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Binarity of Am stars in Praesepe and Hyades[⋆,⋆⋆]

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Abstract. CORAVEL radial-velocity observations of Am stars in the Hyades and Praesepe have allowed the determination of orbital elements for 10 spectroscopic binaries, among which 3 are first determinations. One Am star (KW 40) is found to be a well hierarchised triple system. KW 538 has a rather long period (435 days) for an Am star. Orbits of systems with periods shorter than 8.5 days are circularized, or present eccentricities smaller than 0.04. For 19 Am stars, the number of quadruple-, triple-, double-, single systems is 1:2:14(10+4?):(2?).

The Am stars in a (β, $B-V$) diagram clearly stand away by 0.03 mag from the sequence defined by normal main-sequence stars. This diagram could be a powerful method to identify Am stars in more distant open clusters, provided there is no differential reddening. In the colour-magnitude diagram (M_V, β), double-lined binaries are 0.6 - 0.7 mag above the ZAMS as expected, while most single-lined are close to or on the ZAMS because the secondary does not contribute much light. The absence of X-ray detection of 4 systems in the Hyades is an argument for the presence of a white dwarf secondary.

Key words: Galaxy: open clusters and associations: individual: Praesepe – Galaxy: open clusters and associations: individual: Hyades – stars: chemically peculiar – stars: binaries: spectroscopic

1. Introduction

Am stars are A- or early F-type stars, whose effective temperature lies between 7000 K and 9000 K. They are the coolest chemically peculiar stars on the main sequence (excluding barium or carbon dwarfs, which owe their peculiarity to binary evolution). Their main characteristics are an underabundance of calcium and scandium (about 5 to 10 times lower than in the Sun) and a slight overabundance of iron-peak elements. Three spectral types are identified on the basis of the intensity of the K, Balmer and metallic lines, respectively.

The chemical anomalies of Am stars are usually explained by the radiative diffusion theory developed by Michaud et al. (1983). This theory predicts that, in a slowly rotating star where the large-scale meridional circulation is weak enough, helium is no longer sustained and flows inside the star, gradually disappearing from the atmosphere. The diffusion process could therefore take place just below the thin H I convective zone where the diffusion time is short with respect to the stellar lifetime; as a first approximation, the chemical elements whose radiative acceleration is larger than gravity become overabundant and, in the opposite case, underabundant.

Most Am stars show slow rotational velocities ($v \sin i \leq 100\ \mathrm{km\ s^{-1}}$) and a high rate of spectroscopic binaries with periods shorter than 100 days (Abt & Levy 1985). However, few long-term studies (see for instance Conti & Barker 1973 or Abt & Willmarth 1999) have been undertaken to detect longer period Am stars or to prove that some are not variable in radial velocity. In addition, several questions have not received a satisfactory solution. Among them the nature of the secondary seems of primary importance in understanding the history of Am stars. Carquillat et al. (1997) studied a sample of 33 Am stars and detected a late-type companion for 22 systems from red spectra. We are interested in knowing more precisely what is the frequency of double-lined Am binaries (SB2) and what are the distributions of secondary masses or mass functions in single-lined Am binaries (SB1). Are these distributions similar to those observed for other mass intervals along the main sequence or do we have any evidence for an excess of low-mass companions or white dwarfs?

Therefore, radial velocity observations with the CORAVEL scanner (Baranne et al. 1979) have been obtained for Am stars in nearby open clusters (this paper) and in the field (Ginestet & Carquillat 1998, North et al. 1998, Debernardi 2000). Due to their low rotation and enhanced metallic lines, about half of the Am stars can be measured with the CORAVEL scanner and produce quite good correlation functions. These observations were intended to improve known orbits, search for evidences of secondaries in the correlation functions, monitor stars apparently stable and determine rotational velocities.

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[⋆] based on observations collected at the Haute-Provence Observatory (France)

[⋆⋆] Table 2 is available only in electronic form at CDS by ftp at 130.79.128.5 or on the Web at http://cdsweb.u-strasbg.fr/CDS.html

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Table 1. Coordinates, colours, systemic radial velocities and rotational velocities of Am stars in Praesepe and Hyades

No	HD	α(2000)	δ(2000)	V	B-V	Sp.	V_r	$\sigma(V_r)$	$V \sin i$	σ	Notes
KW 40	73174	8 37 37.0	+19 43 58	7.777	0.198	A4/A8/F2	35.64	0.33	7.3	1.1	Triple, orbits
KW 224	73618	8 39 56.5	+19 33 11	7.32	0.19	A5/A6/F0			44.0	17.0	SB1 Abt & Willmarth (1999)
KW 229	73619	8 39 57.8	+19 32 31	7.542	0.252	A3/A7/F0	35.64	0.17	11.2	0.5	SB2, orbit
KW 276	73711	8 40 18.2	+19 31 56	7.541	0.156	A3/A5/F0			66.1	11.5	
KW 279	73709	8 40 20.8	+19 41 13	7.690	0.195	A2/A5/F0	36.39	0.14	17.3	0.3	SB1, orbit
KW 286	73730	8 40 23.5	+19 50 06	8.018	0.190	A2/A8/F0	34.79	1.30	34.4	3.4	
KW 300	73731	8 40 27.1	+19 32 42	6.294	0.168	A3/A5/F0	29.9	1.1	6.7	10.5	SB2 Abt & Willmarth (1999)
KW 350	73818	8 40 57.0	+19 56 06	8.651	0.321	A7/A8/F0			81.0		SB2? Dickens et al. (1968)
KW 538	73045	8 36 48.1	+18 52 59	8.656	0.314	A3/A9/F3	35.20	0.07	14.1	0.2	SB1, orbit
vB 38	27628	4 22 03.1	+14 04 39	5.720	0.313	A5/F0/F2	39.03	0.51	30.8	3.1	SB1, orbit
vB 45	27749	4 23 24.6	+16 46 39	5.645	0.301	A2/F0/F2	39.61	0.17	13.1	0.3	SB1, orbit
vB 67	28226	4 26 31.4	+21 33 57	5.706	0.270	A6/A9/F0			93.0		SB2? Abt (1961)
vB 74	28355	4 27 25.8	+12 59 37	5.016	0.220	A6/A7/F0			93.0		
vB 83	28546	4 30 38.5	+15 41 32	5.483	0.256	A8/A8/F2	40.02	0.20	26.7	2.7	SB1, orbit
vB 107	29499	4 37 44.6	+07 49 21	5.375	0.258	A9/F0/F2			75.0		
vB 112	30210	4 44 38.1	+11 39 40	5.354	0.200	A3/A7/F0			63.0		SB1? Abt (1985)
vB 130	33254	5 09 19.4	+09 49 47	5.424	0.247	A2/A7/F2	44.55	0.18	13.0	0.3	SB1, orbit
vB 131	33204	5 09 44.8	+28 01 53	6.002	0.270	A9/A9/F2	43.13	0.28	24.0	2.4	SB1, orbit
vB 169	40932	6 02 22.9	+09 38 52	4.122	0.164	A4/A5/A7	42.64	0.89	10.6	0.3	Quadruple, orbits

Several spectroscopic binaries were already kown in the Hyades and orbits had been determined (Abt 1961, 1985; Conti 1969). We obtained a new orbit for vB 83. However, in Praesepe, one orbit of Am star was known for a long time, the double-lined binary KW 229 (Sanford 1931). When we submitted the paper, Abt & Willmarth (1999) published a radial-velocity study of Praesepe, including orbital elements for the triple system KW 40 and KW 279. Both the short and long periods of KW 40 have been determined, independently of Abt & Willmarth's (1999) value, from our observations. The long period is twice as large as Abt & Willmarth's (1999) determination. We have determined new orbital elements for one binary: KW 538.

2. Observations

The observations were obtained with the CORAVEL radial-velocity scanner (Baranne et al. 1979) installed on the Swiss 1-m telescope at the Haute-Provence Observatory (OHP) during regular observing runs devoted to these clusters. The radial velocities are on the standard system defined by Mayor & Maurice (1985), which corresponds to the system defined by the faint IAU standard stars ($m_v > 4.3$). Most of the observations were obtained between 1979 and 1983. Additional measurements were obtained since 1993.

Table 1 lists the basic and observational data for the Am stars in the Hyades and Praesepe. Stars which could not be observed with CORAVEL are also listed, with available remarks on their duplicity. Rotation for KW 350 is from Uesugi & Fukuda (1982) and those for vB 67, vB 74 and vB 107 are from Abt 1961. Such $V \sin i$ are too large to be measured by CORAVEL. All other $V \sin i$ have been determined from the present observations.

Table 2 gives the individual radial velocities: star identifications, heliocentric Julian Dates, radial velocities and their errors in [km s^{-1}]. It is only available in electronic form at the CDS.

3. Results for Praesepe

The stars on the upper main sequence of Praesepe have not received much attention so far as concerns radial-velocity measurements. Raboud & Mermilliod (1998) have summarized the available data from the literature on radial velocities. Table 3 contains a summary of the orbital elements we have determined. The individual binaries are discussed in more detail in the subsections below.

3.1. KW 40 (HD 73174)

The observations of KW 40 (A4/A8/F2, Abt 1986) show a single line spectroscopic binary (SB1) with a period of $5^{\rm d}\!.97$. Recently Abt & Willmarth (1999) published the orbital elements for a triple stars system. However, early attempts to compute an orbit produced residuals larger (2.98 km s^{-1}) than the measurement errors (0.52 km s^{-1}) which could be explained by a change in the systemic velocity. Therefore, this star was continuously monitored, from the end of 1979 to 1997 to follow the variation of the systemic velocity. Only the Am primary is visible. All efforts to detect a correlation for any of the two other components were unsuccessful.

The spectroscopic orbit, represented in Figs. 1 and 2, is solved by taking into account the two periods. Thus the radial velocities of the short period ($P = 5^{\rm d}\!.9701$) are corrected by the motion of the center of masses to compute the short solution and these corrections are used to solve for the long period

Table 3. Orbital elements of Am spectroscopic binaries in Praesepe

Element	KW 40 (Short)	KW 40 (Long)	KW 229	KW 279	KW 538
P [d]	5.97012	2878.	12.91124	7.22026	435.57
	0.00005	23.	0.00004	0.00002	0.96
T [HJD-2440000]	9996.23	5931.	9988.668	49989.95	9722.0
	0.48	29.	0.025	2.60	1.8
e	0.009	0.417	0.296	0.000	0.320
	0.004	0.028	0.004	fixed	0.009
γ [km s^{-1}]	var	35.56	35.64	36.27	35.20
	–	0.06	0.17	0.14	0.07
ω [°]	–	203.77	341.96	–	28.8
	–	2.59	0.78	–	1.6
$K1$ [km s^{-1}]	41.73	4.60	64.92	30.96	11.89
	0.07	0.11	0.33	0.21	0.12
$K2$ [km s^{-1}]	–	–	66.17	–	–
	–	–	0.33	–	–
f(m) [$M_\odot$]	0.0444	0.0221	0.3196	0.0223	0.0662
	0.0015	0.0055	0.0039	0.0004	0.0021
a sini [Gm]	3.410	165.560	11.009	3.074	68.01
	0.038	14.	0.058	0.020	0.70
$\sigma(O-C)$ [km s^{-1}]	0.37	0.37	0.99	0.89	0.49
n_{obs}	86	86	17	33	52

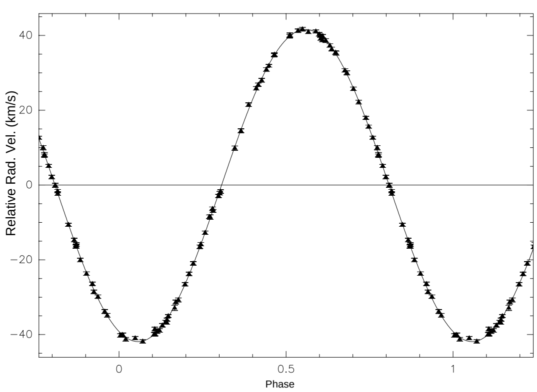

Fig. 1. Radial-velocity curve of the inner binary (P=$5\overset{\rm d}{.}9701$) in KW 40.

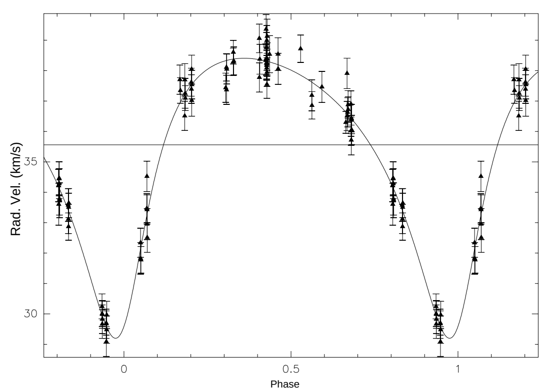

Fig. 2. Radial-velocity curve of the outer binary (P=$2877\overset{\rm d}{.}96$) in the KW 40 system.

(P =$2878\overset{\rm d}{.}$). If the short period solution agrees with Abt & Willmarth (1999), our value for the long period system is twice as large as their value. An attempt to plot our observations in phase with their period failed. Therefore the correct value is P =$2878\overset{\rm d}{.}$

Assuming a mass of 2.0 $M_\odot$ for the Am primary, we get a minimum mass of 0.68 $M_\odot$ for the secondary of the spectroscopic orbit. Taking a minimum total mass of 2.7 $M_\odot$ for the binary, the minimum mass of the third star is again about 0.63 $M_\odot$.

In their speckle investigation of Praesepe, Mason et al. (1993a) have observed KW 40 in 1991, just at the phase where the two components of the long period system had a large difference in radial velocitiy. This implies the two components of the long-period system were close and no evidence of the third component was seen.

KW 40 was detected in X-ray from ROSAT PSPC pointing (Randich & Schmitt 1995) with a luminosity as strong as that of solar-type stars. The observed flux may be the sum of the contributions of the two unseen companions or may result from the effect of the short binary period on the Am companion.

3.2. KW 229 (HD 73619)

Sanford (1931) has already determined an orbit ($P = 12\overset{\rm d}{.}9117$, $e = 0.2$) for the double-lined system KW 229 (A3/A7/F0, Abt 1986). The present orbital solution is in very good agreement with that found by Sanford (1931), although we obtained an eccentricity ($e = 0.30$) somewhat larger than Sanford's value ($e = 0.2$), but in good agreement with Abt & Willmarth's (1999) value ($e = 0.30$). The residual dispersion ($\sigma(O-C)$ = 0.76 km s^{-1}) is quite satisfactory for this type of star. The mass ratio is

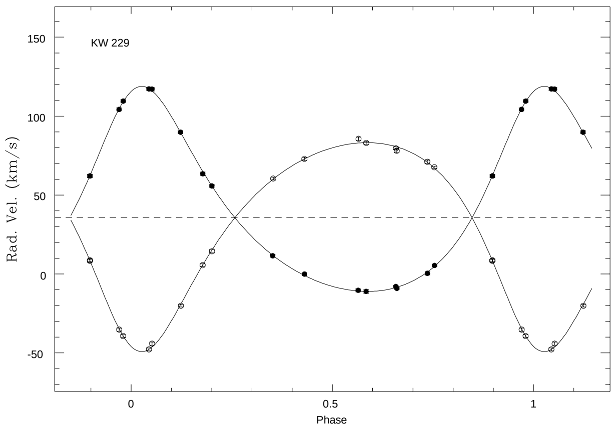

Fig. 3. Radial-velocity curve of KW 229. The period is 12.91124 $\pm$ 0.00007 days.

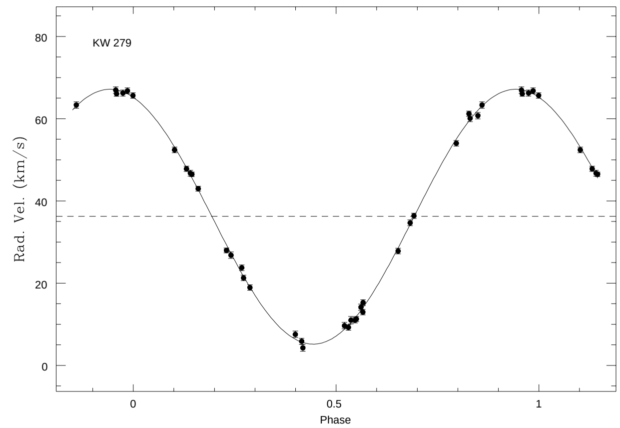

Fig. 4. Radial-velocity curve of KW 279. The period is 7.2203 $\pm$ 0.0003 days.

$q = 0.981$. Because both components are observed, we infer that both are Am stars.

KW 229 and KW 224, another double-lined Am which could not be observed with CORAVEL, were detected in X-ray from ROSAT PSPC pointing (Randich & Schmitt 1995). Their luminosities ($\log L_X$ = 29.94) place them among the three strongest sources detected in Praesepe, just behind the eclipsing binary TX Cnc (KW 244). Because both components seem to be quite similar, the observed flux cannot originate from a solar-type companion. The flux enhancement may arise from the binary short periods, although that for KW 224 is not known.

3.3. *KW 279 (HD 73709)*

KW 279 was classified Am (A2/A5/F0) by Gray et al. (1989), but was found photometrically Ap by Maitzen & Pavlovski (1987) according to the Δa index ($\Delta a = 0.018$). The Geneva peculiarity index gives an ambiguous answer: $\Delta(V1 - G)$ = 0.001 is only a few thousands of magnitude larger than the average of normal stars.

This star is also considered as the third component of the visual quadruple system ADS 6921 (Worley 1996). We found that KW 279 is a single-lined spectroscopic binary, with a short period of 7.22 days, which is in good agreement with the determination of Abt & Willmarth (1999). Two additional radial velocities were taken during the survey for magnetic fields of Ap stars with the spectrograph Elodie (Babel et al. 1995, 1997) and were taken into account in the final solution.

KW 279 is an extremely interesting star because it shows at the same time the characteristics of both an Am and an Ap star, and presents a strong magnetic field (North 2000). It has a reliable Am classification and positive Δa: it was generally accepted that Am stars never show enhanced Δa values (Maitzen 1976, Maitzen et al. 1998) which are characteristic of magnetic Ap stars only. Conversely, large-scale magnetic fields are generally not found in Am stars, with the probable exception of the hot Am star o Peg (Mathys 1988; Mathys & Lanz 1990). The two spectra taken with the Elodie spectrograph consistently show a surface magnetic field of about 7.5 kG which seems very significant, in spite of a relatively large projected rotational velocity $V \sin i = 16$ km s^{-1} (North 2000).

A system formed by an Ap + an Am could explain the presence of the magnetic field. Such systems have been found by Abt & Cardona (1984). However, the mass function is small: $f(M)$ = 0.0223 and if we assume that the star rotation is synchronised with the orbital period, because $e = 0$, the inclination angle $i \cong$ 70.5 $^\circ$and the secondary mass is 0.51 $M_\odot$. This rules out the hypothesis and rejects the presence of an Ap star as primary or secondary and implies that the magnetic field is related to the Am star.

3.4. *KW 538 (HD 73045)*

KW 538, classified Am (A3/A9/F3) by Abt (1986), is a single-lined spectroscopic binary, with a period of 435.571 days. The data were collected from 1979 to 1996, independently by (JCM) and by (JMC), which explains the large number of observations obtained for this star.

KW 538 belongs to the scarce sample of Am stars which have an orbital period between 50 and 800 days (Budaj 1996). The amplitude of the radial-velocity variation is still quite comfortable for CORAVEL, but may require good precision measurements to detect it with classical spectrographs and a long-term observing program.

4. Results for Hyades

Six Am stars in the Hyades had already published orbits. Our elements (Table 4) confirm the previous ones (Abt 1961, 1985; Conti 1969), except for vB 83 and vB 131.

4.1. *vB 38 (HD 27628)*

vB 38 classified Am (A5/F0/F2) by Abt (1995), was already observed as a single-lined spectroscopic binary by Abt (1961). Our orbital parameters are in good agreement with Abt's (1961) elements. The period is short, 2.143 days, and the eccentricity is e = 0.00.

Table 4. Orbital elements of Am spectroscopic binaries in the Hyades

Element	vB 38	vB 45	vB 83	vB 130	vB 131	vB 169 (short)	vB 169 (long)
P [d]	2.14362	8.41772	58.37	155.62	32.5226	4.44757	6953.
	0.00001	0.00003	0.027	0.07	0.0051	0.00005	202.
T [HJD-2400000]	50003.32	49993.30	49969.1	44924.5	59943.2	49993.66	45581.
	0.27	0.79	5.2	2.5	1.1	0.31	56.
e	0.000	0.000	0.264	0.581	0.459	0.013	0.610
	fixed	fixed	0.095	0.044	0.153	0.005	0.036
γ [km s^{-1}]	39.21	39.61	40.02	44.44	43.32	var	42.36
	0.50	0.17	0.28	0.18	0.28	–	0.19
ω [°]	–	–	310.	285.	268.	321.	23.
	–	–	33.	4.	26.	25.	4.
K [km s^{-1}]	28.00	36.85	2.53	7.39	2.30	29.65	10.82
	0.68	0.24	0.35	0.42	0.36	0.18	1.75
f(m) [$M_\odot$]	0.00486	0.04372	0.000088	0.00351	0.000029	0.01204	0.45567
	0.00036	0.00085	0.000038	0.00073	0.000014	0.00129	0.09547
a sini [Gm]	0.825	4.265	1.961	12.87	0.912	1.813	820.1
	0.020	0.028	0.279	0.89	0.153	0.059	7.6
$\sigma(O-C)$ [km s^{-1}]	0.62	0.62	0.95	0.56	1.29	0.83	1.52
n_{obs}	23	19	14	13	31	55	55

vB 38 is one of the two Am stars in the Hyades that has been detected in X-ray from ROSAT All-Sky Survey (RASS) (Stern et al. 1995). However its luminosity is about 20 times fainter than that of KW 224 or KW 229 and 3 times lower than that of KW 40. The luminosity is compatible with a solar-type companion or a M-type dwarf. The mass function ($f(M)$ = 0.04860) favours the first solution: the minimum mass is 0.75 $M_\odot$ for a 1.5 $M_\odot$ primary. It may also happen that the X-ray emission is enhanced by the short binary period. No evidence for a secondary dip has been seen in CORAVEL observations.

4.2. vB 45 (HD 27749)

Abt (1961) had already detected vB 45 (A2/F0/F2, Abt 1995) as a single-line spectroscopic binary and determined a first orbit, which was later improved (Abt 1985). The observations give a short period of $8^{\rm d}_{.}4118$, which agrees well with Abt's (1985) value, and an eccentricity equal to 0.000 ± 0.007. A circular orbit with a period of $8^{\rm d}_{.}4$ is compatible either with the cut-off limit for the Hyades based on solar-type stars ($8^{\rm d}_{.}5$, Mathieu et al. 1992) or with the results of Matthews & Mathieu (1992): stars with an A-type primary may have circular orbits with periods up to $9^{\rm d}_{.}9$.

The mass function gives a minimum mass for the secondary of 0.70 $M_\odot$, but no evidence for the presence of a secondary has been seen in our observations. vB 45 has not been detected in X-ray (Stern et al. 1995). This is surprising because nearly all solar-type stars in the Hyades have been detected by ROSAT.

4.3. vB 83 (HD 28546)

vB 83, classified A8/A8/F2 by Abt & Levy (1985) is a single-lined spectroscopic binary with an orbital period of $58^{\rm d}_{.}367$ and a small amplitude of 2.53 km s^{-1}. The mean errors on the radial velocities reflect the limit inherent to CORAVEL for measuring Am stars and the effect of rotation. But the orbit is well defined (see Table 4 for the orbital parameters) and has a σ(O-C) of 0.95 km s^{-1}, lower than the mean error of each radial-velocity and we assume that the orbital motion is real. During the last 20 years, the mean radial velocity did not change. vB 83 belongs to the small group of Am stars having orbital periods more than 30 days. vB 83 has not been detected in X-ray (Stern et al. 1995).

4.4. vB 130 (HD 33254)

vB 130, classified Am (A2/A7/F2) by Gray & Garrisson (1989), was not taken into account by Abt (1961) during his research of duplicity on Am stars. However, Conti (1969) measured vB 130 during his observations of magnetic Am stars. He detected a magnetic field through the Zeeman effect and also detected a variation in radial velocity. He determined an orbit of this single-lined spectroscopic binary with a period of $155^{\rm d}_{.}83$ and e = 0.67.

CORAVEL observations began in 1979 and ended in 1993 with a 10-year gap between 1983 and 1993, without observation. Fig. 9 shows the orbital curve with the parameters listed in Table 4. The eccentricity is not well constrained by our observations and the differences observed between our elements and Conti's elements are probably not significant.

vB 130 has not been detected in X-ray (Stern et al. 1995).

4.5. vB 131 (HD 33204)

vB 131 is classified Am (A9/A9/F2) by Abt (1995), and is the primary component of the triple system ADS 3730. The secondary is vB 132 (ADS 3730 BC). The separation AxBC is $11''_{.}$ and BxC, $0''_{.}4$. Heintz (1976) derived a visual orbit of 32 yrs for

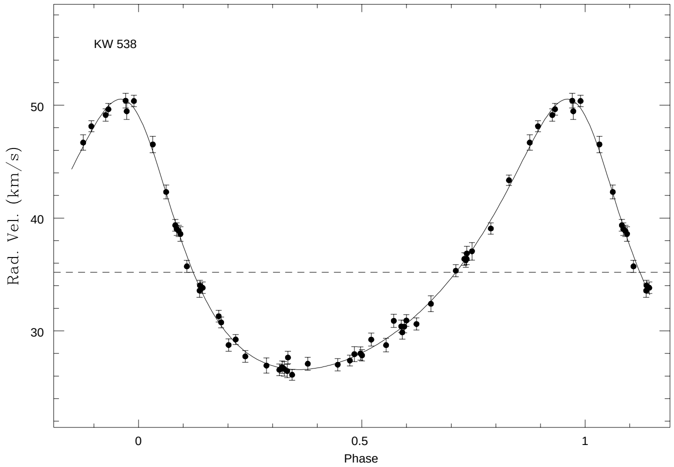

Fig. 5. Radial-velocity curve of KW 538. The period is 435.57 ± 0.19 days.

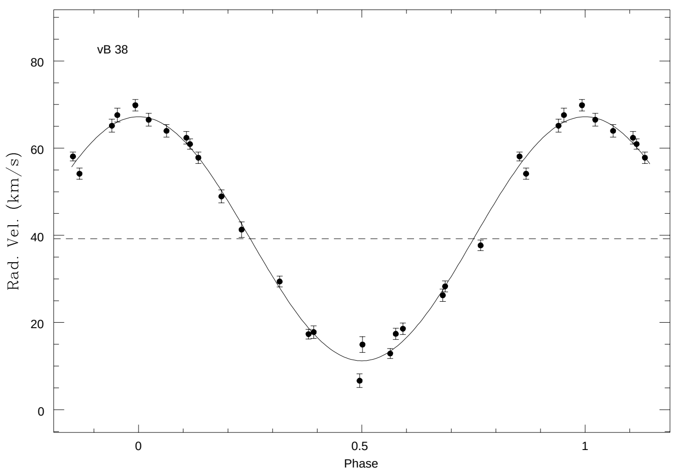

Fig. 6. Radial-velocity curve of vB 38. The period is 2.14361 ± 0.00006 days.

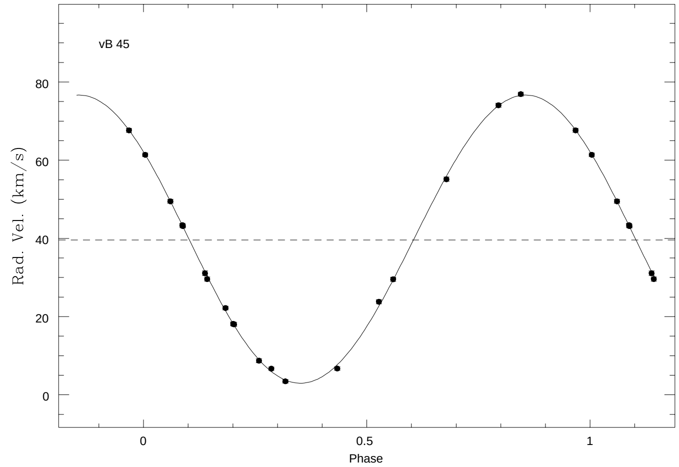

Fig. 7. Radial-velocity curve of vB 45. The period is 8.4177 ± 0.0001 days.

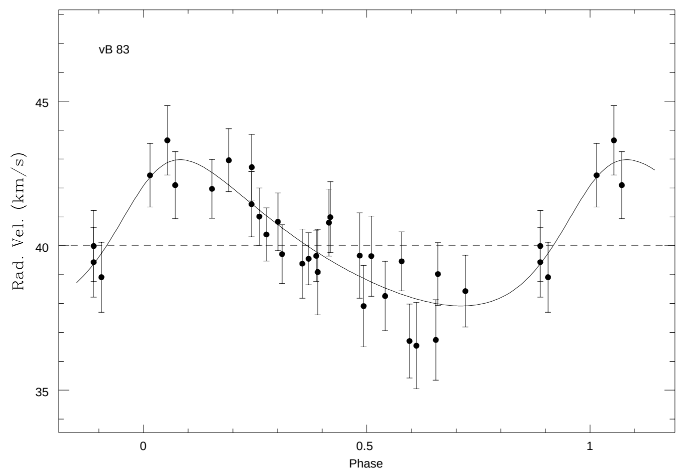

Fig. 8. Radial-velocity curve of vB 83. The period is 58.37 ± 0.03 days.

the visual binary ADS 3730 BC. vB 131 shows a radial-velocity dispersion which is larger than the standard radial-velocity error and $P(\chi^2) = 0.000$. A Fourier analysis gives a possible period of $32^{\rm d}\!.528$. No long-term variation is obviously seen in a simple plot of the radial-velocity in function of time (from 1979 to 1999). The orbital solution shown in Fig. 10 is fitted with the value of the Fourier period. The orbital parameters listed in Table 4 represent a possible solution, but due to the small amplitude of the orbit, and to the radial-velocity errors, the orbital solution is not absolutely certain.

During some observing runs an observation of vB 132 was obtained. vB 132 does not show any radial-velocity variation either on short or long time scales. The separation between vB 131 and vB 132 leads us to predict a long period system and a small radial-velocity variation, which CORAVEL is not able to measure.

vB 131 has been detected in X-ray: $\log L_X$ = 3.9 (Stern et al. 1995), which could be produced by a low-main-sequence star, which is in good agrement with the orbital parameters.

4.6. vB 169 (HD 40932)

vB 169, classified Am (A4/A5/A7) by Abt (1995), is a visual hierarchical quadruple system. Frost (1906) was the first to observe the single-lined binary system. Then Aitken (1914) observed the visual companion. Alden (1942) computed a visual orbit by using some of the spectroscopic elements. He remarked that the visual secondary contains nearly half of the mass of the system (Osvalds 1964).

Fekel (1980) performed a detailed analysis of the whole system. He found that each visual component is itself a spectroscopic binary. The components are noted Aa, Ab and Ba, Bb. A is SB1 with a period of 4.45 days and B is SB2 with a period of 4.48 days. The visual orbit has a period of 18.2 years. Fekel (1980) has answered another important question: which component is the Am star? He observed that Aa is the Am star. Unfortunately the Am star belongs to the SB1 system, which contributes little information about the secondary.

CORAVEL observations began in 1979 and ended in 1993. Due to the 19-year binary motion, a simple analysis of this system will not provide a good orbital solution. To perform a

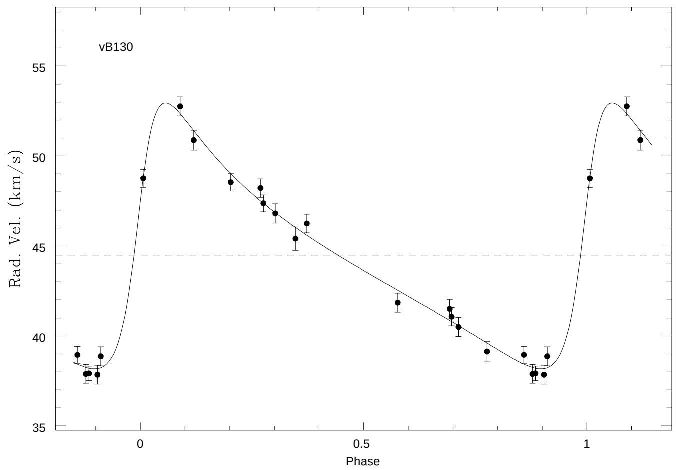

Fig. 9. Radial-velocity curve of vB 130. The period is 155.497 ± 0.099 days.

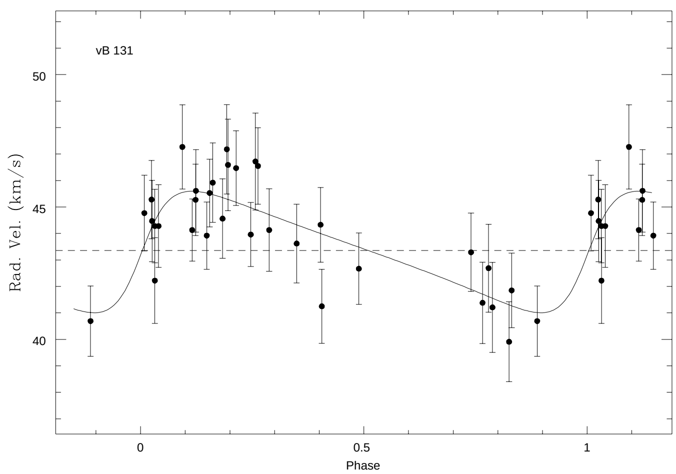

Fig. 10. Radial-velocity curve of vB 131. The period is 32.528 ± 0.009 days.

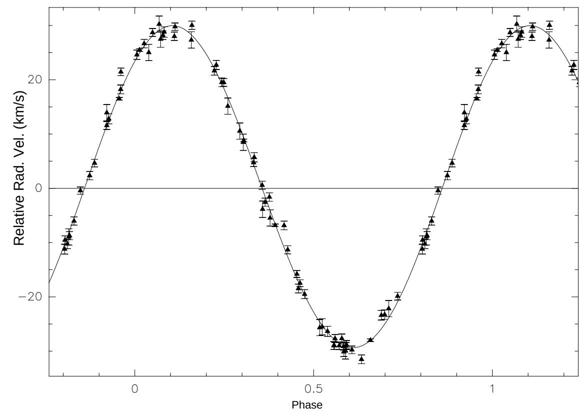

Fig. 11. Radial-velocity curve of vB 169 A. The period is 4.44757 ± 0.00005 days.

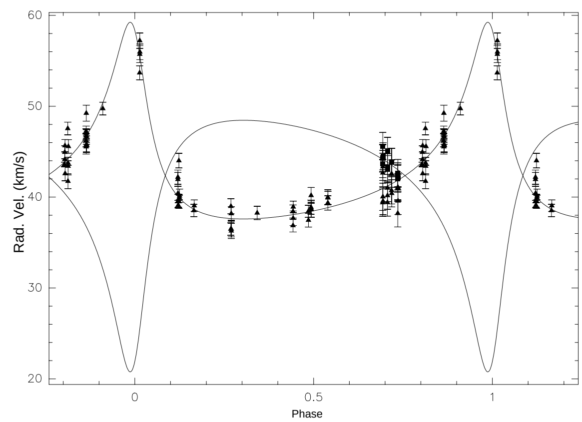

Fig. 12. Radial-velocity curve of vB 169 AB. The period is 6952.7 ± 202.0 days. The radial-velocities of the secondary Bab (square) were measured by Feckel (1980) at a phase where they are close to the systemic radial-velocity of AB.

global solution of the two periods simultaneously, we had to include the radial velocities of Fekel (1980), who was the only observer who measured the visual secondary's radial-velocity, and also the speckle observations listed in the CHARA interferometric catalogue (Hartkopf et al. 1999). Fig. 11 shows the short period ($4^{\rm d}.4475$) SB1 Aa, corrected for the perturbation from the visual companion. Fig. 12 shows the radial-velocity orbital solution for the visual binary. The triangles (55 observations) represent the Aa radial velocities values and the squares the Bab values from Fekel (1980). Note that the B sample is very poor due to the difficulty of detecting the corresponding lines. The observation of the radial-velocities were not obtained in a favorable phase, so the secondary amplitude is not well defined. The radial-velocity orbital elements are listed in Table 4. Fekel's (1980) radial-velocity solution for B is not reproduced here. Fig. 13 shows the visual orbit. The dotted line represents the motion of the secondary around the primary. Due to the large eccentricity of the visual system, the highest precision is needed and we used only the latest data given on CHARA web site (Hartkopf et al. 1999).

The combined analysis of the vB 169 system gives a good estimation of the masses of each visual component, for the primary M(Aa + Ab) = 3.07 ± 0.95 $M_{\odot}$ and M(Ba + Bb) = 2.40 ± 0.28 $M_{\odot}$ for the secondary.

Assuming that the primary Aa is the Am star of the system, and a mass of about 2 $M_{\odot}$, the mass of the secondary is about 1 $M_{\odot}$. Thus the inclination of the orbit is about 30°, which is different from the inclination of the visual orbit (i=60°). Although it is often stated (Batten 1973) that orbital planes, in visual system, are not coplanar. The mass ratio ($q = 0.5$) is in agreement with the observation that the secondary Ab was never seen in the radial-velocity correlations.

For the secondary visual component B, the mass ratio between Ba and Bb is 0.984 Fekel (1980), which allows the determination of the masses of each stars, 1.21 $M_{\odot}$ for Ba and 1.19 $M_{\odot}$ for Bb.

ROSAT X-ray emission has been observed from vB 169, with a luminosity of $\log L_X$ = 29.25 (Hünsch et al. 1998). The detection of this system seems to be normal because there are two or three lower-main-sequence stars in this system. But the

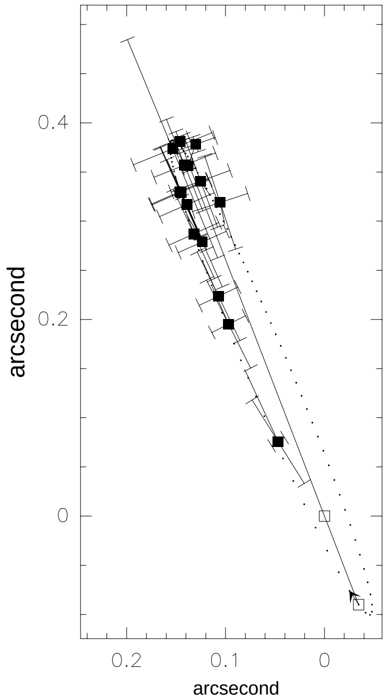

Fig. 13. Speckle orbit of vB 169 AB. The period is 6952.7 ± 202.0 days.

flux is not abnormally large owing to the number of possible emitters and the short periods of both binary sub-systems.

5. Discussion

These new observations enable us to discuss the binary frequency, the $(e, \log P)$ relation, and the nature of the secondaries.

5.1. Mutiplicity

Several spectroscopic and photometric surveys have been made to classify the bright stars in the Praesepe and in Hyades clusters. Therefore we can consider that all Am stars have been detected, nineteen in total, in the two open clusters. Ten orbits were derived from the present observations. Among the nineteen Am stars, twelve have orbital elements, one uncertain orbital elements and two evidences of orbital motion without orbital elements (see Table 1). For the other four, we have only unconclusive evidence of their duplicity.

KW 276 is presumed to have long-term radial-velocity variations stars (Raboud & Mermilliod **?**). Abt & Willmarth (1999) did not observe significant change in radial-velocity during their observations, which argues for the very long-term radial-velocity variations.

KW 286 could be presumed to have long-term radial-velocity variations. Wilson & Joy (1950) published a mean radial velocity of 27.8 km s^{-1} and McDonald (Hill 1978) observed a mean radial velocity of 38.4 km s^{-1}.

vB 74 Abt & Levy (1985) consider a constant radial-velocity for this star of about 40 km s^{-1}. But the old data of Frost et al. (1929) give a mean radial-velocity of about 25 km s^{-1}. It is however not possible to derive any definitive conclusion about vB 74 binarity.

vB 107 has no clear evidence of radial velocities variations, all the available radial-velocity data (Frost et al. 1929, Stilwell 1949) are old and of limited precision, which again precludes any definitive conclusion to be drawn.

Thus if we consider only the certain orbital elements, the rate of Am binary is 63%. Among the nineteen Am stars, only two have no evidence of radial-velocity variations. This would imply a rate of binary of 90%. Another point which must be underlined is that some binary systems, like vB 83, need accurate radial-velocities measurements to determine satisfactory orbital elements. So an evidence of a single Am star could only be expected for vB 74 and vB 107.

Finally the number of quadruple-, triple-, double-, single systems is 1:2:14(10+4?):(2?). The numbers between brackets represent the uncertain numbers, for instance there are 10 certain SB and 4 suspected SB (KW 276, KW 286, vB 67 and vB 112), which represents 14 SB1. And the two possible non-binary stars are vB 74 and vB 107. But we cannot exclude that the nineteen Am stars in the Praesepe and Hyades clusters are all binaries.

5.2. Calibration of rotational velocity

Benz & Mayor (1984) have already studied the rotational velocities obtained with CORAVEL. But this study was based on late-type dwarfs. To estimate the influence of parameters such as temperature and microturbulence on the rotation-velocity calibration, we compare the rotational velocities observed with CORAVEL and those found in the literature (Fig. 14). The maximum rotational velocities, which could be measured by CORAVEL is about 60 km s^{-1}. Up to 40 km s^{-1} the literature and the CORAVEL measurement are in good agreement. Only one observation shows a significant difference (KW 224 open square in Fig. 14). McGee & al. 1967 observe a $\mathrm{V}\sin i$ of 60 km s^{-1} and CORAVEL gives 44.0 km s^{-1}. The CORAVEL value is a mean of three observations, which is not enough to have a good precision for large rotators, i.e. the mean error for this value is 16.98 km s^{-1}. Nordström et al. (1997) have already pointed out that CORAVEL rotational velocities for values larger than 40 km s^{-1} are overestimated.

Therefore we can consider up to 40 km s^{-1} that CORAVEL observations of rotational velocities are also reliable for Am stars.

5.3. Distribution of the periods and eccentricities, circularisation of short period binaries

The eccentricity distribution is strongly dependent on the orbital period (Duquennoy & Mayor 1991). Two different regions could be distinguished in a $(e, \log P)$ plane (Fig. 15). Systems with periods shorter than 10 days have $e < 0.05$, while $e > 0.3$ are obtained for $P > 10$ days. Our cut-off period P (about 10 days)

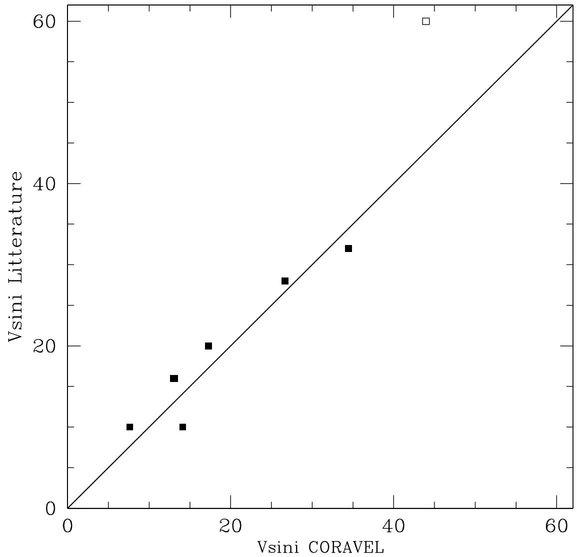

Fig. 14. Comparaison of CORAVEL and literature rotational velocities.

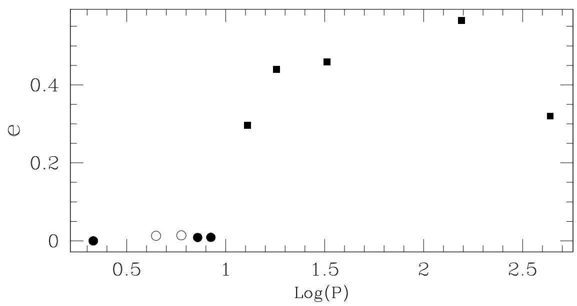

Fig. 15. Distribution of the eccentricity as a fonction of the period.

is in good agreement with the value $9\overset{\mathrm{d}}{.}9$ found by Matthews & Mathieu (1992).

For $\log P < 1$, the binaries are circularized, mainly as a result of pre-main sequence processes (Zahn & Bouchet 1989). For three of them (filled circles in Fig. 15, KW 279, vB 38 and vB 45) the orbit is circular. The two other stars with non-zero eccentricities are the two multiple systems (open circles in Fig. 15, KW 40 and vB 169). This finding confirms that the presence of a third companion will maintain a small eccentricity in the short period binary, even if its orbital period is long (Mazeh 1990). During the circularization process and the synchronization phase between the orbital period and the rotational period, the rotation will be modified. In the case of Am stars, the rotational velocity will slow down from the typically large value for A stars ($\geqslant 100$ km s^{-1}), to a few tens km s^{-1}.

The inclination i of the orbital plane for the synchronised stars, which is assumed to be parallel to the inclination i of the star rotation, can be determined by comparing the observational rotation velocity ($V_{\sin i}$) and the synchronised rotational velocity (V_{sync}), derived from the orbital period and the radius. The radius of each star is calculated from the T$_{eff}$ and the corresponding luminosity L. The effective temperature (Table 5) is obtained for KW 279 in Hui-Bon-Hoa et al. (1997) and for

Table 5. Inclination of the orbit i

Star	m$_V$	T$_{eff}$	P	V$_{\sin i}$	V$_{sync}$	i [°]
KW 279	7.68	8060	7.22026	17.31	18.36	70.5
vB 38	5.71	7400	2.14362	30.83	44.54	43.8
vB 45	5.63	7570	8.41772	13.10	11.62	90.0
KW 40	7.75	8090	5.97013	7.63	21.38	20.9
vB 169	5.48	8190	4.44757	10.56	20.13	31.6

KW 40, vB 45 in Hui-Bon-Hoa & Alecian (1998). For vB 38 and vB 169 we must use the photometric estimation. Therfore we have corrected the photometric values of T$_{eff}$ (Künzli et al. 1997) by the differences of T$_{eff}$ calculated from the spectroscopic and photometric methods at same values of (B-V). Thus we have coherent values of T$_{eff}$. The luminosity is calculated using the apparent magnitude (Table 5), the Hipparcos parallaxes for the Hyades stars and the distance modulus for the Praesepe stars (Mermilliod 1999). Only the apparent magnitude of vB 169 must be corrected to take into account that the apparent magnitude is the sum of all system's stars. Thus we have added $1\overset{\mathrm{m}}{.}35$ (Fekel 1980). The value of i, for vB 169, calculated with this method is in good agreement with the inclination obtained through the orbital parameters determination.

For vB 45 the inclination in Table 5 is assumed to be 90°considering the error of the observational rotational velocity. On the basis of these observations, the inclinations are probably not correlated in an open cluster.

For log$P > 1$ (squares in Fig. 15), binaries are not circularized ($0.3 < e < 0.6$) and not synchronized. Two new long orbital period Am binaries stars were found (KW 538 and vB 130) increasing the range of periods in the e - log P diagram. Long period Am binaries are probably more numerous than usually expected, but past observing campaigns (Abt 1961, 1985) were not long enough to detect them. In addition the correspondingly smaller amplitudes require sufficient radial-velocity precision. Therefore the gap in the orbital period distribution (OPD) (Budaj 1997) may result from bias in the sample.

The Am stars in the Praespe and Hyades open clusters do not represent a large enough sample to perform a significant statistical study of the OPD and to determine a reliable value of the mean eccentricity of non-synchronised system.

6. The nature of the secondaries

6.1. Photometric evidence

The photometric analysis of the Am stars in the Hyades and Praesepe shows several interesting facts. All the photometric data were taken in the WEBDA (Mermilliod 1999[1]) compilation of literature. The Am stars are off the main relation for normal stars by about 0.03 mag, in a (β, $B-V$) diagram (Fig. 16). The ($B-V$) excess results from the line-blanketing in the Am stars. In a coulour magnitude diagram, part of the vertical distance to the ZAMS, usually interpreted as a sign of duplicity, is due to

[1] WEBDA: http://obswww.unige.ch/webda/

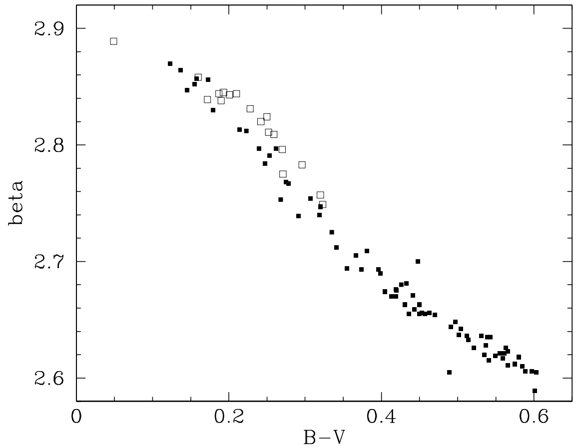

Fig. 16. The Am stars (open symbols) are clearly separated by about 0.03 mag from the sequence of normal stars.

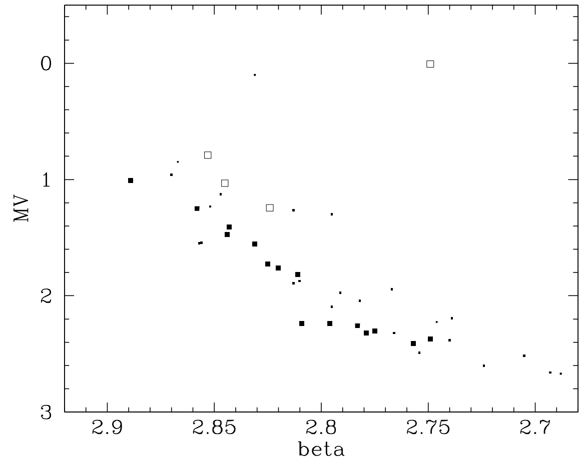

Fig. 17. The double-lined Am stars are nearly close to the binary ridge, as expected. Most single-lined binaries are close to or on the ZAMS. Small dots are Hyades non-Am stars.

the metallicity effect. The β parameter is preferred to $(B-V)$ because β is probably less sensitive to metallicity.This effect offers an interesting possibility of identifying Am stars in the main sequence of more distant clusters, provided that the photometry has a precision of 0.01 mag and that the clusters have no differential reddening.

In a (M_V, β) diagram (Fig. 17), where M_V is estimated from the apparent magnitude and the distance of each open cluster (Mermilliod 1999), the distribution of the Am stars is clearly bimodal. The double-lined systems (open squares) are accordingly located on the binary ridge, about 0.75 mag above the ZAMS, while most other systems are close to or on the ZAMS. This implies that the secondaries are fainter than the primaries by at least 3 to 4 magnitudes, which fixes an upper limit on the secondary masses. The values for the masses derived from the present data are given in Table 6.

6.2. *Secondary masses*

In Tables 3 and 4 the values of the mass function $f(M)$ are listed, and we have derived the inclination for the synchronised binaries. We can therefore estimate the masses of the secondaries (Table 6).

The three synchronised stars (KW 279, vB 38 and vB 45) present quite similar masses of the secondary (M_{sec}) of about 0.5 $M_{\odot}$. For KW 40 the difference between M_{max}, which is derived form the photometry, and M_{sec}, calculated from V_{sync}, results from the composition of two errors. Firstly, the luminosity of KW 40 is not corrected from the third component luminosity, and secondly, a small error on the $V \sin i$ value would result in a significant change of the derived mass. A secondary mass of 1.81 $M_{\odot}$ would imply that the secondary is an A-type star, which probably has a large rotational-velocity and might not be detected by CORAVEL. For vB 169, the value of the secondary mass can be affected by the presence of the third and fourth components of the system.

The six systems not detected in X-rays have secondary masses compatible with that of a white dwarf.

Table 6. Minimum and maximum masses of the secondaries

Star	M_{min}	M_{max}	M_{sec}	log L_X
KW 40	0.64	0.90	1.81	29.15
KW 279	0.48	0.90	0.51	–
KW 538	0.69	0.92	–	–
vB 38	0.25	0.75	0.38	28.70
vB 45	0.58	0.76	0.58	–
vB 83	0.05	0.76	–	–
vB 130	0.23	0.84	–	–
vB 131	0.05	0.68	–	–
vB 169	0.45	1.06	0.96	29.25

7. Conclusions

We have determined new orbital elements for several Am stars in the Hyades and Praesepe clusters and confirmed the high frequency of spectroscopic binaries among Am stars in these two clusters. Three of the systems are found or confirmed to be hierarchical multiple systems (Praesepe: KW 40 (triple); Hyades: vB 131 (triple) and vB 169 (quadruple)).

The improvement of the orbital parameters highlights several points. Firstly, the orbital periods of Am stars are not necessarily smaller than a few of tens days. Secondly, systems with small orbital period are not all circularized. Thirdly, the circularized systems can be used to determine the value of the inclination i of the orbital plane.

These Am multiple and binary systems are worth a detailed study and much can be learned from them if evidence of the nature of their companions could be obtained. Spectroscopic or photometric observations at the appropriate wavelengths might reveal whether the companion are normal main-sequence- or degenerate stars. All three Am binaries (KW 40, vB 38 and vB 169) with periods shorter than 6 days are detected in X-ray by the ROSAT satellite. Two SB2 stars in Praesepe file are detected as the strongest X-ray emitters in this cluster, although one period is not so short (the second is not known) and the stars are not solar-type stars with chromospheric activity.

The surprising point is that not all Am binaries have been detected by ROSAT. Among the binaries with an orbit, the mass of the secondary should be high enough to ensure detection, at least in the Hyades, where a very large fraction of the red dwarfs has been detected. In the case of most SB1, the mass interval computed for the secondary star is compatible with it being a white dwarf. Does it imply that a significant fraction of the secondaries are not red dwarfs, but white dwarfs? Infrared and/or ultraviolet spectroscopic observations would help to discern the nature of the secondaries in the Am binaries in the Hyades and Praesepe.

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References

Abt H.A., 1961, ApJS 6, 37
Abt H.A., 1985, ApJS 59, 229
Abt H.A., 1986, PASP 98, 307
Abt H.A., 1995, ApJS 99, 135
Abt H.A., Cardona O., 1984, ApJ 276, 266
Abt H.A., Levy S.G., 1985, ApJS 59, 229
Abt H.A., Willmarth D.W., 1999, ApJ 521, 682
Aitken R.G., 1914, Bull. Lick Obs. 8, 93
Alden H.L., 1942, AJ 50, 73
Babel J., North P., 1997, A&A 325, 195
Babel J., North P., Queloz D., 1995, A&A 303, L5
Baranne A., Mayor M., Poncet J.-L., 1979, Vistas in Astron. 23, 279
Batten A.H., 1973 Binary and multiple systems of stars, Pergamon Press), p. 68 – 70
Benz W., Mayor M., 1984, A&A 138, 183
Budaj J., 1996, A&A 313, 523, Part I
Budaj J., 1997, A&A 326, 655, Part II
Carquillat J.-M., Ginestet N., Jaschek C., 1997, in: Visual double stars, eds J.A. Docobo, A. Elipe, and H. McAlister, Kluwer Academic, 1997, 205
Conti P., 1969, ApJ 156, 661
Conti P., Barker P., 1973, ApJ 186, 185
Debernardi Y., 2000, in preparation
Dickens R.J., Kraft R.P., Krzeminski W., 1968, AJ 73, 6
Duqennoy A., Mayor M., 1991, A&A 248, 485
Fekel F.C., 1980, PASP 92, 785
Frost E.B., 1906, ApJ 23. 266
Frost E.B., Barrett S.B., Struve O., 1929, Publ. Yerkes Obs. 7, 1
Ginestet N., Carquillat J.-M., 1998, A&AS 130, 415
Gray R.O., Garrisson R.F., 1989, ApJS 70, 623
Hartkopf W.I., McAlister H.A., Mason B.D., 1999, Third Catalog of Interferometric Measurements of Binary Stars, CHARA Contribution No. 4
Heintz W.D., 1976, ApJ 208, 474
Hill G., 1978, Private Communication
Hui-Bon-Hoa A., Alecian G., 1998, A&A 332, 224
Hui-Bon-Hoa A., Burkhart C., Alecian G., 1997, A&A 323, 901
Hünsch M., Schmitt J.H.M.M., Voges W., 1998, A&AS 132, 155
Künzli M., North P., Kurucz R.L., Nicolet B., 1997, A&AS 122, 51
Maitzen H.M., 1976, A&A 51, 223
Maitzen H.M., Pavlovski K., 1987, A&AS 71, 441
Maitzen H.M., Pressberger R., Paunzen E., 1998, A&AS 128, 573
Mason B.D., Hartkopf W.I., MacAlister H.A., Sowell J.R., 1993, AJ 106, 637
Mathieu R.D., Duquennoy A., Latham D.W., Mayor M., Mermilliod J.-C., Mazeh T., 1992, in: Binaries as Tracers of Stellar Formation, eds. A. Duquennoy & M. Mayor (Cambridge: Cambridge University Press), p. 278
Mathys G. 1988, in: Elemental abundance analyses, eds. S.J. Adelman and T. Lanz, Institut d'Astronomie de l'Université de Lausanne, p. 101
Mathys G., Lanz T., 1990, A&A 230, L21
Matthews L., Mathieu R.D., 1992, in: IAU Coll.135, eds H.A. McAlister & W.I. Hartkopf, 224
Mayor M., Maurice E., 1985, in IAU Coll. 88, Eds A.G.D. Philip & D.W. Latham, L. Davis Press (Schenectady, N.Y.), p. 35
Mazeh T., 1990, AJ 79, 675
McGee J.D., Khogali A., Baum W.A., Kraft R.P., 1967, MNRASS 137, 303
Mermilliod J.-C., 1999, in "Very Low-Mass Stars and Brown Dwarfs", Ed. R. Rebolo, (Cambridge Univ. Press), in press
Michaud G., Tarasick D., Charland Y., Pelletier C., 1983, ApJ 269, 239
Nordström B., Stefanik R., Latham D. W., Andersen J., 1997, A&AS 126, 21
North P., 2000, private communication
North P., Ginestet N., Carquillat J.-M., Carrier F., Udry S., 1998, Contributions of the astronomical observatory Skalnaté Pleso 27, 129
Osvalds V., 1964, Pub. McCormick Obs. 11, 175
Randich S., Schmitt J.H.M.M., 1995, A&A 298, 115
Raboud D., Mermilliod J.-C., 1998, A&A 329, 101
Sanford R.F., 1931, ApJ 74,201
Stilwell W.H., 1949, Publ. Dom. Astrophys. Obs. 7, 337
Stern R.A., Schmitt J.H.M.M., Kahabka P.T., 1995, ApJ 448, 683
Uesugi A., Fukuda I. Kyoto: University of Kyoto, Departement of Astronomy, 1982, Rev.ed.
Wilson R.E., Joy A.H., 1950, ApJ 111, 221
Worley C.E., Douglass G.G., 1996, The Washington Visual Double Star Catalog
Zahn J.-P., Bouchet L., 1989, A&A 223, 112