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Membership, binarity, and rotation of red dwarfs in the nearby open cluster Coma Berenices (Melotte 111)⋆,⋆⋆

J.-C. Mermilliod[1], M. Grenon[2], and M. Mayor[2]

[1] Laboratoire d'Astrophysique, École polytechnique fédérale de Lausanne (EPFL), Observatoire de Sauverny, 1290 Versoix, Switzerland
e-mail: Jean-Claude.Mermilliod@epfl.ch
[2] Observatoire de Genève, 1290 Sauverny, Switzerland

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ABSTRACT

Context. Although several attempts have been made to identify solar-type members on the main sequence of the nearby open cluster Coma Berenices (Mel 111), the population of the lower main sequence is still poorly known.
Aims. We observed 46 new candidates to search for new members and monitored known spectroscopic-binary members to determine orbital parameters.
Methods. We obtained a total of 903 radial-velocity measurements of 69 solar-type stars in the field of Mel 111 with the CORAVEL spectrovelocimeter over 20 years.
Results. Among the 35 stars from Trumpler's list, 23 are members according to their radial velocities and photometry. We were able to confirm the membership of only 8 stars among the 46 candidates observed. Six double-lined and ten single-lined spectroscopic binaries were discovered. Six only are members and an orbit was determined for them and for 4 double-lined non-members. The binary frequency is 22% (7/32). The cluster mean radial velocity is +0.01 ± 0.08 km s^{-1} based on 28 members.
Conclusions. The lower main sequence of the Coma Berenices open cluster is still rather poorly populated. The cluster size may be much larger that usually accepted. Accordingly extensive programmes to determine precise proper motions, radial velocities and photometry should be undertaken to identify faint cluster members outside the cluster central area. If a significant population of faint members cannot be identified, Coma Ber could be a prominent example of dynamical evolution leading to star evaporation.

Key words. Galaxy: open clusters and associations: individual: Coma Berenices (Melotte 111)– stars: binaries: spectroscopic – technique: radial velocities

1. Introduction

Coma Berenices (Mel 111) is a nearby, poorly-populated open cluster located in the direction of the North Galactic pole at $\alpha = 12^h25\overset{m}{.}1$ and $\delta = +26°06'$ (J2000) at a distance of 85 pc for a diameter estimated as about 5°. Its age is close to that of the Hyades ($\log t = 8.65$, 445 Myr), but its metallicity is slightly less than solar, [Fe/H] = –0.05 (Gratton 2000). The upper main sequence contains a number of bright stars, while the lower main sequence is poorly populated for $V > 10.5$. The Coma Berenices cluster is therefore considered as a poorly-populated cluster. Several attempts to discover additional faint members were not successful, as described below.

The bright upper-main-sequence stars, which present Ap and Am stars, were intensively observed, but the solar-type stars received less attention. The lower main sequence is unusually short because it terminates at about $V \sim 10.5$, according to the classical *UBV* paper of Johnson & Knuckles (1955) who observed stars from Trumpler's (1938) list of members. This limit corresponds to the spectral type K0V.

A search for fainter, redder members was performed by de Luca & Weis (1981), but without better success than Argue & Kenworthy (1969) who used *BV* photographic photometry. Bounatiro (1993) proposed a few new members, three of which are included in the present study (Bou 38, 49 and 50). Randich et al. (1996) detected X-ray fluxes of almost all late-F and G stars in ROSAT PSPC observations. Optical follow-up of twelve X-ray candidate stars (García Lopez et al. 2000) did not confirm any new members fainter than $V = 11.0$.

Odenkirchen et al. (1998) investigated the radial structure of the cluster and proposed a number of candidates brighter than $V = 10.5$ according to proper-motion criteria. Casewell et al. (2006) produced a list of 60 candidate members with masses between 1.0 and 0.27 $M_\odot$ selected from proper motions and 2MASS photometry within a circle of 4° in radius centered on the cluster. We have ten stars in common. Finally, Kraus & Hillenbrand (2007) used archival data and propose a list of 98 candidate members with probability >80%, among which 61 are newly identified as high-probability candidates.

We conducted a search for new cluster members and observed 46 candidates. We found only 8 stars presenting a radial velocity in agreement with the Coma Ber mean value and fulfilling the three membership criteria.

Radial velocities with precisions comparable to that of CORAVEL were obtained by Kraft (1965), Jeffries (1999) and Ford et al. (2001). However, no long term monitoring of this sample has been carried out so far and no orbital elements

⋆ Based on observations collected at the Haute-Provence Observatory (France).
⋆⋆ Table 1 is also available, and Full Table 8 only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/491/951

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have been published for the spectroscopic binaries discovered in Coma Berenices by Trumpler (1938) or Kraft (1965), with the exception of that for Tr 111 (Kraft 1965).

The chemical composition of A and F dwarf members were determined by Gebran et al. (2008) who found [Fe/H] = 0.07 ± 0.09 dex, slightly higher that the metallicity derived by Friel & Boesgaard (1992). Kraft (1965) and Ford et al. (2001) published $V \sin i$ values for a number of solar-type stars. New values of $V \sin i$ with a precision of 1 $\mathrm{km\,s^{-1}}$ were also determined from CORAVEL correlation functions.

2. Observations

The initial sample of solar-type members in the Coma Ber cluster was taken from the paper of Johnson & Knuckles (1955) who made their own selection according to the paper of Trumpler (1938), who provided membership information deduced from proper motion, photometry, and radial velocity in the central part of the Coma cluster. Reexamination of Trumpler's table showed that he did not include a few stars in the member list because of the lack of radial velocities. Therefore, we added Tr 6, 12, 35, 120, 25a, A20, and B1 to the observing list, as well as Tr 48, 142, and 147 suggested later by Olsen (1984).

A few additional stars were also selected from Argue's (1963) *UBV* data of 180 objects in the Coma Ber region, for example, Argue 8–21, 9–16, and 19–28, also suggested by Olsen. Four stars were selected from Table 1 of Odenkirchen et al. (1998) (HIP 61 205, 62 763, 62 805, 63 493) and one from their Table 2 (HD 106 293).

As Melotte 111 is a poor cluster, an extensive search for additional members was undertaken. The literature, catalogues and lists of stars in the region of the North galactic pole were searched for stars located within the limits of the Coma Ber cluster. Few stars with photometric data and/or radial velocities in agreement with membership were found.

The two papers by Malmquist (1927, 1936) were the best sources of candidates. He determined magnitudes and colours which permitted us to select stars on the basis of their position in the colour-magnitude diagram. The candidates retained are listed in Table 1 with numbers larger than 413. Table 1 gives for stars not in Trumpler's main catalogue (Trumpler's appendices A and B, and candidate stars), J2000 coordinates from SIMBAD or 2MASS, and cross-references for star designations in several catalogues or lists in the Coma Berenices region.

Finally, five more stars were also observed, HD 105 085, HD 106 293, HD 107 512, HD 111 812 and BD +36 2 278.

Three stars (Tr 87, 111 and 25a) did not show any correlation dip with CORAVEL. Tr 111 is a double-lined spectroscopic binary with a period shorter than one day and the lack of correlation was expected due to the rapid rotation resulting from the short orbital period.

Five Am star members of Coma Ber (Tr 62, 139, 144, 145 and 183) produced well-defined correlation functions and were also observed to improve the orbits of Tr 144 (Harper 1927) and Tr 145 (Conti & Barker 1973) available in 1978. We also searched for radial-velocity variations in Tr 62 and 183. These stars are discussed in Sect. 4.

2.1. Coravel 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, France (OHP) for stars later than spectral type F5 and brighter than $B = 12.5$. Between May 1977 and December 1997, eleven to sixteen observations per star were obtained for Trumpler's members. Three to eight measurements were secured for candidates. Binaries were observed more often to derive orbital elements. Radial velocities were determined as usual by fitting a Gaussian curve to the correlation function, or two Gaussians in the cases of blends (for doubled-lined binaries).

The radial velocities are in the system defined by Udry et al. (1999) from high-precision radial-velocities obtained with the ELODIE spectrograph. This calibration corrects for most systematic effects of the CORAVEL system, concerning the dependence of the zero-point shift as a function of the stellar temperature. The integration times ranged from about 200 to as much as 1500 s, the average being about 360 s. The errors on well-exposed individual measurements usually are lower than 0.5 $\mathrm{km\,s^{-1}}$. However, for a few stars with more rapid rotation, the errors may reach 1 $\mathrm{km\,s^{-1}}$.

Projected rotational velocities ($V \sin i$) were derived from the width of the correlation functions, following the outline by Benz & Mayor (1984).

Individual radial velocities will be published in a comprehensive catalogue of 7200 CORAVEL observations of 1253 solar-type dwarfs in nearby open clusters (Mermilliod et al. 2008).

2.2. Mean radial velocities

Weighted mean radial velocities were computed, with weights of individual observations taken as $1/\epsilon^2$. The general information and mean radial-velocity are given for the members (Table 2) and non-members (Table 3) separately. *UBV* magnitudes and colours and spectral types are taken from WEBDA.

The distribution of the mean radial velocities (Fig. 1) shows a clear peak around $V_r = 0$ due to the cluster members. It contrasts with the large range covered by the velocities of the stars classified as field stars.

3. Results

3.1. Membership

The separation between members and non-members was done on the basis of the radial velocities and photometry. The Coma Ber mean radial velocity is close to 0 $\mathrm{km\,s^{-1}}$. Accordingly stars with $-2 < V_r < +2\ \mathrm{km\,s^{-1}}$ were selected as candidate members and their positions in the (V, $B-V$) diagram were examined. Stars falling below the main sequence (MS) were rejected from membership. This concerns only one star, #293 ($V_r = -1.31\ \mathrm{km\,s^{-1}}$) because all other non-members have radial velocities well outside these limits, which provides a clear membership criterion. Conversely, the position on the MS or within the MS band is not a sufficient criterion as shown by the (V, $B-V$) colour-magnitude diagram for the whole sample (Fig. 2).

Although the photometric selection was quite pertinent, we are able to add or confirm very few new members on the lower main sequence. Several stars located on the single-star sequence proved to be non-members according to their radial velocities.

We are however able to confirm the membership of several stars from Trumpler's list: Tr 12, 48, 120, A20. They were not previously considered by Trumpler because he did not obtain radial velocities to decide on their membership, or because the radial velocity was off the cluster mean, which is the case of Tr 120, a newly discovered binary.

Table 1. J2000 coordinates and cross-references for candidate stars.

No.	RA	Dec	Malm	Arty	Upgren	Argue	Abad	BD	Other
203	12 19 16.26	+25 26 10.5	25.087	44	26.082		1038		Tr A3
213	12 24 05.72	+26 07 43.1	26.170				1431	+26° 2342	Tr A13
214	12 24 17.15	+24 19 28.3	24.148	349			1444	+25° 2502	Tr A14, HIP 60 511, J122417.15+241928.4
219	12 27 52.66	+25 05 44.7	25.198	603	25.073		1748		Tr A19
220	12 28 56.43	+26 32 57.2	27.218	648	27.108		1826	+27° 2139	Tr A20, J122856.43+263257.4
221	12 30 14.10	+25 01 42.3	25.230		25.078		1924		Tr A21, HIP 61 012
222	12 20 05.71	+25 54 36.8	26.101	72	26.087	11–14	1097		Tr B1
275	12 18 51.03	+26 19 24.4	26.075	20	27.084	8–21	995	+27° 2113	
280	12 19 05.18	+26 11 04.4	26.084		26.080	9–10	1019		
282	12 21 15.61	+26 09 14.0	26.121	132	26.092	9–16	1183		J122115.63+260914.1
293	12 18 58.70	+26 03 30.9	26.079		26.077	10–21	1009		
299	12 24 22.95	+25 54 56.2	26.175			11–24	1453		
311	12 22 40.65	+25 40 11.9	26.141			13–18	1297		
334	12 22 25.82	+25 19 03.3	25.129		26.093	15–16	1278		
351	12 19 08.52	+25 03 11.6	25.084		25.053	17–14	1023		
379	12 27 26.28	+24 46 57.0	25.194	577	25.071	19–28			
386	12 13 43.90	+22 53 16.7	23.039				589	+23° 2433	HD 106 293, Bou 38
390	12 52 11.61	+25 22 24.6	25.449					+26° 2402	HD 111 878, HIP 62 805
395	12 32 31.07	+35 19 52.3	35.177					+36° 2278	HIP 61 205, Bou 50
399	12 51 41.92	+27 32 26.5	28.448					+28° 2156	HD 111 812, HIP 62 763, LS Com
400	13 00 35.18	+23 39 06.3						+24° 2522	HD 113 037, HIP 63 493
414	12 34 46.91	+24 09 37.9	24.292	993			2248		J123446.93+240937.7
415	12 36 52.49	+24 01 27.1	24.314	1053					
416	12 16 49.44	+24 51 21.1	25.055		25.044		833	+25° 2479	
417	12 22 59.42	+24 58 58.4	25.141	245	25.058		1332		
418	12 18 57.26	+25 53 10.9	26.078	23	26.076		1003		
420	12 23 28.17	+25 53 38.8	26.155	278					J122328.21+255339.9
421	12 26 51.04	+26 16 02.5	26.215	537	27.101	8–06	1660		J122651.03+261601.9
422	12 29 44.66	+25 32 35.5	26.250	686	26.107		1895		
423	12 33 30.19	+26 10 00.2	26.286	908	26.115		2166		J123330.19+261000.1
424	12 38 55.36	+25 53 38.1	26.364		26.126				
425	12 41 04.97	+25 42 17.9	26.392		26.130		2406	+26° 2379	
427	12 33 54.22	+27 08 04.7	27.297	938	27.121		2194		
428	12 51 25.12	+26 47 08.7	27.506						
430	12 18 39.65	+27 45 58.8	28.108	101	28.068				
431	12 33 00.68	+27 42 45.1	28.277	877	28.096		2129		J123300.62+274244.8
432	12 39 45.90	+28 17 56.7	28.345		29.129				
433	12 40 13.00	+28 13 21.0	28.351				2395	+29° 2313	HD 110 195
434	12 28 25.56	+29 53 54.4	30.178		30.077			+30° 2276	
435	12 28 27.51	+29 52 42.3	30.179		30.078			+30° 2277	
436	12 35 00.33	+30 11 33.6	30.252					+30° 2296	HIP 61 409
437	12 21 20.91	+32 10 35.2	32.078					+32° 2236	HD 107 512, HIP 60 256, Bou 49

Note: this table displays the star numbers according to the numbering system used in WEBDA (`http://www.univie.ac.at/webda/`) or extends it (No > 413), J2000 coordinates from SIMBAD or 2MASS, cross-references with the lists of Malmquist (1927, 1936), Artjukhina (1955), Upgren (1962), Argue (1963) and Abad & Vicente (1999). BD refers, as usual, to the Bonner Durchmusterung. Tr A3, A13, A14, A19, A20, A21 and Tr B1 refer to Trumpler's (1938) appendices A and B respectively. J designation are from Casewell et al. (2006). "Bou" refers to Bounatiro (1993). Miscellanous identifications are: HD for the Henry Draper catalogue and HIP for the HIPPARCOS catalogue.

Stars 220 (Tr A20), 282, 420, 421 and 431, confirmed members from our radial velocities, belong to the list of possible members of Casewell et al. (2006) who give membership probabilities of greater than 64%. In addition, J122706.26+265044.5, identical to Tr 132, is also a true cluster member.

Conversely, several stars from the Casewell et al. (2006) list of candidate members, namely J122417.15+241928.4 (#214), J123446.93+240937.7 (#414), J121857.27+255311.1 (#418) and J123330.19+261000.1 (#423) are obviously non-members, as is the case for J123814.94+262128.1 (#199).

The membership of four stars from Table 1 of Odenkirchen et al. (1998), namely #390, 395, 399 and 400, selected from HIPPARCOS astrometry is confirmed with the present radial velocities. However star #386 (HD 106 293) is probably a non-member. The large rotation makes the radial velocity less precise and it would be interesting to obtain further data to settle its membership more conclusively. The radial velocities for Tr 65 and 102, two stars also listed in Table 2 of Odenkirchen et al. (1998), fully confirm their membership. These two objects did not obtain the maximum rating in Trumpler's (1938) paper for the radial-velocity criterion.

Conversely, stars Tr 35, 74, 147, 148, A3, A14, A19, A21 and B1 have velocities which clearly indicate non-membership. Star Tr 35, a double-lined binary, lies slightly below the MS, which cannot support its membership. If a member, one would expect to find Tr 35 about 0.7 mag above the MS, according to the mass ratio. It is therefore more distant from the Sun than the cluster. Its systemic velocity is slightly off the mean cluster value.

Table 2. Mean radial and rotational velocities for 31 member stars.

No.	V	$U-B$	$B-V$	$V-I$	SpT	V_r	ϵ	N	ΔT	$P(\chi^2)$	$V \sin i$	rms	RV_{lit}	Err	n	Src	Rem
12	9.54		0.60		G0	+0.55	0.15	11	6934	0.195	6.6	0.6	+0.7	0.8	1	b	
19	8.12	–0.02	0.39	0.477	F5 V	+0.69	0.29	13	7536	0.069	21.7	2.2	–0.1	0.6	3	a	
36	8.12	–0.04	0.40	0.482	F3 V	+0.03	0.79	12	5820	0.009	35.1	3.5	+0.7	1.8	3	a	
48	8.80	0.08	0.52		F7 V	–0.43	0.14	37	3565	0.000	9.6	1.4					SB2O
53	8.74	0.02	0.51		F7 V	–0.37	0.11	38	5852	0.000	6.1	0.4	–9.7	0.2	1	a	SB1O
58	8.82	–0.00	0.50		F7 V	+0.40	0.16	15	7271	0.441	16.0	0.4	+1.5	0.1	1	a	
65	9.02	0.04	0.57	0.673	F5 V	–0.51	0.12	16	7271	0.754	9.5	0.5	–2.4	1.0	1	d	
76	9.31	0.08	0.59	0.631	G0 V	–0.75	0.12	13	7271	0.769	9.0	0.4	+0.3	1.0	1	d	
85	9.31	0.06	0.59	0.653	G0 V	+0.15	0.12	11	7271	0.976	7.8	0.5	+2.6	1.0	1	d	
86	8.53	–0.02	0.46	0.544	F7 V	–0.77	0.21	13	7536	0.646	20.7	2.1	+1.3	0.9	2	a	
90	8.55	–0.04	0.46	0.542	F6 V	+0.28	0.18	13	7273	0.354	15.3	0.5	+0.7	0.1	1	a	
92	8.68	0.02	0.53	0.697	F8 V	–0.23	0.15	30	7540	0.305	20.8	2.1	–1.5	2.1	4	e	
97	9.18	0.00	0.54	0.643	F8 V	–0.23	0.10	64	4620	0.000	17.7	0.3	+3.6	13.8	5	e	SB1O
101	8.38	–0.03	0.45	0.521	F6 V	–0.16	0.42	13	7273	0.034	25.3	2.5	–1.2	1.3	2	a	
102	9.33	0.07	0.60	0.692	G0 V	+0.18	0.06	59	6218	0.000	4.3	0.4	–3.1	1.0	1	c	SB1O
114	8.58	–0.05	0.45	0.539	F7 V	+0.77	0.18	11	7272	0.974	15.5	0.4	–0.7	0.1	1	a	
118	8.36	–0.03	0.44	0.518	F6 V	+0.27	0.24	11	7539	0.188	16.5	0.5	–0.4	0.2	2	a	
120	9.76	0.28	0.80		G7	+1.03	0.12	26	5510	0.000	6.4	0.5	+12.1	1.0	1	d	SB1O
132	9.88	0.18	0.67	0.728	G5 V	–0.03	0.12	11	7539	0.501	3.5	0.8	–0.5	1.0	1	d	
150	9.78	0.31	0.78	0.852	G9 V	+0.30	0.12	29	4346	0.000	12.5	2.5	+0.1	0.3	1	a	SB2O
162	8.60	–0.04	0.48	0.546	F7 V	–0.04	0.22	12	7537	0.256	18.3	0.5	–0.5	1.0	2	a	
213	10.48	0.38	0.77		K0 V	+0.12	0.14	8	5104	0.846	5.0	0.9	+0.9	1.0	1	c	Tr A13
220	10.78		0.89		K0 III	+0.83	0.16	6	3631	0.738	3.5	1.2	+0.3	0.8	1	b	Tr A20
282	11.46	0.84	1.10		K1 V	–0.01	0.20	4	2834	0.969	1.4	2.8					Argue 9-16
390	8.87				F8 V	–0.83	0.57	2	2168	0.703	12.7	1.6	–2.4	1.0	1	c	Griffin
395	9.71		0.63		G0	–1.46	0.21	4	2063	0.891	6.4	0.9	–0.5	2.0	1	c	Bou 50
400	8.24				F5 V	–0.80	0.79	2	1091	0.722	23.8	6.5					Griffin
420	12.13		1.20			–0.20	0.20	5	4020	0.686	4.7	1.3					Malm 26.155
421	11.94		1.15		K2 V	–0.69	0.25	5	3688	0.153	1.0	3.6					Malm 26.215
431	11.25		1.00		K0 IV	–0.10	0.18	5	3697	0.846	3.8	1.9					Malm 28.277
436	8.63		0.59		F8 V	–1.91	0.20	8	3633	0.251	14.1	0.5					Malm 30.252

Notes: stellar identification, according to Trumpler (1938) and extension in WEBDA, V, $B-V$, $U-B$, and $V-I_K$ photometric indices, spectral types, CORAVEL mean radial velocities and errors in km s^{-1}, the number of observations, probabilit $P(\chi^2)$ that the scatter is due to random errors, projected rotation ($V \sin i$) and error, also in km s^{-1}, radial velocities from the literature, their error and sources, and remarks on binarity and cross-identifications. Literature sources: a: Kraft (1965); b: Glushkova (1993); c: Ford et al. (2001); d: Jeffries (1999) ; e: Trumpler (1938).

Finally, most stars selected outside Trumpler's list were found to be non-members. Their radial velocities are significantly different from the cluster mean velocity, which confirms the difficulty of identifying new members. So far this does not mean that the Coma Berenices open cluster does not contain G- and K-type dwarfs, but that a lot of effort is required to find many more members.

3.2. Mean cluster velocity

The mean cluster velocity is $\langle V_r \rangle = 0.01 \pm 0.08$ (0.44 rms) from 28 members listed in Table 2. The observed dispersion is quite small and the radial velocity is therefore a very efficient criterion for membership determination.

3.3. Spectroscopic binaries

Trumpler (1938) already detected several spectroscopic binaries, namely Tr 48 (Var?), 97, 102, and 150. Kraft (1965) classified stars Tr 53 and 65 as suspected binaries. Concerning Tr 120, the open-cluster database contains only one radial-velocity measurement, by Jeffries (1999), and no mention of its binary character. Its duplicity became evident in March 1979, because the fifth observation differed by 9 km s^{-1} from the previous measurements.

The six spectroscopic binaries, 2 SB2 and 4 SB1, found among the members were monitored until the number of observations permitted us to compute an orbit. The orbital elements are given in Table 4. Tr 97 and 150 have circular orbits as expected for periods around 3 days. The periods for the other binary members are longer and range from 48 to 444 days. Tr 111, a double-lined binary with a period as short as $0^{\rm d}.96$ (Kraft 1965), could not be observed because of the induced rapid rotation and the resulting broad lines. The resulting binary percentage is 22% (7/32), taking Tr 111 into account.

Seven binaries were detected among the non-members, 4 SB2, 3 SB1, and an orbit was determined for the four double-lined binary stars Tr 35, 147, #416 (Malm 25°55), and 433 (Malm 28°351). The orbital elements are also presented in Table 4. We do not support the hypothesis that Tr A21 is a binary. Our mean value, +30.5 km s^{-1} based on 5 observations agrees closely with the Ford et al. (2001) radial velocity, +30.6 km s^{-1}. Accordingly Tr A21 is neither a binary nor a member.

3.4. Rotation

The projected rotational velocities published by Kraft (1965) had a lower resolution at 12 km s^{-1}. Ford et al. (2001) obtained a better resolution limit at 6 km s^{-1}. CORAVEL observations allow us to determine rotational velocities with a precision of 1 km s^{-1}. Figure 13 presents the distribution of the projected rotational velocities as a function of $B-V$.

The two stars with short periods, Tr 97 and especially Tr 150 ($B-V = 0.78$, $V \sin i = 12.5$ km s^{-1}), rotate faster than the other

Table 3. Mean radial and rotational velocities for non-member stars.

No.	V	$B-V$	$U-B$	SpT	V_r	ϵ	n	ΔT	$P(\chi^2)$	$V\sin i$	Err	Rem
6	8.79	0.50	–0.05	F9 V	–24.63	0.18	6	3632	0.745	2.7	1.4	
35	8.37	0.41	0.03	F6 V	–2.49	0.29	39	1138	0.000	21.1	4.0	SB2O
74	8.56	0.56		G5	–6.58	0.15	8	5119	0.650	7.9	0.6	
127	8.80	0.54	0.04	F8/9 V	–19.97	0.23	8	7539	0.025	7.3	0.6	
135	10.10	0.91	0.60	G8 III	+21.08	0.15	6	5463	0.743	3.2	1.1	
142	9.96	0.65	0.13	G5	+8.52	0.21	4	2589	0.975	1.9	1.9	
147	8.58	0.55	0.02	F6 IV-V	–13.68	0.26	19	3565	0.000	21.7	2.2	SB2O
203	10.79	0.87	0.57	G9 V	–14.57	0.17	5	5434	0.844	0.0	0.0	Tr A3
214	10.00	0.79	0.33	G9 V	+62.44	0.19	5	5454	0.400	4.0	1.4	Tr A14
219	11.18	0.82	0.39	G9 V	–16.26	0.20	5	5789	0.713	1.9	1.8	Tr A19
221	10.37	0.82	0.41	G7 V	+30.51	0.22	5	5454	0.220	3.0	1.7	Tr A21
222	11.26	0.98			–44.59	0.15	7	4363	0.880	1.1	1.5	Tr B1
275	10.82	0.95	0.74	K1 V	–6.92	0.87	15	3564	0.000	4.5	0.6	Argue 8–21, SB
280	11.49	0.90	0.57	G8 III	–4.36	0.18	5	5431	0.803	1.8	1.6	Argue 9–10
293	11.70	0.94	0.55	G8 III	–1.31	0.19	5	5082	0.894	3.0	1.9	Argue 10–21
299	12.38	1.14	1.21		–25.49	0.25	3	3628	0.688	1.3	3.9	Argue 11–24
311	10.47	0.71	0.27		–50.24	0.29	5	5454	0.049	0.8	2.6	Argue 13–18
334	11.61	0.88	0.54	G8 III	+13.68	0.21	4	5813	0.686	2.8	0.0	Argue 15–16
351	12.33	1.00	0.57	K0	+41.71	0.27	3	3628	0.492	0.0	0.0	Argue 17–14
379	11.65	1.26	1.24	K2 V	–5.73	0.70	4	3183	0.000	2.3	1.8	Argue 19–28, SB
386	8.08	0.41		F5 V	+6.83	2.29	3	617	0.196	66.8	7.8	Bou 38
414	*12.01*				+10.18	0.24	3	1455	0.390	1.9	0.0	Malm 24.292
415	*12.18*				–6.80	0.95	3	1455	0.000	5.1	3.3	Malm 24.314, SB
416	10.51	0.79		G8 III	+12.45	5.75	5	4319	0.000	1.1	0.0	Malm 25.055, SB2O
417	11.32	1.05			+79.27	0.29	4	4419	0.105	0.0	0.0	Malm 25.141
418	11.51	1.03		G8 III	+75.07	0.20	4	3688	0.856	2.8	0.0	Malm 26.078
422	11.23	1.04		K0 III	+14.78	0.22	4	4427	0.371	2.7	0.0	Malm 26.250
423	11.12	1.05		K0 III	+74.81	2.68	4	4427	0.000	0.0	0.0	Malm 26.286, SB
424	10.91	0.96		K3 V	–15.76	0.19	5	5459	0.341	3.7	1.3	Malm 26.364
425	10.24	0.76		G5	+14.54	0.17	5	3982	0.395	2.1	1.6	Malm 26.392
427	11.72	1.08		G8 V	+12.36	0.22	4	4401	0.652	2.6	2.3	Malm 27.297
428	*11.74*				+10.09	0.55	13	4366	0.000	7.9	1.6	Malm 27.506, SB
430	11.22	0.92		K0 III	–30.10	0.20	4	4432	0.898	1.1	2.7	Malm 28.108
432	*11.51*			K1 V	+7.66	0.25	5	4340	0.126	3.1	1.6	Malm 28.345
433	*10.13*				–16.20	10.50	4	3980	0.000	1.6	2.2	Malm 28.351, SB2O
434	10.67	0.87		G8 III	–15.87	0.18	5	3984	0.965	1.7	0.0	Malm 30.178
435	10.07	0.71		G5	–14.86	0.48	7	5100	0.000	4.8	1.7	Malm 30.179, SB
437	9.10	0.45		G0	–4.05	2.07	7	2063	0.000	9.4	0.5	Bou 49, SB

Notes: stellar identification, according to Trumpler (1938) and extension in WEBDA, V, $B-V$, and $U-B$ photometric indices, spectral types, CORAVEL mean radial velocities and errors in km s^{-1}, the number of observations, probability $P(\chi^2)$ that the scatter is due to random errors, projected rotation ($V\sin i$) and error, also in km s^{-1}, and remarks on binarity and cross-identifications.

members of the same colour, which is easily explained by the acceleration of the rotation due to circularization of the orbits. The rotation of star Tr 120 appears to be normal for its $B-V$ colour, while the three binaries with periods longer than 17 days seem to rotate slightly slower than the other stars with similar colours. The effect is more marked for Tr 53 ($B-V = 0.51$, $V\sin i = 6.1$ km s^{-1}).

3.5. Colour-magnitude diagram

Figure 14 displays the (V, $B-V$) colour-magnitude diagram for the 31 members of Table 2. The main sequence seems normally populated for $V < 10.5$ and is very sparse at fainter magnitudes. The efforts devoted to search for late G- and K-type members in Coma Berenices were not very successful. The main sequence of Casewell et al. (2006) seems to be more evenly populated, although we showed that several candidates of their Table 2 are non-members (see Sect. 3.1).

Two binaries, Tr 120 and 150, are located on the binary ridge, close to each other. Such a location is expected for the double-lined binary Tr 150, but not for Tr 120 because only one component was observed in the correlation functions, although a secondary nearly as bright as the primary would be expected from the photometry. The minimum mass for the secondary is $M_2 = 0.52$, with $f(m) = 0.0699$ and $M = 0.90\ M_\odot$ for the primary.

Star #436 is also located close to the binary ridge, but does not show any sign of variability, $P(\chi^2) = 0.251$, with 8 measures covering a time interval of 3633 days. Two other stars, Tr 65 and 92, are also located above the single-star locus and could be considered as photometrically detected binaries. Although 30 observations were obtained for Tr 92 over a period of 7540 days, no significant variation could be detected, which is reflected by the value of $P(\chi^2) = 0.305$. The same is true for Tr 65, with 16 observations over 7271 days and $P(\chi^2) = 0.754$. However, according to the depth effect discussed below, they could be at a smaller distance than the cluster centre and perhaps belong to the corona of the cluster rather than to the core.

The lower sequence (continuous curve) plotted in Fig. 14 is fitted to the mode of the star distribution with a distance modulus $m - M = 4.65$, corresponding to a distance of 85 pc. The scatter

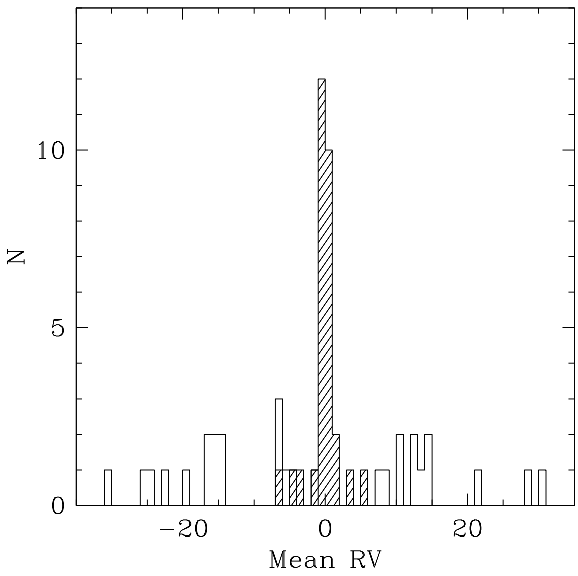

Fig. 1. Distribution of the observed radial velocities. The peak close to $V_r = 0$ (hatched histogram) is due to the cluster members.

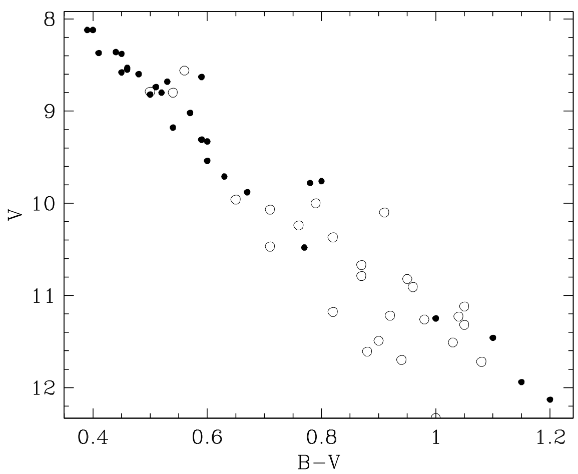

Fig. 2. Colour–magnitude diagram of the whole sample. Members are displayed with filled circles, and non-members with open circles. Several stars selected by the photometry and located closely on the main sequence are in fact non-members.

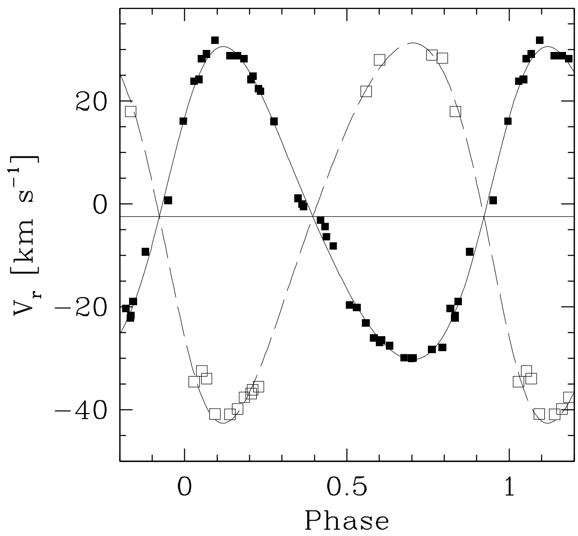

Fig. 3. Radial-velocity curve for the double-lined binary Tr 35.

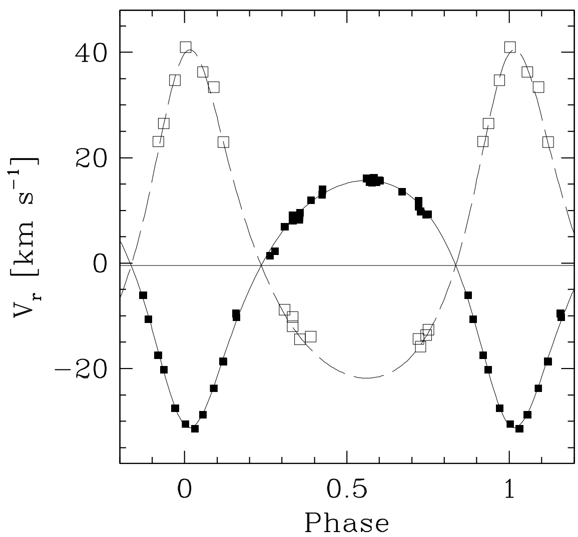

Fig. 4. Radial-velocity curve for the double-lined binary Tr 48.

around this sequence is larger than expected in well-behaved open clusters. This results from the short distance to the cluster and is mainly due to the depth effect, as in the Hyades. If the mean distance is taken as 85 pc and a radius of 5° is adopted, the linear radius is 7.4 pc. Accordingly the closest and farthest distances are 77.6 and 92.4 pc, corresponding to distance-moduli of 4.45 and 4.82 respectively. The resulting depth of 0.37 mag matches the effect observed. If a radius of 10° is used, as would be necessary to take into account probable members located at such a distance from the cluster centre, then the radius is 14.8 pc and the extreme distance-moduli become 4.23 and 4.99 for the closest and most distant edges. Because the cluster proper motion is small and the mean radial velocity nearly zero, no kinematical individual distance can be computed.

3.6. Candidates from other studies

Star #388 (HIP 62 384, HD 111 154, BD +23° 2492, F9 V + G1.5 V), considered as a member from its kinematics by Odenkirchen et al. (1998), was observed in radial velocity by Griffin with his spectrograph in Cambridge (Griffin 2001), but also extensively with the CORAVEL at OHP. He found that this star is a double-lined binary and determined the orbital elements. The period is 26.^{d}971 and the systemic velocity, $\gamma = +0.55$ km s^{-1}, confirms the membership of HD 111 154 in the Coma Ber cluster. The projected rotational velocities determined from CORAVEL correlation functions are $V \sin i = 5.7 \pm 0.5$ km s^{-1} for the primary and $V \sin i = 3.2 \pm 0.8$ km s^{-1} for the secondary (Griffin 2001). Star #388 is represented by a cross in Fig. 14 at $V = 8.40$ and $B - V = 0.56$, and lies close to the upper binary ridge in agreement with it beeing a double-lined binary.

Odenkirchen et al. (1998) produced a list of 11 kinematic cluster members with $V > 8.5$. The membership of two of them, Tr 65 and 102, is confirmed by our observations. The radial velocities of Ford et al. (2001) support the membership of five other stars from Table 2 of Odenkirchen et al. (1998). The radial velocities and V and $B - V$ photometry are reproduced in Table 5, which gives the WEBDA extended numbering, HD/BD identifications and the parameters taken from Ford et al. (2001). These five stars are represented by crosses in Fig. 14. Four are located

Table 4. Orbital elements of ten spectroscopic binaries.

No	P [d]	T [HJD-2 400 000]	γ [km s^{-1}]	e	ω [°]	K_1 [km s^{-1}]	K_2 [km s^{-1}]	$f(m)$ [$M_\odot$]	$a \sin i$ [Gm]	σ(O–C) [km s^{-1}]	n_{obs}
35	42.582	44 985.90	–2.49	0.158	303.2	30.42	36.95	0.215	21.36	1.93	39
	0.0103	0.57	0.29	0.013	4.6	0.42	0.76	0.015	0.49		
48	58.7220	44 994.99	–0.43	0.320	347.9	23.45	31.15	0.0668	17.94	0.87	37
	0.0047	0.29	0.14	0.009	1.2	0.24	0.44	0.0027	0.24		
53	444.19	43 424.9	–0.37	0.191	342.6	11.51		0.0665	69.0	0.56	38
	0.28	4.1	0.11	0.014	3.4	0.14		0.0030	1.1		
97	3.023373	44 999.437	–0.23	0.000		51.39		0.04261	2.1365	0.79	64
	0.000003	0.002	0.10	fixed		0.14	.	0.00035	0.0059		
102	48.03078	44 968.043	+0.18	0.452	193.86	27.74		0.0755	16.34	0.41	59
	0.00036	0.040	0.06	0.003	0.06	0.13		0.0014	0.10		
120	294.90	44 732.5	+1.03	0.327	246.9	13.93		0.0699	53.4	0.54	25
	0.12	1.4	0.12	0.012	2.0	0.20		0.0039	1.0		
147	52.7917	45 005.28	–13.68	0.479	70.1	33.94	49.27	0.1449	31.39	1.24	23
	0.0049	0.37	0.26	0.008	1.2	0.32	0.61	0.0064	0.32		
150	3.558151	45 002.746	+0.30	0.000		75.79	79.12	0.1608	3.708	0.92	29
	0.000003	0.001	0.12	fixed		0.22	0.25	0.0014	0.010		
416	164.621	45 069.04	+18.43	0.788	210.8	25.91		0.069	36.1	2.14	29
	0.080	0.86	0.54	0.026	3.3	0.84		0.018	3.2		
433	17.778507	44 990.055	–15.37	0.569	59.77	55.31	56.43	0.1736	11.118	0.89	30
	0.000044	0.010	0.12	0.002	0.43	0.25	0.27	0.0033	0.071		

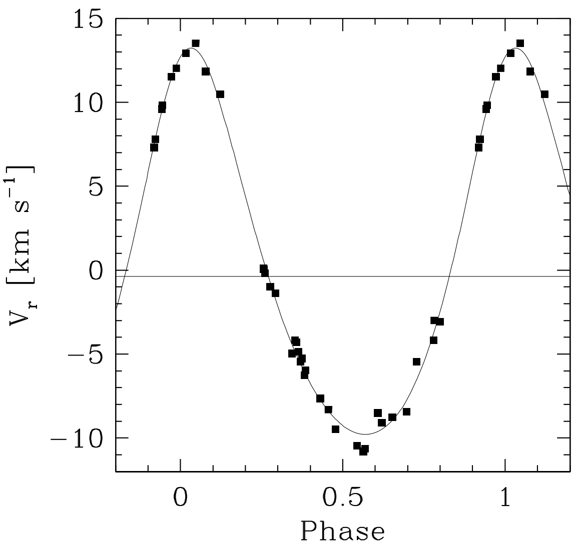

Fig. 5. Radial-velocity curve for the single-lined binary Tr 53.

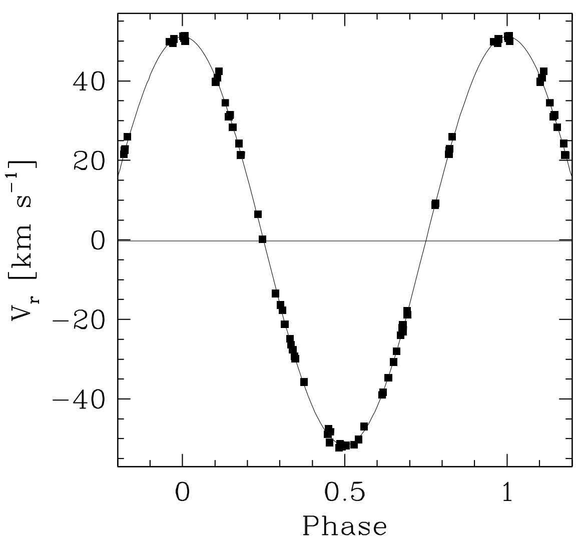

Fig. 6. Radial-velocity curve for the single-lined binary Tr 97.

on, or close to, the single-star locus, while Tr 141 is probably a photometric binary. Star #397 lies some 12° away from the cluster centre.

Ford et al. (2001) concluded that the other stars (BD +16°2505, +25°2631, +36°2312 and TYC 2534-1715-1) are non-members according to their radial velocities and absence of LiI lines at 6708 Å, although their V, $B-V$ photometry would locate them within the MS band. It would be useful to obtain additional radial velocities of BD +16°2505 and +25°2631 to be sure that they are not binaries and settle more definitively their membership status.

4. Am stars

Five Am stars and one Ap (Tr 146) were observed with CORAVEL. Tr 144 and 145 are both spectroscopic binaries with periods of 11.^{d}7 and 68.^{d}3 respectively (Abt & Willmarth 1999).

Table 5. Additional cluster members.

No.	Ident.	V	$B-V$	V_r	Source
141	BD +29°2290	9.72	0.71	+0.6	Ford et al. (2001)
385	BD +21°2514	10.12	0.75	–0.6	Ford et al. (2001)
388	HD 111154	8.40	0.56	+0.6	Griffin (2001)
392	BD +28°2119	10.50	0.79	+2.0	Ford et al. (2001)
394	HD 114400	9.59	0.61	–1.7	Ford et al. (2001)
397	BD +38°2436	9.10	0.54	–2.0	Ford et al. (2001)

Mean radial velocities are given in Table 6. The orbital elements for Tr 144 and 145 given in Table 7 confirm the previous ones. The radial-velocity curves are displayed in Figs. 15 and 16. Spectral types in Table 6 are from Gray & Garrison (1989), and from Abt & Cardona (1984) for Tr 146. Individual observations are given in Table 8. The complete data set is available in electronic form at the CDS.

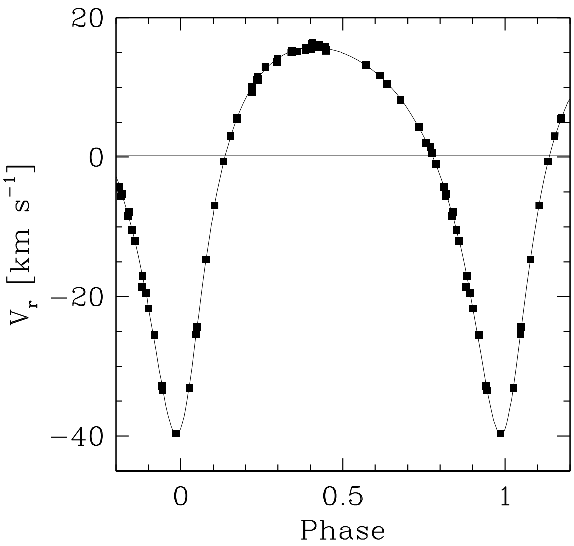

Fig. 7. Radial-velocity curve for the single-lined binary Tr 102.

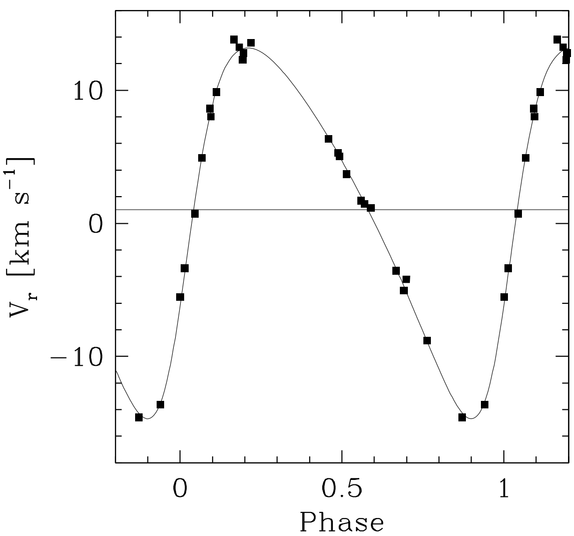

Fig. 8. Radial-velocity curve for the single-lined binary Tr 120.

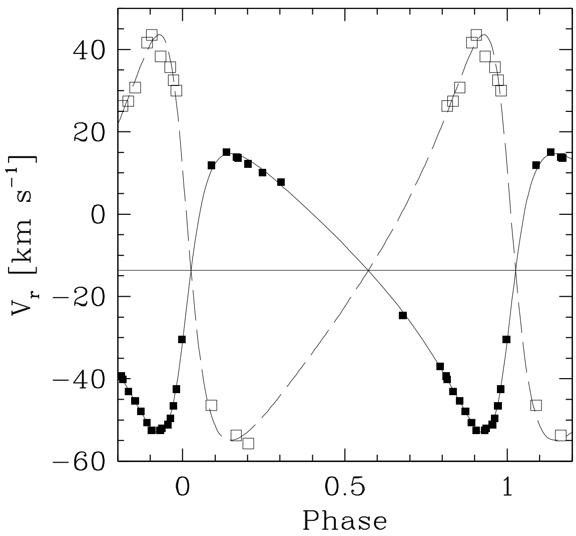

Fig. 9. Radial-velocity curve for the double-lined binary Tr 147.

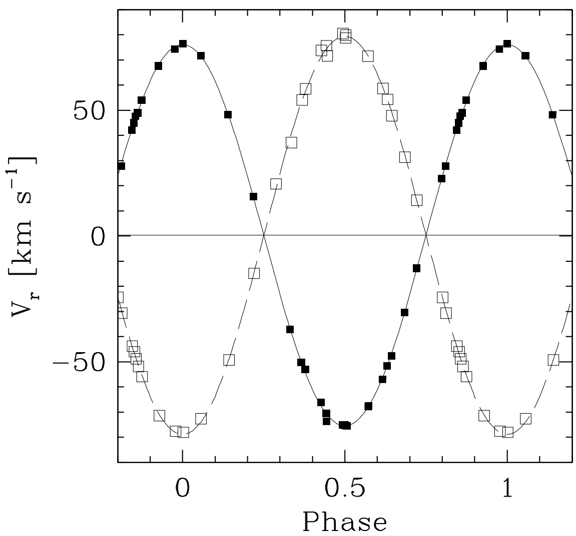

Fig. 10. Radial-velocity curve for the double-lined binary Tr 150.

The other stars classified as Am did not vary in radial velocity. Star Tr 62 was observed 13 times between December 1979 and December 1997 and no variation was found. Similarly, Tr 183 was measured 16 times over the same interval of time and no variation was seen. While Tr 62 is clearly an Am star, Tr 183 may be either a mild Am, with only a deficiency of Ca: SP(K, H, M) = A5-A7-A7 (Abt & Morrell 1995) or a normal star, classified A3 IV-Vs by Gray & Garrison (1989) and A5 III by Cowley et al. (1969). Tr 139 is probably also constant, although the rotation produces larger correlation functions and hence less precise radial velocities. At least two Am stars, Tr 62 and Tr 139, are not spectroscopic binaries, which confirms the conclusions reached by Conti & Barker (1973).

5. Discussion

Among the 74 stars observed, 38 turned out to be simply field stars, i.e. non-members. This high fraction confirms the difficulty of finding new bona fide members although the photometry of many of these candidates located them close together on the single-star locus or within the main-sequence band.

Table 6. Mean radial velocities of the Am and Ap stars.

No.	MK type	V_r	Eps	n	ΔT	$P(\chi^2)$	$V \sin i$	Err	Notes
62	A5m	+1.28	0.17	13	6585	0.484	14.1	0.3	Const.
139	A5m	+2.28	1.08	6	1803	0.535	38.4	3.8	Const.
144	A7m	–0.36	0.10	28	5166	0.000	8.2	0.3	SB1O
145	A2m	+0.05	0.44	17	5166	0.000	20.1	2.0	SB1O
146	A1Vp	+3.79	1.89	2	26	0.210	26.8	2.7	Const.
183	A3IV-Vs	+1.62	0.35	16	6582	0.018	14.7	0.7	Const.

One fundamental aspect in the search for detection of new members is the area in which members are looked for. The fact that star #397 (BD +38°2436) lies some 12° from the cluster centre and #395 (BD +35°2278) at some 9° seems to indicate that the cluster dimension is much larger than usually accepted. These two objects could be considered as belonging to the cluster corona, although they could be runaway stars, still sharing the same motion as the bulk of the cluster stars. This part of the surface has not been much investigated so far. Depending on the real radial distribution of the stars in the Coma Berenices cluster, a sizeable fraction of candidates could be located more than 5° away from the cluster centre. The existence of such a population

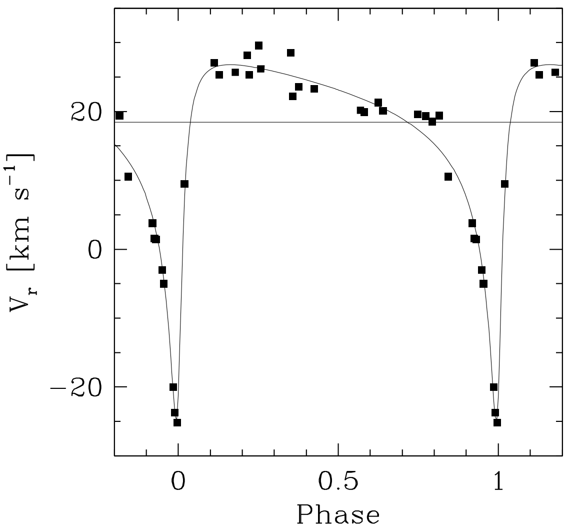

Fig. 11. Radial-velocity curve for the single-lined binary Malm 25.055.

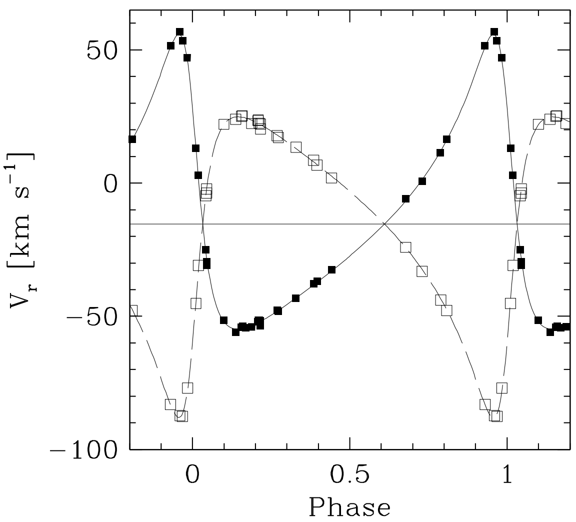

Fig. 12. Radial-velocity curve for the double-lined binary Malm 28.351.

of members in cluster coronae was proved by the CORAVEL radial-velocity surveys of the Pleiades (Rosvick et al. 1992; Mermilliod et al. 1997) and Praesepe (Mermilliod et al. 1990).

6. Conclusions

The radial-velocity survey of solar-type dwarfs in the Coma Berenices open cluster allowed us to confirm the membership of the 19 stars already selected by Trumpler (1938), and of 4 additional stars for which he did not obtain radial velocities. Orbits were determined for the 6 binary members presently known and for 4 double-lined binary non-members. At least one binary, Tr 150 with a short period $P = 3\overset{d}{.}55$, rotates faster than the single stars of similar colours. The contrast is apparent because of the low rotation of the other solar-type members.

Coma Berenices seems to be the first well-studied nearby open cluster with a poorly-populated main sequence. Indeed, most studies performed so far have not succeeded in identifying a significant population of K- and M- type members, as observed in most other nearby open clusters. Lower-main-sequence stars, usually fainter than the limits of the available *UBV* photoelectric photometry, were identified in other nearby clusters by X-ray

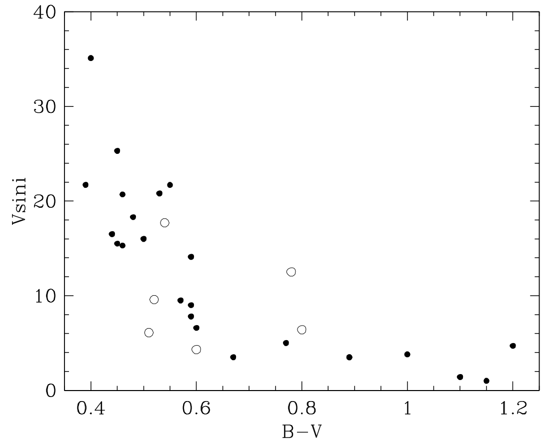

Fig. 13. Distribution of the projected rotational velocities as a function of the $B-V$ colours. The filled circles represent single stars and open circles, binaries.

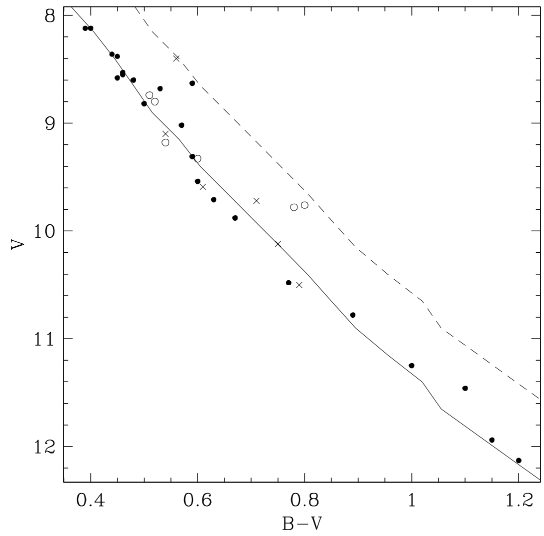

Fig. 14. Colour–magnitude diagram for the cluster members. The lower sequence is the ZAMS, and the upper one, the upper limit for binaries. The filled circles represent single stars and open circles, binaries, and crosses, five stars from Ford et al. (2001).

Table 7. Orbital elements of two Am stars.

No.	Tr 144	Tr 145
P [d]	11.787023	68.252
	0.000034	0.022
T [HJD]	49987.406	49967.7
	0.006	1.3
V_o [km s^{-1}]	–0.36	+0.05
	0.10	0.44
e	0.0349	0.287
	0.0034	0.037
ω [°]	155.1	262.9
	5.6	7.6
K [km s^{-1}]	40.61	13.54
	0.14	0.39
$f(m)$	0.08185	0.0154
	0.00087	0.0013
$a \sin i$ [Gm]	6.579	12.17
	0.023	0.35
σ(O–C) [km s^{-1}]	0.47	1.12
n_{obs}	28	17

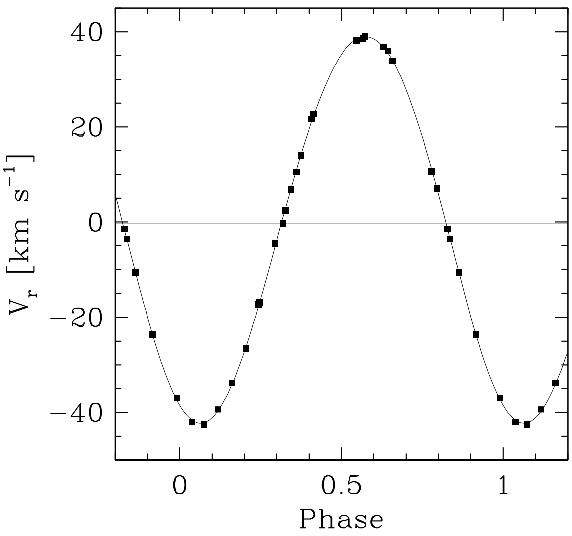

Fig. 15. Radial-velocity curve for the Am binary Tr 144.

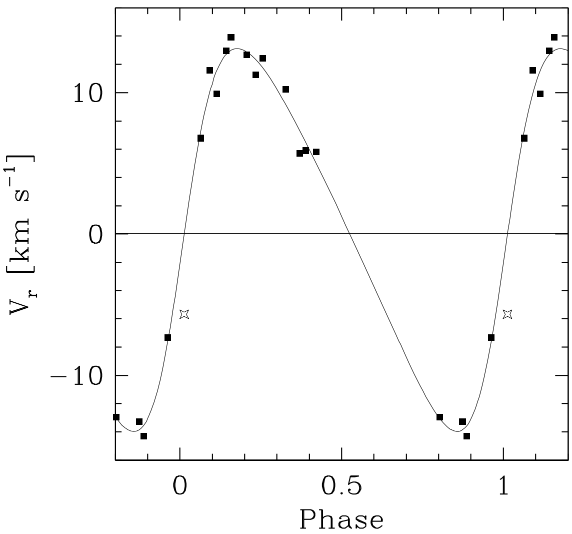

Fig. 16. Radial-velocity curve for the Am binary Tr 145.

imaging. Although most solar-type dwarfs in Coma Ber do emit X-rays, no additional stellar sources were found to be members of the Coma cluster. The candidates listed by Casewell et al. (2006) should be observed to settle their membership. However the very small proper motion and the radial velocity close to zero do not facilitate the selection of members. Depending on the results of these observations, confirming or not the membership of several of the candidates, Coma Ber may be a prominent example of dynamical evolution leading to star evaporation. However, the search area probably should be extended up to 10° or even 12° to identify corona members. The importance of its location at high latitude above the galactic plane should be evaluated to explain the paucity of low-mass members.

Table 8. Individual radial velocities.

No.	HJD	Vr	pe
62	2 444 224.746	+2.50	0.84
62	2 444 227.723	+1.57	0.73
62	2 444 277.556	+1.06	0.67
62	2 444 287.609	+1.21	0.68
62	2 444 307.509	+0.61	0.61

Notes: Table 8 is available in its entirety from the CDS ftp archives at http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/491/951

The study of the Coma Berenices cluster illustrates once again that kinematical data, in this case radial velocities, are of fundamental importance to determine with a high degree of reliability the membership of stars in nearby open clusters.

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