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Red giants in open clusters*

XII. Six old open clusters NGC 2112, 2204, 2243, 2420, 2506, 2682

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

[1] Laboratoire d'Astrophysique de l'École polytechnique fédérale de Lausanne, Observatoire, 1290 Sauverny, Switzerland
e-mail: Jean-Claude.Mermilliod@epfl.ch
[2] Observatoire de Genève, 51 Ch. des Maillettes, 1290 Sauverny, Switzerland

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ABSTRACT

Aims. We studied the membership and binarity of 123 red giants in six old open clusters, NGC 2112, 2204, 2243, 2420, 2506 and 2682, to define more precisely the evolutionary path on the red-giant branch.
Methods. The analysis is based on 185 radial-velocity observations with the Coravel spectrographs and available photometric data.
Results. The membership of 93 red giants was confirmed on the basis of the radial velocities. Seven definitive spectroscopic binaries were identified and 11 additional stars are suspected of being binaries. The binary frequency (19%) is slightly lower than average. This is partly due to the small number of observations secured for each star. Orbital elements have been determined for the first time for the BaII star NGC 2420-173 (D) and those of the other BaII star NGC 2420-250 (X) have been improved. The values of the cluster mean velocities have been significantly improved.
Conclusions. With the new membership estimates and binary detections, the existing CCD data allow precise definition of the red-giant loci. A number of stars in NGC 2506, 2420 and 2204 appear to define an asymptotic branch, the position of which differs significantly from that predicted by the models.

Key words. Galaxy: open clusters and association: general – stars: binaries: spectroscopic – techniques: radial velocities – stars: late-type

1. Introduction

Within a series devoted to the study of red giants in open clusters by means of accurate radial velocities (RVs) obtained with the CORAVEL instruments (Baranne et al. 1979; Mayor 1985), we analyse in the present paper the observations for six old open clusters, NGC 2112, NGC 2204, NGC 2243, NGC 2420, NGC 2506 and NGC 2682.

Interpretation of the red giant branch and clump morphology depends on the separation of members/non-members and the identification of spectroscopic binaries. The composite colours of a binary formed by a red-giant primary and a main-sequence secondary may drive the representative point out of the red-giant track as far as the middle of the Hertzsprung gap. Photometric analysis of membership in the red giant region should therefore be completed with spectroscopic data to detect the binary red giants and determine their systemic velocities. Previous papers in this series (Eigenbrod et al. 2004; Mermilliod et al. 2003) have shown that accurate RVs are very efficient to determine the membership of red giants in open clusters.

However, very few RVs have been published for most of the stars in these six clusters, with the exception of the red giants in M 67. It is often not possible to decide whether a red giant is a non-member or a binary member. In several cases, the uncertainties on the existing data are too large and the data do not discriminate the membership or binarity determination.

Accordingly, an observing program has been set up to improve the quality and number of RVs and put the membership / binarity determination on more solid ground. A total of 123 red giants have been observed in these 6 old open clusters which have well marked clumps and extended red-giant branches but differ in metallicities.

2. Observations

The observations reported in this paper are part of a systematic observing program which contains about 1300 red giants in the field of some 180 open clusters. This program was started in 1979 in the Haute-Provence observatory (France) and in 1983 in La Silla (Chile). The decommissioning of the CORAVEL instruments in 1997 put an end to the observing campaigns.

The radial-velocity observations were made with the photoelectric scanner CORAVEL (Baranne et al. 1979; Mayor 1985) on the Danish 1.54-m telescope at ESO, La Silla, Chile, during several observing runs in 1993 and 1994. Observations of the brighter stars in NGC 2420 have also been obtained at the Haute-Provence Observatory (OHP) with the northern CORAVEL. The RVs are on the system defined by Udry et al. (1999), calibrated with high-precision data from the ELODIE spectrograph (Baranne et al. 1996).

The individual observations, with the Julian dates, will be published in the complete catalogue of RVs for red giants in open clusters obtained with the CORAVEL instruments (Mermilliod & Mayor 2006). They can also be obtained on request from the first author.

* Based on observations collected with the Danish 1.54-m and ESO 1-m telescopes at the European Southern Observatory, La Silla, Chile.

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Table 1. Mean radial velocities for the red giants in NGC 2112.

No	V	$B-V$	V_r	ϵ	N	BWG	Err	n	FJ	Rem
Members										
316	12.34	2.11	+31.75	0.52	1				+21.	
401	12.12	1.69	+28.56	1.46	2					SB
402	11.25	1.57	+32.53	1.87	2	+24.5	3.3	3	+35.	SB
Non members										
116	9.86	2.44	–4.04	0.27	2	–3.6	1.0	1		NM
216	13.24	1.58	–29.02	0.68	1	–23.3	2.2	1	–22.	NM
317	11.79	2.15	+44.76	0.58	1				+40.	NM

The successive columns present Richtler's (1985) identification, V and $B-V$, the mean radial velocity (V_r), uncertainty on the mean velocity (ϵ), and the number of Coravel measurements (N), the mean velocities (BWG), error and number of measurements from Brown et al. (1996), the velocities (FJ) of Friel & Janes (1993), and notes on duplicity (SB: spectroscopic binary) and membership (NM: non-member).

3. Results

3.1. NGC 2112

Due to the limiting magnitude at the 1.5 m Danish telescope ($B <$ 15.), only 6 stars could be observed in NGC 2112, on nights with the best seeing. They were selected from the photometric study of Richtler (1985). Results are given in Table 1. Radial velocities for 5 red giants, one observation per star, have previously been obtained by Friel & Janes (1993) (FJ), and for 6 stars by Brown et al. (1996), (BWG). Three stars can be considered as cluster members (#316, 401 and 402), while stars #116, 216 and 317 are clearly non-members. From Brown et al. (1996), one can consider that star #204 (V_r = +30.1 ± 0.21 km s^{-1} n = 3) is also a member and that #318 (V_r = +25.3 ± 2.2 km s^{-1} n = 1) may be a member, if it is a binary. Stars #416 (V_r = +60. km s^{-1}) and 418 (V_r = +44.6 km s^{-1}) are clearly non-members. From our observations, star #401 and 402 are spectroscopic binaries ($P(\chi^2) = 0.000$).

Friel & Janes (1993) derived a mean cluster velocity of +39. km s^{-1}. Our observations show that the cluster velocity should be smaller and is close to +32. km s^{-1}. More red giants, down to $V \sim 14.5$ need to be observed to better define the membership and the position of the red giant branch.

3.2. NGC 2204

We observed in NGC 2204 35 stars brighter than V = 14.15, selected from the photometric study of Hawarden (1976). The sample includes all red giants in the clump and those brighter than the clump. Most stars have one observation only, but 5 have two. Results are given in Table 2, which presents in the first 6 columns the identification according to Hawarden (1976), the V magnitude, the $B-V$ colour index, the mean RV, uncertainty on the mean velocity, and the number of CORAVEL measurements. Radial velocities for 20 red giants in NGC 2204 have been obtained by Minitti (1995) and for 19 by Friel et al. (2002). The values are given in columns DM and FJT respectively in Table 2. These authors obtained one observation per star.

The difference computed in the sense CORAVEL minus Minniti for 11 stars in common is 24.8 ± 10.9 km s^{-1} (rms). This value is larger than the uncertainty (20 km s^{-1}) claimed by Minniti (1995). The rms reflects the random error on Minniti's single observation. The difference computed with the observations of Friel et al. (2002) is 1.75 ± 6.7 km s^{-1}. The data obtained with the CORAVEL provide a significant improvement of the RV and membership determination, although they are mainly based on one observation as well.

Table 2. Mean radial velocities for the red giants in NGC 2204.

No	V	$B-V$	V_r	ϵ	n	DM	FJT	Rem
Members								
1124	13.835	0.999	+90.92	0.57	1			
1129	12.682	1.242	+90.01	2.09	2	73.3	88.	SB
1133	13.749	1.105	+91.43	0.56	1	68.0		
1136	12.887	1.754	+94.18	0.64	1	119.3		SB?
1212	13.881	0.978	+92.74	0.61	1	89.5		
1320	12.607	1.137	+91.83	0.72	1	74.2	78.	
1330	13.764	1.037	+93.21	0.56	1			
2136	13.122	1.165	+89.09	0.39	1	62.8	94.	
2211	13.043	0.879	+89.85	0.51	1			
2212	12.822	1.242	+92.11	0.42	1	53.0		
2229	13.833	1.014	+92.35	0.54	1	74.3		
2311	13.643	1.087	+92.74	0.49	1		84.	
3205	13.911	0.982	+90.56	0.42	1	67.9	89.	
3215	13.753	1.001	+92.03	0.48	1	66.0		
3304	12.274	1.432	+95.34	0.72	2			SB?
3324	12.83	1.30	+90.73	0.41	1		96.	
3325	11.44	1.80	+92.67	0.38	1			
4115	14.151	1.020	+91.67	0.53	1		97.	
4116	13.927	1.061	+94.58	0.48	1	35.7		
4119	13.691	1.001	+98.42	0.57	1			SB?
4132	11.663	1.703	+97.89	0.32	2	5.3		SB?
4137	11.870	1.578	+91.13	0.45	2	63.3		
4211	13.678	0.984	+91.48	0.46	1			
4223	13.892	1.034	+88.75	0.47	1		92.	
4303	13.897	0.962	+90.57	0.44	1			
Probable non-members								
1329	11.536	1.165	+37.81	0.46	1			NM
2120	11.776	1.363	+66.41	0.24	2	31.5		NM
2333	13.861	0.926	+73.05	0.57	1		73.	NM
3145	13.195	0.950	+47.66	0.47	1	14.7		NM
3207	12.739	1.080	+13.05	0.42	1	-4.3	3.	NM
3323	13.106	0.722	+16.93	0.54	1			NM
4103	13.906	0.986	+71.15	0.45	1		68.	NM
4210	13.821	0.981	+77.85	0.56	1	26.8	52.	NM, SB
4212	12.392	0.975	+22.27	0.39	1	9.9		NM
4319	13.167	1.060	+50.55	0.46	1		53.	NM

The successive columns contain Hawarden's (1976) identification, V and $B-V$, the mean radial velocity (V_r), uncertainty on the mean velocity (ϵ), and the number of Coravel measurements, the velocities (DM) of Minniti (1995) and those (FJT) of Friel et al. (2002) and notes on duplicity (SB: spectroscopic binary) and membership (NM: non-member).

The mean RV of NGC 2204, based on 20 members, excluding the confirmed and suspected binaries, is V_r = +91.38 ± 0.30 km s^{-1} (s.e.), (1.33 km s^{-1} rms). The value of Friel et al. (2002), +89. ± 6. km s^{-1}, is not different, however that of Minniti (1995), +69. ± 9. km s^{-1}, is different by 22.7 ± 9.7 km s^{-1}.

Star # 1129 appears to be a binary from the two observations obtained. As the dispersion of the observations is small, four stars (# 1136, 3304, 4119 and 4132) deviating from the cluster mean by more than 2. km s^{-1} are suspected of being binary stars. Ten stars are tentatively classified as non-members because their velocities differ by more than 20 km s^{-1} from the cluster mean velocity. The probability of finding red-giant spectroscopic binaries with semi-amplitudes larger than 20 km s^{-1} is about 20% (Mermilliod & Mayor 2006).

Most stars, including the suspected binaries, are located either in the clump or on the red giant branch. Most non-members are bluer than the red-giant branch (Fig. 3). Three of them (#2333, 4103, 4210), although located within the clump, have RVs of approximately +75. km s^{-1} and are most probably non-members. It would be surprising if these three stars were binaries with large amplitudes and that they have similar velocities at the same time. Star #4210 seems to be a binary from the

Table 3. Mean radial velocities for three red giants in NGC 2243.

No	Haw	V	$B-V$	V_r	ϵ	N	lit.	n	S	Rem
1313	4110	12.88	1.11	+60.44	0.43	1	+62.	1	a	M
3633	4209	12.01	1.38	+59.27	0.42	1	+60.	1	a	M
3668	1219	11.80	1.13	+92.16	0.41	1	+93.	2	b	NM

The successive colums give WEBDA and Hawarden's (1975) identification, V, $B-V$, the mean radial velocity (V_r), uncertainty on the mean velocity (ϵ), and the number of Coravel measurements, literature data. a: Gratton (1982); b: Friel & Janes (1993), number of measurement and sources, and notes on membership.

available RVs, but the values are not distributed around the cluster mean velocity. Star #1136 is a probable binary according to the available observations, although one cannot exclude that it could be a non-member due to its position in the CM diagram. However, none of the non-members show such a high velocity. Two stars (#1320 and 2211) could be binaries according to their positions in the CM diagram, with their RVs being close to the cluster mean value at the time of observation and those favor their membership.

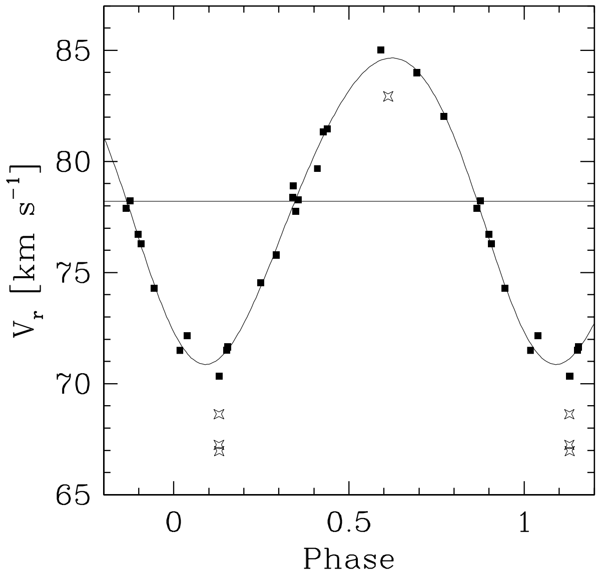

Fig. 1. Radial-velocity curve of the BaII red giant #250 in NGC 2420. Open diamonds denote rejected points from Liu & Janes 1987.

3.3. NGC 2243

Only three stars could be observed in NGC 2243. Results are presented in Table 3. The RVs are in good agreement with those of Gratton (1982) (Source *a*) and that of Friel & Janes (1993) (Source *b*). Star #3668 is clearly a non-member.

Minniti (1995) published RVs for 13 stars and Friel & Janes (1993) for 8 stars. Recently Friel et al. (2002) published additional RVs for 12 stars. The mean cluster velocities from these three papers are $+61.\pm15.$ km s^{-1} and $+62.\pm9.$ km s^{-1} and $+55.\pm5.$ km s^{-1} respectively. Most published velocities have however rather large errors of 7. and 10. km s^{-1}. The velocities of the two member stars observed with CORAVEL (#1313 and #3633) support a mean cluster velocity of approximately +61. km s^{-1}.

3.4. NGC 2420

We observed 31 red giants brighter than B = 14.6 in NGC 2420 from La Silla, which represents a large part of the red giant branch. Two observations could be obtained for most. The brighter stars were also observed from the Haute-Provence Observatory to follow their variations. The results are presented in Table 4. Scott et al. (1995), (SFJ), and Cameron & Reid (1987), (CCR), data are based on a single observation. The published errors are 2. and 7. km s^{-1} respectively.

There are several sources of RVs on NGC 2420. Most are quoted in Table 4. Liu & Janes (1987), (lj) obtained 23 RVs for 10 stars and computed a mean velocity of +70. ± 1.4 km s^{-1} (rms). With the four constant-velocity red giants we computed a difference in the sense Coravel - Liu & Janes equal to 2.77 ± 0.61 km s^{-1}. The mean residuals from three observations for the spectroscopic binaries #173 and #250 amount to 3.1 ± 0.46 and 3.5 ± 0.89 respectively as shown below.

McClure, (mcc), provided us by personnal communication with the individual RVs which were not published in McClure & Woodsworth (1990). The mean values, errors and number of spectra are displayed in Cols. 9 to 11 of Table 4 with reference *mcc*. The mean difference, based on three stars is 0.46 ± 0.43 km s^{-1}. Smith & Suntzeff (1987), (ss), also measured several stars.

Scott et al. (1995) obtained one measurement for 21 stars (column SFJ) and a mean velocity of +67. ± 8. km s^{-1} (rms). Cameron & Reid (1987), (CCR), obtained also one observation for 20 stars. The relevant values are presented in column (CCR).

The data collected in Table 4 allow us to confirm the membership of 25 red giants in NGC 2420 and identify 11 probable non-members. In addition to stars #173 and 250 which were already known as binaries (Smith & Suntzeff 1987; McClure 1983), we detected one certain SB (#34) from our measurements, and suspect 5 more stars of being binaries because of the differences between the existing sources (#76, 111, 174) or differences with respect to the mean cluster velocity (#126, 136).

The orbital elements of star #250 (X) have been improved by adding our 5 observations to those of McClure & Woodsworth (1990). The three observations by Liu & Janes' (1987) present residuals of –3.87, –2.49 and –4.16 km s^{-1} with a mean difference of -3.5 ± 0.89 km s^{-1}. Orbital elements have been computed for the first time for star # 173 (D), which is another BaII red giant. The values are given in Table 5. The three observations by Liu & Janes (1987) presented residuals of –2.56, –3.18 and –3.46 km s^{-1}, with a mean difference of -3.06 ± 0.46 km s^{-1}. Liu & Janes' data have not been corrected and are therefore not included in the solution, because the uncertainty on the exact value of the correction to be applied (four constant-velocity stars present a difference of 2.77 km s^{-1}) is larger that the residuals on the orbits (0.49 and 0.51 km s^{-1}). The radial-velocity curves are presented in Figs. 1 and 2.

3.5. NGC 2506

We have selected 34 red giants from the photometric study of McClure et al. (1981) and observed them once. The results are presented in Table 6.

Radial velocities for red giants in NGC 2506 have been obtained by Minitti (1995) for 20 stars and by Friel & Janes (1993) for 5 stars. Both sources are based on one observation per star only. Their results are given in columns (DM) and (FJ) in Table 6. The differences computed in the sense Coravel minus Minniti give a difference of the radial-velocity zero point of 14.6 ± 8.0 km s^{-1} based on 11 stars in common. This value

Table 4. Coravel and literature radial velocities for red giants in NGC 2420.

No	V	$B-V$	V_r	ϵ	E/I	N	$P(\chi^2)$	RV_{lit}	σ	n	Diff	Src	SFJ	CCR	Remarks
Members															
34	13.087	1.006	+74.16	1.84	4.68	2	0.000	+72.30	0.50	1	1.80	mcc	+67.		SB
41	12.671	1.077	+73.66	0.33	0.41	2	0.686						+76.		
62	(14.40	0.86											+62.		
66	14.560	0.885						+70.79	0.50	1		mcc	+67.	+68.	
68	(14.03	0.64											+60.	+75.	
73	11.086	1.433	+73.94	0.23	0.50	2	0.619								
76	12.656	0.990	+74.13	0.34	1.03	2	0.312	+69.78	0.26	2	4.35	lj	+75.		SB?
91	12.650	1.021	+73.85	0.37	0.83	2	0.424						+65.		
111	12.629	0.898	+73.44	0.36	0.93	2	0.359	+75.64	0.50	1	–2.20	mcc	+68.		SB?
111								+69.62	0.36	2	3.82	lj			
114	13.103	1.004	+73.23	0.53		1							+62.		
115	11.561	1.123	+73.94	0.51	2.06	2	0.039	+73.44	0.17	4	0.50	mcc			
115								+70.50	0.28	3	3.44	lj			
115								+73.3		3	0.64	ss			
118	12.613	0.996	+73.53	0.35	0.92	2	0.367						+60.		
119	12.541	0.983	+74.08	0.35	0.10	2	0.921	+73.21	1.13	2	0.87	mcc	+64.		
119								+71.97	0.59	2	2.11	lj			
126	13.695	0.922	+66.64	0.63		1								+77.	SB?
131	(13.16	0.97	+72.81	0.69		1							+63.		
136	(13.38	0.89	+73.55	0.57	2.32	3	0.005								SB?
140	11.529	1.273	+72.89	0.39	1.68	2	0.093	+72.88	0.27	5	0.01	mcc	+63.		
140								+70.46	0.68	3	2.43	lj			
140								+72.5		1	0.39	ss			
169	(12.34	0.97	+74.12	0.31	0.22	2	0.823						+76.		
173	11.768	0.908	+74.09	1.81	9.05	4	0.000	+72.37	0.75	15	1.72	mcc	+73.		SB
173								+70.78	0.49	3	3.31	lj			
173								+68.8		2	5.29	ss			
174	12.397	1.011	+73.18	0.31	0.95	2	0.341	+67.57	0.43	2	5.61	lj	+69.		SB?
176	13.537	0.965	+71.56	0.67		1								+57.	
188	13.478	0.943	+70.95	0.64		1								+65.	
192	12.937	1.033	+72.83	0.69	2.10	2	0.042								
236	12.587	0.983	+73.24	0.50	1.46	2	0.149						+74.		
250	11.37	1.37	+75.60	2.00	10.46	4	0.000	+77.68	1.10	18	–2.08	mcc			SB
250								+67.70	0.89	3	7.90	lj			
250								+78.6		2	–3.0	ss			
Non members															
6	13.09	1.01	–12.85	0.55		1									NM
77	14.38	0.93											+24.		NM
102	13.42	1.17	+59.99	0.74		1									NM
181	13.96	1.01											+45.		NM
189	11.19	0.86	–27.48	0.41	1.54	2	0.123	–30.61	0.39	2	3.13	lj			NM
212	13.251	0.970	+33.04	0.65		1								+41.	NM
221	11.89	1.06	–23.81	0.71	2.66	2	0.008								NM
255	11.93	1.14	–32.07	0.42		1									NM
262	12.90	0.90	–0.54	0.82		1									NM
270	13.56	1.00	+55.09	0.65		1							+61.		NM
279	12.96	1.02	–22.90	0.63		1									NM

The columns give Cannon & Lloyd's (1970) identification, V and $B-V$ (V values with a leading parenthesis are photographic), the mean radial velocity (V_r) and the error on the mean (ϵ) in km s^{-1}, the number of observations, N, the probability $P(\chi^2)$ of variability from Coravel. Columns (9) to (15) reproduce literature data, RVs (RV_{lit}) and errors (σ) in km s^{-1}, the number of observations (n), the difference with Coravel results (Diff), the sources (Src) (mcc: McClure & Woodsworth 1990; lj: Liu & Janes 1987; ss: Smith & Suntzeff 1987), RVs from Scott et al. (1995), (SFJ) and Cameron & Reid (1987), (CCR). The last column provides notes on binarity (SB: spectroscopic binary) and membership (NM: non-member).

is within the possible error (20 km s^{-1}) as claimed by Minniti (1995). The rms reflects the random error on each velocity.

The membership of 30 stars can be confirmed, and only 4 appear to be obvious non-members. Two stars are suspected of being binaries since their velocities differ by about 4 km s^{-1} from the cluster mean. The mean RV of NGC 2506, based on 28 members, excluding two stars marked as suspected binaries is $\overline{V}_r$ = +83.18 ± 0.21 km s^{-1} (s.e.), (1.13 km s^{-1} rms). Although based on one observation only per star, this result greatly improves on the previous values of Minniti (1995), +68. ± 8. km s^{-1}, and Friel & Janes (1993), +87. ± 5. km s^{-1}, thanks to the precision of CORAVEL RVs.

3.6. NGC 2682

Radial velocities of red giants in NGC 2682 have been obtained by several observers, and numerous references can be found in

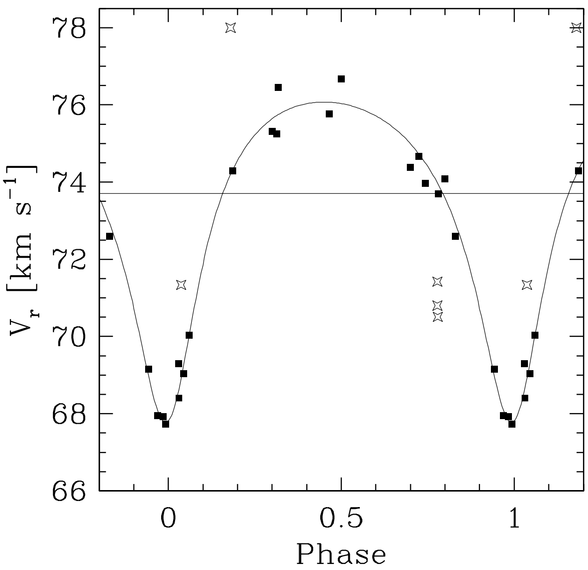

Fig. 2. Radial-velocity curve of the BaII red giant #173 in NGC 2420. Open diamonds denote 3 rejected points from Liu & Janes 1987, 1 from Friel et al. (1989) and 1 from McClure & Woodsworth (1990).

Table 5. Orbital elements for 2 SBs in NGC 2420.

Element	173	250
P [d]	1479.0	1403.6
	9.1	3.5
T [HJD-2 400 000]	42213.	45258.
	25.	64.
e	0.433	0.08
	.050	.03
γ [km s^{-1}]	73.71	78.20
	.17	.13
ω [°]	187.9	141.
	8.1	16.
K [km s^{-1}]	4.15	6.90
	.18	.21
$f(m)$ [$M_\odot$]	0.0080	0.0473
	.0017	.0047
a sini [Gm]	76.1	132.7
	5.8	4.6
σ(O−C) [km s^{-1}]	0.49	0.51
n_{obs}	25	26

WEBDA. The major study has been published by Mathieu et al. (1986) who obtained more than 2500 measurements for 170 stars in the field of M 67. Mathieu et al. (1990) published orbital elements for 22 spectroscopic binaries. We have obtained 2 to 3 observations of 26 red giants in the field of NGC 2682. Five spectroscopic binaries (F136, 143, 170, 224 and 244) were observed more intensively. These observations were included in the paper of Mathieu et al. (1990) and used to compute the orbits. The zero-point calibration of the Coravel database was revised in 1999 and the present velocities are in the new system defined by Udry et al. (1999).

Stars #4169 (S494), 6474 (S676) and 6513 (S1533) are non-members.

Table 6. Mean radial velocities for the red giants in NGC 2506.

No	V	$B-V$	V_r	ϵ	N	DM	FJ	Rem
Members								
1112	12.970	0.955	+83.02	0.44	1	+70.9		
1229	13.161	0.971	+82.04	0.46	1			
1320	13.21	0.94	+85.27	0.43	1			
1325	13.17	0.95	+82.76	0.42	1	+60.3		
1359	13.31	1.00	+88.98	0.55	1			SB?
2109	13.160	0.882	+80.92	0.43	1			
2122	11.712	1.119	+81.98	0.39	1	+71.1	+87.	
2212	11.945	1.062	+83.56	0.37	1	+65.5	+93.	
2251	13.231	0.934	+79.52	0.45	1			SB?
2255	13.48	0.80	+82.72	0.57	1			
2309	13.07	0.99	+82.56	0.40	1	+54.2		
2329	13.15	0.96	+84.84	0.50	1			
2364	13.04	0.89	+81.48	0.51	2	+60.1		
2375	13.59	1.01	+84.80	0.50	1			
2380	13.164	0.953	+82.70	0.44	1			
2401	11.09	1.59	+84.25	0.34	1			
3204	12.648	0.910	+83.08	0.42	1	+72.7		
3231	13.101	0.978	+84.18	0.44	1	+75.4	+83.	
3254	11.122	1.391	+83.17	0.33	1	+77.0		
3255	13.074	0.828	+81.10	0.50	1			
3265	13.168	1.057	+85.33	0.46	1	+57.3		
3324	13.27	0.98	+83.74	0.43	1	+63.9		
3359	14.139	0.938	+83.92	0.49	1	+75.9		
3392	13.12	0.91	+84.03	0.44	1			
4128	13.067	0.873	+82.92	0.47	1			
4138	13.299	0.921	+82.60	0.46	1		+92.	
4143	13.284	0.927	+82.51	0.46	1			
4205	13.245	0.956	+83.29	0.45	1			
4240	13.123	0.963	+82.14	0.44	1	+73.0		
4376	13.04	1.01	+85.71	0.48	1	+64.7		
Probable non-members								
1343	13.25	0.86	+22.73	0.56	1			NM
2101	11.927	0.890	+34.77	0.43	1			NM
3316	10.90	1.43	+58.92	0.36	1			NM
4401	11.86	0.64	+28.72	0.46	1			NM

The columns contain successively McClure et al. (1981) identification, V and $B-V$, the radial velocity (V_r) and error (ϵ) in km s^{-1}, the number of measurements (N) from Coravel, the data from Minitti (1995), (DM), and Friel & Janes (1993), (FJ), and remarks on duplicity and membership.

4. Discussion

4.1. Binary frequency

The number of confirmed or suspected binary members (18/93 = 19%) is slightly lower than the overall mean frequency for red giants (23%) as published by Mermilliod & Mayor (1992), or 26% as determined from the larger sample (Mermilliod & Mayor (2006). This can be explained because we have observed the brighter stars, on the upper part of the red giant branch and clump stars. These stars reach large radii on the upper part of the red giant branch, so binaries with periods shorter than the critical period corresponding to the filling of the Roche lobe, will enter into contact and evolve most probably through mass-transfer episodes. As shown by Mermilliod & Mayor (1996) the critical period for stars of 1.5 $M_\odot$ is of the order of 300 days. Therefore, only those red giants which are single stars or which have orbital periods longer than this critical period will achieve their normal evolution. It appears therefore normal that the observed binary frequency is lower for evolved and clump red giants.

One should however take into account that the number of observations per star is smaller than for the bulk of the red giants included in the main program and that the detection probability with one or two measurements is smaller. This partly explains the lower frequency.

Table 7. Mean radial velocities for the red giants in NGC 2682.

No	V	$B-V$	V_r	ϵ	N	RM	σ	n	Rem
Members									
84	10.519	1.095	+33.99	0.25	3	34.1	0.4	23	
104	11.130	1.092	+33.38	0.25	2	33.5	0.9	20	
105	10.287	1.267	+35.17	0.18	3	34.3	0.7	33	
108	9.702	1.369	+35.03	0.22	2	34.7	0.6	327	
135	11.428	1.074	+35.01	0.21	3	34.3	0.6	21	
136	11.303	0.609	+32.85	0.38	19	32.2	2.2	38	SBO
141	10.454	1.109	+33.83	0.40	3	33.6	0.4	25	
143	11.477	0.885	+32.44	1.28	19	32.0	6.3	36	SBO
151	10.492	1.085	+33.98	0.33	3	33.9	0.5	27	
164	10.533	1.123	+33.25	0.19	3	33.4	0.4	27	
170	9.656	1.344	+33.33	0.18	19	34.3	1.1	31	SBO
223	10.580	1.10	+32.89	0.20	3	32.8	0.4	24	
224	10.761	1.135	+33.50	0.77	14	34.1	3.1	35	SBO
244	10.758	0.938	+33.20	1.01	21	33.0	3.5	35	SBO
266	10.520	1.096	+34.53	0.18	3	34.3	0.4	23	
286	10.894	0.981	+25.71	7.47	3	33.6	0.5	28	SB
305	11.240	1.085	+33.85	0.43	2	34.2	0.9	12	S721
2152	10.915	1.120	+33.84	0.26	2	33.6	0.4	14	S1402
4202	8.854	1.563	+33.25	0.23	2	33.0	0.3	20	S488
6469	9.510	1.34	+34.01	0.25	2	34.1	0.2	17	S258
6470	9.833	1.316	+33.36	0.24	2	33.3	0.3	18	S364
6495	9.370		+34.51	0.24	2	34.2	0.4	18	S1135
6515	10.120		+34.00	0.25	2	33.9	0.5	11	S1557
Non members									
4169	9.968	1.068	+44.83	0.25	2	45.0	0.4	18	NM
6474	10.522	1.194	+9.31	0.27	2	9.5	0.6	11	NM
6513	10.020		+67.67	0.36	2	67.8	0.5	12	NM

The columns contain the identifications of Fagerholm (1906) (No ≤ 305) or WEBDA, V and $B-V$, mean radial velocities (V_r) and errors (ϵ) in km s^{-1}, the number of measurements N from Coravel, the mean velocities of Mathieu et al. (1990) (RM), its error (σ) and the number of observations, n, and remarks on duplicity and membership, and/or Sanders (1977) numbers.

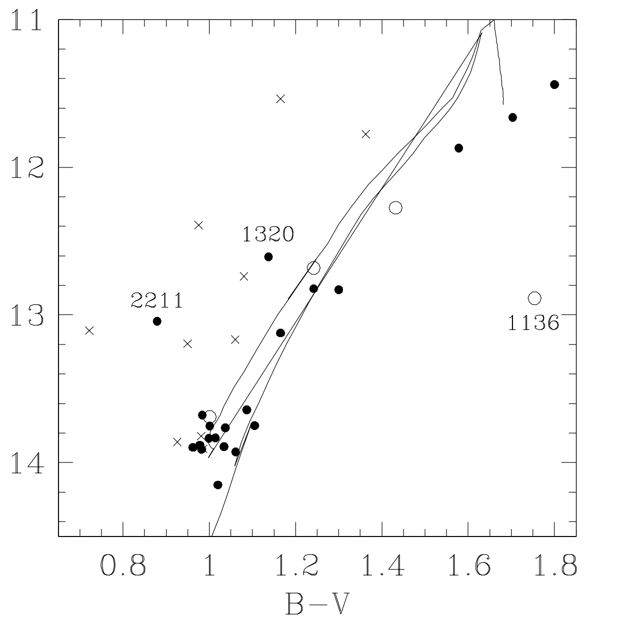

Fig. 3. CMD of the observed red giants in NGC 2204. *Filled circles:* members; *circles:* binary members; *crosses:* non-members. The curve is the isochrone for $Z = 0.08$, $\log t = 9.25$ from Girardi et al. (2000a) for $m - M = 13.28$ and $E(B-V) = 0.07$.

4.2. Colour–magnitude diagrams

With the new information on membership and binarity, we are now in a position to examine the colour–magnitude diagrams (CMD) of these clusters and compare the red-giant distribution in the $(V, B-V)$ plane with theoretical isochrones.

The colour–magnitude diagrams of NGC 2204 (Fig. 3), NGC 2420 (Fig. 4), NGC 2506 (Fig. 5) and NGC 2682 (Fig. 6) present well defined ascending giant branches and populated clumps. The various symbols denote the members (filled circles), binary members (circles) and non-members (crosses). The cluster parameters given in the figure captions have been estimated from the fit on the entire colour–magnitude diagram, hence including the main sequence and turnoff, of the isochrones from Girardi et al. (2000a). These curves reproduce well the main sequence and turnoff, the lower part of the red giant branch, the position of the bump in the ascending branch and the position of the clump. The transformation from $T_{\rm eff}$ into $B-V$ however fails to reproduce the observed colours on the upper giant branches which appear to be redder than the models.

The structure of the clump of NGC 2204 has been analysed by Girardi et al. (2000b) in relation to the morphology of the zero age horizontal branch (ZAHB). The CM diagram of NGC 2420 has been used by several authors to compare with their models. Pols et al. (1998) obtain good agreement with their isochrone with parameters close to ours: $m - M = 11.95$ and $E(B-V) = 0.05$. Castellani et al. (1999) used also NGC 2420 and NGC 2682 to test their models. The goodness of the fit is obtained at the price of a rather high and improbable value of the reddening for NGC 2420, $E(B-V) = 0.16$.

The colour–magnitude diagram of NGC 2682 (Fig. 6) presents a very tight red giant branch and a well-defined clump. In addition, it contains several spectroscopic binaries. The positions of three of them (F143, 244 and 286) in this diagram can be easily explained by the combination of a red giant primary and an upper-main-sequence secondary. The curve plotted in Fig. 6 shows the locus obtained by adding to the red-giant primary a companion taken on the isochrone. The secondary is on the subgiant branch, a solution which has been preferred to a position within the HEP gap. However, the position of F136 cannot be reproduced by such a combination. This last point, as well as the spectrum of F136 = S1072, have been discused by van den Berg et al. (1999) who have no explanation for this anomalous position and the presence of X-ray emission reported from ROSAT observations (Belloni et al. 1998).

The CMD for NGC 2506 raises a number of questions because the red giants which seem to be evolving away from the clump are not located on the theoretical isochrone. The observed position of the stars delineating the asymptotic giant branch is much bluer and/or brighter than predicted by the models. Although less pronounced, this feature is also observed in the CMD of NGC 2204 and 2420. In both clusters, one finds one star in a similar, although somewhat less extreme, position. This feature is best brought into evidence in the composite colour–magnitude diagram built with these three clusters (Fig. 7). The single members (filled circles) clearly delineate the ascending giant branch and the clump. Spectroscopic binaries are marked with open circles. The triangles denote the 8 stars, NGC 2506 #3254, 2122, 2212, 3204 – NGC 2204 #1320, 2211 – NGC 2420 #173 (BaII), which occupy this blue position. It is remarkable that they appear to also define a sequence. Interestingly enough, one of them, NGC 2420-173, is a well known binary red giant with BaII anomaly.

In addition, 4 stars (#886, 958, 966, 967) are found in the same position in the CMD of NGC 6819, a cluster quite similar to NGC 2420. Three of them (#886, 966, 967) are undoubtedly members on the basis of the RVs published by Glushkova (1993).

These stars raise a number of questions. Do they represent the locus of stars during their evolution after the clump phase, i.e. asymptotic giant branch? Do some of them present chemical peculiarities, as #173 in NGC 2420 does, although they are not

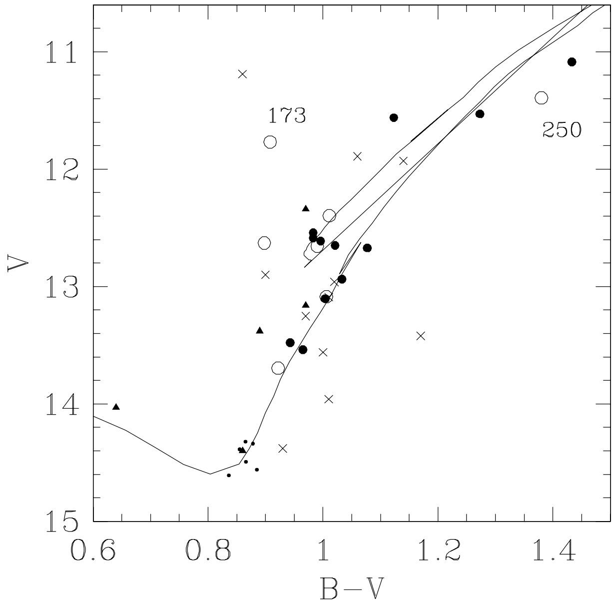

Fig. 4. CMD of the observed red giants in NGC 2420. *Filled circles and triangles:* members; *open circles:* binary members; *crosses:* non-members; *dots:* candidates not observed with Coravel. The position of the stars represented by triangles is based on photographic data, while that of the other stars is based on CCD or photoelectric data. The curve is the isochrone for $Z = 0.08$, $\log t = 9.30$ from Girardi et al. (2000a) for $m - M = 12.15$ and $E(B - V) = 0.04$.

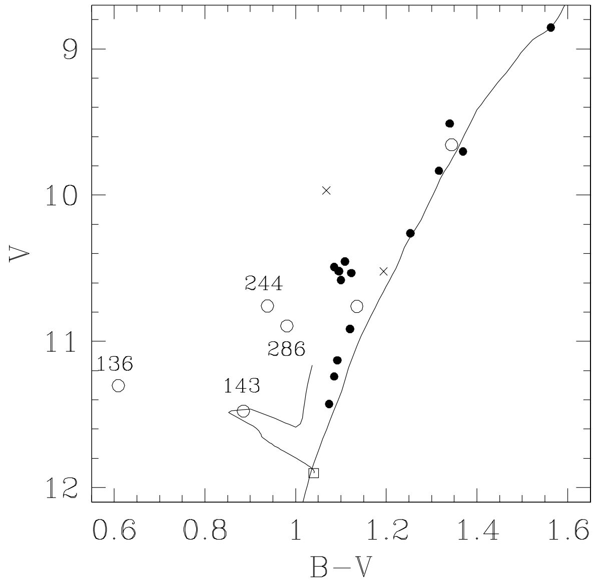

Fig. 6. CMD of the observed red giants in NGC 2682. *Filled circles:* members; *circles:* binary members; *crosses:* non-members. The isochrone for $\log t = 9.65$, $Z = 0.02$ from Girardi et al. (2000a) reproduces well the long giant branch. The curve passing through star #143 symbol is the binary locus computed by adding to the red-giant primary main-sequence secondaries taken on the isochrone. The open square at (11.90, 1.04) shows the position of the red-giant primary resulting from the photometric separation.

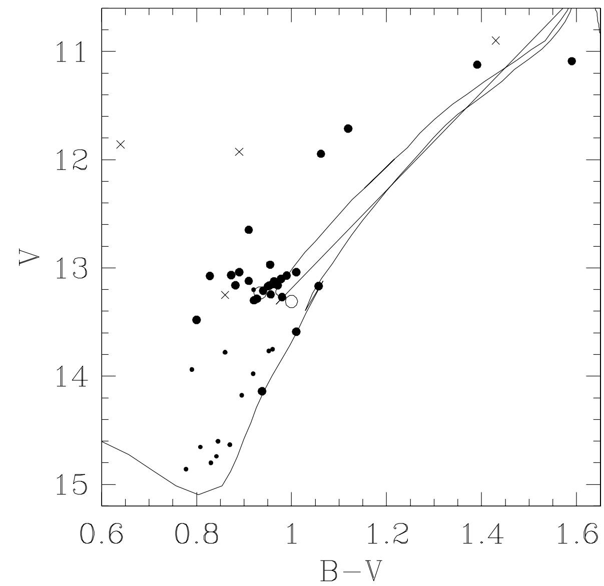

Fig. 5. CMD of the observed red giants in NGC 2506. *Filled circles:* members; *open circles:* binary members; *crosses:* non-members; *dots:* candidates not observed with Coravel. The curve is the isochrone for $Z = 0.08$, $\log t = 9.30$ from Girardi et al. (2000a) for $m - M = 12.65$ and $E(B - V) = 0.04$.

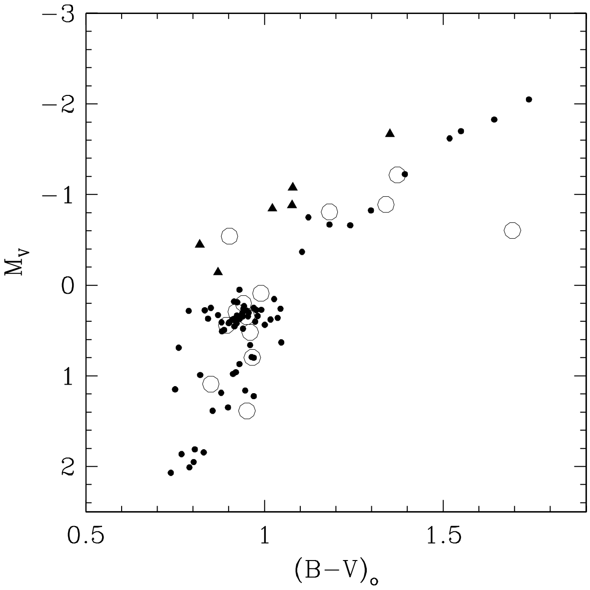

Fig. 7. Composite diagram of the red giants in NGC 2204, NGC 2420 and NGC 2506. *Filled circles:* members; *circles:* binary members; *triangles:* AGB.

known to be spectroscopic binaries? Do they have close companions altering their colours?

Our RVs strongly support their membership and indicate that most of them are probably single. The precision of the photometric data does not allow us to question the reality of the effect, because the difference in $(B - V)$ colours reaches 0.3 mag. We tentatively conclude that around $\log t = 9.25{-}9.30$, the evolution after the clump is not that predicted by the models. This result may be considered in light of the results of Girardi et al. (2000b) concerning the peculiar structure of the red-clump morphology of clusters such as NGC 7789 and NGC 752, which have an age of $\log t = 9.20$, i.e. only slightly less than that of the present clusters.

5. Conclusion

Although the number of observations per star is small, the results prove that even with one accurate radial velocity, it is possible to have a reliable first estimate of the membership of the red giants and detect or suspect binaries. The reason is laregly related to the characteristics of the orbital elements of the red giants in old clusters. The orbital periods have to be larger than 300 days so that a primary of 1.5 $M_{\odot}$ does not fill its Roche lobe and survives after it reaches the red-giant tip. Furthermore, long-period binary usually have low amplitudes. Consequently, the distribution of RVs is rather tight and often presents a significant separation between cluster-and field stars.

We confirmed the membership of 93 red giants and detected 7 definite spectroscopic binaries with our observations or in combination with published data. Eleven stars are suspected of being binaries. We determined a first orbital elements for the BaII red giant NGC 2420 #173 and improved the orbital elements of NGC 2420 #250, another BaII giant. We also computed more precise mean RVs for each cluster.

Various features (red-giant branch and clump morphology, binarity effect) have been examined from the colour–magnitude diagrams, as a result of the clear separation between members and field stars and detection of binaries. Precision RVs and accurate CCD photometric data form a powerful tool to study the evolution at the red-giant phase. We found that a number of stars, probably in a late evolutionary state after the clump phase, have colours much bluer and/or brighter than predicted by the theoretical isochrones. This is obvious in NGC 2506, but stars in similar positions are also found in NGC 2204, 2420 and NGC 6819. The composite colour–magnitude diagram enhances the visibility of this effect. Spectroscopic studies of these objects would be useful to understand their positions in the colour–magnitude diagrams.

Most of these stars are quite faint for the telescopes used (1.5 m Danish at La Silla, 1 m at OHP) and new multi-object spectrographs could yield more precise data for most.

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