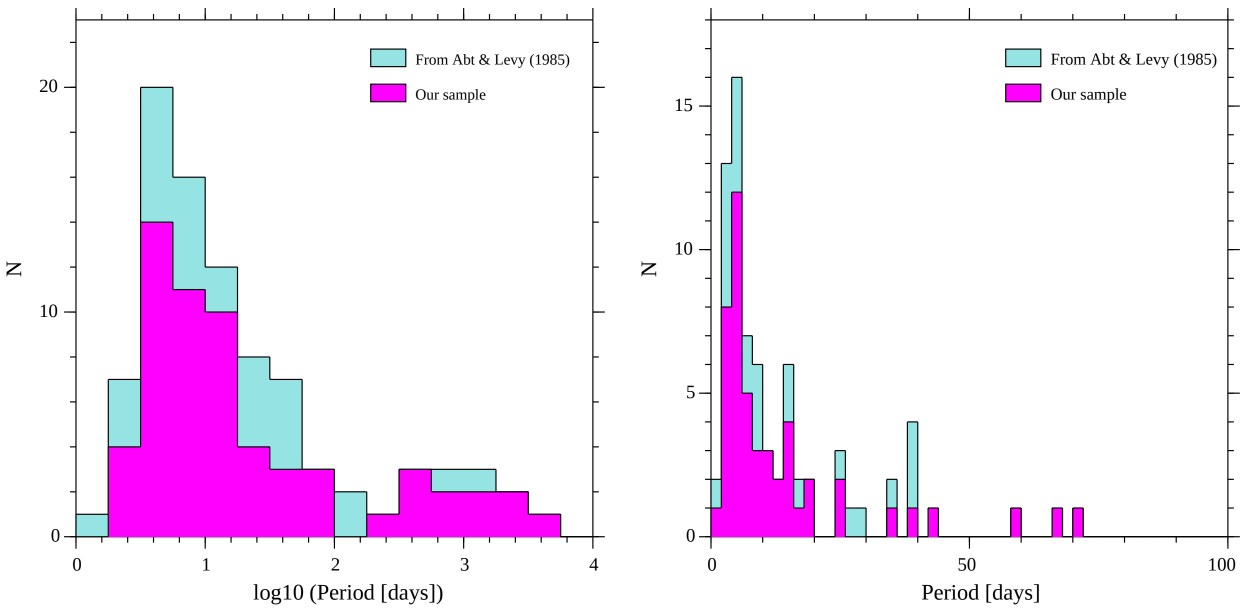

Figure 4. Distribution of the orbital period P for the extended SB sample of Am stars. Histograms of log(P) (left) and of P (right) limited to $P < 100$ d.

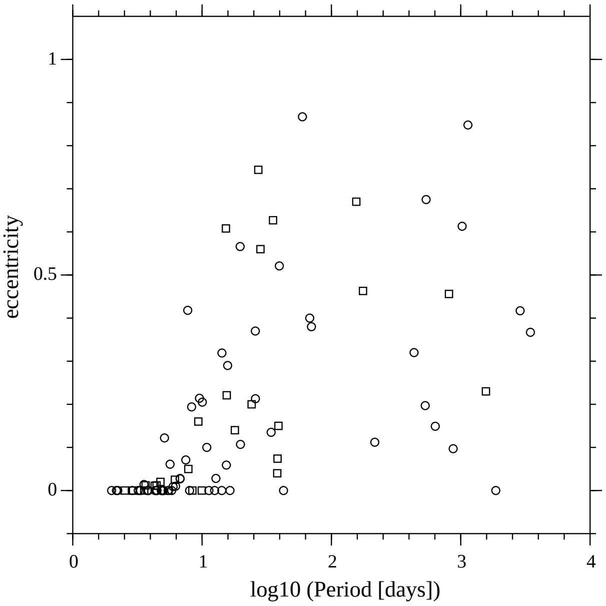

Figure 5. Diagram e vs log P for all the SBs of our sample of Am stars (circles) and the selection from Abt & Levy (1985) (squares).

The value of P_c is linked to the time necessary for the tidal effects to circularize the orbits: as time goes by, more and more systems are circularized. As a consequence P_c increases with time. For a given sample of stars P_c is an indicator of the age of this sample. From the calibration table of Duquenoy & Mayor (1991) derived from observations of stellar clusters, the typical age of the Am stars of our programme is found to be about 0.5–1 $\times 10^9$ yr. This is in agreement with the values obtained with the theoretical isochrones in the HR diagram (see Sect. 4.4 and the papers of this series).

7.3 Distribution of $f(m)$ and incidence on the mass distribution of the companions

In Sect. 4.5, we have seen that $f(m) = M_1 \sin^3 i\, \mu^3/(1+\mu)^2$ (Eq. 1). Although the values of M_1 and i are unknown for each system, we have some knowledge about their statistical distribution ($M_1 \approx 2 \pm 0.4$ M$_\odot$ and uniform orientation of the orbits). From the distribution of the 89 values of $f(m)$ obtained for the extended SB sample, it is thus possible to derive some constraints on the mass distribution of the companions.

We have studied this problem with a Monte-Carlo-type method, by writing and using specially-designed programmes. We first implemented a procedure to generate simulated samples of $f(m)$ compatible with the two theoretical mass distributions we wanted to test: a power-law distribution for which the number $N(m)$ of stars of mass m is proportional to $m^{-\alpha}$ and a Gaussian law $N(m) \propto \exp[-(m-m_0)^2/2\sigma_m^2]$ so that we could estimate the average mass m_0 of the companions from our study.

This procedure was based on the following steps:

- Generation of random samples of companions with masses following power-law or Gaussian distributions, and truncated to 2 M$_\odot$ (since the companions are assumed to be less massive than the Am primary stars).
- Generation of a random inclination for each companion, corresponding to a uniform orientation of the axes of the orbits in three dimensions.
- Computation of the corresponding $f(m)$ for each companion, using Eq. (1) and assuming $M_1 = 2$ M$_\odot$.

We were thus able to generate simulated samples whose distribution functions of $f(m)$ could be compared with the observed distribution of our extended SB sample of Am spectroscopic binaries. We then determined the best parameters for the power-law and Gaussian distributions by minimizing the corresponding residuals. We obtained $\alpha = 0.3 \pm 0.2$ for the power-law and $m_0 = 0.8$ M$_\odot$ with $\sigma_m = 0.5$ M$_\odot$ for the Gaussian distribution. The corresponding fits are displayed in Fig. 6. They are both in good agreement with the observed distribution within the error bars that we computed from a series of simulated samples with the same number of orbits than that of the extended SB sample (i.e., 89). Note that the small bump at $f(m) \approx 0.42$ M$_\odot$ can be explained by a selection effect favouring the study of eclipsing binaries (in Abt & Levy's sample).

We finally performed statistical tests to check the consistency of the two models with the observed sample of $f(m)$. This was done both with a χ^2-test which compares the distributions of $f(m)$ and with a Kolmogorov-Smirnov test which operates on the cumulative functions. The two tests led to the same conclusion: the sample is not significant at the 5% level for the two models. Hence both the power-law and the Gaussian distributions are compatible with the observed $f(m)$ distribution.

We also tested the influence of the truncation at around $i \approx 10^\circ$, due to the lower detection threshold for the SBs (see Table 16), and found that this effect was negligible for the distribution of $f(m)$.

The typical mass of $M_2 = 0.8 \pm 0.5$ M$_\odot$ found for the companions favours a spectral type of G-K-M V. This is in agreement with the small number of SB2 found in our sample (21% of the SBs in Sect. 6.2) and indicates that the contribution of the secondaries can be generally considered as negligible for the global photometric indices (e.g. $B-V$ and Strömgren indices). Those indices can thus, in most cases (like in Sect. 4.3), be affected to the primary components only, with a good approximation.

Since we have assumed that $M_1 = 2 \pm 0.4$ M$_\odot$, the typical mass found for $M_2 = 0.8 \pm 0.5$ M$_\odot$ corresponds to a mass ratio $\mu = 0.40 \pm 0.33$. This value is consistent with the value $\mu = 0.23 \pm 0.42$ found by Duquenoy & Mayor (1991) for their sample of main sequence solar-type stars. This would support the conclusions of those authors that most binaries are "formed by random association of stars from the same initial mass function". Am binaries seem to follow this rule, too.

7.4 Discussion on the mass distribution found for the companions

In his pioneering work, Salpeter (1954) found that the initial mass function (or IMF) of the stars between 0.4 and 10 M$_\odot$ could be approximated with a power-law $N \propto m^{-\alpha}$ with $\alpha = 2.35$. Subsequent observational studies have then shown that this law seemed rather universal, but with some possible variations of the value of this coefficient α according to the mass range. In a recent review, Kroupa (2001) finds that the available observational constraints are compatible with multi-part power-law IMF for single stars with values of α equal to 1.3±0.5, 2.3±0.3 and 2.3±0.7 for mass values such that $m \in [0.08, 0.5]$, $m \in [0.5, 1.0]$ and $m > 1.0$ $M_\odot$, respectively.

To derive the IMF from an observed mass function (MF), one should take into account the number of stars that have evolved off the main sequence. In our case, all the Am stars that we have studied in our series of papers are located in the main sequence. Their companions that are less massive have thus not left the main sequence: their observed MF can be thus assimilated to their IMF.

From a statistical study of a sample of 60 Am stars Abt & Levy (1985) obtained a negative exponent for the power-law accounting for the mass distribution of the companions, with $N \propto m^{0.60}$. Statistical tests show that this value of $\alpha = -0.60$ is incompatible with our data at 0.01% level.

The value of $\alpha = 0.3 \pm 0.2$ that we have derived from the $f(m)$ distribution of our sample in Sect. 7.3 is in better agreement with the values found by Kroupa (2001) for single stars with similar masses, but still at about 2σ from his values. In the scenario of co-eval formation of the two components of the binary system, this would indicate that the stars formed close to Am stars are globally more massive than isolated stars, possibly because of the proximity of the Am star (?). Indeed higher temperatures of the star-forming clouds seems to favour higher masses (Larson 1998). In the capture formation scenario, which assumes that binary stars formed in star clusters, this small excess of large masses in the MF could be explained with the dynamical history of those systems. The most massive stars have spent more time in the cluster than less-massive stars that were lost earlier due to energy equipartition within the cluster (mass segregation). As a consequence, Am-type stars would have preferentially accreted more massive companions.

8 CONCLUSION

This paper concludes the series of papers devoted to the radial velocity study of a sample of 91 Am stars. Our work has responded to our initial objectives that were recalled in Sect. 1. The statistics about the circularisation of the orbits and spin-orbit synchronism of Am systems have already been largely discussed in Papers VI and VII. Let us now summarize the main results obtained in the second part of this paper.

In our sample of 91 Am stars, 58 were found to be new SBs. The rate of SBs among Am stars is therefore at least 64 %, which is significantly greater than that of normal stars. Nevertheless it is likely that a significant fraction of Am stars (around 30%) do not belong to SBs: they are either isolated stars or members of wide binary systems (Sect. 6.2). This is in agreement with the previous conclusions of the statistical study of Am stars of Abt & Levy (1985). They suggested that another mechanism than tidal effects in a tight binary system had to be envisaged as an alternative (e.g. evolutionary expansion of a single star) for reducing the rotational velocity of an A-type star, which seems a necessary (and maybe also sufficient) condition to convert it into an Am star (Michaud et al. 1983, Abt 2000, Talon et al. 2006).

The statistical study of the orbital elements of the SBs containing an Am star has led to the following results:

- The distribution of the periods with $P < 100$ d (Sect. 7.1) is compatible with the theoretical models that explain the origin of Am stars as a consequence of the slowing down of the axial rotation of A-type stars produced by the rotation-revolution synchronism due to tidal effects. But the presence of long-period systems with $P > 100$ d shows that some Am stars were not produced by this mechanism.
- The cutoff separating the circular and the eccentric systems in the e vs $\log P$ diagram is $P_c \approx 5.6 \pm 0.5$ d, which in-

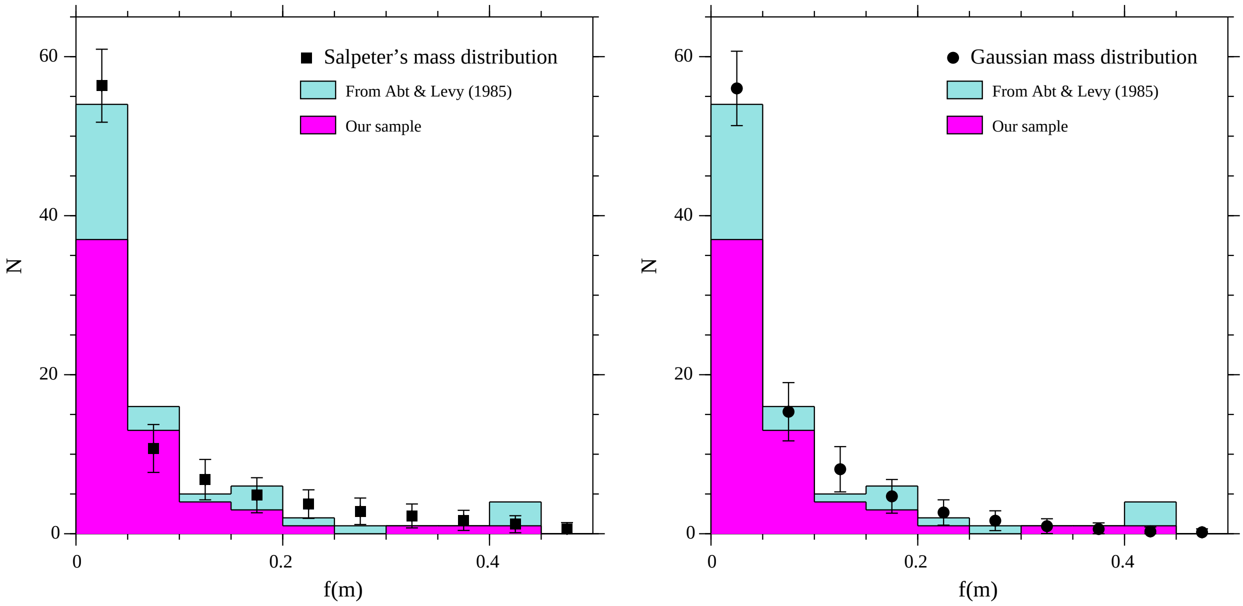

Figure 6. Histogram of f(m) for 89 Am SBs and comparison with two models assuming that the distribution of the masses of the companions is a power-law in $m^{-\alpha}$ with $\alpha = 0.3$ (left) or a Gaussian centered on 0.8 ± 0.5 $M_{\odot}$ (right).

dicates that the typical age of the Am stars is 0.5–1 $\times 10^9$ yr (Sect. 7.2). This age is in agreement with the values obtained in the detailed studies published in our series of papers.

- Our Monte-Carlo analysis shows that the distribution of $f(m)$, the mass function values, is compatible with a power-law distribution $N(m) \propto m^{-\alpha}$ for the masses m of the companions with $\alpha = 0.3 \pm 0.2$ (which is smaller that what is generally found for single stars), or with a Gaussian distribution with an average mass of 0.8 ± 0.5 $M_{\odot}$ which indicates that the companions are typically dwarf stars of type G-K-M.

We finally presented the list of radial velocity measurements of the remaining objects from the original sample, for which the small number of observations prevented us either from computing an orbit or, in other cases, from concluding to the probable constancy of the radial velocity. We hope that this list will be useful for other colleagues. We can also provide the code of the programs quoted in this series of papers.

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