A&A 473, 829–845 (2007)
DOI: 10.1051/0004-6361:20078007

Astronomy & Astrophysics

Red giants in open clusters

XIII. Orbital elements of 156 spectroscopic binaries⋆,⋆⋆

J.-C. Mermilliod[1], J. Andersen[2,3], D. W. Latham[4], and M. Mayor[5]

[1] Laboratoire d'Astrophysique de l'École polytechnique fédérale de Lausanne, 1290 Sauverny, Switzerland
e-mail: Jean-Claude.Mermilliod@epfl.ch
[2] The Niels Bohr Institute, Astronomy Group, Juliane Maries Vej 30, 2100 Copenhagen, Denmark
[3] Nordic Optical Telescope Scientific Association, Apartado 474, 38700 Santa Cruz de La Palma, Canarias, Spain
[4] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138, USA
[5] Observatoire de Genève, 51 Ch. des Maillettes, 1290 Sauverny, Switzerland

Received 4 June 2007 / Accepted 9 July 2007

ABSTRACT

Context. The identification and characterisation of spectroscopic binaries with red-giant primaries in open clusters is important for a proper understanding of the colour-magnitude diagrams of the clusters. Moreover, the orbital eccentricities and axial rotations of these binaries are valuable probes into the inner structure and tidal interaction of the stars.
Aims. We report on a comprehensive, long-term monitoring programme aiming to improve our knowledge of such binary systems.
Methods. The radial velocities of 1309 red giants in 187 open clusters in the whole sky have been monitored with the CORAVEL and CfA spectrometers for 20 years, with a typical accuracy of 0.4 km s^{-1} per observation.
Results. In total, 289 spectroscopic binaries were detected in the sample. We present first orbits for 67 systems and improved elements for another 64 previously published orbits, based on additional observations. For completeness, 25 published orbits are listed as well. The orbits are based on a total of 4039 observations, an average of 26 per system. Orbital periods range from 41.5 to 14 722 days (40 yrs), eccentricities from 0.00 to 0.81. The remaining 133 systems have too long periods, too few observations, and/or inadequate phase coverage for an orbit determination at this time.
Conclusions. This paper provides a dramatic increase in the body of homogeneous orbital data available for red-giant spectroscopic binaries in open clusters. It will form the basis for a comprehensive discussion of membership, kinematics, and stellar and tidal evolution in the parent clusters.

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

1. Introduction

Open star clusters are important tracers of Galactic structure, kinematics, and evolution (e.g. Friel 1995). They are also important test objects for studies of stellar evolution, the initial mass function (IMF), and the dynamical evolution of stellar systems (e.g. Nordström et al. 1997). Open clusters therefore have a long history of observational studies, but the amount of data available depends heavily on the observational technique, and spectroscopic data such as radial and rotational velocities are still lacking for many cluster stars.

As the brightest cluster stars and having strong-lined late-type spectra, the giant members offer the best opportunities for determining the systemic velocity of a cluster. In themselves, they are also important tracers of the precise shape of stellar evolution tracks in the HR diagram, in a domain where significant uncertainties remain in theoretical models and in their translation into observable parameters.

Identifying and characterising the binary systems among the cluster giants is important for several reasons. First, only their mean or systemic velocities are reliable guides to the velocity of the cluster itself and/or the membership of the star. Second, the presence of a companion may change the position of the star in the colour–magnitude diagram in ways that may confuse its interpretation: e.g., the combined colours of a red-giant primary with a bluer main-sequence companion may place the system within the Hertzsprung gap, mimicking a blue loop in the evolutionary track. Finally, the time scales for tidal circularisation of the orbit and synchronisation of the rotation of binary red giants in open clusters are particularly informative, because the masses, radii, and ages of the stars are known from stellar evolution theory (Mermilliod & Mayor 1996).

Furthermore, observations of the red giants provide information on long-period, low-amplitudes binaries that are not easily detected among A-type main-sequence stars because of the small number of lines and more rapid rotation. Accordingly, the red giants may provide important information on the binary frequency among the more massive cluster members.

⋆ Based on observations collected with the Danish 1.54-m telescope at the European Southern Observatory, La Silla, Chile and at the Haute-Provence Observatory (France).

⋆⋆ Full Table 1 and the catalogue of orbital elements are 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/473/829

Article published by EDP Sciences and available at http://www.aanda.org or http://dx.doi.org/10.1051/0004-6361:20078007

A survey of the literature shows that the characteristics of spectroscopic binaries with red-giant primaries and members of open clusters are still poorly known. When our observing programme was initiated in 1977, only two orbits were known, one for Tr 91 in the Coma Bererenices cluster (VinterHansen 1940) and one for vB 41 in the Hyades (Griffin & Gunn 1977).

Since then, orbital elements for some eleven binaries in northern open clusters have been published in addition to those from the CORAVEL programme. Mathieu et al. (1986) published orbital elements for the 7 red-giant spectroscopic binaries in M67, the best-observed cluster. Lee et al. (1989) published an orbit for the two binaries discovered in NGC 6705 (M11). McClure & Woodsworth (1990) determined an orbit for the Barium red giant #250 in NGC 2420. Torres et al. (1997) published orbital elements for the long-period binary vB 71 in the Hyades, and Gim et al. (1998) obtained radial velocities for 115 red giants in the field of NGC 7789. They discovered 21 spectroscopic binaries, but no orbits were determined.

In 1977 we therefore initiated a long-term observing programme to determine accurate radial velocities of red giants in a large number of open clusters, using the CORAVEL instruments (Baranne et al. 1979) from Haute-Provence Observatory (OHP), France, in the north and extended it in 1983 to the southern hemisphere, in the ESO Observatory at La Silla, Chile. A special aim of this programme was to follow suspected or confirmed binaries over the lifetime of these instruments in order to determine their orbital elements as far as possible, and some systems were followed even later at the CfA.

This paper presents the results of this programme and provides first orbital elements for 67 new spectroscopic binaries and improved elements for another 64 systems published earlier (cf. Mermilliod et al. 1989). To our knowledge, except for the CORAVEL results, no orbit has been published for any of the objects discussed here. We thus provide a dramatic increase in the number of known orbits for red-giant binaries in galactic open clusters. Moreover, the homogeneity of the data and the observing strategy will allow reliable assessment of the statistical properties of the sample, which will follow in a forthcoming paper.

2. Observations

In defining the sample, we tried to include all stars in each cluster, which presented reasonable chances of being red-giant members, as judged from their positions in the colour–magnitude diagrams and other available data. Stars located within the Hertzsprung gap were prime candidates for being binaries, and in many cases were confirmed by subsequent observations. A few additional red stars in the fields of some clusters were noticed at the telescope and added to the observing program. Consequently, the sample observed should contain a high fraction of the potential red-giant cluster members.

2.1. Coravel observations

In a systematic programme with the two CORAVEL photoelectric radial-velocity scanners (Baranne et al. 1979; Mayor 1985), we have observed 1309 red giants in the field of 187 open clusters over the whole sky. For the northern observations we used the CORAVEL mounted on the 1-m Swiss telescope at OHP during the 19 years from January 1978 to October 1997. The southern CORAVEL was installed on the Danish 1.54-m telescope at La Silla during the 15 years from March 1981 to July 1996. The CORAVEL programme ended when both instruments were decommissioned in 1997.

Table 1. CfA observations.

Cluster	No.	JD	V_r	σ
NGC 752	75	2 447 427.953	–1.32	0.16
NGC 752	75	2 447 459.795	–1.71	0.18
NGC 752	75	2 447 523.571	–1.45	0.27
NGC 752	75	2 447 575.659	–2.77	0.20
NGC 752	75	2 447 789.981	–2.85	0.23

The complete version of the table is available at the CDS.

The radial velocities listed here are on the system defined by Udry et al. (1999), calibrated with high-precision data from the ELODIE spectrograph (Baranne et al. 1996). This calibration implies a zero-point change of the order of 0.3−0.4 km s^{-1} with respect to data published before 2001 and modifies the systemic velocities of binary orbits published earlier by a similar amount. Integration times were typically 180−300 s, but could exceed 600 s if needed to obtain a minimum of 1000−1200 counts per channel in the cross-correlation profile. Typical errors of a single measurement are then 0.3−0.7 km s^{-1}, the majority being close to 0.4 km s^{-1}.

2.2. CfA observations

After 1997, additional radial velocities were obtained by DWL with the CfA Digital Speedometers (Latham 1992) in order to complete the orbits for a number of binaries. The error of a single observation is ~0.5 km s^{-1}. The CfA radial velocities are on an absolute system defined by extensive observations of minor planets, as described by Stefanik et al. (1999), except that 0.139 km s^{-1} have been *added* to the velocities on the native CfA system, rather than subtracted as specified by mistake by Stefanik et al. (1999).

The 335 CfA observations are available in electronic form only. Table 1 contains the cluster and star designations, the Julian dates, the radial velocities and errors in km s^{-1}. Only five records are displayed in Table 1 to illustrate the format.

2.3. Additional observations

Radial velocities for a number of stars in IC 4756 were measured with a CORAVEL-type spectrometer attached to the 1.65-m telescope at Moletai Observatory, Lithuania, in 2003 and kindly communicated by Dr. J. Sperauskas (2005). The instrument is described by Upgren et al. (2002). These observations are listed in Table 2. Comparison of the mean radial velocities for constant stars showed that these radial velocities are on the same system as CORAVEL.

2.4. Catalogue of the individual radial velocities

The publication of the complete set of radial velocities obtained with CORAVEL in both hemispheres is in preparation (Mermilliod & Mayor 2007a). The detailed data (Julian dates, radial velocities and errors) for all binaries discussed in this paper will become available there. Meanwhile, specific data may be obtained from the first author (JCM).

Table 2. Sperauskas observations in IC 4756.

No.	JD	V_r	σ	No.	JD	V_r	σ
25	2 452 789.472	–24.2	0.7	80	2 452 794.455	–25.4	0.7
25	2 452 795.491	–23.6	0.6	80	2 452 800.476	–23.8	0.7
25	2 452 803.503	–24.3	0.6	80	2 452 809.442	–24.2	0.7
25	2 452 840.398	–24.4	0.6	80	2 452 841.397	–25.9	0.7
25	2 452 842.350	–24.8	0.6	80	2 452 842.417	–24.1	0.7
25	2 452 866.321	–25.8	0.6	80	2 452 866.395	–23.4	0.7
25	2 452 870.296	–26.3	0.6	139	2 452 794.443	–28.5	0.7
69	2 452 793.498	–23.6	0.7	139	2 452 803.422	–27.9	0.7
69	2 452 800.457	–23.1	0.6	139	2 452 809.490	–28.0	0.7
69	2 452 809.433	–23.1	0.6	139	2 452 841.420	–28.8	0.8
69	2 452 841.383	–23.8	0.7	139	2 452 842.436	–27.8	0.8
69	2 452 842.408	–23.8	0.7	139	2 452 870.321	–28.2	0.6
69	2 452 866.369	–24.1	0.7				

2.5. Catalogue of orbital elements

The orbital elements contained in Tables 3 to 8 are merged in a single electronic file available in the ftp archive at the CDS. The records are ordered by cluster name and star number, one line per star. J2000 coordinates are given for each system.

2.6. Computer code

The orbital solutions were computed with a Fortran code developed by Imbert at Marseille observatory and adapted to the CORAVEL database at Geneva observatory by Lucke.

3. Results from La Silla observations

Among the 896 southern giants observed, we found a total of 192 spectroscopic binaries; as many as possible were monitored to determine the orbital elements. Tables 3–5 present our orbital elements for 86 binaries in 37 southern open clusters. No orbits could be determined for the remaining 106 systems, either because the periods were too long or because the shape of the orbits prevented us from getting satisfactory phase coverage during the available observing runs.

Essentially all the systems are single-lined binaries, although several must have mass ratios close to unity. This is easily understood, because the companions are mainly A-type upper main-sequence stars rotating too fast ($\geq$50 km s^{-1}) to be observable with the CORAVELs. IC 4651-8665, L244 in Mermilliod et al. (1995), is the only double-lined system discovered.

When the secondary is an upper main-sequence star, the combined photometry of the system can be decomposed to yield the magnitudes and colours of both components as described by Mermilliod & Mayor (1992, Fig. 6). Once the mass of the red giant has been estimated from an isochrone, the minimum mass of the secondary follows from $f(m)$. We will make systematic use of this possibility in discussing such stars.

3.1. First orbits for 36 binaries

Our new orbital elements for 36 new spectroscopic binaries are presented in Table 3, and the corresponding radial-velocity curves are shown in Figs. 1 and 2. Most of the new orbits pertain to open clusters which have not been discussed previously, mainly because they contain few red giants. As judged by their systemic velocities, several of these red-giant binaries are in fact non-members, as discussed below for each cluster.

Most of the new orbits have enough observations to characterise the radial-velocity curves completely. We have also completed the orbits for some stars that were flagged as binaries in previous papers, but for which no orbital elements could be determined at the time. For some of the longest-period systems only one entire cycle could be covered, and a few tentative orbits are based on only ~12 points. If several solutions were found by the code, we retained the solution which was the most stable after performing several iterations.

3.2. Improved orbits for 35 binaries

Orbital elements for another 35 binaries were published in earlier papers on CORAVEL data for red giants in open clusters: IC 2488 (Clariá et al. 2003), IC 4651 (Mermilliod et al. 1995; Meibom et al. 2002), Melotte 71 (Mermilliod et al. 1997b), NGC 2360 (Mermilliod & Mayor 1990), NGC 2437, NGC 2489, NGC 2567, NGC 3033, NGC 6134 and NGC 6664 (Mermilliod et al. 1997a), NGC 3680 (Mermilliod et al. 1995; Nordström et al. 1997), and NGC 5822 (Mermilliod et al. 1989; Mermilliod et al. 1997a).

For many of these systems, additional observations were obtained since those papers. In addition, the zero point of the radial velocities was corrected (by 0.3–0.4 km s^{-1}; see above) to bring them onto the CORAVEL radial-velocity system of Udry et al. (1999). When no new measurements were obtained since the first publication, we recomputed the orbits with the corrected radial velocities. We do not show the radial-velocity curves again, because the changes are generally not visible on small-scale plots.

Revised orbital elements for these systems are listed in Table 4, in the same format as Table 3. The changes are not large, but the errors are much reduced.

3.3. 15 published orbits

Orbital elements for 3 binaries in NGC 1817 and 13 in NGC 2477 have been published earlier (Mermilliod et al. 2003; Eigenbrod et al. 2004). For completeness, these orbits are summarised in Table 5 (format as for Table 3). The orbit for NGC 1817-56 has been revised and appears in fact in Table 4.

3.4. Comments on individual objects

Many clusters in our observing program were not yet discussed, because earlier papers focused on objects with larger numbers of red giants ($N > 10$). These clusters are briefly discussed below, with references to the star numberings used. These references should be identical to those in the open-cluster data base WEBDA (`http://www.univie.ac.at/webda/`).

IC 2488 Observations of 13 red giants in the field of IC 2488 were analysed by Clariá et al. (2003). An orbit was obtained for star #67, which is however a non-member.

IC 4651 Radial-velocity observations of 20 red giants in the field of IC 4651 were analysed by Mermilliod et al. (1995). New observations allow us to improve the orbital elements for #6686 (L97), 14290 (L236), and 14641 (L139), while the orbits of #8665 (L244) and 10195 (L241) were updated. Star #8665 is a double-lined binary (Mermilliod et al. 1995) with a mass ratio of $M_2/M_1 = 1.10$. The red giant thus seems to be slightly

Table 3. New orbital elements for 36 binaries observed at La Silla.

Cluster	No.	P	T	e	γ	ω	K	$f(m)$	$a \sin i$	σ	N	Notes
Mel 105	17	211.05	45 147.5	0.204	+0.54	104.7	12.52	0.040	35.6	0.52	16	
		0.13	4.6	0.018	0.18	8.5	0.40	0.0043	1.3			
NGC 1817	244	43.2485	45 117.1	0.000	+65.79		4.61	0.00044	2.72	0.50	17	
		0.0071	1.1	fixed	0.13		0.18	0.00005	0.10			
NGC 2324	1006	399.9	45 290.	0.444	+40.34	0.1	18.60	0.192	91.6	0.91	12	
		2.0	15.	0.041	1.07	4.6	1.15	0.050	8.2			
NGC 2360	44	8398.	46 771.	0.482	+27.42	168.9	6.81	0.185	689.	0.45	23	
		80.	42.	0.016	0.14	3.2	0.15	0.020	28.			
NGC 2360	52	4861.	42 606.	0.000	+27.13		4.29	0.0398	286.	0.35	22	
		96.	103.	fixed	0.09		0.10	0.0036	12.			
NGC 2360	62	770.2	45 121.	0.542	+26.50	165.5	6.31	0.0119	56.1	0.45	12	
		3.9	37.	0.028	0.23	8.8	0.54	0.0038	6.3			
NGC 2423	43	1827.	44 802.	0.58	+18.75	82.	2.03	0.00085	41.5	0.51	24	
		30.	88.	0.10	0.16	10.	0.21	0.00025	4.5			
NGC 2437	29	3348.3	43 851.	0.709	+49.51	123.6	5.37	0.0189	174.	0.40	30	
		7.7	14.	0.025	0.08	3.9	0.29	0.0052	16.			
NGC 2447	42	378.7	45 058.	0.273	+18.2	357.	10.5	0.041	52.	0.72	42	
		0.44	18.	0.076	1.1	12.	1.7	0.034	14.			
NGC 2477	1272	297.8	44 788.	0.31	+8.42	346.	1.22	0.000048	4.7	0.55	11	
		3.2	45.	0.20	0.19	57.	0.31	0.000047	1.6			
NGC 2477	3170	5110.	40 808.	0.53	+7.06	234.2	3.47	0.0135	207.	0.54	16	
		132.	167.	0.05	0.16	7.3	0.26	0.0050	29.			
NGC 2477	4067	244.68	45 172.7	0.499	+7.26	196.0	2.35	0.00022	6.9	0.23	23	
		0.35	4.2	0.041	0.10	5.9	0.31	0.00010	1.1			
NGC 2482	23	5142.	45 641.	0.452	+38.36	127.6	5.74	0.0717	362.	0.30	22	
		25.	27.	0.017	0.07	2.6	0.13	0.0074	13.			
NGC 2533	17	203.41	45 063.8	0.504	+35.43	283.0	5.23	0.00194	12.6	0.67	17	
		0.34	9.3	0.046	0.18	7.6	0.35	0.00056	1.2			
NGC 2670	5	274.45	45 134.8	0.000	+6.69		11.17	0.0397	42.15	0.46	23	
		0.14	2.0	fixed	0.11		0.16	0.0017	0.62			
NGC 2925	92	619.27	45 254.3	0.33	+12.68	352.3	13.51	0.1334	108.62	0.33	20	
		0.63	3.8	0.008	0.07	1.4	0.12	0.0047	1.3			
NGC 2972	14	340.86	45 142.2	0.000	+21.09		6.12	0.00812	28.69	0.40	21	
		0.24	2.5	fixed	0.09		0.13	0.00053	0.64	.		
NGC 3532	152	2244.2	45 484.	0.234	+5.89	157.0	9.31	0.1728	279.3	0.29	21	
		4.9	12.	0.012	0.07	2.5	0.10	0.0073	4.3			
NGC 3532	160	239.616	45 017.7	0.126	+4.27	172.6	7.45	0.01003	24.33	0.23	28	
		0.062	3.2	0.008	0.05	4.8	0.08	0.00035	0.29			
NGC 3532	522	336.595	45 156.15	0.000	-19.59	0.0	21.50	0.3476	99.53	0.27	29	nm
		0.052	0.43	0.001	0.05	0.1	0.07	0.0033	0.32			
NGC 4349	79	754.1	45 157.8	0.325	-12.86	94.0	10.88	0.0852	106.7	0.50	25	
		1.4	6.7	0.017	0.13	3.8	0.18	0.0059	2.6			
NGC 4349	203	129.449	44 969.7	0.028	-11.38		10.71	0.01651	19.06	0.47	25	
		0.043	9.9	0.014	0.10	28.	0.14	0.00068	0.26			
NGC 5316	204	1002.	46 068.	0.195	-7.22	200.	4.34	0.0080	58.6	0.67	13	nm
		11.	57.	0.061	0.20	19.	0.29	0.0020	5.2			
NGC 5749	7	3592.	46 011.	0.55	+7.81	285.	1.85	0.0014	76.1	0.42	19	nm
		140.	171.	0.11	0.10	12.	0.16	0.0004	9.6			
NGC 5822	4	4470.	45 133.	0.580	-29.39	60.7	4.59	0.0242	229.	0.28	17	
		31.	44.	0.014	0.09	3.9	0.13	0.0031	11.			
NGC 5822	276	6048.	43 007.	0.63	-29.47	211.	2.51	0.0046	162.	0.62	20	
				0.17	0.72	17.	0.50	0.0083				
NGC 6124	29	1495.7	45 295.	0.444	-20.92	281.2	3.83	0.00626	70.5	0.35	27	
		9.8	24.	0.024	0.08	4.1	0.10	0.00076	3.1			
NGC 6124	33	118.008	45 097.64	0.00	-20.89		30.80	0.358	49.99	0.94	29	
		0.019	0.39	fixed	0.18		0.29	0.010	0.47			
NGC 6134	204	59.674	45 011.4	0.00	-24.92		9.50	0.00531	7.79	0.43	11	
		0.015	1.0	fixed	0.18		0.22	0.00038	0.18			
NGC 6192	96	393.7	44 731.	0.24	-7.01	355.	2.46	0.00055	12.9	0.53	10	
		1.8	27.	0.11	0.20	25.	0.32	0.00026	2.1			
NGC 6249	154	2321.	45 648.	0.378	-38.70	126.7	3.70	0.0097	109.3	0.26	22	nm
		11.	26.	0.023	0.06	4.1	0.09	0.0010	4.3			
NGC 6475	58	458.45	44 863.4	0.355	-11.94	302.9	8.71	0.0256	51.3	0.65	25	
		0.80	4.4	0.023	0.14	3.9	0.21	0.0026	1.8			
NGC 6694	14	3880.	41 698.	0.70	-8.51	232.	1.94	0.00108	74.	0.38	23	
		32.	76.	0.11	0.10	11.	0.31	0.00048	11.			
Rup 46	2191	1732.	44 262.	0.328	+7.37	246.0	4.97	0.0186	111.9	0.34	16	nm
		13.	46.	0.026	0.09	5.7	0.16	0.0025	5.5			
Rup 79	2	199.236	45 330.45	0.00	+29.02		32.42	0.705	88.82	0.72	28	
		0.044	0.63	fixed	0.15		0.21	0.014	0.59			
Tr 26	201	605.32	45 810.4	0.210	-9.69	331.4	9.44	0.0493	76.8	0.36	21	
		0.59	5.7	0.013	0.08	3.3	0.13	0.0024	1.3			

Table content: cluster name and star designation (as used in the June 2007 WEBDA version; see also references given for each cluster). For each system, the first line gives the orbital elements: the period (P), the time of periastron passage (T), the eccentricity (e), the systemic velocity (γ), the orientation of the nodes (ω), the semi-amplitude (K), the mass function ($f(m)$), the separation ($a \sin i$), the (O−C) residuals (σ), the number of observations (N), and notes on membership: nm means that the star is considered as non-member to the cluster. The second line lists the corresponding standard errors when relevant.

Table 4. Improved orbital elements for 35 binaries observed at La Silla (same format as Table 3).

Cluster	No.	P	T	e	γ	ω	K	$f(m)$	$a\sin i$	σ	N	Notes
IC 2488	67	520.58	45 525.2	0.153	+14.61	48.8	21.12	0.491	149.4	0.48	25	nm
		0.26	4.3	0.008	0.11	2.8	0.19	0.015	1.6			
IC 4651	6686	5020.	45 817.	0.183	−30.78	112.9	4.97	0.0607	337.	0.33	20	
		40.	91.	0.022	0.08	7.4	0.11	0.0053	11.			
IC 4651	8665	1321.2	45 216.1	0.774	−30.29	283.3	20.33	0.29	234.	0.48	28	SB2
		1.8	6.6	0.025	0.19	4.3	1.63	0.11	30.			
IC 4651	10195	75.162	45 047.9	0.091	−30.74	57.3	11.04	0.01038	11.36	0.44	22	
		0.012	1.5	0.015	0.10	7.5	0.14	0.00044	0.16			
IC 4651	14290	335.550	45 265.707	0.00	−31.36		15.97	0.1420	73.70	0.23	27	
		0.056	0.39	fixed	0.05		0.08	0.0020	0.36			
IC 4651	14641	2761.	45 376.	0.189	−31.20	59.	2.61	0.00482	97.3	0.30	21	
		30.	75.	0.041	0.07	11.	0.10	0.00073	5.6			
Mel 71	107	806.53	44 781.4	0.485	+50.76	197.7	19.25	0.399	186.7	0.49	30	
		0.98	3.3	0.006	0.10	1.2	0.17	0.016	2.6			
Mel 71	110	74.056	45 167.20	0.00	+50.62		32.14	0.2554	32.73	0.77	25	
		0.019	0.76	fixed	0.17		0.20	0.0049	0.21			
Mel 71	118	155.773	45 041.9	0.128	+50.70	66.0	24.49	0.2317	52.02	0.46	26	
		0.038	1.2	0.006	0.10	2.6	0.16	0.0050	0.38			
Mel 71	151	1635.	45 415.	0.868	+50.88	282.10	20.04	0.1673	223.8	0.52	38	
		10.	20.	0.002	0.14	0.65	0.13	0.0081	4.5			
NGC 1817	56	2542.3	46 817.	0.818	+66.02	166.8	6.15	0.0117	124.	0.41	23	
		7.2	15.	0.011	0.10	2.3	0.33	0.0029	10.			
NGC 2360	51	98.886	45 113.34	0.287	+27.62	25.65	20.02	0.0724	26.1	0.43	28	
		0.010	0.44	0.007	0.09	1.3	0.12	0.0018	0.22			
NGC 2360	181	634.17	45 116.4	0.503	+26.45	212.2	22.35	0.474	168.4	0.58	22	
		0.48	2.1	0.013	0.15	1.5	0.61	0.052	6.2			
NGC 2437	242	248.30	44 759.7	0.084	+48.51	81.0	23.29	0.3223	79.23	0.51	36	
		0.12	2.6	0.006	0.09	3.8	0.13	0.0059	0.51			
NGC 2447	25	113.795	45 094.75	0.00	+22.15		26.05	0.2089	40.77	0.40	35	
		0.020	0.29	fixed	0.08		0.10	0.0024	0.16			
NGC 2489	25	1589.5	46 194.	0.560	+38.35	93.5	13.35	0.223	241.	0.56	24	
		7.4	15.	0.019	0.16	1.8	0.31	0.027	10.			
NGC 2567	104	98.5479	44 979.28	0.00	+36.10		30.14	0.2803	40.85	0.49	43	
		0.0074	0.27	fixed	0.08		0.11	0.0032	0.15			
NGC 3033	12	793.0	44 960.	0.189	0.16	+305.2	6.48	0.0212	69.4	0.43	25	nm
		2.3	12.	0.021	0.11	6.0	0.17	0.0020	2.3			
NGC 3033	19	2122.8	44 044.	0.344	+27.15	85.9	8.50	0.112	233.0	0.40	20	
		7.8	16.	0.025	0.09	2.5	0.16	0.010	7.5			
NGC 3680	18	27.29994	45 005.78	0.136	−2.11	200.5	17.02	0.01360	6.332	0.36	39	nm
		0.00085	0.17	0.005	0.07	2.1	0.11	0.00029	0.044			
NGC 3680	27	869.4	45 061.	0.681	+1.32	33.2	5.57	0.0061	48.7	0.45	12	
		6.4	37.	0.49	0.20	4.6	0.36	0.0024	6.5			
NGC 3960	50	328.77	44 980.7	0.159	−22.31	262.9	12.92	0.0708	57.6	0.70	12	
		0.30	8.4	0.024	0.23	9.1	0.34	0.0065	1.8			
NGC 3960	91	209.12	45 020.3	0.366	−23.19	359.6	11.98	0.0301	32.1	0.54	15	
		0.24	5.1	0.026	0.20	5.0	0.67	0.0061	2.2			
NGC 3960	275	96.918	45 138.5	0.035	−22.32	167.	18.88	0.0676	25.15	0.53	12	
		0.018	5.9	0.018	0.23	23.	0.21	0.0024	0.30			
NGC 5822	2	1002.2	44 780.	0.132	−29.22	4.7	4.49	0.00916	61.3	0.30	18	
		3.5	26.	0.029	0.08	9.3	0.11	0.00082	1.9			
NGC 5822	3	3535.	45 917.	0.204	−29.35	104.5	4.06	0.0230	193.2	0.32	25	
		27.	60.	0.022	0.07	6.8	0.09	0.0021	6.8			
NGC 5822	11	880.08	45 482.1	0.361	−29.04	304.7	8.10	0.0394	91.4	0.21	19	
		0.65	3.3	0.011	0.06	1.5	0.11	0.0022	1.7			
NGC 5822	80	65.4630	45 071.28	0.00	−28.25		23.43	0.08743	21.09	0.26	26	
		0.0040	0.11	fixed	0.06		0.06	0.00071	0.058			
NGC 5822	151	1391.5	44 609.	0.212	−29.57	58.1	4.42	0.0117	82.7	0.36	17	
		5.4	39.	0.028	0.09	9.1	0.14	0.0014	3.4			
NGC 5822	312	977.87	45 012.9	0.727	−31.52	220.93	18.17	0.196	167.5	0.48	25	
		0.61	1.9	0.005	0.10	0.90	0.21	0.011	3.3			
NGC 5823	1034	1127.5	45 288.	0.240	−19.27	80.5	13.90	0.288	209.2	0.77	19	
		2.9	15.	0.022	0.18	4.6	0.32	0.025	6.4			
NGC 6134	8	702.7	45 316.5	0.502	−26.69	157.6	8.97	0.0341	75.0	0.39	21	
		1.1	5.6	0.027	0.11	1.9	0.38	0.0063	4.7			
NGC 6134	34	257.83	44 876.6	0.418	−25.69	326.1	8.91	0.0142	28.68	0.39	21	
		0.21	3.0	0.015	0.10	2.4	0.21	0.0013	0.92			
NGC 6475	134	217.42	45 229.3	0.00	−15.57		9.27	0.01799	27.72	0.26	19	
		0.18	1.1	fixed	0.06		0.08	0.00046	0.25			
NGC 6664	54	739.29	44 780.1	0.310	+19.00	29.6	21.71	0.675	209.8	0.48	22	
		0.59	3.6	0.009	0.13	1.9	0.18	0.023	2.5			

Table 5. Published orbital elements for 15 binaries observed at La Silla (same format as Table 3).

Cluster	No.	P	T	e	γ	ω	K	$f(m)$	$a \sin i$	σ	N
NGC 1817	44	68.0293	49 979.24	0.000	+65.69		21.00	0.0654	19.64	0.72	24
		0.058	0.11	fixed	0.16		0.22	0.0020	0.20		
NGC 1817	164	165.760	49 771.	0.020	+64.69	236.	26.09	0.3054	59.45	0.62	26
		0.021	10.	0.007	0.14	22.	0.20	0.0071	0.46		
NGC 2477	1025	41.5540	49 991.8	0.040	+6.72	240.	11.75	0.00698	6.71	0.50	21
		0.0044	2.4	0.016	0.13	20.	0.21	0.00039	0.13		
NGC 2477	1044	3108.	47 747.	0.074	+7.46	157.	3.22	0.0107	137.	0.47	15
		52.	358.	0.060	0.13	42.	0.20	0.0023	11.		
NGC 2477	2064	4578.	48 031.	0.273	+6.14	222.5	5.78	0.0819	350.	0.29	18
		76.	45.	0.022	0.09	3.9	0.13	0.0084	16.		
NGC 2477	2204	1318.9	49 157.3	0.581	+7.62	244.8	19.47	0.545	287.	0.69	18
		5.0	10.0	0.012	0.18	1.6	0.41	0.053	10.		
NGC 2477	3003	1782.4	48 059.	0.355	+7.49	15.3	11.13	0.209	255.2	0.54	23
		4.9	16.	0.015	0.13	3.5	0.24	0.018	7.7		
NGC 2477	3176	276.74	49 964.8	0.153	+7.01	28.7	7.74	0.01286	29.10	0.44	26
		0.17	5.3	0.016	0.09	6.7	0.13	0.00073	0.56		
NGC 2477	4137	372.367	49 465.9	0.374	+9.04	142.6	14.56	0.0952	69.14	0.32	26
		0.069	1.0	0.005	0.11	1.5	0.10	0.0025	0.63		
NGC 2477	5073	326.10	50 024.4	0.579	+6.13	169.0	14.66	0.0579	53.6	0.50	21
		0.12	1.1	0.008	0.12	1.4	0.26	0.0043	1.3		
NGC 2477	6020	226.20	49 686.4	0.367	+8.55	313.2	9.33	0.0154	27.00	0.57	22
		0.11	2.1	0.019	0.13	3.7	0.22	0.0015	0.89		
NGC 2477	6062	482.3	49 338.	0.103	+10.16	243.	6.21	0.0118	41.0	0.73	19
		1.1	36.	0.053	0.21	26.	0.32	0.0021	2.5		
NGC 2477	6251	412.6	49 637.	0.117	+7.40	110.	1.92	0.00030	10.8	0.58	10
		3.2	90.	0.146	0.20	81.	0.28	0.00015	1.8		
NGC 2477	8017	60.3169	49 866.26	0.000	+8.33	360.	21.74	0.0643	18.03	0.79	21
		0.0083	0.38	0.014	0.19	313.	0.25	0.0023	0.21		
NGC 2477	8018	140.149	49 780.9	0.274	+6.28	349.7	6.77	0.00401	12.54	0.26	15
		0.044	1.5	0.018	0.08	3.8	0.12	0.00029	0.30		

less massive than the main sequence component. The respective amplitudes are 20.08 ± 1.55 km s^{-1} for the red giant and 18.21 ± 1.50 km s^{-1} for the main sequence component. The latter may be a close binary itself, which would explain its larger mass. Numbers are from Meibom (2000), L numbers from Lindoff (1972). See also the comprehensive study of the cluster by Meibom et al. (2002).

Melotte 71 Radial velocities of 24 red giants in Melotte 71 were discussed in Mermilliod et al. (1997b). Eight binaries were discovered and four orbits determined. The orbital elements have been updated to the new zero point.

Melotte 105 The radial velocities of #17, 83, 120, 182 in Melotte 105 (Piatti et al. 2001) form two possible pairs for membership. Examination of the colour–magnitude diagram supports the membership of stars #17 and 182. Star #17 is a spectroscopic binary, but shows no effect of a companion in the CMD. Star #270, not observed, is a possible member according to its position close to star #17.

NGC 1817 The orbital elements of two of the three red-giant binaries determined by Mermilliod et al. (2003) are repeated for completeness in Table 5; they were already on the new zero-point system. Five new observations of star #56 (Cuffey 1938) obtained at CfA showed that the true period is twice that given in the earlier paper; the new elements are included in Table 4. Six observations also obtained at CfA permitted to compute a first orbit for star #244. The period is the second shortest in our sample, $P = 43\overset{\rm d}{.}2488$, and the orbit is circular (e = 0.021 ± 0.035).

NGC 2324 Seventeen stars were observed in the field of NGC 2324. The membership of 9 red giants was confirmed, and three spectroscopic binaries were discovered (Mermilliod et al. 2001). A preliminary orbit, based on 12 points, was determined for star #1006 (Piatti et al. 2004). The systemic velocity confirms its membership in the cluster.

NGC 2360 Five spectroscopic binaries were identified in NGC 2360 (Mermilliod et al. 1999). Orbital elements for #51 and 181 (Becker et al. 1976) were published earlier (Mermilliod et al. 1989). Three new orbits were determined. Additional observations permitted to compute a circular orbit with a period of 4861 ± 96 days for #52, rather unusual for such a long period. An observation made on Feb. 20, 2007 (JD = 2 454 152.667, $V_{\rm r}$ = +26.55 ± 0.01 km s^{-1}) by M. Marmier with the CORALIE spectrograph at the 1.2 m Euler telescope at La Silla permitted to cover one entire cycle for star #44 and compute the fourth orbit in this cluster, with a period as long as $8398^{\rm d}$. Finally, adding a radial velocity by Hamdani et al. (2000) to our CORAVEL data permitted to find a stable solution for #62, although the phase coverage is incomplete and the orbital elements preliminary. We thus now have orbital solutions for all five binaries in this cluster.

The photometric deconvolution of star #181 gives $M_2 \sim 2.15\ M_\odot$, while the mass function ($f(m)$ = 0.474) combined with $M_1 = 2.36\ M_\odot$ gives a minimum mass for M_2 of 2.12 $M_\odot$.

NGC 2423 Three spectroscopic binaries were found in NGC 2423 (Mermilliod & Mayor 1990). A preliminary orbit was determined for #43, but the eccentricity is high, the amplitude small, and not all critical phases are well covered.

Table 6. New orbital elements for 31 binaries observed from OHP (same format as Table 3).

Cluster	No.	P	T	e	γ	ω	K	$f(m)$	$a\sin i$	σ	N	Notes
Cr 463	55	848.9	44 598.	0.130	−51.95	68.3	6.51	0.0237	75.3	0.29	21	nm
		1.0	14.	0.018	0.07	5.9	0.10	0.0013	1.4			
Cr 463	73	1898.	44 583.0	0.87	−47.20	251.8	11.07	0.0320	142.	0.43	20	nm
		12.	4.3	0.11	0.28	9.2	0.80	0.0071	11.			
IC 4756	25	1510.3	45 405.	0.272	−23.57	144.	4.51	0.0128	90.0	0.34	16	
		7.4	38.	0.38	0.17	11.	0.19	0.0021	5.2			
IC 4756	80	5791.	40 980.	0.035	−25.61	268.	6.96	0.203	554.	0.41	54	
		23.	368.	0.014	0.07	23.	0.10	0.010	10.			
IC 4756	139	3834.	44 093.	0.216	−26.29	22.	2.59	0.00645	133.4	0.39	49	
		36.	92.	0.034	0.06	10.	0.10	0.00092	7.2			
Mel 111	91	396.54	44 502.4	0.566	1.06	95.5	22.42	0.26	101.	0.38	32	
		0.12	8.0	0.050	1.50	3.5	2.22	0.11	14.			
NGC 1027	27	5639.	46 152.	0.306	−43.87	351.1	5.40	0.0796	399.	0.36	41	
		24.	44.	0.015	0.06	3.1	0.09	0.0055	10.			
NGC 1502	59	123.546	44 971.18	0.00	−12.90		25.37	0.2096	43.11	0.48	21	nm
		0.015	0.14	fixed	0.11		0.16	0.0039	0.27			
NGC 1528	4	1071.4	44 003.3	0.225	−9.13	131.9	20.65	0.907	296.7	0.74	28	
		1.2	9.4	0.11	0.15	3.5	0.28	0.045	5.2			
NGC 1545	98	486.24	44 476.1	0.617	0.64	15.5	14.17	0.0701	74.6	0.45	26	nm
		0.23	1.8	0.007	0.11	1.1	0.17	0.0040	1.4			
NGC 1778	2	425.71	44 682.6	0.332	4.95	129.7	3.20	0.00121	17.6	0.42	28	
		0.56	6.9	0.051	0.08	6.6	0.15	0.00024	1.2			
NGC 2099	748	15338.	48 064.	0.581	8.99	226.8	8.68	0.56	1490.	0.65	38	
		500.	49.	0.049	0.26	2.9	0.16	0.19	312.			
NGC 2215	26	190.207	44 808.8	0.316	−3.43	14.5	11.09	0.0230	27.53	0.59	27	
		0.056	2.2	0.014	0.12	3.3	0.18	0.0015	0.59			
NGC 2264	73	78.105	44 982.07	0.00	25.84		12.10	0.01438	13.00	0.46	30	nm
		0.011	0.25	fixed	0.10		0.12	0.00044	0.13			
NGC 2287	21	1509.6	44 168.6	0.658	23.22	254.1	6.27	0.0164	97.9	0.37	37	
		1.0	4.0	0.10	0.07	1.8	0.11	0.0014	2.9			
NGC 2287	97	461.07	44 764.7	0.68	22.83	129.	1.14	0.000027	5.3	0.22	16	
		0.26	9.3	0.10	0.10	23.	0.48	0.000045	2.8			
NGC 2287	102	1337.6	44 187.6	0.368	23.40	121.3	18.17	0.670	310.7	0.86	47	
		2.0	5.9	0.010	0.14	1.7	0.18	0.030	4.9			
NGC 2287	107	1212.6	44 273.3	0.575	23.34	1.4	8.18	0.0378	111.6	0.28	33	
		2.6	2.5	0.007	0.05	1.2	0.10	0.0021	2.3			
NGC 2287	204	1978.5	42 844.	0.058	6.57	138.	6.48	0.0555	175.9	0.33	20	nm
		5.9	90.	0.017	0.07	16.	0.11	0.031	3.6			
NGC 2335	4	300.76	44 933.0	0.00	21.82		7.87	0.01525	32.56	0.45	22	
		0.16	1.5	fixed	0.10		0.15	0.00088	0.63			
NGC 2420	173	1479.6	44 216.	0.421	73.65	190.2	4.10	0.0079	75.6	0.46	25	
		9.1	20.	.048	0.12	5.4	0.15	0.0015	5.0			
NGC 2539	209b	11655.	44 352.	0.163	0.00	91.	2.37	0.0154	374.	0.44	43	triple, outer system
		722.	735.	0.050	fixed	28.	0.10	0.0033	42.			
NGC 2539	233	164.83	44 928.9	0.00	26.97		0.91	0.000013	2.07	0.29	17	
		0.28	4.8	fixed	0.08		0.12	0.000005	0.28			
NGC 2539	663	1917.6	41 908.	0.237	29.17	268.	1.86	0.00117	47.5	0.38	39	
		7.7	70.	0.052	0.06	12.	0.10	0.00023	3.2			
NGC 2548	1296	1302.7	43 677.1	0.753	7.29	91.6	5.89	0.0079	69.4	0.57	34	
		1.7	6.2	0.022	0.11	3.4	0.26	0.0020	5.8			
NGC 2548	1560	14624.	43 178.	0.413	8.25	235.7	7.82	0.547	1431.	0.37	55	
		147.	75.	0.017	fixed	3.4	0.23	0.066	68.			
NGC 6709	303	329.849	44 764.3	0.207	−9.53	110.8	16.75	0.1508	74.34	0.54	35	
		0.099	2.1	0.008	0.11	2.5	0.15	0.049	0.82			
NGC 6882	26	1144.4	45 043.	0.315	−17.87	94.3	5.87	0.0206	87.7	0.27	21	
		1.8	11.	0.015	0.07	3.7	0.11	0.0015	2.3			
NGC 7082	174	2076.	44 509.	0.312	21.26	166.6	4.58	0.0177	124.2	0.46	21	nm
		15.	36.	0.032	0.10	6.3	0.16	0.0026	6.7			
NGC 7209	95	178.769	44 837.2	0.260	−18.87	51.3	10.27	0.01813	24.39	0.45	36	
		0.022	1.1	0.011	0.08	2.5	0.12	0.00080	0.36			
St 2	120	34.93760	44 989.676	0.296	−59.30	159.82	24.36	0.04569	11.177	0.34	24	nm
		0.00041	0.083	0.005	0.08	0.88	0.13	0.00097	0.079			

Table 7. Improved orbital elements for 29 binaries observed from OHP (same format as Table 3).

Cluster	No.	P	T	e	γ	ω	K	$f(m)$	$a \sin i$	σ	N	Notes
IC 4725	150	2315.3	44 346.6	0.523	2.84	219.45	13.29	0.349	360.6	0.32	31	
		3.2	3.5	0.006	0.06	0.99	0.12	0.015	5.4			
IC 4756	69	1994.3	43 331.	0.0043	−24.95	161.	4.86	0.0237	133.1	0.31	43	
		3.4	115.	0.015	0.05	21.	0.08	0.0013	2.6			
NGC 0129	170	2457.1	43 756.	0.165	−38.11	68.0	15.51	0.914	516.9	0.83	52	
		5.4	25.	0.012	0.15	4.1	0.20	0.043	8.8			
NGC 0752	75	3321.6	40 851.	0.218	4.85	152.9	6.56	0.0903	292.2	0.44	85	
		6.2	26.	0.010	0.05	3.0	0.07	0.0037	4.4			
NGC 0752	110	127.3384	44 846.223	0.00	5.17		25.47	0.2186	44.60	0.42	53	
		0.0041	0.073	fixed	0.06		0.09	0.0023	0.16			
NGC 0752	208	5214.	40 296.	0.140	5.30	353.7	5.35	0.0804	379.7	0.47	89	
		23.	89.	0.014	0.06	5.7	0.08	0.0043	7.8			
NGC 2099	49	162.247	44 870.37	0.393	8.49	240.6	14.52	0.0401	29.79	0.41	25	
		0.049	0.76	0.010	0.09	1.4	0.19	0.0021	0.53			
NGC 2099	149	918.2	44 237.	0.128	6.57	113.	4.92	0.01104	61.5	0.42	24	
		3.4	34.	0.026	0.09	11.	0.13	0.00099	2.0			
NGC 2099	412a	262.71	45 190.1	0.00	8.13		1.26	0.000054	4.54	0.38	21	
		0.45	7.5	fixed	0.10		0.13	0.000017	0.48			
NGC 2099	412b	910.2	44 831.	0.050	8.25	329.	1.31	0.000214	16.4	0.27	21	
		3.8	189.	0.077	0.06	76.	0.09	0.000046	1.2			
NGC 2099	485	455.46	44 222.1	0.168	9.15	45.9	16.08	0.1884	99.3	0.52	27	
		0.29	4.8	0.009	0.10	3.4	0.15	0.0061	1.1			
NGC 2099	599	168.89	44 985.6	0.049	21.67	77.	11.65	0.0276	27.02	0.74	19	nm
		0.11	1.3	0.023	0.18	25.	0.28	0.0021	0.70			
NGC 2099	685	1673.	45 086.	0.135	15.44	252.	15.44	0.0038	64.4	0.39	15	nm
		25.	106.	0.053	0.12	24.	0.12	0.0007	4.9			
NGC 2099	782	886.2	45 567.9	0.224	−3.53	210.9	16.64	0.392	197.6	0.45	18	nm
		1.0	7.3	0.008	0.11	2.9	0.16	0.014	2.5			
NGC 2099	838	1559.	45 346.	0.328	21.18	121.9	10.22	0.145	206.9	0.81	19	nm
		11.	21.	0.026	0.21	7.1	0.31	0.018	9.7			
NGC 2099	865	433.1	45 259.	0.041	−3.93	252.	9.50	0.0384	56.5	0.41	20	nm
		0.4	21.	0.018	0.10	17.	0.14	0.0018	0.9			
NGC 2099	966	3084.	45 400.	0.372	9.98	30.9	3.53	0.0112	138.9	0.35	15	
		36.	54.	0.037	0.10	6.3	0.15	0.0021	9.6			
NGC 2099	1505	2404.	43 835.	0.761	−17.72	250.4	17.48	0.363	375.	0.23	11	nm
		18.	32.	0.013	0.27	1.8	0.56	0.063	23.			
NGC 2420	250	1430.6	45 258.	0.08	78.20	141.	6.90	0.0473	132.7	0.51	26	
		3.5	64.	0.03	0.13	16.	0.21	0.0047	4.6			
NGC 2539	114	405.41	44 624.8	0.690	28.33	291.0	9.20	0.0124	37.1	0.42	26	
		0.26	2.0	0.014	0.10	1.6	0.19	0.0015	1.5			
NGC 2539	209a	242.27	44 992.6	0.197	27.41	110.	8.99	0.0172	29.3	2.02	43	triple, inner system
		0.11	9.4	0.049	0.32	16.	0.48	0.0032	1.8			
NGC 2539	223	585.16	44 535.3	0.199	29.46	49.4	18.30	0.351	144.3	0.56	24	
		0.44	4.7	0.009	0.13	3.3	0.18	0.012	1.8			
NGC 2632	428	996.65	43 951.09	0.809	33.62	62.59	9.67	0.01898	77.8	0.24	40	
		0.27	0.45	0.002	0.04	0.74	0.07	0.00075	1.0			
NGC 6633	70	1220.3	44 435.3	0.294	−28.92	49.1	19.40	0.807	311.1	0.59	35	
		1.1	5.0	0.007	0.10	1.7	0.16	0.026	3.5			
NGC 6940	84	54.1647	44 957.82	0.00	8.83		17.69	0.0311	13.17	0.84	30	
		0.0033	0.11	fixed	0.16		0.22	0.0011	0.16			
NGC 6940	92	552.26	44 771.8	0.429	7.31	278.1	5.02	0.0053	34.4	0.72	24	
		0.80	7.7	0.043	0.15	6.6	0.24	0.0011	2.5			
NGC 6940	100	82.5753	44 993.35	0.00	8.47		25.07	0.1812	28.47	1.37	35	SB2
		0.0079	0.18	fixed	0.20		0.20	0.0041	0.29			
NGC 6940	111	3571.	41 292.	0.302	8.50	359.9	4.00	0.0205	187.2	0.28	30	
		20.	38.	0.019	0.05	3.7	0.09	0.0018	6.3			
NGC 6940	130	281.53	44 882.4	0.165	7.25	216.9	9.95	0.0276	37.9	0.69	20	
		0.37	6.3	0.024	0.18	8.5	0.22	0.0022	1.0			
NGC 6940	189	210.764	44 988.80	0.300	7.82	69.6	24.52	0.280	67.77	0.71	25	
		0.047	0.85	0.008	0.16	1.9	0.23	0.010	0.83			

NGC 2437 All four stars observed, #29, 150, 174, 242 (Cuffey 1941), are members of NGC 2437, and three are spectroscopic binaries. We provide new orbital elements for #29 and improved elements for #242. The rather large value of $f(m) = 0.322$ for #242 gives a minimum mass of 2.08 $M_{\odot}$ (for $\sin i = 1$), while the photometric separation gives $M_2 = 2.17\ M_{\odot}$. The period of #174 is probably long and the orbit eccentric. The radial velocity of star #150 is so far constant, although the star is well inside the

Table 8. Published or revised orbital elements for 10 binaries observed from OHP (same format as Table 3).

Cluster	No.	P	T	e	γ	ω	K	$f(m)$	$a \sin i$	σ	N
Mel 25	41	529.9	44 972.2	0.47	39.42	354.3	3.00	0.00101	19.2	0.83	43
		1.1	9.8	0.06	0.14	8.9	0.25	0.00036	2.3		
Mel 25	71	5997.	39 057.	0.64	38.79	75.8	8.39	0.17	532.	0.27	39
		22.	30.	0.07	0.45	8.3	1.3	0.12	128.		
NGC 0129	200	684.39	47 163.3	0.347	−36.80	27.4	16.59	0.2675	146.4	0.90	160
		0.36	2.1	0.008	0.13	1.3	0.14	0.0073	1.3		
NGC 2682	136	1495.	45 372.	0.32	+32.87	160.	2.60	0.0023	51.	0.5	66
		16.	37.	0.07	0.12	11.	0.16	0.0005	3.		
NGC 2682	143	42.8271	44 759.25	0.00	+32.93		8.45	0.00268	4.97	0.5	57
		0.0022	0.08	fixed	0.07		0.11	0.00010	0.006		
NGC 2682	170	4410.	43 220.	0.50	+33.59	87.	2.70	0.0059	142.	0.4	68
		87.	90.	0.03	0.10	5.	0.12	0.0010	8.		
NGC 2682	224	6445.	46 686.	0.00	+32.55	.	5.97	0.142	529.	0.4	60
		50.	21.	fixed	0.07	.0	11.0	009.11	.		
NGC 2682	244	697.8	45 176.	0.105	+33.55	256.	5.03	0.0091	48.0	0.3	61
		0.7	15.	0.015	0.05	8.	0.07	0.0004	0.6		
NGC 6705	926	209.57	45 077.	0.01	33.8	312.	32.6	0.75	.0	64.45	
		0.02	15.	0.004	0.1	17.	0.1	0.01			
NGC 6705	1223	660.0	44 589.	0.53	35.4	146.	21.8	0.43		0.73	53
		0.4	2.	0.005	0.1	1.	0.1	0.01			

Hertzsprung gap. The photometric separation yields a mass of 2.72 $M_{\odot}$ for the presumed upper main-sequence secondary.

NGC 2447 NGC 2447 was discussed by Mermilliod & Mayor (1989). They found 3 definite and one suspected spectroscopic binaries among the 13 members and determined an orbit for star #25 (Becker et al. 1976). The new observations enable us to compute orbital elements for #42 as well. Although not all phases have been observed, the number of cycles covered makes the period determination quite secure. The radial velocity of #38 seems to be constant, although this star is located in the middle of the Hertzsprung gap. The mean velocity supports its membership. The separation must be large, since no motion has been detected during 13 years and the dispersion around the mean velocity corresponds to the average internal error.

NGC 2477 Eigenbrod et al. (2004) discussed NGC 2477 in detail. They found 26 definite spectroscopic binaries and determined orbital elements for 13 systems, which are reproduced in Table 5 for completeness. Here, we provide preliminary orbital elements for another 3 binaries, #1272, 3170 and 4067 (Hartwick & Hesser 1974).

NGC 2482 Five stars were observed in NGC 2482. Among the three members, #7 and 23 are binaries (Moffat & Vogt 1975), while #9 is constant.

NGC 2489 Of the seven red giants measured in NGC 2489, #14, 25, 36, 37, 50 and 103 are members (Lindoff & Johansson 1968). The orbit of star #25 by Mermilliod et al. (1997a) has been improved.

NGC 2533 #17, 109 and 125 (Lindoff 1968) are confirmed members, and #17 is a long-period binary.

NGC 2567 Of the nine stars observed in the field of NGC 2567, the radial velocities confirm the membership of #16, 37, 54, 104, 114 (Lindoff 1968). #104 is the only binary among them; the orbital elements by Mermilliod et al. (1997a) were improved.

NGC 2670 Star #5 (Lyngå 1959) is the only red giant in the field of NGC 2670. Its position in the colour–magnitude diagram is compatible with membership, but its membership cannot be checked because no radial velocities of main-sequence stars are available. Its circular orbit conforms to the relation between cutoff period for orbital circularization and the red-giant mass (Mermilliod & Mayor 1996).

NGC 2925 All three stars observed in NGC 2925, #92, 95 and 108 (Topaktas 1981), are cluster members. #92 is a binary.

NGC 2972 Four stars were observed in the field of NGC 2972. #2 is a non-member, and #3, 11 and 14 are members (Vogt & Moffat 1973). #14, a bright giant, is a binary with a circular orbit of period compatible with the mass of the stars (cf. comment under NGC 2670).

NGC 3033 Both red giants in the field of NGC 3033, #12 and 19 (Vogt & Moffat 1973) are spectroscopic binaries with known orbits (Mermilliod et al. 1997a). Only #19 seems to be a member, but radial velocities for main-sequence stars are required for confirmation.

NGC 3532 Eleven stars were observed in NGC 3532. Three (#273, 522 (SB1O), and 649, Fernandez & Salgado 1980) are non-members, and 8 are members (#19, 100, 122, 152, 160, 221, 596, and 670). #152 and 160 are spectroscopic binaries, and their orbits have been determined.

NGC 3680 Radial-velocity observations of 15 red giants in the field of NGC 3680 were analysed by Mermilliod et al. (1995); the orbital elements have been updated here. A comprehensive study of stellar and dynamical evolution in NGC 3680 was published by Nordström et al. (1997).

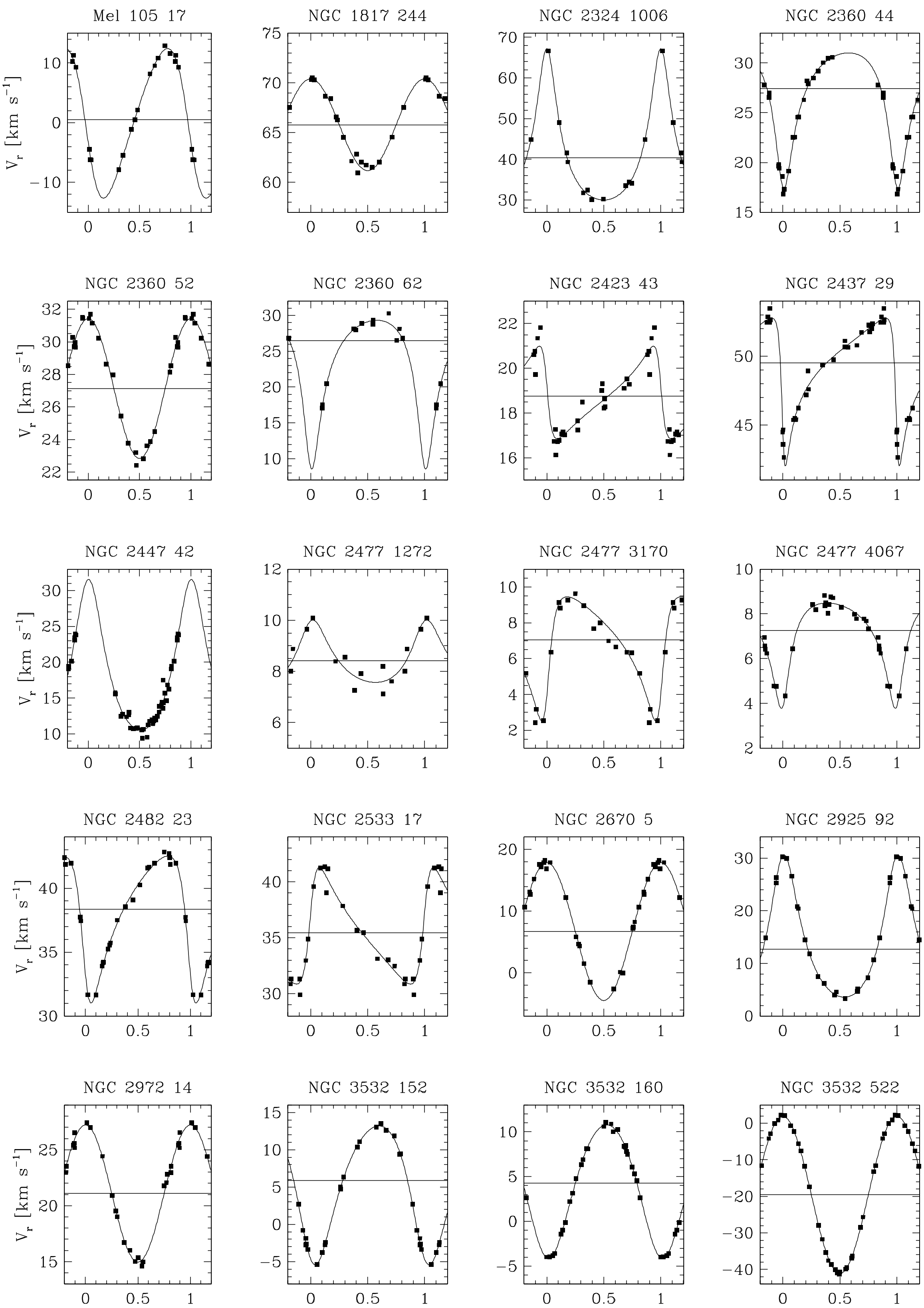

Fig. 1. Radial-velocity curves for 20 of the 36 new southern orbits in Table 3.

NGC 3960 Observations of 14 red giants in NGC 3960 have been published by Mermilliod et al. (2001). Five binaries were discovered and three orbits determined. The orbital elements have been updated.

NGC 4349 Five red-giant candidates noticed on the ESO survey and 8 stars selected from the photometry of NGC 4349 were observed. 11 stars were confirmed as members, and 3 spectroscopic binaries were discovered: #79, 168 and 203

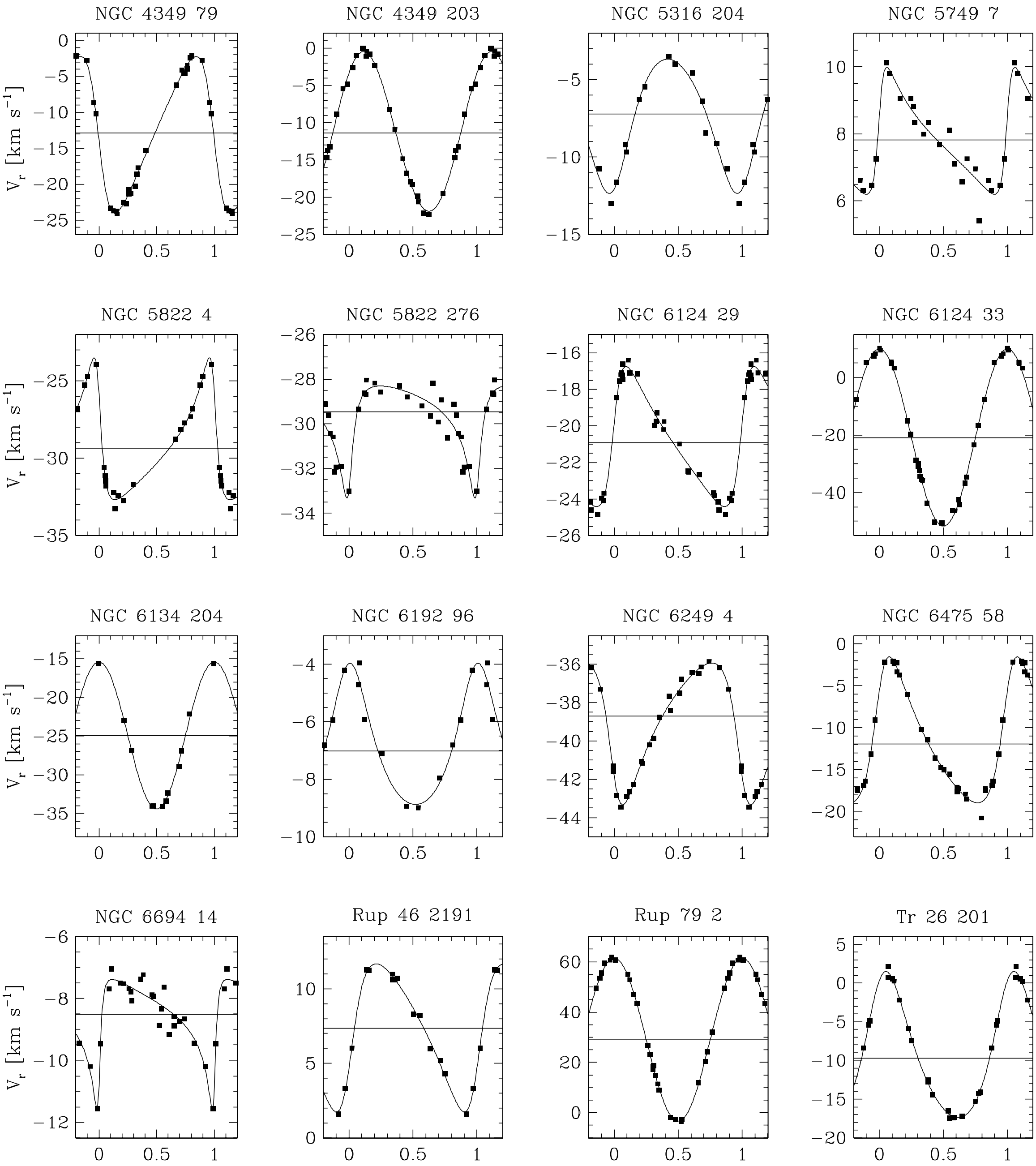

Fig. 2. Radial-velocity curve for the remaining 16 southern binaries from Table 3.

(Lohman 1961); orbital elements have been determined for two of them. The eccentricity of #203 is small, but the period is close to the cutoff period for circular orbits, which may explain the observed value.

NGC 5316 Both spectroscopic binaries discovered in NGC 5316, #3 and 204 (Rahim 1966), are non-members as their systemic velocities (-54.4 and -7.2 km s^{-1}) are far from the cluster mean velocity of -15.1 ± 0.3 km s^{-1}. The velocities of all four members, #31, 35, 45 and 72, are constant over 4400 days. The zero binary frequency in NGC 5316 contrasts with the value of 75% observed in NGC 2437.

NGC 5749 Both stars observed in NGC 5749, #7 and 29 (Clariá & Lapasset 1992), are non-members, and #7 is a binary.

NGC 5822 This cluster was discussed by Mermilliod & Mayor (1990). Ten spectroscopic binaries were discovered. The binary nature of star #201 is not confirmed by the new observations. Four orbits were published by Mermilliod et al. (1989) and two by Mermilliod et al. (1997a). Continued monitoring of the binaries now permits us to determine orbits also for the cluster members #4 and 276 (Bozkurt 1974), bringing the total number of orbits to 8 of the 9 binaries known in this cluster. The binary rate is remarkably high: 9/21 or 43%.

NGC 5823 Nine stars were observed in NGC 5823, but only one, #1034 (#34 in Janes 1981) is a probable member. It is a spectroscopic binary and first elements were published by Mermilliod et al. (1989). Seven new observations were obtained and the orbit improved.

NGC 6124 In NGC 6124, we have observed #1, 14, 29, 33, 35, 36, 41, 233 (Koelbloed 1959). All stars are cluster members, and #29 and 33 are binaries with orbit determinations.

NGC 6134 Observations of 24 red giants in NGC 6134 have been analysed by Clariá & Mermilliod (1992). Orbital elements for stars #8 and 34 were published by Mermilliod et al. (1997a); these elements have been updated here. Preliminary elements were determined for star #204. The period is short (59 days) and the orbit is circular.

NGC 6192 Radial-velocity observations in NGC 6192 were analysed by Clariá et al. (2006). Among the 10 stars observed, #9, 45, 91, 96 and 137 (Kilambi & Fitzgerald 1983) were found to be members. #91 and 96 are spectroscopic binaries, and a preliminary orbit has been derived for #96.

NGC 6249 The two red giants observed in NGC 6249, #154 and 179 (McSwain & Gies 2005), are non-members, as their positions in the colour–magnitude diagram are incompatible with the young age of the cluster (McSwain & Gies 2005). No radial velocities for main-sequence stars exist. An orbit has been determined for star #154.

NGC 6475 Both red-giant members in NGC 6475 are spectroscopic binaries. A circular orbit has been published for #134 (=HD 162391, Mermilliod et al. 1989). Star #58 (Koelbloed 1959; also known as HD 162587, HR 6658, and WDS17534-3454) is a close visual binary (separation $0\farcs4$) composed of two red giants, one of which is a spectroscopic binary. The correlation functions clearly show one variable-velocity component and another one, stable at the cluster velocity. Thus, NGC 6475 must contain three red giants. The photometry of #58 is that of the triple system.

NGC 6664 This cluster contains the Cepheid EV Sct. Observations of 6 red giants in the field were discussed by Mermilliod et al. (1987). The initial orbit for #54 (Arp 1958) by Mermilliod et al. (1997a) has been slightly improved.

NGC 6694 Both giants observed, #14 and 23 (Madore & van den Bergh 1975) are members, and #14 is also a binary.

Ruprecht 46 Both stars observed, #2189 and 2191 (Carraro & Patat 1995) appear to be non-members according to their positions in the colour–magnitude diagram. Their mean velocities are quite different, and no radial-velocity data are available for the main-sequence stars, so the systemic velocity of Rup 46 is unknown. Star #2191 is a spectroscopic binary, and the orbit was determined.

Ruprecht 79 Ruprecht 79 was analysed by Mermilliod et al. (1987) because it contains the Cepheid CS Vel. Star #2 (Moffat & Vogt 1975, #141 in Topatkas 1981) is a binary. The systemic velocity confirms its membership of the cluster.

Trumpler 26 We observed #19, 105, 122 and 201 (Terzan & Bernard 1981) in Trumpler 26. #122 and 201 are members, and #201 is a binary with a new orbit.

4. Results from OHP observations

Among the 413 red giants observed, we found a total of 97 spectroscopic binaries; as many as possible were monitored to determine the orbital elements. Tables 6–8 present our orbital elements for 70 binaries in 31 open clusters with $\delta > -20°$. No orbits could be determined for the remaining 27 systems.

Again all systems are single-lined binaries with single the exception of NGC 6940-100, which is an SB2, although several systems must have mass ratios close to unity.

4.1. New orbital elements for 31 binaries

First orbital elements for 31 new spectroscopic binaries are presented in Table 6; the corresponding radial-velocity curves are shown in Figs. 3 and 4. Most new orbits have enough observations to characterise the radial-velocity curves completely, and most pertain to binaries in clusters which have not been discussed previously, mainly because they contain few red giants. As judged by their systemic velocities, a number of the red-giant binaries are in fact non-members, as discussed below.

4.2. Improved orbits for 24 binaries

Orbital elements for another 24 binaries have been published in earlier papers on CORAVEL data for red giants in northern clusters: IC 4725 & NGC 129: Mermilliod et al. (1987), IC 4756: Mermilliod & Mayor (1990), NGC 752: Mermilliod et al. (1998), NGC 2099: Mermilliod et al. (1996), NGC 2539, NGC 2632, NGC 6633 & NGC 6940: Mermilliod & Mayor (1989).

For many of these systems, additional observations have been obtained since those papers. In addition, the zero point of the radial velocities has been corrected (by 0.3−0.4 km s^{-1}; see above) to bring them onto the CORAVEL radial-velocity system of Udry et al. (1999). When no new measurements have been obtained since the first publication, we have recomputed the orbits with the corrected radial velocities. We do not show the radial-velocity curves again, because the changes are generally not visible on the plots.

Revised orbital elements for these systems are listed in Table 7, in the same format as Table 6. The changes are not large, but the errors are reduced.

4.3. Ten published orbits

A large number of CORAVEL observations were included in the determination of orbital elements of spectroscopic binaries in M67 (Mathieu et al. 1986) and NGC 129 (Gieren et al. 1994). The published results are reproduced here for these six stars. For four binaries, vB 41 (Griffin et al. 1985) and vB 71 (Torres et al. 1997) in the Hyades and # 926 and 1223 in NGC 6705 (Lee et al. 1989), we recomputed the orbital elements with CORAVEL observations, which extends the number of cycles covered. These new values are summarized in Table 8.

4.4. Comments on the individual objects

Many clusters in our observing program have not yet been discussed, because earlier papers focused on objects with large numbers of red giants ($N > 10$). These clusters are briefly discussed below, with references to the star numberings used. These references should be identical to those in the open-cluster data base WEBDA (`http://www.univie.ac.at/webda/`).

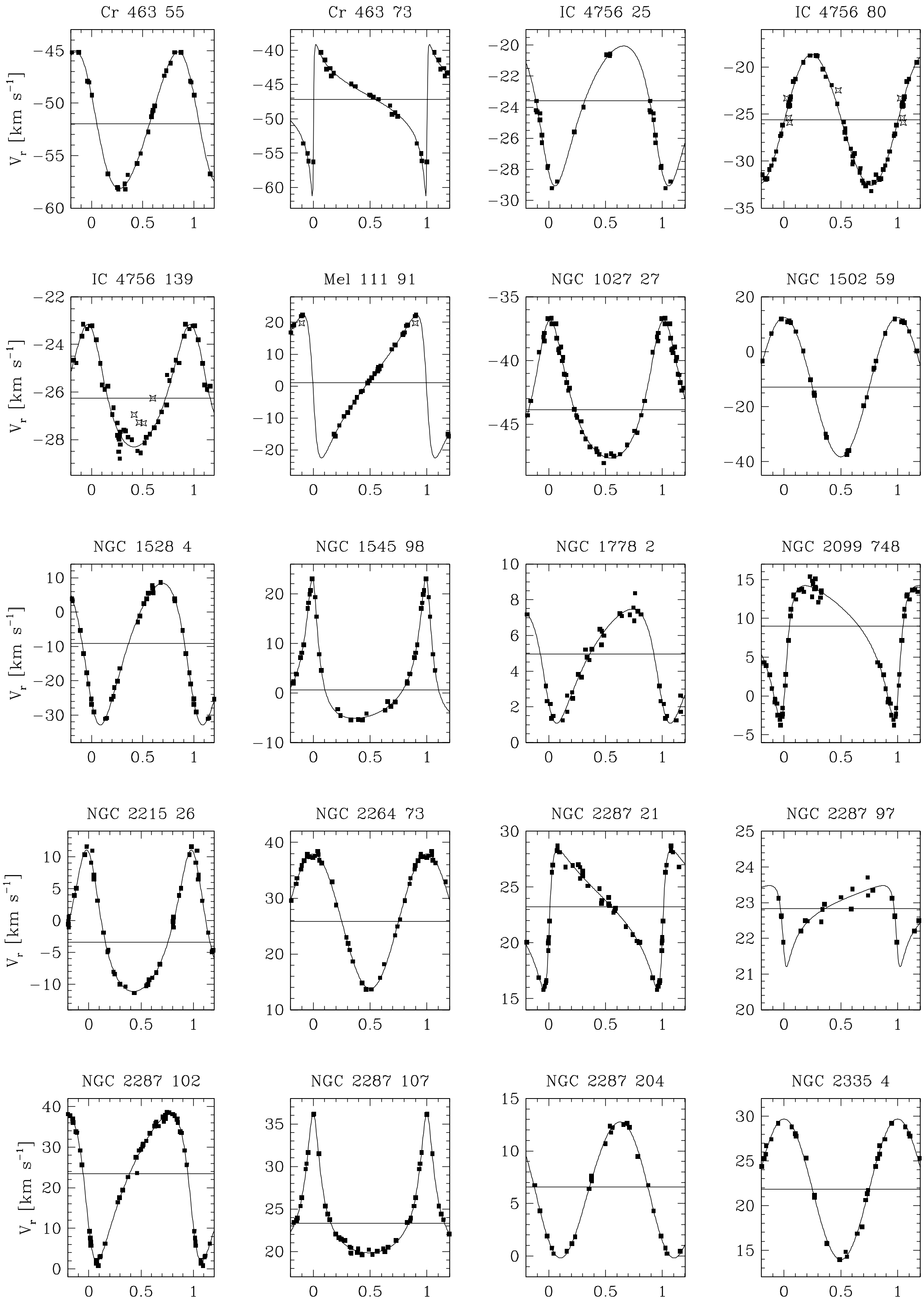

Fig. 3. Radial-velocity curve for the first 20 red-giant northern binaries.

Collinder 463 Both orbits are well defined with 21 and 20 observations respectively, and good phase coverage. Although the membership of the red giants in Cr 463 is uncertain, both #55 and 73 (Townsed 1975) are certainly non-members.

IC 4725 Since the first analysis of the red giants in the field of IC 4725 by Mermilliod et al. (1987), additional measurements have been obtained. They confirm the membership of the Cepheid U Sgr in the cluster and improve the orbital elements

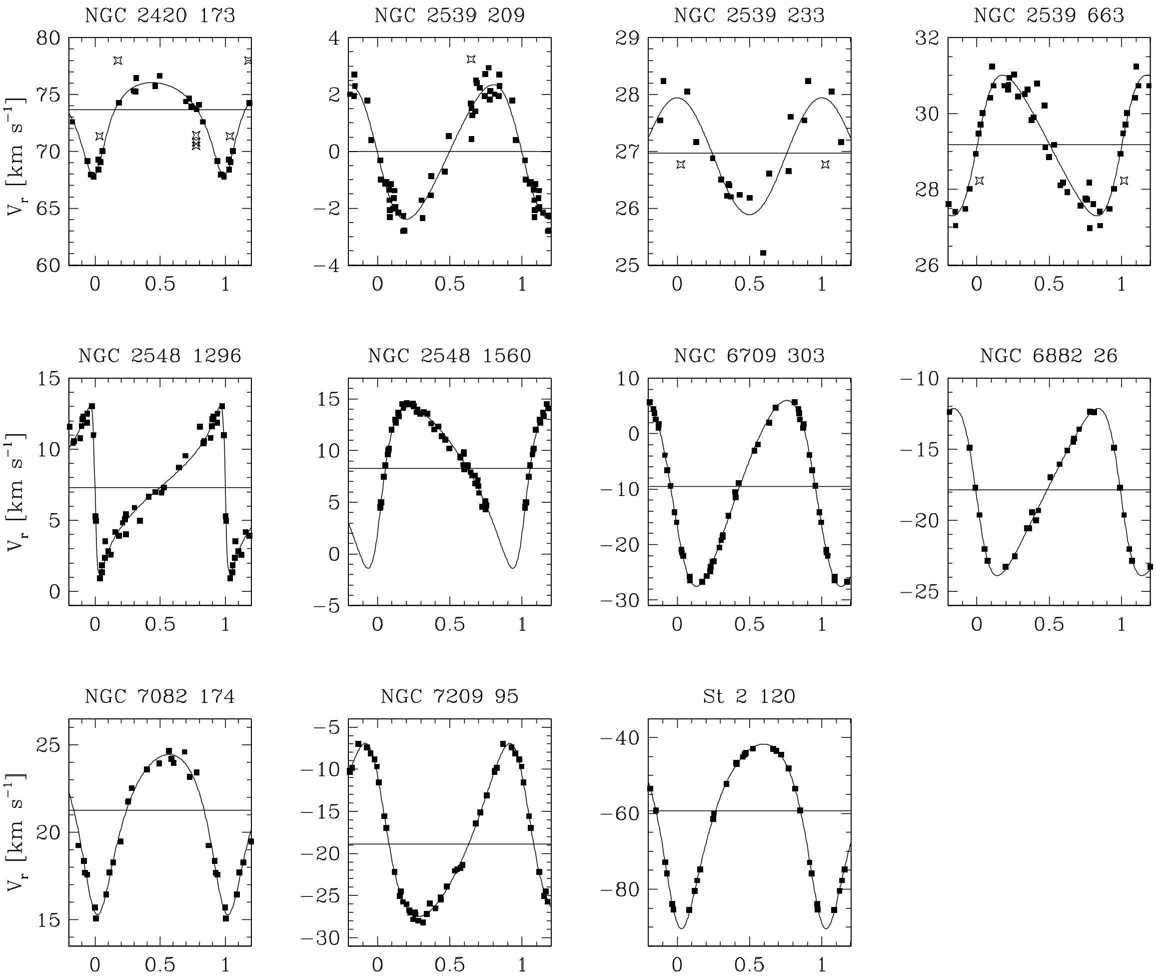

Fig. 4. Radial-velocity curve for the remaining 11 red-giant northern binaries.

of the spectroscopic binary #150 (Johnson 1960). The third red giant of the cluster, #251, has a constant radial velocity.

IC 4756 This cluster was discussed by Mermilliod & Mayor (1990), who discovered 3 spectroscopic binaries and determined an orbit for star #69 (Kopf 1943). The orbital parameters for stars #80 and 139 include both the new CORAVEL radial velocities and the observations obtained by Sperauskas (Table 2). Moreover, Sperauskas' data permitted us to compute an orbit for star #25, a newly detected binary. Although the systemic radial velocity is close to the cluster mean value, it is probably a non-member because of its position in the colour–magnitude diagram, nearly three magnitudes brighter than the clump.

The periods of star #80 and #139 are long, 15.8 yrs and 10.8 yrs respectively, but at least one cycle has been well covered. A few deviating points with residuals larger than 1.4 km s^{-1} (#80) and 1.0 km s^{-1} (#139) have been rejected from the orbit calculation and are indicated with open symbols.

Mel 111 The bright giant Tr 91 (Trumpler 1938) in Mel 111 (Coma Berenices) is a well-known spectroscopic binary, classified as G7 III + A2.5 IV by Ginestet & Carquillat (2002). An orbit was published by Vinter Hansen (1940) and Abt & Willmarth (1999). The orbital elements given in Table 6 are based on CORAVEL observations only, but confirm the previous results. The A-type star is not seen in the CORAVEL cross-correlation function.

NGC 129 Early CORAVEL data for NGC 129 (Mermilliod et al. 1987) showed that the Cepheid variable DL Cas and star #170 (Arp et al. 1959) were spectroscopic binaries, and a first orbit was determined for #170. An extensive observing program on DL Cas and star #170 was performed with several instruments and resulted in an orbit for both DL Cas and star #170 (Gieren et al. 1994). The published values are reproduced in Table 8.

NGC 752 A detailed analysis of radial-velocity data for NGC 752, spanning 18 years, was published by Mermilliod et al. (1998) who determined orbital elements for three binaries. The orbital elements in Table 7 include numerous CORAVEL and CfA observations. With 85, 53 and 89 observations for stars #75, 110 and 208 respectively, the orbits are very well determined. The observations obtained at CfA for H213 confirm the duplicity announced by Mermilliod et al. (1998), but the period is over 20 000 days, i.e. more than 50 yr, so only a fraction of the orbit has yet been covered.

NGC 1027 Among the 3 red giants observed in NGC 1027, star #27 (Hoag et al. 1961) is the only member. It is a binary with a long period, 15.4 yrs, but the orbit is well covered thanks to the 15 measurements obtained at CfA.

NGC 1502 Star #59 (Purgathofer 1964) is clearly a non-member of NGC 1502, which is too young to possess this type of red giant. With a period of 123^d, the circular orbit is expected (Mermilliod & Mayor 1992).

NGC 1528 Star #4 (Hoag et al. 1961) is the only spectroscopic binary among the 3 red-giant members (#4, 5, 32) in NGC 1528. With 28 observations, the orbital elements are well defined. The system is located well inside the Hertzsprung gap in the $(V, B-V)$ colour–magnitude diagram. The photometric separation gives $(V, B-V)_{gK}$ = (10.31, 1.28) and $(V, B-V)_{MS}$ = (11.49, 0.27). The photometric mass ratio is 0.80. By assuming a primary mass of 2.91 $M_\odot$ and with $f(m) = 0.907$, the only solution at $\sin i = 1$ gives M2 = 3.26 $M_\odot$ (minimum mass).

This suggests that the secondary is itself a binary, the mass of the third star being at least 0.88 $M_\odot$. Thus, it contributes to the mass, but not much to the total light of the secondary component. Star #5 is also within the Hertzsprung gap, although its colour is less blue; with $P(\chi^2) = 0.008$, it is a probable binary.

NGC 1545 #98 (HD 27395) is a red star in the field of NGC 1545, noticed at the telescope, but turned out to be a non-member; it is a spectroscopic binary. Stars #3, 4 (Hoag et al. 1961) are members and constant, while #26 is a non-member. Star #99 (HD 27276), is another red star noticed at the telescope, and is a radial-velocity member. NGC 1545 would therefore has 3 single red-giant members.

NGC 1778 Star #2 (Hoag et al. 1961) is the only red giant in the field of NGC 1778 and most probably a member, judged by its position in the colour–magnitude diagram. Its systemic velocity also agrees well with that of the main-sequence stars by Liu et al. (1988, 1989, 1991). The amplitude is small, but the orbit is well defined.

NGC 2099 Radial velocities of 55 red giants in NGC 2099 were analysed by Mermilliod et al. (1996). 16 spectroscopic binaries were discovered and 11 orbits determined, among which only 5 were found to be members. A period of $P = 261\overset{d}{.}3$ was determined for star #412 (von Zeipel & Lindgren 1921). With 21 observations, we find that two periods ($262\overset{d}{.}71$ and $910\overset{d}{.}2$) are possible and produce small O–C residuals, 0.41 and 0.27 km s^{-1} respectively. They are included in Table 7 under the entries 412a and 412b, but the longer period is preferred. A preliminary orbit has been obtained for star #748. Although the period is long ($P >$ 15 $000\overset{d}{.}$), the important phases of this eccentric orbit have been well covered, which allows to determine preliminary elements. The orbits for the six non-members have been updated.

NGC 2215 Star #26 (Becker et al. 1976) is the only red giant in the field of NGC 2215. Its position in the CM diagram is in agreement with its membership. The observed colours (V = 10.54, $B-V$ = 1.13) show clear evidence of the companion. A deconvolution with respect to Geneva isochrones for $\log t$ = 8.50 gives the following values $(V, B-V)_{gK}$ = (10.73, 1.41) and $(V, B-V)_{MS}$ = (12.53, 0.29) for the red-giant primary and the main-sequence secondary respectively, which corresponds to a mass ratio of 0.71. There are no radial-velocity data for main-sequence stars to compare with that of the red giant.

NGC 2632 The orbit for star KW 428 in Praesepe (NGC 2632) was first published by Mermilliod & Mayor (1989). Four additional observations were obtained to better cover the phases between 0 and 0.2. The period has been improved.

NGC 2264 The binary red giant #73 (Walker 1965) in NGC 2264 is not a member from the photometry, but the systemic velocity (25.8 km s^{-1}) does not rule out membership: According to Fürész et al. (2006), the cluster mean velocity is 22 km s^{-1}. However, #73 can be neither an evolved red giant nor a contracting star, so it is most probably a non-member.

NGC 2287 Six among the 8 red giants observed in the field of NGC 2287 proved to be spectroscopic binaries. Orbits have been determined for five of them: #21, 97, 102, 107 (Cox 1954) and 204, also named #224 in Harris et al. (1993). #204 is a non-member. Star #102 is located in the middle of the Hertzsprung gap, indicating that the components have similar V magnitudes. The photometric separation of the combined colours, $(V, B-V)$ = (7.31, 0.58), gives $(V, B-V)_{gK}$ = (7.80, 1.15), $(V, B-V)_{dB}$ = (8.42, −0.02), and a mass ratio of 0.92.

NGC 2335 Star #4 (Clariá 1975) is the only probable red-giant member among the four stars observed. It is a spectroscopic binary with a circular orbit although the period is 300^d, in agreement with the result of Mermilliod & Mayor (1996) that the cut-off period increases with mass.

NGC 2420 The CORAVEL data for red giants in NGC 2420, added to those by McClure & Woodsworth (1990), Smith & Stuntzeff (1987), Liu & Janes (1987) and Friel et al. (1989), permitted to compute a first orbit for the BaII red giant #173 (Cannon & Lloyd 1970), with a period of 1480^d. Five measurements with residuals larger than 2.3 km s^{-1}, mainly from Liu & Janes (1987), were rejected from the orbit computation. The orbital elements by McClure & Woodsworth (1990) for #250, the other BaII giant in NGC 2420, have been improved with our new observations. NGC 2420 was discussed in more detail by Mermilliod & Mayor (2007b).

NGC 2539 An analysis of 13 red giants in NGC 2539 was published by Mermilliod & Mayor (1989), who determined orbital elements for 3 spectroscopic binaries, #209 = P32, 223 = P38, 114 = P42, (numbers from Lapasset et al. 2000). The trend of the residuals showed that star #209 is in fact a triple system. Later observations at CfA permitted us to improve the orbital elements for the short-period system, #209a ($P = 242\overset{d}{.}27$) and compute a preliminary orbit for the wide system #209b ($P \sim 11\,655^d$ or ∼32 yr), shown in Fig. 4. First orbits have been determined for two other red giants (#233 = P44 and 663 = P21), considered as suspected binaries in the 1989 paper. Open symbols denote measurements rejected from the orbit computation.

NGC 2548 Orbital elements have been determined for two of the three red-giant binaries in NGC 2548, #1296 and 1560 (Li 1954). The period of #1560, close to 40 yr, is preliminary because a complete cycle has not been covered. The smallest residuals, σ(O–C) = 0.37 are found for orbital periods between 12 249 and 14 624 days; the corresponding systemic velocities vary from 9.45 to 8.25 km s^{-1}. We adopt γ = 8.25 km s^{-1}

because the cluster mean velocity is +7.7 km s^{-1}. The period of the third binary, #1260, is even longer ($P \sim 50$ yr).

NGC 6633 Observations of 8 red giants were analysed by Mermilliod & Mayor (1989), who determined an orbit for star #70 (Kopff 1943). Additional observations permitted to improve the parameters. As for NGC 1528-4, the minimum mass for the secondary star ($M_2 = 2.97\ M_\odot$) as deduced from the mass function ($f(m) = 0.807$) is larger than the estimated mass of the red giant ($M_1 = 2.71\ M_\odot$). The photometric separation gives masses of 2.71 and 2.10 $M_\odot$ for the red-giant primary ($V, B-V$) = (8.53, 1.07) and main-sequence secondary ($V, B-V$) = (9.76, 0.26), respectively. The primary again appears to be at least 0.9 $M_\odot$ more massive than a single star, suggesting that the system is in fact triple.

NGC 6709 Star #303 (Hakkila et al. 1983), one of the two red giants in the field of NGC 6709, is a binary and an orbit has been determined. Both red giants are members.

NGC 6882 Among the 11 stars observed in the field of NGC 6882, only one, #26 (Hoag et al. 1961), is a probable member. It is also a binary, and its orbit has been determined.

NGC 6940 Twenty red giants in the field of NGC 6940 were found to be members by Mermilliod & Mayor (1989). Six are spectroscopic binaries, and their orbits were computed. 3–7 new measurements have been obtained and the orbital elements improved. Star #100 (Vasilevskis & Rach 1957) is the only double-lined spectroscopic binary among the 413 northern red giants observed with CORAVEL. The secondary is not a red star, but most probably an Am star, as low rotation and numerous metallic lines are necessary to produce a good correlation.

NGC 7082 The 3 red giants observed in the field of NGC 7082, #163, 174, 197 (Hassan 1973), seem to be non-members. #174 is a spectroscopic binary. An orbit has been determined.

NGC 7209 Star #95 (Mävers 1940) is a spectroscopic binary and an orbit has been determined. The systemic velocity confirms its membership in NGC 7209. In the ($V, B-V$) diagram, #95 is displaced to the left of the isochrone by about 0.15 mag. Interpreting this as the effect of the MS companion, we computed $(V, B-V)_{\rm gK}$ = (10.5, 1.32) and $(V, B-V)_{\rm dA}$ = (12.76, 0.22) for the two stars from the combined photometry. The mass ratio is 0.63 (1.87/2.97 $M_\odot$).

Stock 2 Of the seven stars observed in the field of Stock 2, #11a, 17, 43, 82a, 109a, 120, 160 (Krzeminski & Serkowski 1967), four proved to be binaries (#17, 43, 82a, 120). We obtained an orbit for #120 (Krzeminski & Serkowski 1967), which is clearly a non-member, however.

5. Discussion

Among our 1309 cluster red giants (members and non-members), 289 are found to be spectroscopic binaries. Orbits have so far been determined for only 156 of these, showing that the number of orbits could be more than double if the velocities of the rest of the known variables were kept under precise, long-term monitoring. The binaries without orbits have long periods, mostly above 13 years, and their orbital eccentricities are likely high. Thus, we have not been able to obtain adequate coverage of the important phases within the assigned observing runs, especially in Chile.

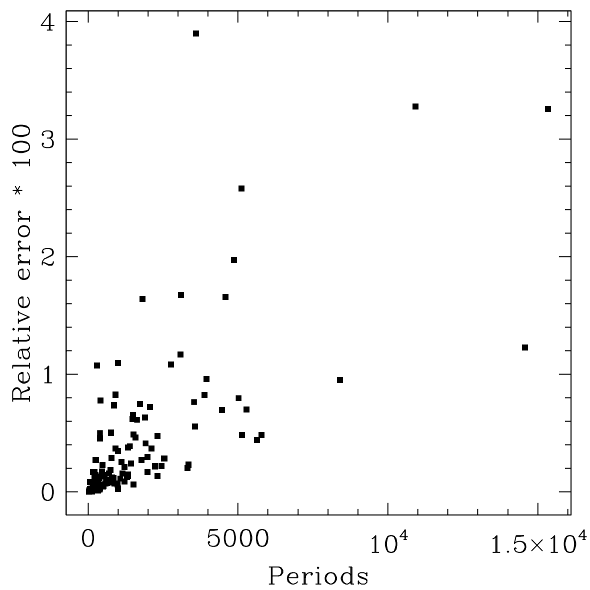

Fig. 5. Relation between the relative errors on the orbital period and the values of the period. The periods are in days.

The absolute error of a period depends on the number of cycles covered and is therefore larger for the long-period systems. However, the relative error of the period is below 1%, except for a few preliminary long-period orbits (Fig. 5).

The binary frequency varies from cluster to cluster: some clusters with 4 red-giant members have 3 binaries while other, similar clusters have none. Thus, the binary frequency may range from 0 to 100% (when a single red giant member is also a binary). However, the small numbers of red giants in the clusters studied do not allow firm conclusions on any variations in binary frequence among clusters.

Cluster binaries composed of a red-giant primary and an upper-main-sequence secondary can provide very useful independent distance determinations for open clusters if both spectroscopic and interferometric orbits can be obtained. Moreover, the chances of observing eclipses by these large stars may not be negligible. These techniques offer interesting prospects for determining physical parameters of the components and performing direct comparisons with evolutionary models.

6. Conclusion

This paper summarises our determination of orbital elements for a large sample of red-giant spectroscopic binaries in galactic open clusters, determined in a 20-year radial-velocity programme covering both hemispheres. This data set is the largest and most homogeneous ever presented in the field of open-cluster (giant) binaries.

New orbital elements are presented for 67 binaries and improved elements for 64 systems, while published elements for a further 25 binaries are summarised for completeness. The orbital periods range from 41.5 to 14 722 days (40 yr). Another 133 spectroscopic binaries have been discovered during the observations, but their periods are generally of the order of decades.

The properties of this sample of 156 binary systems, and the full data for the all-sky sample of 1309 (single and double) giants in 187 open clusters will be analysed in subsequent papers.

Acknowledgements. This project was made possible by large amounts of observing time and travel and other financial support from ESO, the Fonds National Suisse pour la Recherche Scientifique, the Danish Natural Science Research Council, and the Danish Board for Astronomical Research. It succeeded primarily thanks to the contributions of many colleagues, who patiently performed many observations and covered crucial orbital phases. We are grateful to Dr J. Sperauskas (Astronomical Observatory of Vilnius University, Lithuania), for contributing his observations of red giants in IC 4756. We are also grateful to Maxime Marmier (Geneva Observatory) for obtaining a radial velocity for star #44 in NGC 2360. Last, but not least, we thank Dr Stephane Udry, in charge of the CORAVEL database, for extracting the observations performed for this programme and for helping us to correct any problems in the database.

References

Abt, H. A., & Willmarth, D. W. 1999, ApJ, 521, 682
Arp, H. C. 1958, ApJ, 128, 166
Arp, H. C., Sandage, A., & Stephen, C. 1959, ApJ, 130, 80
Baranne, A., Mayor, M., & Poncet, J.-L. 1979, Vistas Astron., 23, 279
Baranne, A., Queloz, D., Mayor, M., et al. 1996, A&AS, 119, 373
Becker, W., Svolopoulos, S. N., & Fang, C. 1976, Astron. Inst. Univ. Basel (Katalogue)
Bozkurt, S. 1974, Rev. Mex. Astron. Astrofis., 1, 89
Cannon, R. D., & Lloyd, C. 1970, MNRAS, 150, 279
Carraro, G., & Patat, F. 1995, MNRAS, 276, 563
Clariá, J. J. 1975, A&AS, 9, 251
Clariá, J. J., & Lapasset, E. 1992, Acta Astron., 42, 343
Clariá, J. J., & Mermilliod, J.-C. 1992, A&A, 95, 429
Clariá, J. J., Piatti, A. E., Lapasset, E., & Mermilliod, J.-C. 2003, A&A, 399, 543
Clariá, J. J., Mermilliod, J.-C., Piatti, A. E., & Parisi, M. C. 2006, A&A, 453, 91
Cox, A. N. 1954, ApJ, 119, 188
Cuffey, J. 1938, Ann. Harv. Coll. Obs., 106, 39
Cuffey, J. 1941, ApJ, 94, 55
Eigenbrod, A., Mermilliod, J.-C., Clariá, J. J., Andersen, J., & Mayor, M. 2004, A&A, 423, 189
Fernandez, J. A., & Salgado, C. W. 1980, A&AS, 39, 11
Friel, E. D. 1995, ARA&A, 33, 381
Friel, E. D., Liu, T., & Janes, K. A. 1989, PASP, 101, 1105
Fűrész, G., Hartmann, L. W., Szentgyorgyi, H., et al. 2006, ApJ, 648, 1090
Gieren, W. P., Welch, D. L., Mermilliod, J.-C., Matthews, J. M., & Hertling, G. 1994, AJ, 107, 2093
Gim, M., Hesser, J. E., McClure, R. D., & Stetson, P. B. 1998, PASP, 110, 1172
Ginestet, N., & Carquillat, J. M. 2002, ApJS, 143, 513
Griffin, R. F., & Gunn, J. E. 1977, AJ, 82, 176
Griffin, R. F., Gunn, J. E., Zimmerman, B. A., & Griffin, R. E. M. 1985, AJ, 90, 609
Hakkila, J., Sanders, W. L., & Schroeder, R. 1983, A&AS, 51, 541
Hamdani, S., North, P., Mowlavi, N., Raboud, D., & Mermilliod, J.-C. 2000, A&A, 360, 509
Harris, G. L. H., FitzGerald, M. P. V., Mehta, S., & Reed, B. C. 1993, AJ, 106, 153
Hartwick, F. D. A., & Hesser, J. E. 1974, ApJ, 192, 391
Hassan, S. M. 1973, A&AS, 9, 273
Hoag, A. A., Johnson, H. L., Iriarte, B., et al. 1961, Pub. USNO XVII, part VII
Janes, K. A. 1981, AJ, 86, 1210
Johnson, H. L. 1960, ApJ, 131, 620
Kilambi, G. C., & Fitzgerald, M. P. 1983, Bull. Astr. Soc. India, 11, 226
Koelbloed, D. 1959, BAN, 14, 265
Kopff, E. 1943, AN, 274, 69
Krzeminski, W., & Serkowski, K. 1967, ApJ, 147, 988
Lapasset, E., Claria, J. J., & Mermilliod, J.-C. 2000, A&A, 361, 945
Latham, D. W. 1992, in Complementary Approaches to Binary and Multiple Star Research, ed. H. McAlister, & W. Hartkopf, IAU Coll. 135, ASPC, 32, 1000
Lee, C. W., Mathieu, R. D., & Latham, D. W. 1989, AJ, 97, 1710
Li, H. 1954, Ann. Obs. Astron. Zo-Se, 23, 1
Lindoff, U. 1968, Ark. Astr., 4, 587
Lindoff, U. 1972, A&AS, 7, 231
Lindoff, U., & Johansson, K. 1968, Ark. Astron., 5, 45
Liu, T., & Janes, K. A. 1987, PASP, 99, 1076
Liu, T., Janes, K. A., Bania, T. M., & Phelps, R. L. 1988, AJ, 95, 1122
Liu, T., Janes, K. A., & Bania, T. M. 1989, AJ, 98, 626
Liu, T., Janes, K. A., & Bania, T. M. 1991, AJ, 102, 1103
Lohmann, W. 1961, AN, 286, 105
Lyngå, G. 1959, Ark. Astr., 2, 379
Madore, B. F., & van den Bergh, S. 1975, ApJ, 197, 55
Mathieu, R. D., Latham, D. W., Griffin, R. F., & Gunn, J. E. 1986, AJ, 92, 1100
Mävers, F. W. 1940, AN, 270, 201
Mayor, M. 1985, in IAU Coll. 88, ed. A. G. D. Philip, & D. W. Latham, L. Davis Press (N.Y.: Schenectady), 35
McClure, R. D., & Woodsworth, A. W. 1990, ApJ, 352, 709
McSwain, M. V., & Gies, D. R. 2005, ApJS, 161, 118
Meibom, S. 2000, A&A, 361, 929
Meibom, S., Andersen, J., & Nordström, B. 2002, A&A, 386, 187
Mermilliod, J.-C., & Mayor, M. 1989, A&A, 219, 125
Mermilliod, J.-C., & Mayor, M. 1990, A&A, 237, 61
Mermilliod, J.-C., & Mayor, M. 1992, in Binaries as Tracers of Stellar Formation, ed. A. Duquennoy, & M. Mayor (Cambridge Univ. Press), 183
Mermilliod, J.-C., & Mayor, M. 1996, ASP Conf. Ser., 109, 373
Mermilliod, J.-C., & Mayor, M. 1999, A&A, 237, 61
Mermilliod, J.-C., & Mayor, M. 2007a, in prep.
Mermilliod, J.-C., & Mayor, M. 2007b, A&A, 470, 919
Mermilliod, J.-C., Mayor, M., & Burki, G. 1987, A&AS, 70, 389
Mermilliod, J.-C., Mayor, M., Andersen, J., et al. 1989, A&AS, 79, 11
Mermilliod, J.-C., Andersen, J., Nordström, B. & Mayor, M. 1995, A&A, 299, 53
Mermilliod, J.-C., Huestamendia, G., del Rio, G., & Mayor, M. 1996, A&A, 307, 80
Mermilliod, J.-C., Andersen, J., & Mayor, M. 1997a, A&A, 319, 481
Mermilliod, J.-C., Clariá, J. J., Andersen, J., & Mayor, M. 1997b, A&A, 324, 91
Mermilliod, J.-C., Mathieu, R. D., Latham, D. W., & Mayor, M. 1998, A&A, 339, 423
Mermilliod, J.-C., Clariá, J. J., Andersen, J., Piatti, A. E., & Mayor, M. 2001, A&A, 375, 30
Mermilliod, J.-C., Latham, D. W., Glushkova, E. V., et al. 2003, A&A, 399, 105
Moffat, A. F. J., & Vogt, N. 1975, A&AS, 20, 85
Nordström, B., Andersen, J., & Andersen, M. I. 1997, A&A, 322, 460
Piatti, E., & Clariá, J. J. 2001, A&A, 370, 931
Piatti, A. E., Clariá, J. J., Ahumada, A. V., et al. 2004, A&A, 418, 979
Purgathofer, A. 1964, Ann. Univ. Sternw. Wien, 26, 37
Rahim, M. A. 1966, AN, 289, 41
Smith, V. V., & Stuntzeff, N. B. 1987, AJ, 92, 359
Sperauskas, J. 2005, Priv. comm.
Stefanik, R. P., Latham, D. W., & Torres, G. 1999, in Precise Stellar Radial Velocities, IAU Coll. 170, ed. J. B. Hearnshaw, & C. D. Scarfe, ASP Conf. Ser., 185, 354
Terzan, A., & Bernard, A. 1981, A&AS, 46, 49
Topaktas, L. 1981, A&AS, 45, 111
Torres, G., Stefanik, R. P., & Latham, D. W. 1997, ApJ, 485, 167
Townsed, R. E. 1975, PASP, 87, 753
Trumpler, R. J. 1938, LOB, 18, 167
Udry, S., Mayor, M., & Queloz, D. 1999, in Precise Stellar Radial Velocities, ed. J. B. Hearnshaw, & C. D. Scarfe, IAU Coll. 170, ASP Conf. Ser., 185, 367
Upgren, A., Sperauskas, J., & Boyle, R. P. 2002, Baltic Astron., 11, 91
Vasilevskis, S., & Rach, R. A. 1957, AJ, 62, 175
VinterHansen, J. M. 1940, LOB, 19, 101
Vogt, N., & Moffat, A. F. J. 1973, A&AS, 9, 97
von Zeipel, H., & Lindgren, J. 1921, Kungl. Sven. Vet. Handl., 61, 15
Walker, M. F. 1956, ApJS, 2, 365