Astron. Astrophys. 248, 485–524 (1991)

ASTRONOMY
AND
ASTROPHYSICS

Multiplicity among solar-type stars in the solar neighbourhood★

II. Distribution of the orbital elements in an unbiased sample

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Received December 4, 1990; accepted January 30, 1991

Abstract. The results of a CORAVEL spectroscopic survey whose radial velocities have been published in Paper I are presented. 37 spectroscopic orbits are derived, of which 23 are for stars without previously known orbit or for stars with *e*-quality orbits in the recent catalogue of Batten, Fletcher and McCarthy.

The duplicity of solar-like stars in the solar neighbourhood is then reconsidered, using a complete subsample of 164 primaries in the spectral range F7 to G9 IV–V, V, VI taken from Gliese's catalogue. Within this subsample represented by about 4200 CORAVEL radial-velocity measurements obtained in almost 13 years with a precision better than 0.3 km s^{-1}, added to published data on visual binaries and common proper motion systems and allowing for detection biases, we derive significant new results on the present-day distribution of orbital elements and of mass-ratios;

i) The period distribution is unimodal and can be remarkably appoximated by a Gaussian-type relation with a median period of 180 yr.

ii) The tight binaries with $P < 11$ d are all circularized due to tidal effects occurring during their evolution on the main sequence. This result can be used as an age indicator of the galactic disk, which is found to be statistically in agreement with the current estimations. However, it is thought that such a clock is not presently reliable and that the agreement obtained here is merely due to chance.

iii) The tight binaries not affected by tidal effects ($11 \leq P \leq 1000$ d) may reflect the initial binary formation process and have an observed mean eccentricity of $\bar{e} = 0.31 \pm 0.04$.

iv) Less tight binaries ($P \geq 1000$ d) are probably subject to large scale dynamical interactions and have an eccentricity distribution, when corrected for detection biases, which tends roughly towards $f(e) = 2e$, expected if that distribution is a function of energy only (Ambartsumian).

v) The secondary-mass distribution shows no maximum toward values close to unity, but a continuous increase toward small secondary masses. In fact, this distribution is found remarkably similar to the mass-function found recently by Kroupa, Tout and Gilmore for low-mass field stars. It seems that binaries, on average, can be formed by random association of stars from the same IMF. Although this result may be surprising for binaries of shortest period, we think it premature to claim a difference in the observed mass-ratio distribution among nearby G-dwarf stars on one side or the other of any cut-off period.

vi) The proportion of very low mass secondaries with $M_2 = 0.01 - 0.10\,M_\odot$ for which we have no firm detection yet, may be estimated as $(8 \pm 6)\%$ of the primaries in our sample.

Such new distributions should be useful as constraints on stellar formation processes, keeping in mind that binaries are found in a proportion which varies from 65% to 100% at the middle of the MS, following the most recent studies. From the present one, only about one third of the G-dwarf primaries may be real single stars, i.e. having no companion above $0.01\,M_\odot$.

Besides, the recent and exciting search for brown dwarfs led us to investigate our CORAVEL radial velocity data base to produce a first sample of 11 spectroscopic binaries with probable very low mass secondaries ($M_{2_{\min}} < 0.10\,M_\odot$) extracted from velocity standards and dM stars samples. Including 8 astrometric candidates, we observe that the mean orbital eccentricity for $11 \leq P \leq 1000$ d is $\bar{e} = 0.34 \pm 0.07$. Our preliminary conclusion is that the binary formation process seems to be the same for stars and for brown dwarfs. This dominant process would be fragmentation, according to the most recent views on the subject. Conversely, giant planets seem to form only with very small eccentricities which would result from different processes. We can also estimate the proportion of very low mass secondaries among the IAU velocity standard sample to be about 10% which is in reasonable agreement with that found among the nearby G-dwarfs.

Key words: Galaxy (the): solar neighbourhood – radial velocities – stars: binaries: spectroscopic, visual binaries – stars: formation

1. Introduction

The importance of the studies of stellar duplicity has been reported by a number of authors in various domains, such as:

i) The constraints on possible scenarios of stellar formation, that can be derived from:

– the distribution of the orbital elements such as eccentricity *e*, orbital period *P*, mass ratio $q = M_2/M_1$, (Abt & Levy 1976; Halbwachs 1986, 1987a; Trimble 1987, 1990), and their possible dependence on the age of the systems;

– the correlation between orbital elements such as $(e, \log P)$, (q, P);

– the frequencies of singles: doubles: triples: quadruples sys-

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★ Based on photoelectric radial-velocity measurements collected at Haute-Provence and la Silla Observatories.

tems, and the hierarchy observed in the plane ($\log P_{\rm inner}/\log P_{\rm outer}$) in multiple systems (Abt & Levy 1976; Fekel 1981; Duquennoy & Mayor 1986).

ii) The constraints on the evolution and interaction of the binary components evidenced by:

– tidal circularization of short period binaries (Zahn 1977, 1989; Mayor & Mermilliod 1984);

– mass exchange between components in very close binaries filling their Roche lobe (Paczyński 1966; Webbink 1985);

– chromospheric activity in short period binaries (Young et al. 1987);

– peculiar surface element abundances: S, Ba, CH stars (McClure 1983; Jorissen & Mayor 1988; McClure & Woodsworth 1990).

iii) The constraints on the evolution of stellar systems such as:

– orbital elements distribution related to the evolution and disruption of small stellar systems (Van Albada 1968a,b; Harrington 1975; Anosova 1989);

– duplicity rate in globular clusters related to the collapse of the cluster core and to their dynamical evolution (see for example Spitzer 1987).

iv) The search for very low mass companions (Campbell et al. 1988; Latham et al. 1989; Marcy & Benitz 1989; Skrutskie et al. 1989). The most reliable estimation of their masses can only be derived from joint sets of visual and spectroscopic orbital elements, keeping in mind the difficulty of detecting hypothetical brown dwarfs or giant planets.

v) The improvement of the knowledge of the stellar mass-luminosity relation, which may be not unique (Gilmore & Roberts 1988).

vi) The history of star formation in the Galaxy through the study of samples of various ages.

vii) The constraints on heavy stellar remnants in the Galaxy, using the stability of binaries with extremely long orbital periods (Bahcall et al. 1985).

The present study is intended to be an up-to-date version of the paper by Abt & Levy (1976, hereafter AL) on the stellar duplicity, in the solar neighbourhood. Like those authors we shall deal with a specific part of the main sequence, the solar-type stars. Sect. 2 of this paper summarizes the results of a few recent analyses of stellar duplicity, starting with that of AL. The results presented in the following sections are essentially based on a long term spectroscopic survey performed with the spectrometer CORAVEL, whose radial velocities have been listed by Duquennoy et al. (1991, hereafter Paper I). Section 3 defines the unbiased sample on which is based our study. The results of our spectroscopic survey (new spectroscopic orbits and tables of orbital elements obtained with CORAVEL) are presented in Sect. 4, and the compilation of observational data is summarized in Sect. 5. A study of incompleteness is made in Sect. 6, and the corrected distributions of orbital elements are presented in Sect. 7. The case of the very low mass companions is treated and discussed in Sect. 8 and several concluding remarks can be found in Sect. 9.

2. Some recent observational analyses of stellar duplicity

The distributions of orbital elements of solar-type spectroscopic binaries have only been systematically investigated for slightly more than a decade. But major discrepancies still exist today among these different studies. The theory of star formation is advancing, and perhaps is about to be able to use the distribution functions of orbital elements as constraints (Boss 1987, 1988; Pringle 1989; Clarke & Pringle 1991). So before presenting the results of our survey, we wish to recall some of the most important recent steps. For an interesting review on binary statistics, see e.g. Zinnecker (1984). We will restrict ourselves here to the following comments:

Abt & Levy (AL 1976) studied the stellar multiplicity in a sample of 135 F3–G2 IV or V bright field stars ($m_v \leq 5.5$). They obtained 20 radial-velocity measurements per star, with a mean precision of 1.3 km s^{-1} and a mean timespan of 1800 days. The study of AL was certainly the most systematic effort to obtain a comprehensive view of the duplicity among solar-like stars. Their main results are:

i) The observed frequencies of singles: doubles: triples: quadruples are 42:46:9:2.

ii) The period distribution has a single maximum, with a median period of 14 years.

iii) The secondary masses distribution depends on the orbital period: for $P > 100$ yr it fits the van Rhijn distribution, while for $P < 100$ yr it varies as $M_2^{1/3}$. They conclude on the existence of two binary formation processes: fragmentation for the former (gravitationally bound pair of protostars that contracted separately), fission for the latter (one single protostar subdivided because of excessive angular momentum).

iv) there are really 1.4 companions for each primary star, and the total mass in the companions is just half of the total mass in the primaries.

However, Branch (1976) has pointed out that the sample of AL was selected in magnitude, introducing a bias already noted by Öpik (1924) which favours the inclusion of SB2s having generally large mass ratios. Branch concluded that AL's conclusion that all stars have short period fission companions is plausible but is not well established.

Moreover, Morbey & Griffin (1987, hereafter MG) discussed the 25 new spectroscopic orbits derived by AL. They find that 24 are not supported by a statistical analysis applied to the same original data, and that in at least 21 cases the evidence does not show that the stars are binaries at all. As a result, these binaries are not present in the most recent version of the spectroscopic binaries catalogue of Batten et al. (1989). It is to be noted that these 24 (probably erroneous) SBs represent about 59% of the SBs with $P < 10$ yr in AL's sample, and this implies that the inferred multiplicity among G-dwarf stars probably has been overestimated. Abt (1987) replied to this objection by re-analysing the data after suppression of the spurious binaries and by re-evaluating the criteria of incompleteness. He found that the number of undected binaries then increases in such a way that the conclusions on the multiplicity frequencies and on the two forms of the secondary mass-function remain the same as in the original paper.

Trimble studied the mass-ratio distribution $q = M_2/M_1$ among binaries contained in catalogues. Among the spectroscopic binaries (Trimble 1974, 1978), she found a bimodal distribution of q, with a peak near $q = 0.25$ and another of nearly equal size near $q = 0.95$. This result has been interpreted as follows (Abt & Levy 1978; Trimble 1978): the $q \simeq 0.3$ peak would be attributed to a combination of close systems that underwent mass-transfer and of wide systems that are random members of the same IMF, while the $q \simeq 1$ peak would be attributed to unevolved close systems formed by fragmentation of a single rotating cloud. For the visual and CPM binaries also taken from catalogues, Trimble (1986) found a mass-ratio distribution that peaks strongly toward $q = 1$.

However these results both on SBs and VBs are unfortunately strongly biased by selection and evolutionary effects, as stated by Scarfe (1986). For the SBs, Scarfe (1986) suggests that the double-lined binaries (SB2s) in the sample of Trimble may be over-represented by a factor of about 10 compared with their true frequency in space. He suggests in counterpart that the real distribution of q increases monotonically as q approaches zero, as estimated by him from CORAVEL data on southern bright stars published by Andersen et al. (1985). Trimble herself (1987, 1990) made a new study taking into account the selection effects: among the catalogued VB and CPM, she (Trimble 1987) finds that only the CPM pairs could have come from a power law distribution rising toward small q, while the distribution for the VBs is, at best, flat in q. For the SBs (this time taken among Griffin's binary systems) she (Trimble 1990) finds that the best fit for the q-distribution is a power law near q^{-1} over the range $q = 0.1 - 1.0$. The principal conclusion of her latest paper is that the differences between the various results arise more from the selection of the systems than from the methods of analysis, a conclusion that we entirely share here.

The mass-ratio distribution has also been recently studied by Halbwachs (1986, 1987a), also using the SB and VB published in the same kind of catalogues as those used by Trimble. In his studies the numerous selection, detection and evolutionary biases affecting these catalogues have been very carefully taken into account. His main resuts are:

i) There is no maximum in the mass ratio distribution for $q = 1$, but a possible maximum around $q = 0.3$. This result is in agreement with that of Scarfe (1986).

ii) There is no difference in this distribution between long and short period binaries, while AL found a dividing period of 100 yr.

The variety of results found in these studies illustrates the difficulty in dealing with the numerous and huge observational biases contained in the catalogues and compilations. It also illustrates the uncertainties that still exist in the mass-ratio distribution which is produced during the star formation processes.

3. Definition of the complete sample

A study of multiplicity should be based on a sample as far as possible free of any observational bias. Branch (1976) and Halbwachs (1987b) pointed out that the sample of AL was based on a magnitude-limited sample, thus favouring the inclusion of SB2 binaries. We have chosen to select a distance-limited sample in order to avoid, at least partly, this kind of bias. From the 291 stars whose velocities have been listed in Paper I, which may constitute the extended sample', the so-called 'nearby G-dwarf star complete sample' has been extracted in order to study the duplicity of nearby solar-type stars. This complete sample is defined by all primary stars in the Gliese (1969) catalogue with spectral types F7 to G9, luminosity classes IV–V, V, VI, declination above $-15°$, and trigonometric parallax greater than 0.045 arcsec (or distance $r \leq 22$ pc). 164 primaries fit the definition, plus 30 CPM secondaries of which only 17 were independently measurable with CORAVEL. A total of 4206 CORAVEL radial velocities has been obtained for the 181 stars, 91% of them with the northern CORAVEL. About 30% of the measurements are of 10 IAU velocity standard stars.

Let us comment on the limits and on the advantages of our sample:

i) The limiting declination is imposed by the location of the Haute-Provence Observatory (at northern latitude +43°). Although some bright stars can be observed down to $\delta = -32°$, the completeness of the extended sample is 100% of Gliese's catalogue at $\delta = -15°$, 75% at $\delta = -20°$, and only 50% at $\delta = -25°$.

ii) It is parallax-limited, instead of magnitude-limited in the case of AL's study of bright field stars. Moreover, the choice of π_{trig} as the relevant parallax is justified as follows: both spectroscopic and photometric parallaxes may introduce a bias toward SB2s, somewhat the same as selecting by magnitude, and in all period ranges smaller than 10 yr: an SB2 with $\Delta m_v = 0$ at the edge of the sample (with $\pi_{\mathrm{phot}} = 0''.045$) is actually $\sqrt{2}$ times further away, having a real parallax of 0''.032 (see the case of HD 13612, rejected from the complete sample on this basis). The trigonometric parallax may also be biased, but probably only in the restricted range of the SB1s with $P \simeq 1$ yr. An examination of the number of binaries in two equal volumes around the limiting parallax shows a great bias if we use the former (photometric) parallaxes, while the bias is not detectable (although it remains possible) if we use the latter (trigonometric) parallax. In particular, the star HD 20727 has been also rejected from the complete sample on this basis.

Several stars having only π_{phot} or π_{spec} determinations but greater than the limit were included in the complete sample because they are classified single and thus are not affected by such biases. Then we plotted the number of stars (N) having a given parallax π. If we assume that the density of stars is constant in the solar neighbourhood, we must have $\log N \propto -3 \log \pi$. This is actually observed down to $\pi = 0''.045$ with a correlation coefficient of 0.998, which confirms the conclusion of Upgren & Armandroff (1981) that the detection of G-type stars in Gliese's catalogue is complete up to 22 pc from the Sun.

iii) The limiting spectral-type toward early-types is imposed by the presence of large rotators and by the decrease in the number of observable metallic lines, which both decrease the precision of the radial velocity determination with CORAVEL. In fact we had to eliminate the 'blue' stars down to the spectral type F6V, because they produced too many marginally velocity-variable cases (see also Sect. 5.2 for a discussion). This limited spectral range allows us to eliminate as far as possible the various causes of velocity variations other than center-of-mass motion: noise due to rotational broadening, pulsation (δ Scuti type), and spots. The only star in our sample to show evidence for star spots is the known RS CVn binary HD 21242. The spectral types of our stars were taken from the Gliese (1969) catalogue. Since then, several stars have received other spectral classifications from various sources. An inspection of the SIMBAD database (Centre de Donnees Stellaires, Strasbourg) indicates that fewer than 15% of the stars of the complete sample are affected by these changes. We believe these fluctuations of spectral types should, as a mean, have negligible effects.

iv) The large time coverage of the observations (up to $\Delta T \simeq 13$ yr). This is a necessary step to overlap the orbital periods of binaries detected by various techniques (spectroscopy, astrometry, interferometry, speckle and visual). The mean timespan of the observations in our complete sample is 3125 ± 1060 (s.e.) days and is 1800 ± 450 days in AL. A histogramme of the timespans is given in Paper I.

v) The sample belongs to one of the most studied catalogues of stars (Gliese 1969), so that spectral types, photometry, kinematics, activity, age, and as complete as possible inventory of visual and common proper motion pairs are all known.

vi) The high precision of the derived velocities ($\varepsilon \leq 0.3\,\mathrm{km\,s^{-1}}$) and the extremely well defined determination of the error on each individual measurement allows a reliable statistical detection of radial-velocity variables (see the definition of $P(\chi^2)$ in paper I), among solar-type stars. This is to be compared with the mean uncertainty of $1.2\,\mathrm{km\,s^{-1}}$ for the data of AL 15 years ago. We acknowledge the formidable work of data acquisition and reduction done by AL; we recall that CORAVEL uses simultaneously about 1500 lines to derive the radial velocities and that the reduction work is much simplified thanks to the cross-correlation technique. The instrumental stability of CORAVEL appears also greater by a factor of 4 to 6, if we compare the time-dependent corrections used for each spectrometer.

vii) The mean number of measures for each constant-velocity star is smaller in our study than in AL's (11 instead of 20), but the mean measuring error is only one fourth as big. All the observational effects (instrumental errors, timespan, number of measures) will be simulated in Sect. 6 in order to estimate the number of undetected binaries.

viii) The ability of CORAVEL to detect small amplitude SB2s through the variation of the shape of the cross-correlation function (see the example of HD 137107 in Paper I). This may be a useful feature for a direct estimation of the mass-ratios in binaries, without using spectral types.

4. Results of the spectroscopic survey

4.1. *Means, dispersions and multiplicity status*

Table 1 presents the velocity means and dispersions for all stars in the extended sample. The table is based only on CORAVEL radial velocities, as presented in paper I. An asterisk in the first column indicates the stars that do not satisfy the complete sample definition fo Sect. 3 and which are thus rejected from the duplicity analysis. The spectral types are taken from Gliese's catalogue. The parallaxes are as follows:

no specification: available trigonometric parallax from Gliese (1969)

1: other than trigonometric (i.e. photometric or/and spectroscopic) parallax from Gliese (1969)

2: absolute parallax from Heintz (1986)

3: absolute parallax from McAlister (1978)

4: parallax from model by Duquennoy & Mayor (1988)

The variability status is based only on the CORAVEL survey and is coded as follow:

C: constant velocity

SB(1, 2, 0): spectroscopic binary (single-lined, double-lined, with orbit)

LWSB: line-width spectroscopic binary

VAR: variable velocity from uncertain origin and probably not due to binarity.

?: uncertain

Additional information on duplicity is given in the notes (see Sect. 4.3).

4.2. *Velocity curves and orbital elements*

Table 2 and Fig. 1 give the new orbital elements and velocity curves that were derivable for the spectroscopic binaries contained in the whole extended sample. Table 2 contains in addition the remaining SBs with orbits belonging to the complete sample but which are already published elsewhere (star names with a numerical prefix in parentheses). The star names with asterisks have been rejected from the complete sample, as not satisfying the sample definition (see Sect. 3). Figure 1 presents the orbits of 37 SBs based mainly on the velocities from our survey. They include 12 visual or astrometric binaries for which the observed velocity variations are assumed to coincide with the visual motion and therefore to have the same orbital period. The 37 orbits presented here may be classified as follow:

– 6 are first orbits: HD 13612, 20727, 89707, 114260, 134323, 144287.

– 2 are revised orbits, i.e with significantly improved elements for d-quality orbits in the catalogue of Batten (1989): HD 101177 B, 219834.

– 17 are preliminary orbits, i.e. for stars without orbit or with e-quality orbits in the catalogue of Batten (1989), and with still uncertain elements with CORAVEL: HD 3196 AB, 3443 AB, 6582 AB, 10307, 39587, 81997 A, 110010, 129333, 130819, 137107 AB, 158614 AB, 160269 A, 164765 A, 176051 A, 189340 AB, 191854 AB, 224930 A.

– 12 are additional orbits, for stars with known orbits, i.e. with quality c or better in the catalogue of Batten (1989), for which an independent CORAVEL orbit is available: HD 3196 Aa, 4676, 16739, 21242, 64606, 72945 Aa, 122742, 144284, 146361, 149414, 170153, 178428.

For incompletely covered spectroscopic orbits, we fixed one or more orbital elements (P, T, e, ω) to a probable value: the one obtained for the visual or astrometric orbit when available, or an arbitrary but reasonable one in the other cases. For the SB2 cases with spectral lines always blended during the timespan of our observations (called "line-width binaries", after Griffin 1985), meaning with CORAVEL a velocity difference between the two components less than approximately $12\,\mathrm{km\,s^{-1}}$, we used the method described in Paper I to derive the individual velocities on which are based the orbital elements. For some cases, it was possible to use early radial velocities from sources listed in the Bibliography of Stellar Radial Velocities (Abt & Biggs 1972). For other cases, we preferred not to use them because of problems relating different velocity systems, and velocity dispersions too large for the small amplitudes encountered in our study.

4.3. *Notes on peculiar stars*

These notes primarily concern the stars belonging to the complete sample. Several stars out of this sample are also listed in connection with their parallaxes or aspects of their duplicity found in CORAVEL.

Notes:

*, or **: companion not quoted in Gliese (1969) or Woolley (1970) catalogues.

Gl: Gliese (1969).

W: Wooley et al. (1970).

WH: Worley & Heintz (1974).

AL: Abt & Levy (1976).

NLTT: NLTT catalogue (Luyten 1979a,b, 1980a,b).

BS: Bright Star Catalogue (Hoffleit & Jaschek 1982).

SBS: Supplement to Bright Star Catalogue (Hoffleit et al. 1983).

MG: Morbey & Griffin (1987).

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Table 1. Results of the spectroscopic survey. π is the parallax from various sources (see text), RV is the mean radial velocity, ε and σ are the uncertainty on the mean and the velocity dispersion (rms) respectively. E/T is the ratio of external to internal errors, $P(\chi^2)$ is the probability that the velocity of the stars is constant, N is the number of CORAVEL measurements and ΔT the timespan of the observations. The last column is the radial velocity status and does not indicate the VB and CPM systems: more information is given in the *Notes*

	Gl	HD	Sp	π "	RV *km/s*	ϵ *km/s*	σ *km/s*	E/T	$P(\chi^2)$	N	ΔT *days*	Spec. status
	4.1 AB	123	dG4	0.045	-12:	-	-	-	-	0	0	-
*	6	400	dF5	0.047	-15.20	0.11	0.32	1.07	0.339	8	1769	C
	16.1	1461	G5IV-V	0.052	-10.44	0.08	0.26	1.14	0.252	10	3377	C
	17.3	1835	G2V	0.049	-2.56	0.06	0.27	1.24	0.087	19	2645	C
	23 A	3196	F8V	0.063	13.61	4.01	27.18	22.37	0.000	46	3733	SB1O
	23 B			0.063	5.00	0.75	5.07	15.72	0.000	46	3733	SBO
*	25 A	3443	G5V	0.074	13.58	0.18	0.72	2.33	0.014	16	4461	LWSB
*	25 B			0.074	25.04	0.22	0.89	3.73	0.000	16	4461	
	34 A	4614	G0V	0.170	8.25	0.05	0.25	1.07	0.368	29	4475	C
	34 B	4614	M0V	0.170	10.46	0.08	0.34	1.18	0.160	18	4406	C
	34.1a	4676	F8V	0.046	14.91	5.99	35.41	85.44	0.000	35	117	SB2O
	34.1b			0.046	-0.94	6.52	38.56	110.00	0.000	35	117	
	37	4813	F8V	0.064	8.16	0.13	0.45	1.83	0.000	12	3296	SB?
	41	5015	F8V	0.064	20.82	0.05	0.22	0.89	0.752	21	3988	C
	42.1	5294	G5	0.049	-8.56	0.08	0.30	1.13	0.238	13	3376	C
	46.1	5857	G5	0.050	-36.67	0.13	0.47	1.84	0.000	13	3376	SB?
	53 AB	6582	G5VI	0.130	-98.74	0.31	1.48	5.82	0.000	23	4379	SB1O
	53.4	6920	F8V	^{1}0.050	-14.17	0.09	0.23	0.72	0.916	14	2899	C
*	54.2B	7438	F5V	0.051	21.20	0.16	0.38	1.22	0.229	6	1891	C
*	54.2A	7439	K1V	0.051	22.12	0.14	0.36	1.31	0.122	7	1891	C
*	59.1	9407	G6V	0.038	-33.43	0.10	0.23	0.82	0.693	8	2244	C
	59.2	9562	dG2	^{1}0.068	-15.27	0.10	0.32	1.16	0.205	10	2206	C
	61	9826	F8V	0.062	-28.70	0.10	0.36	1.29	0.065	14	3391	C
	65.1	10086	dG4	^{1}0.051	1.90	0.12	0.39	1.40	0.039	10	2246	C
	67	10307	G2V	0.087	3.33	0.33	1.40	5.71	0.000	18	3945	SB1O
	72	10697	dG4	^{1}0.061	-46.44	0.10	0.36	1.33	0.047	13	2243	C
*	71	10700	G8Vp	0.277	-17.00	0.11	0.24	0.85	0.647	7	2468	C
	81.1A	11964	G5	0.050	-9.94	0.08	0.24	1.03	0.410	8	3659	C
	81.1B		M	0.050	-9.00	0.31	0.33	0.53	0.852	4	1040	C
	82.1	12051	dG7	^{1}0.048	-35.47	0.09	0.28	1.00	0.432	10	2246	C
*	83.2	12235	dG1	0.037	-18.47	0.10	0.35	1.24	0.120	11	2590	C
*	87.1Aa	13612	dF9	0.045	-6.32	2.19	12.57	33.11	0.000	33	2228	SB2O
*	87.1Ab			0.045	-5.18	2.74	15.73	31.92	0.000	33	2228	
*	87.1B		dG4	0.045	-5.57	0.10	0.31	1.02	0.412	10	2228	C
	92a	13974	G0Ve	0.097	1.04	1.21	3.44	8.18	0.000	14	3062	SB2O
	92b			0.097	-6.59	1.02	2.88	4.08	0.000	14	3062	
*	99.1	15335	dG0	^{2}0.031	41.01	0.09	0.28	1.00	0.440	10	2242	C
	105.4A	16620	F8V	0.069	14.64	1.21	5.15	9.37	0.000	18	3674	LWSB
	105.4B			0.069	16.83	1.86	7.89	13.15	0.000	18	3674	
	105.6a	16739	F9V	^{3}0.046	-25.36	4.32	15.58	46.19	0.000	13	1288	SB2O
	105.6b			^{3}0.046	-19.48	4.84	17.43	47.11	0.000	13	1288	
	107 A	16895	F7V	0.079	24.40	0.10	0.29	0.89	0.682	11	4456	C
	107 B		dM2e	0.079	25.12	0.18	0.46	0.87	0.634	8	2249	C
	113.1	17433	G9e	0.047	-5.91	3.62	20.45	78.08	0.000	32	3189	SB1O
*	120.1C	18445	G5	^{1}0.050	49.61	0.19	0.68	2.70	0.000	13	2604	SB1
*	120.1AB	18455	G5	^{1}0.050	50.63	0.09	0.26	1.05	0.413	9	2604	C
	120.2	18803	dG6	^{1}0.055	9.65	0.09	0.29	1.06	0.349	10	2240	C
	121.2	19034	dG5	0.046	-20.59	0.11	0.27	0.84	0.666	8	2243	C
	124	19373	G4V	0.086	49.51	0.11	0.26	0.85	0.669	7	4138	C
	128 AB	19994	F8V	0.049	19.24	0.20	0.61	2.10	0.000	9	1924	SB?
	135	20619	dG2	0.065	22.52	0.10	0.22	0.76	0.777	8	2248	C
	137	20630	G5Ve	0.107	18.88	0.11	0.36	1.59	0.005	11	3740	SB?
*	138.1AB	20727	dG2	0.049	7.30	1.36	5.26	14.50	0.000	15	1628	SB1O
*	141.1a	21242	dG5e	^{1}0.050	33.39	8.59	50.10	125.75	0.000	34	4132	SB2O

(continued)

Table 1 (continued)

	Gl	HD	Sp	π "	RV km/s	ϵ km/s	σ km/s	E/T	$P(\chi^2)$	N	ΔT days	Spec. status
*	141.1b			^{1}0.050	43.66	9.72	42.36	21.68	0.000	19	4126	
	147	22484	F8V	0.061	27.88	0.02	0.27	1.26	0.000	220	4382	SB?
	147.1	22879	F9V	0.047	120.31	0.05	0.31	0.99	0.553	41	4460	C
*	159	25457	F6V	0.055	17.67	0.16	0.66	1.24	0.085	17	1599	VAR?
	160	25680	dG1	0.069	23.87	0.10	0.29	1.23	0.162	9	4047	C
	160.1AB	25893	dK2	0.037	26.72	0.12	0.40	1.46	0.018	12	4039	C
*	161.1	25998	dF7	0.037	26.16	0.25	0.66	1.26	0.148	7	2209	C
*	168.3AB	27710	dF2	0.055	21.56	2.02	2.11	0.52	0.859	4	1440	C
*	168.3C			0.055	24.89	0.23	0.29	0.51	0.938	6	1440	C
	172.1	29203	G8V	^{1}0.053	-1.86	0.08	0.34	1.30	0.050	17	4422	C
*	177	30495	dG1	0.077	21.68	0.15	0.40	1.40	0.069	7	2261	C
*	177.1	30562	G0V	0.037	77.14	0.11	0.16	0.58	0.892	6	1916	C
*	178	30652	F6V	0.130	24.52	0.16	0.44	0.92	0.579	9	2871	C
	182.1	31966	G5V	^{1}0.048	-18.27	0.09	0.22	0.78	0.798	10	2248	C
*	187.2A	32537	F0V	0.049	0.62	1.39	2.41	4.00	0.000	3	2997	SB1O
	188 AB	32923	G4V	0.059	20.37	0.08	0.31	1.28	0.063	17	4412	C
	189.1	33093	dF9	^{1}0.049	53.16	0.13	0.34	1.18	0.210	7	1918	C
*	189.2	33256	F5V	0.048	10.38	0.29	0.64	1.98	0.004	5	2163	SB?
*	196	33564	F6V	0.053	-10.70	0.14	0.21	0.58	0.918	7	1923	C
*	194 A	34029	G5IIIe	0.075	22.16	5.21	16.46	56.18	0.000	10	1485	SB2O
*	194 B		G0III	0.075	33.93	5.77	16.32	9.27	0.000	8	1237	
	197	34411	G0V	0.067	66.50	0.07	0.29	1.11	0.315	16	4410	C
*	198	34721	dG0	0.064	40.34	0.08	0.35	1.17	0.155	18	4098	C
	201	35171	dK5e	0.063	37.92	0.11	0.29	0.97	0.477	8	1957	C
	202	35296	F8Ve	0.063	38.09	0.17	0.20	0.44	0.981	7	3989	C
	209	37124	G4IV-V	0.055	-23.20	0.12	0.34	1.15	0.245	8	1879	C
*	214	37986	G5	0.080	59.03	0.12	0.31	1.04	0.374	7	2864	C
	222	39587	G0V	0.101	-13.86	0.47	1.76	6.30	0.000	14	3539	SB1
	224	39881	G0V	0.047	0.09	0.08	0.23	0.83	0.763	13	2242	C
*	225	40136	F0V	0.065	-1.41	0.19	0.39	0.74	0.803	8	2682	C
	226.3	41330	dG0	0.046	-15.52	0.12	0.35	1.39	0.055	9	3540	C
	230	42807	G6V	0.057	5.99	0.12	0.43	1.76	0.000	13	3291	SB?
	231.1A	43587	dG0	0.050	9.61	0.14	0.36	1.39	0.079	7	1957	C
	231.1B			0.050	8.93	2.33	-	-	-	1	0	-
	240.1	46588	F8V	0.047	15.72	0.24	0.59	2.05	0.001	6	2087	SB?
	245	48682	G0V	0.068	-23.94	0.10	0.11	0.42	0.983	7	3568	C
	252	50692	dG0	^{1}0.052	-15.10	0.11	0.33	1.18	0.195	9	2178	C
	262	52711	G4V	0.058	24.53	0.09	0.08	0.33	0.999	9	3568	C
*	274 AB	58946	F0V	0.053	3.14	6.18	8.74	5.18	0.000	2	207	SB?
*	280 AB	61421	F5IV-V	0.285	-4.02	0.22	0.55	2.01	0.001	6	3513	SB1O
	285.1a	61994	dG5	0.045	-22.88	1.74	6.96	25.12	0.000	16	2566	SB2O
	285.1b			0.045	-21.39	3.93	11.80	7.37	0.000	9	1399	
	290	62613	dG8	0.070	-7.95	0.13	0.35	1.24	0.165	7	2085	C
	291 A	64096	G1V	0.069	-13.96	0.42	1.41	2.35	0.000	25	3454	SB2O
	291 B			0.069	-28.57	0.89	2.94	3.07	0.000	25	3454	
	292.2	64606	G8V	0.052	102.41	0.88	3.64	10.53	0.000	17	1821	SB1O
	295	65583	G8V	0.058	14.57	0.04	0.27	0.92	0.846	64	3972	C
*	296.2a	66751	dF8	^{4}0.025	-21.00	1.26	6.16	15.16	0.000	30	3264	SB2O
*	296.2b			^{4}0.025	-6.22	1.43	7.13	10.67	0.000	30	3264	
	297.2A	68146	dF7	0.050	32.95	0.18	0.50	1.72	0.005	8	2159	SB?
	297.2B		M3	0.050	34.35	0.92	2.05	2.10	0.006	5	1000	SB?
	302	69830	G8V	0.079	29.72	0.15	0.33	1.22	0.206	5	1854	C
*	303	69897	F6V	0.063	33.03	0.16	0.52	2.00	0.000	10	3568	SB?
*	306	70958	dF2	0.054	73.04	8.11	19.86	4.24	0.000	6	1313	SB1O

(*continued*)

Table 1 (continued)

	Gl	HD	Sp	π "	RV *km/s*	ϵ *km/s*	σ *km/s*	E/T	$P(\chi^2)$	N	ΔT *days*	Spec. status
	307.1	71148	dG4	0.047	-32.57	0.09	0.15	0.58	0.954	9	3986	C
	311	72905	G0V	0.064	-12.66	0.17	0.33	1.23	0.210	4	1838	C
*	310.1A	72945	dF6	0.050	24.44	4.63	13.11	49.83	0.000	8	3226	SB1O
*	310.1B	72946	dG5	0.050	29.21	0.20	0.45	1.75	0.017	5	2527	C
	324 A	75732	G8V	0.074	27.23	0.12	0.35	1.56	0.015	9	3568	C
	324 B		M5	0.074	25.18	2.86	-	-	-	1	0	-
	327	76151	dG3	0.085	31.83	0.16	0.42	1.59	0.026	7	4132	C
*	332 AB	76943	F5V	0.074	27.07	0.32	0.72	1.17	0.254	5	1153	SB1O
	335 AB	78154	F7IV-V	0.054	-2.87	0.13	0.40	1.41	0.045	9	2461	C
	334.2	78366	dG0e	0.046	26.22	0.11	0.37	1.43	0.035	11	4338	C
	337.1	79028	dF9	0.046	-8.82	9.09	25.70	86.94	0.000	8	1895	SB1O
	344 A	81809	G2V	[4]0.050	56.85	1.44	2.88	3.60	0.000	14	4084	SB2O
	344 B			[4]0.050	53.68	2.78	5.56	2.89	0.000	14	4084	
*	348 A	81997	F6V	0.071	10.14	0.46	2.05	4.48	0.000	23	2946	SB1O
*	348 B			0.071	11.53	0.13	0.37	1.32	0.099	8	2589	C
*	355.1	82210	G4IV	0.039	-27.28	0.08	0.20	0.74	0.853	11	2224	C
*	354 AB	82328	F6IV	0.052	14.74	0.16	0.46	1.55	0.019	8	2423	VAR?
	354.1	82443	dG9	0.054	8.17	0.11	0.24	0.85	0.637	7	2800	C
	356 AB	82885	G8IV-Ve	0.109	14.23	0.08	0.18	0.70	0.872	9	4012	C
	368	84737	G1V	0.066	4.96	0.08	0.22	0.94	0.568	9	3982	C
	376	86728	G4V	0.054	55.80	0.11	0.29	1.28	0.142	7	3534	C
*	387 A	89125	dF3	0.060	37.49	0.08	0.25	1.05	0.375	10	2821	C
*	387 B		dM1	0.060	38.43	0.74	-	-	-	1	0	-
*	388.2	89707	F8V	0.046	82.95	0.32	1.41	5.17	0.000	20	2826	SB1O
*	392.1	89862	F2V	0.045	19.01	0.15	0.25	0.80	0.599	4	642	SB
*	392.1	90089	F2V	0.045	4.17	2.71	6.64	1.84	0.012	6	2284	SB
	392 AB	90508	G1V	0.052	-7.04	0.08	0.25	0.94	0.552	11	3396	C
	395	90839	F8V	0.083	8.61	0.14	0.45	1.86	0.001	10	3653	SB?
	394	90839	K7Ve	0.083	8.42	0.12	0.24	0.91	0.537	5	668	C
	398.1A	91889	F8V	0.045	-6.15	0.13	0.38	1.51	0.028	9	2816	C
	398.1B			0.045	-0.59	9.82	17.01	7.03	0.000	3	1005	SB
*	403.1	94388	F6V	0.052	-3.77	0.24	0.59	1.75	0.009	6	1785	C?
	407	95128	G0V	0.074	11.20	0.09	0.22	0.99	0.447	6	3536	C
	417	97334	G0V	[1]0.052	-3.66	0.08	0.22	0.81	0.793	12	3810	C
*	421.1A	97855	dF2	0.053	-42.12	0.14	0.43	1.22	0.163	9	2257	C
*	421.1B			0.053	-42.41	0.16	0.45	1.24	0.161	8	2257	C
	423 AB	98231	G0Ve	0.127	-10.37	0.60	1.71	6.07	0.000	8	77	SB1O
	423.1	98281	G8V	0.054	13.08	0.18	0.45	1.47	0.056	6	2237	C
*	426.1AB	99028	F2IV	0.047	-11.46	0.18	0.48	1.11	0.293	7	2217	C
*	431.1AB	100203	F6V	0.051	-47.92	0.15	0.41	1.27	0.144	7	1587	C
	433.2A	101177	G0V	0.049	-17.28	0.24	1.16	3.76	0.000	23	2626	C?
	433.2B		K2V	0.049	-22.72	3.27	17.63	49.45	0.000	29	2564	SB1O
	434	101501	G8Ve	0.110	-5.93	0.10	0.32	1.25	0.138	10	4056	C
	449	102870	F8V	0.100	4.33	0.04	0.34	1.55	0.000	74	4648	SB?
	451 AB	103095	G8VI	0.113	-99.01	0.04	0.33	1.10	0.158	60	4646	C
	452.3B	103431	dG7	0.053	5.71	0.12	0.30	0.98	0.459	7	2499	C
	452.3A	103432	dG6	0.053	5.86	0.12	0.20	0.65	0.864	7	2499	C
*	455.3	105452	F2V	0.068	2.90	0.50	1.75	1.89	0.000	12	3254	SB
	458.1	106116	G4V	0.046	14.32	0.16	0.42	1.42	0.061	7	2362	C
*	464.1	108021	G6IV	0.051	-4.42	0.12	0.21	0.62	0.912	8	2506	C
	469.1	108754	G8V	0.051	0.34	1.63	5.41	12.98	0.000	11	1210	SB1O
	469.2A	108799	dF8	0.048	1.95	0.22	0.55	1.71	0.012	6	2617	C
	475	109358	G0V	0.109	6.39	0.08	0.30	1.31	0.070	13	4161	C
	479.1	110010	dG2e	0.051	-17.70	0.43	2.03	6.87	0.000	22	2668	SB1

(*continued*)

Table 1 (continued)

	Gl	HD	Sp	π "	RV km/s	ε km/s	σ km/s	E/T	$P(\chi^2)$	N	ΔT days	Spec. status
*	482 AB	110379	F0V	0.099	-19.94	0.80	1.95	1.79	0.007	6	2591	VAR?
	484	110897	G0V	0.065	80.37	0.08	0.33	1.17	0.153	18	3682	C
*	486.1	111395	G7V	0.034	-9.06	0.08	0.20	0.73	0.854	10	3027	C
*	496 AB	113415	dF8	^{1}0.039	26.72	0.11	0.15	0.52	0.951	7	2623	C
*	500	114260	dG7	0.076	-12.09	1.26	5.48	16.73	0.000	19	2249	SB1O
*	501 A	114378	F5V	0.053	-11.63	0.20	0.95	1.98	0.000	22	4401	LWSB
*	501 B	114379		0.053	-27.71	0.27	1.25	2.48	0.000	22	4401	
*	501.1a	114519	F4	0.048	24.40	20.53	41.07	55.47	0.000	4	2922	SB2O
*	501.1b			0.048	19.73	1.84	-	-	-	1	0	
	502	114710	G0V	0.120	5.11	0.08	0.23	0.95	0.525	8	3397	C
*	503.1	114946	dG6	0.008	-48.98	0.15	0.39	1.40	0.067	7	2623	C
	503.2	115043	G1.5Ve	0.050	-8.86	0.08	0.20	0.75	0.845	10	4149	C
	504	115383	G0V	0.077	-27.43	0.11	0.35	1.41	0.044	10	3399	C
*	506	115617	G6V	0.119	-8.36	0.11	0.31	1.26	0.151	8	2550	C
	506.2	116459	dF7	0.049	8.73	0.15	0.36	1.13	0.279	6	2543	C
*	511.1	117043	dG6	0.027	-31.13	0.11	0.23	0.82	0.681	7	2610	C
*	512.1	117176	G5IV-V	0.041	4.61	0.09	0.27	1.08	0.332	9	4156	C
	518.2A	118576	G	0.048	3.58	0.11	0.25	0.69	0.918	10	4431	C
	518.2B			0.048	3.82	0.16	0.26	0.54	0.977	9	4431	C
	521.2A	119124	dF9	0.050	-11.99	0.16	0.40	1.11	0.296	6	3006	C
	521.2B			0.050	-13.60	0.31	0.76	1.57	0.035	6	1871	C
	527 A	120136	F7V	0.057	-16.10	0.18	0.73	1.84	0.000	17	3361	SB?
	529.1	120787	dG3	^{1}0.064	-13.96	0.21	0.54	1.99	0.001	7	2666	SB
*	534	121370	G0IV	0.102	-3.16	1.97	5.59	17.06	0.000	8	3004	SB1O
	538	122742	G8V	0.061	-10.52	0.58	2.40	8.41	0.000	17	2669	SB1O
	541.1	125184	G8V	^{1}0.062	-12.84	0.15	0.46	1.60	0.006	10	2621	SB?
	547	126053	G1V	0.061	-19.47	0.02	0.26	1.12	0.036	176	3859	C
	549 A	126660	F7V	0.068	-11.44	0.29	1.49	1.33	0.009	27	2356	C?
	549 B		M3.5	0.068	-11.34	0.35	1.28	1.30	0.115	13	2206	C
*	550.2AB	126868	G2III	0.045	-10.10	0.18	0.61	1.55	0.007	11	2267	SB?
*	557	128167	F2V	0.063	0.87	0.15	0.53	1.77	0.000	12	1579	VAR?
	559.1	129333	dG0e	0.048	-25.74	0.92	3.89	7.50	0.000	18	4171	SB1O
*	563.4	130819	F5IV-V	0.053	-24.96	0.68	2.79	8.93	0.000	17	4430	SB1
	564	130948	dG2	0.070	-2.67	0.07	0.31	1.07	0.389	17	4479	C
	566 A	131156	G8Ve	0.148	0.85	0.06	0.17	0.77	0.880	14	4414	C
	566 B		K4Ve	0.148	3.04	0.13	0.33	1.31	0.126	7	3657	C
	575 AB	133640	dG1	0.084	-30.66	0.23	0.61	2.07	0.000	7	4393	SB1
*	578	134083	F5V	0.062	-9.82	0.69	2.74	0.80	0.947	24	2545	C
	577	134319	dG5e	0.053	-6.38	0.13	0.17	0.44	0.993	9	4158	C
*	579.1	134323	dG6	^{2}0.013	-48.76	0.36	1.55	5.60	0.000	18	2632	SB1O
	580.2	136064	F8V	0.047	-48.11	0.12	0.39	1.53	0.014	10	3423	C
	584 A	137107	G2V	0.060	-4.59	0.15	0.70	2.72	0.000	23	4432	LWSB
	584 B	137108	G2V	0.060	-10.59	0.19	0.93	3.01	0.000	23	4432	
	596.1AB	140538	dG5	0.046	18.73	0.09	0.32	1.27	0.106	13	4423	C
	598	141004	G0V	0.094	-66.79	0.09	0.28	1.22	0.159	11	3366	C
	602	142373	F9V	0.056	-56.44	0.08	0.35	1.32	0.042	18	4493	C
*	603	142860	F6V	0.081	6.59	0.12	0.21	0.73	0.758	6	2524	C
*	606.2	143761	G0V	0.042	17.91	0.08	0.29	1.29	0.072	14	4102	C
	609.1	144284	F8IV-V	0.046	-5.48	3.24	16.22	17.05	0.000	25	2978	SB1O
	609.2	144287	G8V	0.053	-47.54	0.38	3.15	12.73	0.000	68	4603	SB1O
	611	144579	G8V	0.080	-59.94	0.02	0.27	0.97	0.746	150	4503	C
	616	146233	G1V	0.061	11.61	0.08	0.20	0.81	0.759	10	3435	C
	615.2Aa	146361	F8V	0.045	8.47	17.15	48.50	30.99	0.000	8	1233	SB2O
	615.2Ab			0.045	1.18	16.44	56.95	63.99	0.000	12	2987	

(*continued*)

Table 1 (continued)

	Gl	HD	Sp	π ″	RV km/s	ϵ km/s	σ km/s	E/T	$P(\chi^2)$	N	ΔT days	Spec. status
	615.2B	146362	G1V	0.045	-15.00	0.10	0.32	1.13	0.304	11	4110	C
	618.3	147266	dG7	^{1}0.099	-24.05	0.08	0.32	1.14	0.194	15	2608	C
*	624.1AB	148387	G8III	0.043	-15.50	0.19	0.21	0.81	0.420	2	187	C
	629.2AB	149414	G5Ve	0.051	-165.42	2.51	13.51	34.36	0.000	29	3307	SB1O
	634.1	150433	dG2	0.045	-40.44	0.11	0.25	0.76	0.808	9	2263	C
*	635 AB	150680	G0IV	0.104	-70.60	0.28	1.24	5.27	0.000	20	4600	SB1
	632	150706	dG3	0.056	-17.16	0.09	0.25	0.94	0.540	9	3393	C
*	636	150997	G7III-IV	0.054	8.16	0.06	0.23	1.05	0.386	15	4139	C
*	635.1	151623	gG9	0.046	-21.48	0.09	0.23	0.83	0.719	10	2607	C
	641	152391	G8V	0.067	44.86	0.09	0.16	0.61	0.941	9	3387	C
*	648	153597	F6V	0.059	-24.43	4.56	9.12	29.06	0.000	4	1355	SB1O
	650	153631	G3	0.059	83.93	0.99	4.64	15.69	0.000	22	1582	SB1O
	651	154345	G8V	0.062	-47.28	0.08	0.13	0.46	0.997	12	2265	C
	654.1	154417	dF8	0.049	-16.94	0.02	0.28	1.10	0.065	201	4397	C
*	652.1	154633	dG5	0.030	-24.41	0.10	0.26	0.96	0.485	8	2203	C
	668.1	156826	G9V	^{1}0.081	-33.13	0.10	0.22	0.77	0.763	8	2212	C
	672	157214	G2V	0.073	-79.14	0.07	0.29	1.09	0.290	15	4479	C
	678 A	158614	G8IV-V	0.052	-80.62	0.33	1.22	3.72	0.000	14	3428	LWSB
	678 B			0.052	-73.75	0.33	1.24	3.68	0.000	14	3428	
	679	159222	G5V	0.051	-52.01	0.08	0.18	0.65	0.947	12	2265	C
	684 AB	160269	G1V	0.067	-14.61	0.17	0.60	2.16	0.000	12	2814	SB1
	685		M1Ve	0.067	-16.31	0.23	0.30	0.52	0.932	6	2077	C
*	695 A	161797	G5IV	0.124	-16.68	0.07	0.29	1.25	0.072	19	3393	C
*	695 B			0.124	-13.90	0.23	0.70	1.08	0.335	9	2155	C
*	694.1A	162003	F5IV-V	0.047	-13.70	0.10	0.42	1.16	0.172	16	2578	C
*	694.1B	162004	F8V	0.047	-10.93	0.12	0.36	1.21	0.176	9	2205	C
*	700.1AB	164765	dF3	0.059	-40.30	0.80	3.67	5.06	0.000	21	2207	SB1O
*	700.1C			0.059	-14.02	0.18	0.46	0.82	0.756	10	2207	C
	702.2	165401	G2V	0.045	-120.45	0.10	0.37	1.29	0.065	14	3760	C
	703		G6	0.072	25.54	0.12	0.36	1.03	0.400	9	2264	C
	704 AB	165908	F7V	0.061	1.57	0.11	0.40	1.52	0.005	14	3714	SB?
	708.4	168009	dG0	0.046	-64.94	0.09	0.30	1.21	0.160	11	3358	C
*	708.1	168151	F5V	0.047	-36.12	0.16	0.34	0.93	0.488	5	1513	C
	713a	170153	F7V	0.125	30.30	2.73	10.56	30.18	0.000	15	2668	SB2O
	713b			0.125	28.87	3.76	14.57	15.28	0.000	15	2668	
*	725.2	173667	F6V	0.049	22.34	0.25	0.35	0.63	0.834	5	1404	C
	732.1	175225	dG8	0.075	-1.62	0.11	0.44	1.60	0.001	15	2378	SB?
	738 AB	176051	G0V	0.054	-49.04	0.14	0.55	2.01	0.000	15	4456	SB1
	740.1	176982	dG5	0.054	-7.23	0.12	0.21	0.59	0.933	8	2264	C
	743	177745	G9	0.057	-16.94	0.11	0.27	0.87	0.651	8	4453	C
	746	178428	dG4	0.059	14.02	2.16	8.89	32.59	0.000	17	2257	SB1O
*	748.1	180777	F2V	0.046	0.62	3.90	7.80	4.98	0.000	4	1883	SB?
*	754.2	181655	G8V	0.041	1.82	0.08	0.19	0.66	0.942	12	2300	C
*	759	182572	G8IV	0.058	-100.65	0.03	0.44	2.05	0.000	260	4538	SB?
	761.1	183650	dG5	0.049	-10.03	0.09	0.17	0.62	0.944	10	2324	C
	762.2	184385	G5V	^{1}0.046	11.19	0.09	0.40	1.53	0.002	20	4534	SB?
*	764.2	184985	dF6	0.045	-15.36	0.10	0.17	0.64	0.887	7	3628	C
*	765 AB	185395	F4V	0.056	-27.31	0.17	0.43	1.76	0.010	6	2638	C
*	765.1A	186408	G2V	0.036	-27.42	0.08	0.27	1.12	0.260	11	4065	C
*	765.1B	186427	G5V	0.036	-28.08	0.08	0.29	1.22	0.131	13	4065	C
	765.3	186760	F8	0.045	-29.82	0.11	0.33	1.14	0.244	9	2296	C
*	765.4AB	186858	dK5	0.047	4.39	0.14	0.32	1.06	0.348	5	1156	C
*	767.1A	187013	F5V	0.047	4.21	0.13	0.42	1.30	0.083	11	1863	C
*	767.1B	225732	dK6	0.047	4.54	0.13	0.40	1.15	0.233	10	1830	C

(*continued*)

Table 1 (continued)

	Gl	HD	Sp	π "	RV km/s	ϵ km/s	σ km/s	E/T	$P(\chi^2)$	N	ΔT days	Spec. status
	768.1AB	187691	F8V	0.047	-0.15	0.02	0.28	1.13	0.012	203	4446	C
	768.1C		dM4	0.047	-1.19	1.00	-	-	-	1	0	
*	771 AB	188512	G8IV	0.070	-40.71	0.09	0.21	0.92	0.539	6	3927	C
*	773.3	189340	G0V	0.040	30.24	0.34	1.26	4.31	0.000	14	2223	SB1O
*	773.3A	189340	G0V	0.040	30.37	0.64	2.40	5.44	0.000	14	2223	SB2O
*	773.3B			0.040	30.12	0.93	3.48	4.01	0.000	14	2223	
	775.1	190067	G8V	0.049	20.05	0.09	0.21	0.71	0.903	12	2321	C
	777 AB	190360	G8IV-V	0.056	-45.90	0.07	0.28	1.06	0.334	17	4438	C
	779	190406	G1V	0.058	4.84	0.10	0.30	1.07	0.326	9	2580	C
	783.1A	191854	G5V	0.046	-40.80	0.24	0.96	2.30	0.000	16	4345	LWSB
	783.1B			0.046	-46.36	0.21	0.84	1.61	0.005	16	4345	
	788	193664	G5V	0.067	-4.65	0.08	0.19	0.71	0.893	11	3286	C
*	789	194012	dF5	0.030	4.54	0.12	0.38	1.33	0.077	10	3306	C
*	792.1AB	195564	G3V	0.032	9.53	0.10	0.18	0.65	0.887	8	2246	C
	793.1	195987	G9V	0.051	4.07	4.56	19.33	69.61	0.000	18	4365	SB1O
	794.3	196850	G2V	0.048	-21.43	0.08	0.31	1.19	0.159	13	3995	C
	797 A	197076	dG2	0.049	-35.82	0.08	0.28	1.01	0.427	13	3995	C
	797 B		M	0.049	-35.39	0.97	2.18	1.66	0.034	5	1517	C
	808.3	198802	dG1	^{1}0.046	-3.45	0.11	0.23	0.77	0.744	7	2205	C
	814	199803	dG4e	0.054	-22.27	0.13	0.30	0.85	0.641	7	2205	C
	822 A	202275	F8V	0.055	-7.10	3.63	11.49	22.94	0.000	45	3523	SB2O
	822 B		F8V	0.055	-25.00	2.96	11.46	22.75	0.000	45	3523	
*	822.1AB	202444	F0IV	0.050	-23.12	1.28	2.22	1.13	0.308	3	412	VAR?
	822.2	202573	G5V	^{1}0.055	-26.59	0.08	0.18	0.65	0.949	12	2310	C
	823	1916	G5	0.066	-65.01	0.12	0.28	0.85	0.672	8	4342	C
*	836.6A	206826	F6V	0.046	15.76	0.31	0.93	2.70	0.000	9	2205	SB?
*	836.6B	206827	dF3	0.046	23.46	0.52	1.17	3.63	0.000	5	2125	SB?
	836.7	206860	dG0e	0.066	-17.04	0.09	0.36	1.23	0.096	16	4147	C
*	838.5	207958	F0V	0.047	0.00	0.00	0.00	1.00	9.999	0	0	-
	838.3A	207966	G5	0.046	-25.60	0.07	0.23	0.84	0.807	14	4463	C
*	848	210027	F5V	0.075	-13.49	18.16	31.45	131.23	0.000	3	30	SB1O
	848.4	210277	dG9	0.047	-21.44	0.10	0.22	0.78	0.756	8	2204	C
	862.1a	213429	F8	0.046	-9.79	1.29	6.68	22.93	0.000	27	2287	SB2O
	862.1b			0.046	-8.05	2.91	13.66	11.39	0.000	27	2287	
	867.1A	214615	dG9e	0.047	-12.66	0.33	0.94	2.49	0.000	8	2128	SB?
	867.1B		dG9e	0.047	-13.85	0.14	0.35	0.94	0.513	7	2128	C
*	872 A	215648	F6IV-V	0.048	-6.01	0.09	0.18	0.68	0.889	9	2911	C
*	872 B		dM1	0.048	-7.24	-	-	-	-	1	0	-
	878.1A	216777	G6V	0.048	-28.34	0.12	0.23	0.66	0.879	8	2119	C
	882	217014	G4V	0.073	-33.69	0.06	0.26	1.05	0.366	18	4047	C
*	891.1	219080	F0V	0.046	6.71	5.10	-	-	-	1	0	-
*	893		sdF6	0.013	-56.39	1.05	5.91	4.50	0.000	32	833	SB
*	894.2A	219834	G5IV-V	0.039	11.14	1.31	4.16	14.86	0.000	10	2543	SB1O
*	894.2B		K2V	0.039	10.26	0.12	0.27	0.88	0.595	7	2543	C
	904	222368	F7V	0.071	5.51	0.03	0.32	1.30	0.000	128	4524	SB?
	914 AB	224930	G3V	0.084	-39.39	0.34	1.65	6.45	0.000	24	4486	SB1O

IM: Interferometric Measurements (McAlister & Hartkopf 1988).
DM: Duquennoy & Mayor (1988).
Bat: Batten et al. (1989).
COR: CORAVEL 1977–1990 (this work).
LWSB: Line-Width Spectroscopic Binary.

HD 123: ADS 61. VBO, $P = 107$ yr, $a = 1\farcs43$ (WH). IM. COR: not observed because of the angular separation and $\Delta m_v = 0.8$ not favourable to interpretation of which component is seen. Parallax and mass ratio: Lippincott 1963, AJ 68, 45. BS: component B has a possible invisible companion, $P = 6.9$ yr. Variations of m_v with $P = 1.08$ d, amplitude 0.05 V. (Com. 27 IAU, circ. info. 2389, 1983).

HD 3196: ADS 490. Triple. AB: VBO, $P = 6.9$ yr, $a = 0\farcs20$ (WH). IM. Comp. A: SB1, $P = 2.08$ d (Bat 27). Gatewood & Sofia (1976, PASP 88, 50) find that the astrometric data suggest that the principal components

Table 2. Spectroscopic orbital elements for the programme stars. All the SBs in the complete sample are present (star names without asterisk). Some of the SBs (new CORAVEL orbits) out of the limits of the complete sample (star names with an asterisk) are included. The corresponding velocity curves are presented in Fig. 1, except for star names with a number in parenthesis which are stars in the complete sample whose orbital elements are taken from other sources than the present paper: (1) Duquennoy & Mayor 1988, (2) Batten et al. 1989, (3) Jasniewicz & Mayor 1988, (4) Imbert 1980, (5) Duquennoy et al. 1988

Star HD	P *days*	T_0 *HJD* -2440000	e	V_0 kms^{-1}	ω_1 °	$K_{1,2}$ kms^{-1}	$\mathcal{M}_{1,2}\sin^3 i$ $f_1(\mathcal{M})$	$a_{1,2}\sin i$ $10^6 km$	N	(O-C) kms^{-1}
3196	2.081891	3400.4573	0.	11.23	0.	43.98	0.01844	1.260	105	2.65
Aa	0.000005	0.0032	(fixed)	(var.)	(fixed)	0.39	0.00046	0.010		
3196	2527.	6864.8	0.77	8.83	109.0	10.90	0.837	242.	5	0.69
A-B	(fixed)	3.9	(fixed)	0.22	3.1	0.59	0.122	13.		
						16.44	0.555	364.4	7	
						0.43	0.103	9.5		
*3443	9130.	2000.	0.22	18.63	143.5	5.64	1.025	691.	16	0.59
A-B	(fixed)	(fixed)	(fixed)	0.11	1.7	0.22	0.164	26.		
						7.13	0.810	874.	16	
						0.20	0.143	25.		
4676	13.8318	3468.808	0.238	3.76	202.3	57.31	1.078	10.59	35	0.65
	0.0017	0.018	0.002	0.08	0.5	0.19	0.018	0.04		
						59.77	1.034	11.04	35	
						0.18	0.018	0.04		
6582	7827.	2694.	0.61	-98.10	147.9	2.68	0.0078	228.	23	0.44
A	(fixed)	(fixed)	(fixed)	0.09	4.8	0.18	0.0015	15.		
10307	7122.	3363.	0.42	3.12	210.8	2.81	0.0123	250.	18	0.23
	(fixed)	(fixed)	(fixed)	0.13	3.5	0.25	0.0033	22.		
*13612	94.7878	7731.384	0.689	-5.95	74.3	19.08	0.1117	18.02	33	0.58
Aa-Ab	0.0045	0.055	0.003	0.07	0.5	0.15	0.0071	0.22		
						19.77	0.1078	18.67	33	
						0.15	0.0068	0.23		
(1)13974	10.02008	6695.18	0.	-6.60	0.	10.49	0.0062	1.45	14	0.61
	0.00004	0.03	(fixed)	0.12	(fixed)	0.20	0.0011	0.03		
						11.89	0.0055	1.62	13	
						0.33	0.0008	0.04		
(1)16620	969.4	5453	0.19	15.68	246	5.86	0.172	76.7	18	0.94
A-B	5.2	26	0.03	0.17	11	0.28	0.026	4.5		
						8.61	0.117	112.6	18	
						0.29	0.016	5.1		

(*continued*)

of the system are over luminous for their masses. System also discussed by Mayor & Mazeh (1987). COR: SB2(Aa + B), preliminary spectroscopic elements for the VB. With $i = 45.6°$, derived masses of 2.3 and 1.5 $M_\odot$ for (Aa + Ab) and B respectively, in agreement with the spectral types observed but inconsistent with the sum of the masses of 1.2 $M_\odot$ found and discussed by Gatewood & Behall (1975, AJ 80, 1065). The long-period orbit is also followed by Fekel (priv. comm.). BS: var?, δ Sct? Hyades group. ADS 490C (m_v 12.5): 65°, 37.″1 (1899) to 43°, 24.″5 (1950), optical (W).

HD 3443: ADS 520. VBO, $P = 25$ yr, $a = 0.″67$ (WH). COR: first preliminary SB2 orbit; with $i = 78°$ (van den Bos 1937, Union Circ. Obs. 4,

Table 2 (continued)

Star HD	P *days*	T_0 *HJD* -2440000	e	V_0 kms^{-1}	ω_1 °	$K_{1,2}$ kms^{-1}	$\mathcal{M}_{1,2} \sin^3 i$ $f_1(\mathcal{M})$	$a_{1,2} \sin i$ $10^6 km$	N	(O-C) kms^{-1}
16739	330.935	6462.63	0.657	-22.78	269.8	21.03	0.652	72.2	13	0.60
	0.031	0.92	0.010	0.12	0.9	0.30	0.086	2.1		
						22.90	0.599	78.6	13	
						0.32	0.079	2.2		
(1)17433	13.19828	6478.03	0.074	-2.75	153.7	30.35	0.0380	5.49	28	0.39
	0.000011	0.12	0.004	0.08	3.2	0.11	0.0005	0.03		
*20727	321.6	6842.4	0.504	7.23	233.0	7.47	0.0090	28.5	15	0.33
	2.2	1.3	0.020	0.09	2.0	0.16	0.0010	1.2		
*21242	6.43792	3447.7007	0.	27.48	0.	66.92	0.6157	5.92	36	1.10
	0.00002	0.0026	(fixed)	0.19	(fixed)	0.24	0.0022	0.02		
						58.60	0.7041	5.19	21	2.68
						0.91	0.0048	0.08		
39587	5205.	6286.	0.441	-13.37	107.1	1.90	0.00269	122.2	26	0.13
	(fixed)	43.	0.018	0.07	6.0	0.03	0.00021	3.1		
(1)61994	553.51	6657.4	0.415	-22.58	225.3	10.69	0.425	74.1	17	0.61
	.31	3.0	0.021	0.14	3.1	0.23	0.070	1.6		
						14.94	0.304	103.5	9	
						0.51	0.46	3.6		
(1)64096	8580.	6405.4	0.734	-21.52	255.1	9.94	1.00	796.	26	0.69
A-B	31.	9.2	0.16	0.11	1.5	0.25	0.0022	40.		
						9.49	1.05	761.	18	
						0.27	0.16	40.		
64606	447.32	6589.7	0.359	101.99	227.9	5.85	0.00756	33.59	17	0.26
	0.87	4.0	0.017	0.07	3.4	0.11	0.00062	0.96		
*72945	14.29955	6781.30	0.332	26.61	227.1	21.95	0.0132	4.07	8	0.30
Aa	0.00005	0.12	0.008	0.15	3.0	0.22	0.0005	0.05		
(2)79028	16.2397	-16951.5	0.09	-14.6		35.3	0.0073	7.85		
*81997	2807.	5260.	0.33	10.85	340.	2.98	0.0065	109.	35	1.23
Aa	23.	150.	0.12	0.28	27.	0.39	0.0035	20.		
*89707	298.48	7920.6	0.927	82.76	108.0	4.38	0.000137	6.74	34	0.27
	0.71	2.0	0.014	0.08	12.6	0.44	0.000042	0.69		
(2)98231	669.18	-21418.	0.53	-15.0		8.0	0.0022	62.4		
Aa				(var.)						
(2)98231	3.9805	-15000.	0.	-15.9		5.0	0.000052	0.274		
Ba			(fixed)	(var.)						
101177	23.5409	6974.581	0.408	-18.93	352.8	24.31	0.0267	7.18	29	0.46
Ba	0.0018	0.085	0.010	0.24	1.1	0.20	0.0011	0.09		

(*continued*)

Table 2 (continued)

Star HD	P days	T_0 *HJD* -2440000	e	V_0 kms^{-1}	ω_1 °	$K_{1,2}$ kms^{-1}	$\mathcal{M}_{1,2} \sin^3 i$ $f_1(\mathcal{M})$	$a_{1,2} \sin i$ $10^6 km$	N	(O-C) kms^{-1}
(3)108754	25.9347	5982.46	0.217	0.10	62.6	8.08	0.0013	2.81	11	0.39
	0.0062	0.79	0.033	0.16	10.2	0.32	0.0002	0.13		
110010	4000.	2122.	0.14	-18.38	0.1	3.09	0.0117	167.3	22	0.27
	(fixed)	122.	0.03	0.09	12.2	0.12	0.0015	7.3		
*114260	20.49255	6788.270	0.556	-12.42	272.4	7.94	0.000612	1.86	19	0.17
	0.00037	0.027	0.005	0.05	1.0	0.06	0.000022	0.02		
122742	3607.4	4820.	0.524	-11.59	185.1	6.78	0.0721	286.4	27	0.29
	3.7	11.	0.015	0.06	1.5	0.14	0.0071	9.6		
129333	4575.	6932.	0.665	-23.10	188.0	5.09	0.0261	239.	18	0.52
	(fixed)	20.	0.023	0.27	5.8	0.20	0.0051	16.		
*130819	5227.	2501.	0.362	-23.47	203.5	3.69	0.0222	248.	18	0.52
	19.	92.	0.041	0.15	7.9	0.17	0.0043	17.		
(2)133640	0.2678	-11364.6	0.			115.4	0.77	0.425		
Aa-Ab			(fixed)	(var.)						
						231.1	0.39	0.851		
*134323	2059.	6713.	0.46	-47.94	124.3	2.53	0.00238	63.5	21	0.24
	22.	45.	0.04	0.07	7.6	0.20	0.00083	7.4		
137107	15200.	3717.	0.320	-7.26	72.5	4.52	0.759	895.	23	0.33
A-B	(fixed)	220.	0.029	0.05	6.8	0.18	0.256	40.		
						5.47	0.637	1083.	23	
						0.21	0.214	47.		
144284	3.07084	5501.6108	0.	-7.74	0.	24.77	0.0048	1.05	25	0.97
	0.00002	0.0058	(fixed)	0.20	(fixed)	0.28	0.0002	0.01		
144287	4450.8	7679.7	0.683	-48.17	18.8	5.30	0.0269	237.1	68	0.30
	6.8	5.4	0.007	0.04	1.0	0.07	0.0019	5.8		
146361	1.139788	5292.0557	0.	-12.60	0.	63.01	0.0296	0.99	8	2.88
Aa-Ab	0.000004	0.1206	(fixed)	0.70	(fixed)	1.45	0.0026	0.02		
						63.59	0.1195	1.00	12	
						1.00	0.0026	0.02		
149414	133.13	4340.5	0.274	-171.56	298.8	16.11	0.0514	28.36	29	0.59
Aa	0.13	1.1	0.009	0.20	3.6	0.15	0.0019	0.37		
(1)153631	386.72	6548.9	0.185	83.39	48.4	6.14	0.0088	32.17	19	0.23
	0.55	4.2	0.023	0.09	5.1	0.09	0.0005	0.75		
158614	16950.	-2170.	0.17	-77.34	328.	4.87	1.009	1119.	16	0.52
A-B	(fixed)	(fixed)	(fixed)	0.11	(fixed)	0.18	0.203	42.		
						5.53	0.888	1270.	14	
						0.18	0.187	42.		

(*continued*)

Table 2 (continued)

Star	P	T_0 HJD	e	V_0	ω_1	$K_{1,2}$	$\mathcal{M}_{1,2}\sin^3 i$	$a_{1,2}\sin i$	N	(O-C)
HD	*days*	-2440000		$km s^{-1}$	°	$km s^{-1}$	$f_1(\mathcal{M})$	$10^6 km$		$km s^{-1}$
160269	27087.	-6816.	0.19	-16.30	126.4	3.84	0.151	1405.	12	0.27
A	(fixed)	(fixed)	(fixed)	(fixed)	4.2	0.41	0.048	150.		
*164765	184.085	6741.2	0.60	-38.39	48.1	9.08	0.0073	18.4	27	1.08
Aa	0.013	1.5	0.08	0.28	9.3	1.72	0.0058	4.9		
170153	280.547	6848.5	0.466	32.02	120.4	18.22	1.024	62.2	23	0.57
	0.039	1.4	0.025	0.26	3.4	0.66	0.111	3.2		
						26.0	0.718	88.7	17	1.55
						1.1	0.075	5.1		
176051	22423.	1398.	0.25	-45.82	102.	3.51	0.091	1047.	16	0.36
A	(fixed)	(fixed)	(fixed)	0.69	(fixed)	0.74	0.058	222.		
178428	21.95536	5592.23	0.080	14.36	57.4	13.42	0.00546	4.04	17	0.28
	0.00080	0.29	0.010	0.08	4.9	0.12	0.00016	0.04		
*189340	1698.	7043.	0.574	29.95	316.7	2.35	0.00126	45.0	14	0.19
orbit 1. A	24.	18.	0.033	0.07	7.3	0.20	0.00044	5.7		
*189340	1790.	7078.	0.60	30.22	332.4	5.12	0.089	100.7	14	0.67
A-B	(fixed)	(fixed)	(fixed)	0.13	1.9	0.36	0.027	7.0		
orbit 2.										
						6.70	0.068	131.9	14	
						0.46	0.021	9.1		
191854	31470.	891.	0.48	-43.32	340.0	3.86	0.696	1467.	16	0.75
A-B	(fixed)	(fixed)	(fixed)	0.25	(fixed)	0.47	0.315	183.		
						4.51	0.597	1710.	16	
						0.49	0.283	184.		
(4)195987	57.3240	3328.589	0.306	-6.13	356.8	28.73	0.1219	21.57	64	0.54
	0.0013	0.097	0.003	0.07	0.7	0.10	0.0017	0.10		
(1)202275	2082.90	6854.3	0.448	-15.77	185.6	12.26	1.136	314.2	200	0.57
A-B	0.49	2.8	0.004	0.05	1.0	0.07	0.028	2.7		
						12.25	1.139	313.7	16	
						0.07	0.028	2.5		
(5)213429	632.54	5889.7	0.396	-9.59	173.0	11.44	1.11	91.3	139	1.20
	0.81	2.4	0.012	0.08	1.7	0.16	0.11	1.3		
						20.83	0.61	166.4	28	
						0.59	0.05	4.6		
*219834	2441.	6765.	0.205	10.32	202.0	5.53	0.0402	181.	10	0.20
Aa	87.	90.	0.036	0.26	12.0	0.14	0.0054	12.		
224930	9595.	7498.	0.38	-37.63	274.0	4.10	0.0543	500.	24	0.32
A	(fixed)	(fixed)	(fixed)	0.10	(fixed)	0.15	0.0060	18.		

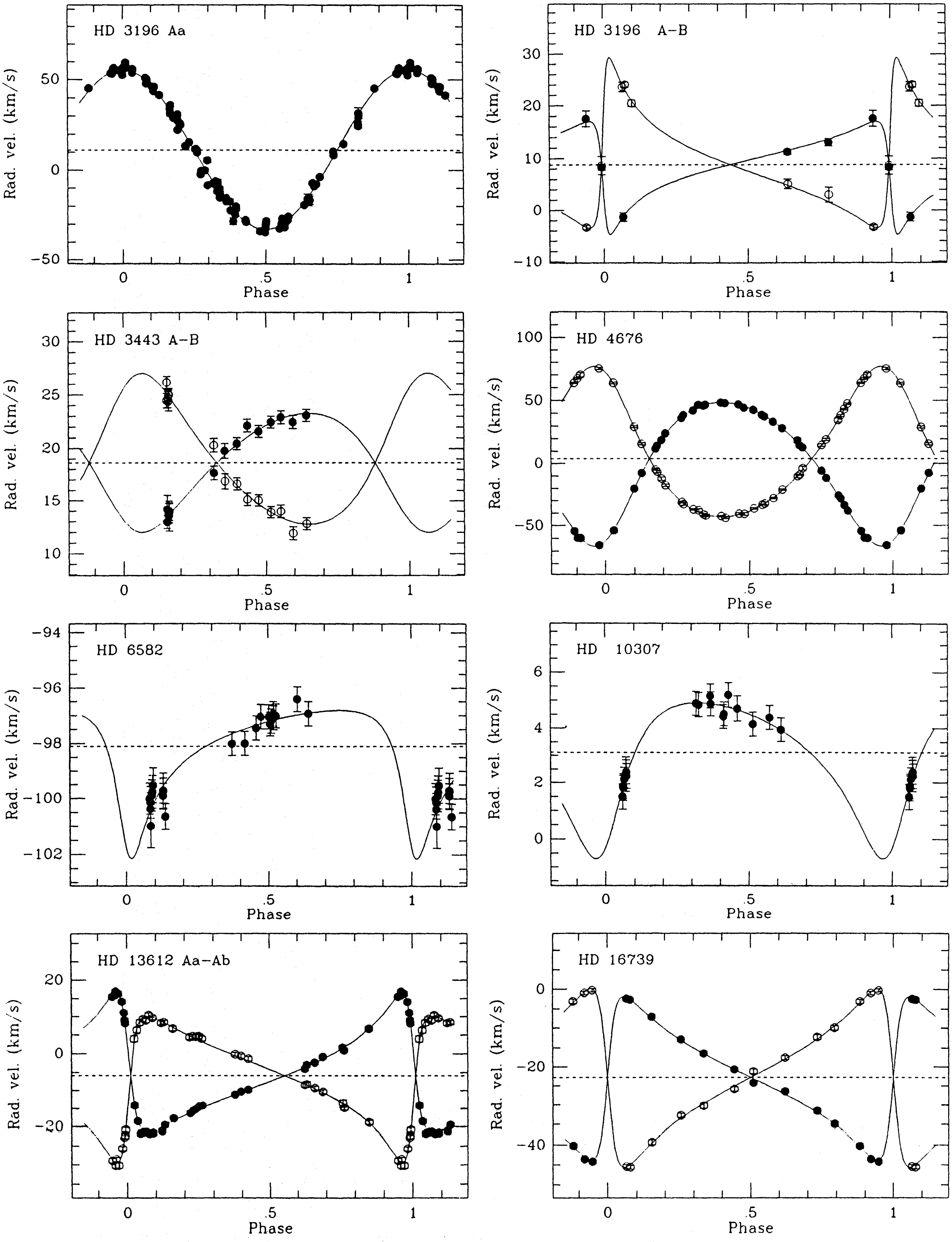

Fig. 1. Velocity curves for 38 stars in the extended sample of nearby G-dwarfs observed with CORAVEL. Circles are CORAVEL observations, triangles are from other sources (see Notes in Sect. 4.3).

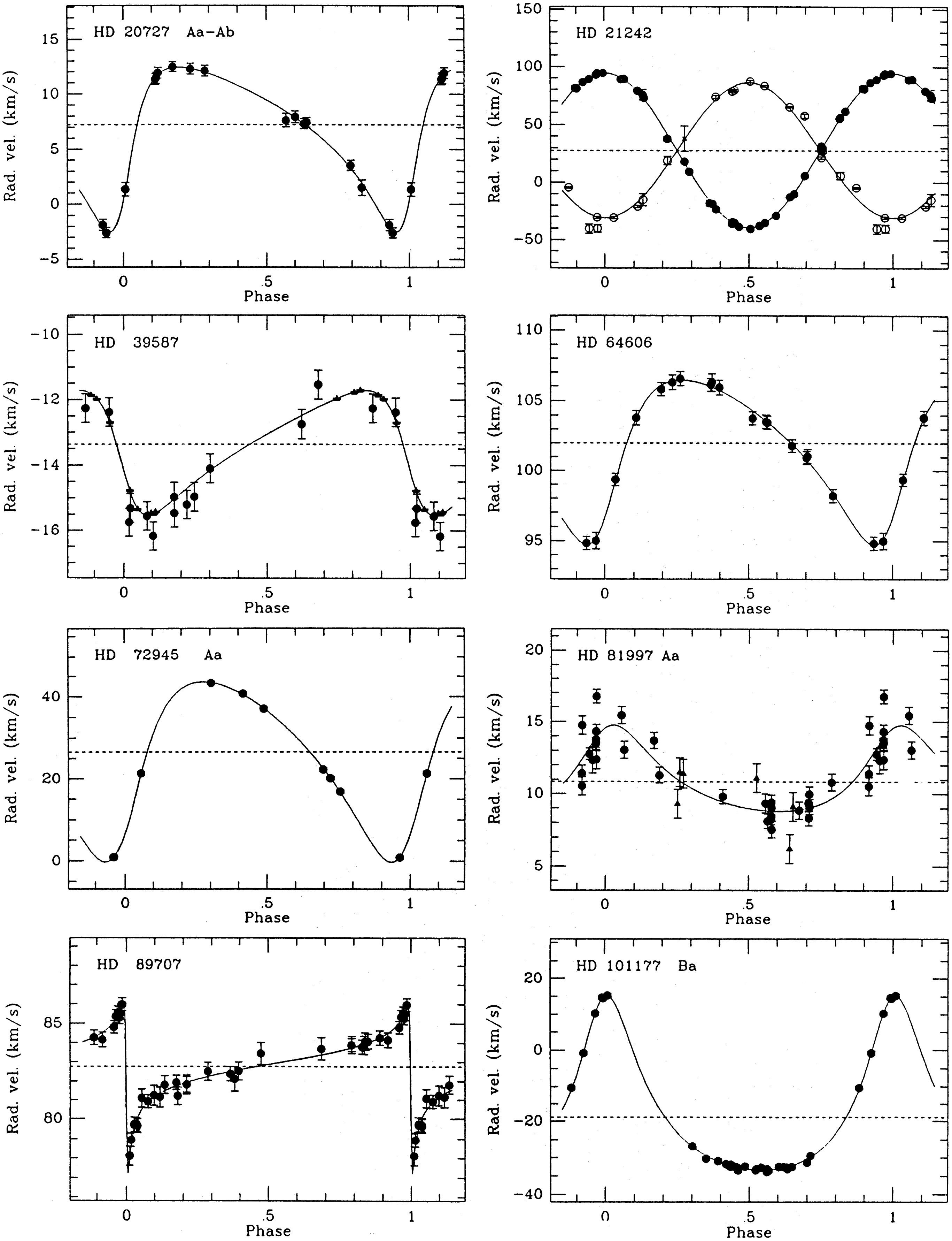

Fig. 1 (continued)

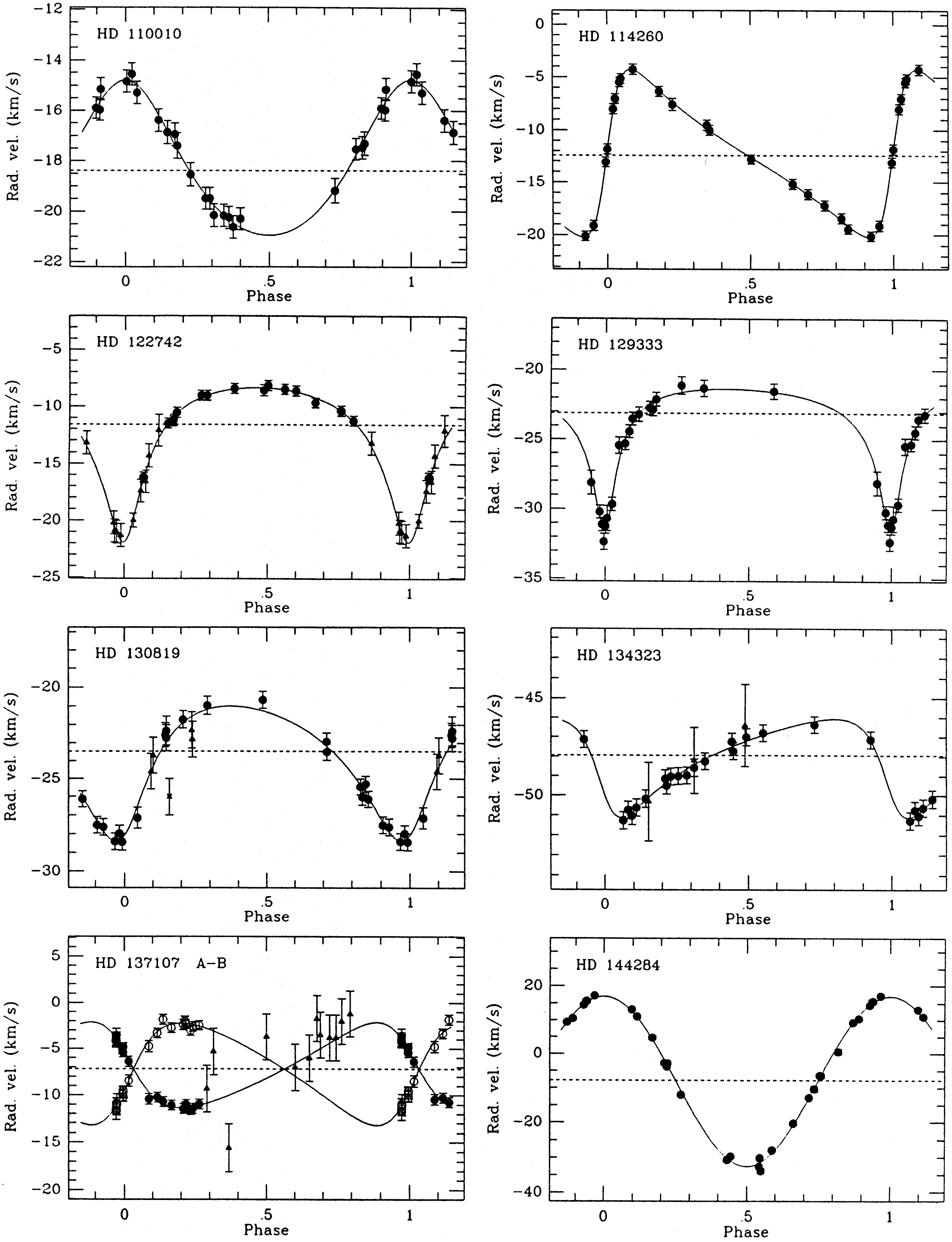

Fig. 1 (continued)

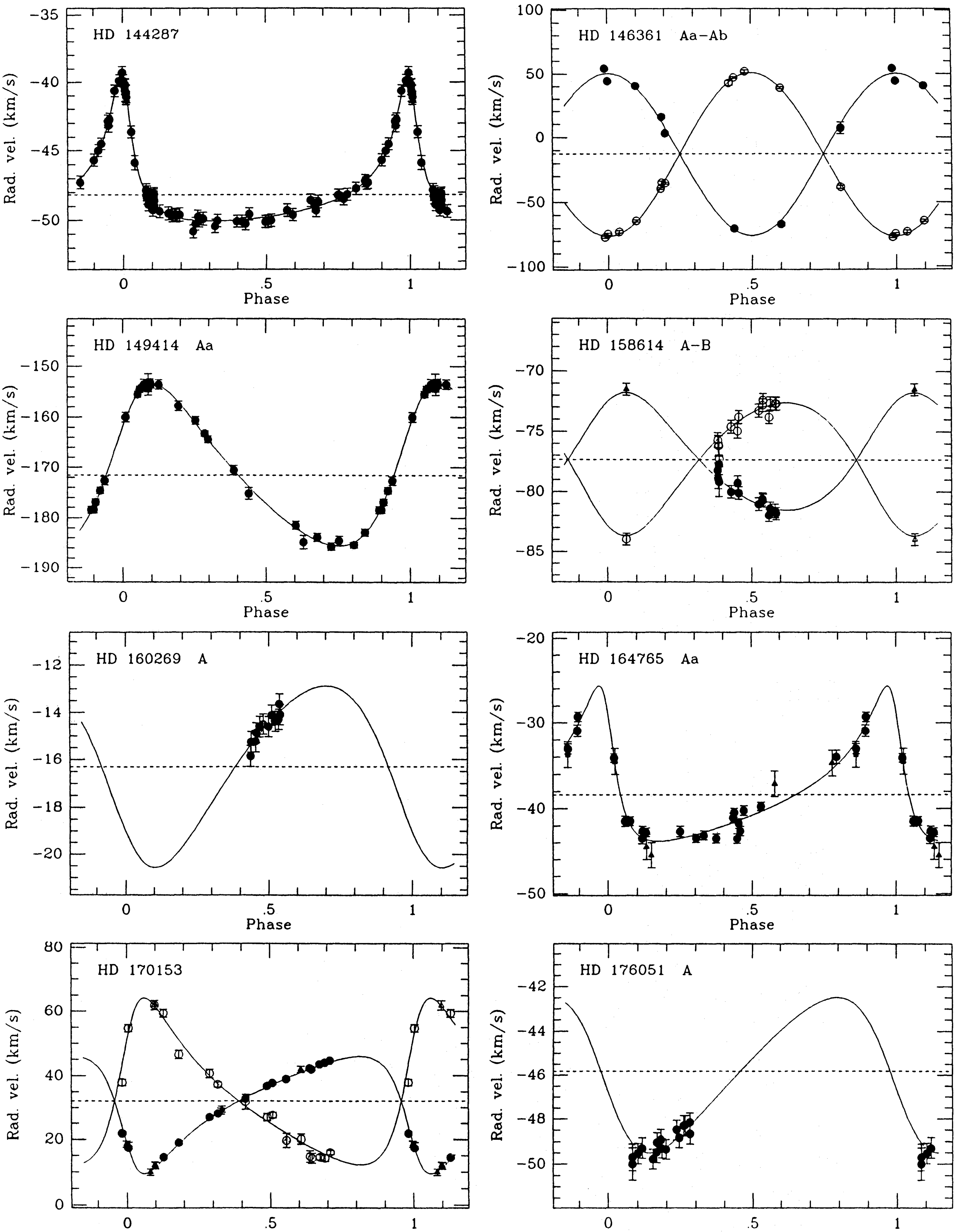

Fig. 1 (continued)

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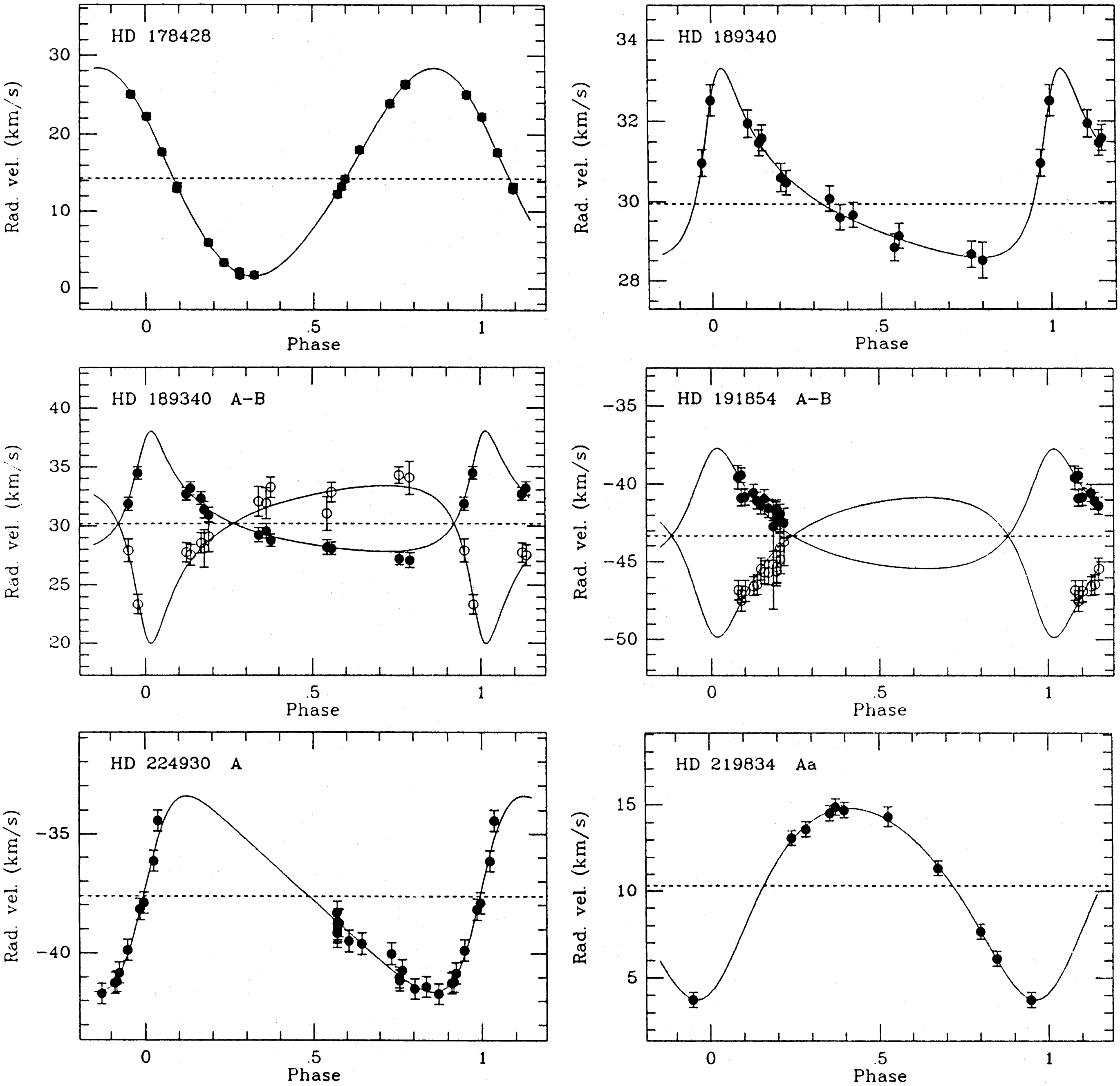

Fig. 1 (continued)

342), derived masses of 1.10 and 0.87 $M_\odot$ slightly higher than expected from spectral type G8V.

HD 4614: ADS 671. VBO, $P = 480$ yr, $a = 12''$ (WH). Comp. A: SB1 ($P = 9.2$ d, $K_1 = 2.2\,\mathrm{km\,s^{-1}}$, AL) refuted by MG. BS: possible invisible comp. with $P = 40$ yr. Strand (1969, AJ 74, 260): no evidence for a previously unknown companion. COR: constant velocity for A and for B. 6 companions (m_v 8.6 to 11.6: ADS 671 C to H) at 1.0′, 1.0′, 3.2′, 4.7′, 5.7′, 10.9′ (*, **), all optical (BS).

HD 4676: Bat 46. SB20, $P = 13.8$ d. IM: not resolved. COR: additional SB2 orbit. W: Two faint companions listed in IDS: C (m_v 12.0): 327°, 76″.7 and D (m_v 13.0): 164°, 70″.8, both optical. (also regarded as optical by AL, BS).

HD 6582: Astrometric orbit, $P = 22.1$ yr, $a = 0''.19$ (Russell & Gatewood 1984, PASP 96, 429). IM. Δm_v at least 3 mag. (McCarthy 1983) Spectroscopic elements by Worek & Beardsley (1977, ApJ 217, 134), slightly different from visual ones ($e = 0.3$, $K = 2.8\,\mathrm{km\,s^{-1}}$, Bat 57), but highly uncertain. COR: preliminary SB1 orbit, with $e = 0.6$ fixed to its value in the astrometric orbit. BS: five visual components at large separation in IDS, optical (NLTT).

HD 10307: Astrometric binary, $P = 19.5$ yr, $\Delta m_v = 3$–4 (Lippincott et al. 1983, PASP 95, 271). Hyades group (*, **). COR: SB1, preliminary orbital elements.

HD 11964: CPM pair. Star B ($m_v = 11.2$) at 137°, 29″ (Gliese & Jahreiss 1978). COR: constant velocity for A and for B.

HD 13612: ADS 1703. Triple. AB: 232°, 16″.2 (1832–1958), $\Delta m_v = 2.1$, CPM pair. COR: Comp. A is SB2, $P = 95$ d (first orbit); comp. B: constant velocity. ADS 1703 C (m_v 11.5) at 2′.9 (*), optical (Worley 1967). Discordance between spectral and photometric parallaxes of A (0″.052) and of B (0″.030) probably due to SB2 nature of A.

HD 13974: Bat 117. SB1O, $P = 10.0$ d. COR: Secondary component detected, SB2O, discussion of the RV by DM. Star is the brighter component of ADS 1739: comp. B (m_v 13.7) at 64″ is regarded by AL as probably optical; NLTT: optical. BS: ζ Her group.

HD 16620: VBO, $P = 2.5$ yr, $a = 0''.12$ (WH). IM. Spectroscopic elements by AL: $K_1 = 2.2\,\mathrm{km\,s^{-1}}$ (SB1, Bat 135), revised by DM: $K_1 = 5.9\,\mathrm{km\,s^{-1}}$, $K_2 = 8.6\,\mathrm{km\,s^{-1}}$ (SB2). Finsen gives spectral type F5IV–V.

HD 16739: Bat 136. SB2O, $P = 331$ d. Visual elements by McAlister (1978, ApJ 223, 526) using 5 IM and P, e fixed by spectroscopic orbit. COR: Additional SB2 orbit; early velocities by Colacevich (1941, Oss. e Mem. Arcetri, No. 59, 16) have been used only to get a more precise determination of the period, which has been fixed in our solution using COR alone.

HD 16895: ADS 2081. VBO, $P = 2720$ yr, $a = 22''.4$, uncertain (WH). B: Ca II Em. ADS 2081 C at 1′.5 (*, **), optical (NLTT).

HD 17433: Gl: RV var. IM: not resolved. COR: SB1O, $P = 13.2$ d (DM). SBS: BY Dra, m_v 6.83–7.01, and variations of $(B–V)$, $(U–B)$ with periods 7.85 d and 43.9 d.

HD 18455: At least quadruple system. Comp. AB (HD 18455): VBO, $P = 137$ yr, $a = 1''.55$ (WH); COR: constant velocity. Comp. C (HD 18445) at 219°, 27″.2 (1824) and 224°, 28″.6 (1954); COR: SB1, with probable period around 559 d, $e \simeq 0.5$ and $K_1 \simeq 1.8\,\mathrm{km\,s^{-1}}$, confirmed by recent CORAVEL measurements made after the closing date of january, 1990. The corresponding minimum secondary mass in the C-system is $0.058\,M_\odot$.

HD 19994: ADS 2406. CPM pair, AB: 253°, 5″.1 (1871), 231°, 3″.3 (1958). $\Delta m_v = 6.5$. COR: Comp. A: SB? (velocity range $1.8\,\mathrm{km\,s^{-1}}$ $P(\chi^2) = 0.000$); comp. B not measurable independently.

HD 20727: Triple. AB: 81″, $\Delta m_v = 7.8$, CPM pair. The spectral type is not consistent with the trigonometric parallax. COR: Comp. A is SB1, $P = 322$ d (first orbit); comp. B not measurable.

HD 21242: Bat 169. $P = 6.44$ d. Binary with strong H and K emission in the spectrum of the later type and more massive component. Not known to be eclipsing, the system is nevertheless probably of the RS CVn type. SBS: RS CVn type, m_v 6.37–6.49. Hα profile varies. Period of light equals period of motion. Form and amplitude of light curve vary. COR: additional SB2 orbit; large velocity dispersion of the secondary velocity due to often strongly distorted cc-dip (probably due to large spots added to rotational broadening). Parallax certainly smaller than 0″.045.

HD 29203: Gl: RV var?. SBS: also classified G5II. COR: constant velocity (17 measures with $\Delta T = 4400$ d).

HD 32923: ADS 3701. Observations of this close pair are so scattered that all computed visual orbits are highly conjectural. IM uncertain. Spurious binary (Heintz & Borgman 1987, AJ 89, 1068). COR: Constant velocity, classified single star. BS: uncertain parallax, 0″.023 to 0″.138. Hyades?

HD 35296: CPM pair. Star B (HD 35171, Gl 201, m_v 8.0, Sp dK5) at about 12′. Noted with 40% chance to be optical pair by Halbwachs (1986). COR: Physical pair according to velocity difference $0.2\,\mathrm{km\,s^{-1}}$ between the 2 comp. BS: Comp. A SB, not confirmed by COR. Companion m_v 7.9 at 96″ optical. A and B: Ca II Em (W).

HD 39587: Astrometric orbit, $P = 14$ yr, $a = 0''.10$ (Lippincott & Worth 1978, PASP 90, 330). IM: only upper limits. COR: preliminary SB1 orbit for the astrometric pair, with P fixed to its value in the astrometric orbit, and using relative velocities of Campbell et al. (1988) shown as triangles in Fig. 1 and increased by the systemic velocity $-13.44\,\mathrm{km\,s^{-1}}$ found in the solution using COR only; minimum mass for the secondary $0.17\,M_\odot$ in agreement with the astrometric determination. UMa group. Sirius group (W).

HD 42807: COR: SB? (velocity range $1.4\,\mathrm{km\,s^{-1}}$, $P(\chi_2) = 0.001$), possible long period.

HD 43587: CPM pair. B (m_v 13.4) at 95″. COR: one measure of B made at La Silla confirms the probable physical bounding of AB. W list 3 faint companions: C (m_v 9.3) at 190″, D (m_v 11.3) at 58″, E at 69″, probably all optical (NLTT).

HD 61994: SB2O, $P = 554$ d (DM). Secondary marginally seen.

HD 64096: ADS 6420. VBO, $P = 23$ yr, $a = 0''.58$ (WH). IM. Discussion of the RV's by AL (SB1 solution, $K_1 = 4\,\mathrm{km\,s^{-1}}$, Bat 478) and by DM (SB2 solution, $K_1 = 9.9\,\mathrm{km\,s^{-1}}$, $K_2 = 9.5\,\mathrm{km\,s^{-1}}$). BS: UMa stream.

HD 64606: SB1O, $P = 447$ d (Latham et al. 1988, AJ 96, 567). CORAVEL orbit announced by Jasniewicz & Mayor (1988) and published in this study. Elements in agreement with those derived by Latham et al. Pop II star.

HD 66751: Gl: SB, vel.range $16\,\mathrm{km\,s^{-1}}$. Trigonometric parallax probably too large. COR: SB2O, $P = 244$ d (DM), parallax uncertain, adopted $\pi = 0''.025$ as in DM's model.

HD 68146: CPM pair. Probably quadruple (COR). B (m_v 11.5) at 237°, 92″. COR: Comp. A: SB? (velocity range $1.2\,\mathrm{km\,s^{-1}}$, $P(\chi^2) = 0.006$), probably not due to the CPM (too far); comp. B: SB, orbit not established, velocity range $4.8\,\mathrm{km\,s^{-1}}$. Hyades group (W, BS).

HD 69897: Probable SB of very low amplitude, but lying out of the limits of the complete sample due to its spectral type given as F6V.

HD 72945: ADS 6886. Triple. AB = 10″.3 (1832–1955), CPM pair. Comp. A: SB1O, P = 14.3 d (Bat 523). COR: additional SB1 orbit, no secondary detected; the solution uses early measurements by Joy & Abetti (1919; ApJ 50, 391) only for a precise determination of the period; the other elements are obtained with P fixed and COR measurements alone, the residuals being 5 times smaller; comp. B: constant velocity. Three faint companions listed in ADS: C (m_v 10.7) at 1′.5 (1893 to 1950, W, *), D (m_v 12.0) at 18″ (*, **), E (m_v 8.8) at 22″ (*, **), all components not quoted in BS; NLTT: probably optical. Spectral and photometric data lead to a parallax smaller than the trigonometric parallax.

HD 75232: CPM pair. B (m_v 13.2) at 125°, 85″. COR: Comp. A: marginally variable, but classified as constant velocity; comp. B: Only one observation made at La Silla confirms the probable physical bounding of the pair. W: strong metallic line star with enhanced CN and C2. BS: perhaps also enhanced CH. Hyades group.

HD 78154: ADS 7203 AB. Orbits: $P = 1067$ yr, $a = 6''.2$ (Baize 1948), $P = 678$ yr, $a = 5''.6$ (Bespalov 1964). BS: Comp. B. var. m_v 7.5–10.0 ?. ADS 7203 C probably optical. COR: Comp. B not measurable, too close for the $\Delta m_v = 3.6$; comp. A: constant velocity.

HD 79028: Bat 558. SB1O, P = 16.2 d. Classed sgG0 (Eggen). COR: no secondary detected. A companion at 49″ is listed in IDS, regarded as optical.

HD 81809: VBO, $P = 35$ yr, $a = 0''.36$ (WH). IM. Spectroscopic elements by AL with $P = 917$ d contested by MG and not confirmed by COR (DM). COR: SB2, orbital elements of the VB by DM.

HD 81997: Triple. AB: 3°, 65″.7 (1821–1935), CPM pair. COR: Comp. A: SB1O, first preliminary orbit with $P = 2800$ d, minimum mass of the secondary: $0.25\,M_\odot$; high dispersion of the velocities around computed curve, probably due to the large width of the cc-dip ($v \sin i = 30\,\mathrm{km\,s^{-1}}$); no particular distribution of the residuals; the solution uses early Lick measurements (1928, PLO 16, 145, indicated with triangles in Fig. 1), consistent with an earlier solution using only COR measures. But elements remain preliminary, in particular there may exist a possible longer period (about 4000 d) with higher eccentricity.

HD 82885: ADS 7441. VB without orbit. AB: 35°, 5″.8 (1905), 31°, 2″.0 (1937), 1941–1958 comp. not seen, 67°, 2″.5 (1962), difficult (W). IM: not resolved. COR: Only comp. A seen ($\Delta m_v = 7.6$), constant velocity. BS: G8III, binary?

HD 89707: COR: SB10, first orbit with $P = 298$ d; no secondary detected, the mass function indicates a probable very low mass secondary ($M_{2_{\rm min}} = 0.053\,M_\odot$, which however is able to explain the observed discrepancy between trigonometric (46 ± 12 m″) and photometric (24 m″) parallaxes.

HD 90508: CPM pair. B(m_v 12.5) at 15°, 4″.7 (1935–58). COR: Comp. A: constant velocity; comp. B not measurable. BS: Arcturus group.

HD 90839: CPM pair. AB: 120″ (Gl 394 = HD 237903, K7V, Ca II Em) COR: Comp. A: SB? (velocity range 1.3 km s^{-1}, $P(\chi^2) = 0.003$), possible planetary companion (Campbell et al. 1988); comp. B: RV var (Gl), constant velocity (COR, this study). AC: separation 1°. (HD 89862 = BD + 57 1266, KOIV). BS: cpm and RV for ABC, but C not physical (Gliese & Jahreiss 1988), confirmed by COR (velocity difference $\Delta RV(C\text{–}AB) = 10$ km s^{-1}).

HD 91889: CPM pair. AB: 75°, 14″.4 (1958). COR: Comp. A: constant velocity; comp. B: SB, orbit not established, velocity range 20 km s^{-1}, wide cc-dip.

HD 98231/0: ADS 8119. Quadruple. VBO, $P = 59.8$ yr, 2″.5 (WH). IM. BS: first visual double for which an orbit determined, in 1828 by Savary. Heintz (1967, Astron. Nachr. 289, 269) computed the mass ratio ($q = 0.81$) of the pair AB. Comp. A: SB10, P = 669 d (Bat 668), Ca II Em (W). IM: not resolved. Comp. B: SB10, $P = 3.98$ d (Bat 667), weak Ca II Em (W). IM: not resolved. COR: angular separation and $\Delta m_v = 0.4$ not favourable to interpretation of which component is seen.

HD 101177: ADS 8250. Triple. AB: 226°, 10″.5 (1831), 253°, 9″.7 (1955). Comp. B: SB10, $P = 23.5$ d (Bat 680). COR: Comp. A: constant velocity (1 discordant); comp. B: additional SB1 orbit. 3 faint comp. listed in W(*): C (m_v 9.2, BD + 45 1948) at 86°, 32″.3 (1783), 90°, 120″.7 (1931) optical. BS: VR(C) = -40 km s^{-1}. Comp. D (m_v 8.6) at 314°, 85″ (1931)(**), E (m_v 12.4) at 307°, 94″(1923), 309°, 91″(1930); NLTT: probably all optical

HD 103095: Groombridge 1830. CPM pair. AB: 175°, 2″. BS: comp. B (m_v 8.5–12) at 1″.7. IM: not resolved. B flared 1968, Feb. 21 to a magnitude difference at maximum of about 2m (van de Kamp). B normally unseen (W). COR: Comp. A: constant velocity, also found by Griffin (1984, Observatory 104, 192); comp. B not measurable.

HD 103432/1: CPM pair. AB: 35°, 73″.2 (1875–1920)

HD 108754: COR: SB10, $P = 25.9$ d (Jasniewicz & Mayor 1988). Pop. II star. *HD 108799:* ADS 8573. VBO, $P = 162$ yr, $a = 1″.4$ (WH). COR: Only comp. A seen ($\Delta m_v = 3.8$), long-period SB1, compatible with VB motion.

HD 109358: Probably single star. SB1 with $P = 2900$ d by AL, contested by MG. IM: 1 resolution not confirmed by 15 other trials. COR: constant velocity.

HD 110010: COR: SB1, first preliminary orbit. 3 solutions with fixed $P = 3000$, 4000, 5000 d give respectively $e = 0.04$, 0.17, 0.26, σ(O–C) = 0.26, 0.27, 0.28 km s^{-1} and minimum secondary mass of 0.21, 0.27, 0.32 $M_\odot$. We adopted the second solution as mean preliminary orbit. The system should be observed with speckle interferometry. W: Ca II Em. Not known as velocity variable in the SBS.

HD 114260: COR: SB1O, first orbit with $P = 20.5$ d; no secondary detected; the mass function indicates a probable very low mass secondary ($M_{2_{\rm min}} = 0.075\,M_\odot$). The eccentricity is unusually high ($e = 0.56$) for such a short period.

HD 114378: ADS 8804. VBO, $P = 25.9$ yr, $a = 0″.66$ (WH), $\Delta m_v = 0$. IM. BS: possible eclipses. COR: our method of blend analysis gave rather negative result: we get a constant velocity difference between the 2 components during 12 yr, inconsistent with the ephemeris by Dommanget & Nys (1982); actually no clear variations are seen in the width of the cc-dip. ADS 8804 C (m_v 10.2) at 10″ (*, **), not quoted in BS. NLTT: probably optical.

HD 115383: CPM pair. B (m_v 14.3) at 89°, 34″.3 (1958). COR: Comp. A: constant velocity; comp. B not measurable.

HD 118576: ADS 8970, CPM pair. AB: 68°, 20″.0 (1831–1914). Gl: RV var? Pop II? ($B\text{–}V = 0.6$, $M_v = 8$). COR: constant velocity for A and for B.

HD 119124: ADS 8992, CPM pair. AB: 134°, 17″.6 (1879–1958). COR: constant velocity for A and for B.

HD 120136: ADS 9025. B (m_v 10.7) at 348°, 10″.3 (1849) to 7°, 5″.4 (1958). IM: not resolved. BS: orbital period several centuries. Var. δ Sct? (m_v 4.40–4.58). COR: Comp. A: SB? velocity variation could be due to the CPM component with $P \simeq 500$ yr; comp. B: not measurable independently.

HD 120787: Gl: the large discrepancy between spectral and photometric parallax does not support the classification as a dwarf. COR: probable SB from velocities listed in Paper I, confirmed by 4 early-1990 CORAVEL measures of this star, all about 3 to 4 km s^{-1} above the mean velocity listed in the present paper.

HD 122742: Astrometric binary, $P = 12$ yr, $a = 0″.15$ (Wagman 1949, AJ 54, 138). IM: not resolved. Spectroscopic orbit (Bat 799) by Kamper (1987, AJ 93, 683). COR: using 10 measures by Kamper around periastron (triangles in Fig. 1), additional purely spectroscopic orbit; no secondary detected.

HD 125184: One discordant measure. Probable constant velocity.

HD 126660: Wide triple. AB: 182°, 69″.2 (1854–1918). IM: not resolved Approximately cpm with C (m_v 13.5), about 1.5° north of AB. BS: Wolf 630 moving group. COR: Comp. A: SB? (but wide cc-dip). C not measurable.

HD 129333: SB1, first preliminary orbit with arbitrary fixed period (but probably true to the nearest unit of log P), $P = 4575$ d; the mass function indicates $M_2 \geq 0.37\,M_\odot$; other periods (1340, 2320, 2680, 3700 d) eliminated; early measures from Mt Wilson (Abt 1973, ApJ 234, 365) not discriminating. The system should be observed with speckle interferometry.

HD 130819: Triple. CPM pair with HD 130841 (m_v 2.8, A3V), comp. A, var. velocity? (Slipher 1904, LOB 1, 57), not observed with COR. Comp. B (HD 130819) at 314°, 231″; COR: SB1, first preliminary orbital elements with $P = 5230$ d; other solutions with $P = 6850$ or 10050 d less credible; the adopted solution is the best fit using early Lick observations (PLO 16, 216, 1928, shown as triangles in Fig. 1) and 1 measure made with CORAVEL on March 21, 1990 ($RV \simeq 27.2$ kms^{-1}, not included in Paper I).

HD 130948: Gl: SB. IM: not resolved. COR: constant velocity, classified as single.

HD 131156: ADS 9413. VBO, $P = 152$ yr, $a = 4″.9$ (WH). Suspected unseen companion ($P = 2.2$ yr, $a = 0″.02$, BS), not confirmed. IM: not resolved. A and B: Ca II Em (W). UMa stream. ADS 9413 C (m_v 12.6) at 1 (*, **), and -D (m_v 9.6) at 49″ (*, **). BS: comp. C optical. COR: Constant velocity for A and for B.

HD 133640: ADS 9494. Triple. AB: VBO, $P = 225$ yr, $a = 3″.8$ (Heintz 1978, ApJS 37, 71). IM. Star B is a SB2 eclipsing binary (*W* UMa-type) and X-ray source, with $P = 0.27$ d (Bat 826). Binnendijk also give $i = 68.1°$ for the inner system. BS: variations in light curve may be caused by mass-transfer between close pair. COR: Only comp. A seen, long-period SB1 compatible with VB motion.

HD 134323: Gl: Small proper motion and the photoelectric colours do not support the classification as a dwarf. COR: SB1O, $P = 2059$ d, first orbit. Velocities from Fick observatory have been used (Beavers & Eitter 1986; ApJS 62, 147, shown with triangles in Fig. 1), but are not very constraining because they are on the slowly ascending velocity branch. The 3 points representing the Fick observations each are actually means of 4 to 6 measures with their rms forming the plotted error bars. The system should be observed with speckle interferometry, although the mass function indicates only $M_2 \geq 0.15\,M_\odot$. Heintz (1986, AJ 92, 446) finds the classification of the stars as G6V erroneous and $\pi_{\rm abs} = 0.013''$. Although we are unable to quantify the effect of the newly discovered binarity on the parallax determination (apart from $a''/\pi'' = P^{2/3} M_{AB}^{1/3} \simeq 3.4$), we adopted Heintz' parallax in our study, the star not being detected as astrometric binary.

HD 137107/8: ADS 9617. VBO, $P = 42$ yr, $a = 0''.90$ (WH). IM. Spectroscopic elements by Chang (1929, ApJ 70, 185): $K_1 = 4.5\,{\rm km\,s^{-1}}$ (Bat 842). COR: LWSB, first preliminary SB2 orbit; early measures of Chang are also shown on the velocity curve (Triangles in Fig. 1) but are blended and have not been used in the solution; derived masses of 1.19 and 0.98 $M_\odot$ with $i = 58°$ (Silbernagel 1929, Astron. Nachr. 234, 441), in agreement with the spectral types G2V. UMa group. W: Sirius group. ADS 9617–C (m_v 13.4) at 57″ (*, **, $B-V = 0.5$) optical (BS). ADS 9617–D (m_v 11.0) at 3′.6 probably optical (BS); NLTT: optical.

HD 140538: ADS 9763. CPM pair. B (m_v 12.0) at 103°, $3''.6$ (1910), 61°, $4''.2$ (1957). SB (Gl, BS). COR: Comp. A: constant velocity; comp. B not measurable independently. ADS 9763–C (m_v 9.0, HD 140527, K2, *): 208°, 3′.4, ADS 9763–D (m_v 10.4): 281°, 1′.2, ADS 9763–E (m_v 7.1): 236°, 3′.0 (1909–1918). BS: quintuple system. NLTT: 3 distant companions probably optical.

HD 141004: Previously quoted SB1, $P = 1837$ d by AL, contested by MG (long period low amplitude binary with no observations on the steep descending branch). COR: constant velocity (11 measures with $\Delta T = 3400$ d).

HD 144284: SB1O, $P = 3.07$ d (Bat 882). COR: possible third component through observed variation of K_1 (Mayor & Mazeh 1987, A&A 171, 157); a new orbit using recent CORAVEL observations is presented in this study. BS: Hyades group.

HD 144287: Gl: SB. Present in SBS. COR: SB1O, $P = 4451$ d, first orbit. The mass function indicates $M_2 \geq 0.32\,M_\odot$. The estimated apparent semi-major axis ($a > 0''.16$) indicates that the system could be resolved with speckle interferometry.

HD 144579: CPM pair. Star B (m_v 14.2) at 281°, 70″ (Gliese & Jahreiss 1978). Comp. A listed in SBS. COR: velocity standard, 150 measures, $P(\chi^2) = 0.987$; comp. B not measurable with COR.

HD 146361/2: ADS 9979. Quadruple. Star A is SB2O, $P = 1.14$ d (Bat 894), δ Sct var, amplitude 0.05V (BS). IM: not resolved. AB: VBO, $P = 1000$ yr, $a = 6''.6$ (WH). Radio binary (BS). CPM with component C (m_v 12.5) at 633″ (van de Kamp 1943, BS). COR: Additional SB2 orbit (**A**a–Ab) with $\gamma = -12.6\,{\rm km\,s^{-1}}$; comp. B: constant velocity; $\Delta RV(B-A) = -2.4\,{\rm km\,s^{-1}}$ consistent with the ephemeris by Dommanget (1982); comp. C not measurable. ADS 9979-C (m_v 13.3, *) (different from comp. C above): 234°, 21″ (1851) to 148°, $8''.7$ (1935) optical, ADS 9979–D (m_v 10.8, *): 89°, 44″ (1836) to 85°, 71″ (1933) optical.

HD 149414: Triple. B (m_v 15.0) at 19′.5. W: Ca II Em. COR: Comp. A: SB1O, $P = 133$ d (Mayor & Turon 1982, A&A 110, 241). Halo star (High velocity, metal deficient); comp. B not measurable with COR.

HD 153631: COR: SB1O, $P = 387$ d (DM).

HD 158614: ADS 10598. VBO, $P = 46$ yr, $a = 1''.02$ (WH). IM. Two spectra seen in 1965, relative velocity $12.47\,{\rm kms^{-1}}$ (West 1966, AJ 71, 186). (Bat 967). COR: LWSB, preliminary SB2 orbit using visual elements and also West's data (triangles in Fig. 1); derived masses of 1.00 and 0.92 $M_\odot$ with $i = 99°$ (Wilson 1976, MNRAS 177, 645) consistent with the observed $\Delta m_v = 0.1$. BS: ζ Her group.

HD 160269: ADS 10660. Wide triple. AB: VBO, $P = 76$ yr, $a = 1''.5$ (WH). CPM with comp. C (Gl 685, m_v 9.9, Sp M1Ve, Ca II Em) at 162°, $738''.3$. Discussion of the orbital motion of the triple (Upgren 1962, AJ 67, 539). COR: Only comp. A seen in the VB ($\Delta m_v = 2.7$), SB1, (very) preliminary spectroscopic elements with fixed (P, T, e) visual elements and with systemic velocity fixed to that of comp. C as observed with COR: with $i = 106°$ (Baize 1965, J. Obs, 48, 1), and $M_1 = 1.00\,M_\odot$, we derive $M_2 = 0.82\,M_\odot$ in reasonable agreement with the mass-magnitude relation; comp. C: constant velocity.

HD 164765/4: ADS 11005. Triple. VBO, $P = 280$ yr, $a = 1''.49$, RV of the primary may be variable (WH), RV of AB variable (Gl). IM. Comp. C (m_v 11.3) at 127°, $100''.3$ (1879–1959) optical? (BS). COR: RV (AB) variable, variations attributed to comp. A; first preliminary SB1 orbit with $P = 184$ d, using 6 early velocities (LOB 6, 140, 1911, triangles in Fig. 1); but probable blend (with B which seems of constant velocity) in the cc-dip, nearly resolved at some phases. Further analysis of the triple system should be done.

HD 165908: ADS 11077. VBO, $P = 56$ yr, $a = 0''.74$ (WH). IM: not resolved. COR: Only comp. A seen ($\Delta m_v = 3.6$), marginally variable, probably due to VB motion. BS: metal deficient, helium rich. ADS 11077–C (m_v 10.7) at 1.6′(*, **), not quoted in BS, probably optical.

HD 170153: Astrometric and interferometric binary, $P = 0.77$ yr, $a = 0''.12$ (McAlister 1980, AJ 85, 1265). SB1, $P = 280.6$ d (Bat 1058). Discussion by Spite (1967, Ann. Astroph. 30, 211). Agreement between Vinter-Hansen (1942) and Spite (1967) works, justifies Luyten's (1934) dismissal of the evidence for a third spectroscopic component. COR: additional SB2 orbit. Rufener (1981): possible microvariable in V. Gl: two faint companions are listed in IDS at about 150″. BS: comp. B (m_v 12, K1V) at 149″, C (m_v 13.5) at 10″; NLTT: both probably optical.

HD 175225: Gl: luminosity class possibly brighter than main sequence. COR: possible variable ($P(\chi^2) = 0.001$). Velocity residuals before 1989 suggest a possible long period.

HD 176051: ADS 11871. VBO, $P = 61$ yr, $a = 1''.23$ (WH). IM. 4 faint comp. listed in ADS (*, **): 1950.0: COR: very preliminary SB1 orbit, with fixed visual elements; the secondary is not significantly detected through cc-dip's width variation, consistent with the $\Delta m_v = 2.4$ observed; with $i = 115°$, and $M_1 = 1.00\,M_\odot$, we derive $M_2 = 0.71\,M_\odot$ in agreement with the mass-magnitude relation. 4 companions listed in IDS: C (m_v 12.1) at 56″, D (m_v 12.2) at 287°, 1′.5, E at 264°, 1′.7, F at 320°, 1′.7. BS: C and D optical; NLTT: probably all optical.

HD 178428: SB1O, $P = 21.9$ d (Bat 1122). Beavers & Saltzer (1985, PASP 97, 35) suggest that there is a possibility that the period has decreased since the star was first recognized as binary. In fact the mean period over 65 yr quoted by these authors $P = 21.9556 \pm 0.0002$ d is in full agreement with the period derived from CORAVEL measures alone. So we do not confirm the suspected change in the orbital period. COR: additional SB1 orbit, the non-zero eccentricity is confirmed ($e = 0.08 \pm 0.01$ in our solution); no secondary detected. A 10.5 mag companion at about 22″ is listed in IDS (BD + 16 3751); NLTT: optical.

HD 184985: Gl: SB. W: SB (GCRV). BS: SB. COR: constant velocity (7 measures with $\Delta T = 3600$ d).

HD 187691: ADS 13012 AC. CPM pair. Star B (m_v 13.5, 14″) is optical; C (m_v 13.7, dM4 (BS)) is physical: 222°, $22''.5$ (1910–1958). COR: Comp. A: velocity standard, 203 measures, $P(\chi^2) = 0.578$; comp. C: according to 1 observation (by M. Imbert), common velocity with A.

HD 189340: VB (Finsen 378), separation less than $0''.2$, without previously known orbit. IM. COR: periodic low-amplitude variations, SB1 solution with $P = 1698$ d and $K_1 = 2.4\,{\rm km\,s^{-1}}$ (orbit 1) probably due to VB motion; marginally variable width of the cc-dip; marginal LWSB binary, provisional SB2 solution (orbit 2) derived with assumption $\Delta m_v = 1.0$ (close to that observed by van den Bos, 1983, AJ 68, 57), giving the best fit to the 12 CORAVEL and 8 speckle observations to date. The also provisional elements obtained are $i = 26°$, $a = 0.15''$, $\Omega = 319°$. Fig. 2 shows the plot of the IM with our computed orbital elements. Efforts should be made to observe with high resolution spectroscopy the phases of expected maximum velocity difference.

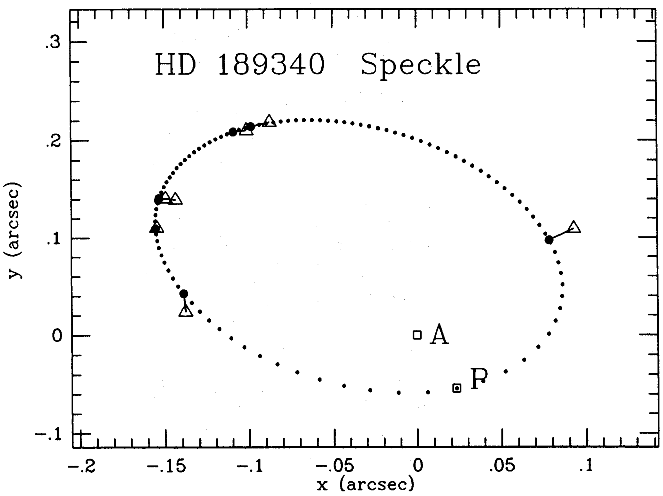

Fig. 2. Visual orbit for HD 189340 with $P = 1790$ d, combined solution from interferometric and CORAVEL observations. The orbital elements are found in the text. East is up (positive y-axis), North is right (positive x-axis), P indicates periastron

HD 190360: CPM pair. AB: 234°, 178″. m_v(B) = 14.4 (Gl) or 15.5 (BS). Observed trig. parallaxes of A (46 ± 6 m″) and of B (87 ± 12 m″) do not agree very well but are combined. A is most often classified as G6IV but also as G8IV–V, G8V. BS: Comp. A iron rich star. COR: Comp. A: constant velocity; comp. B not measurable.

HD 191854: ADS 13461. VBO, $P = 86$ yr, $a = 0''.46$ (WH). COR: LWSB, preliminary SB2 orbit, with fixed visual elements; derived masses of 0.98 and 0.84 with $i = 116°$ (Heintz 1963, Veröff. Sternw. München 5, 265) in reasonable agreement with spectral types (G4V, G8V).

HD 195987: SB1O, $P = 57.3$ d (Bat 1245) based on CORAVEL observations (Imbert 1980, A & AS 42, 331: possibility for eclipses). This study: additional SB1 orbit, recent CORAVEL measures improve the precision on P. SBS quotes: SB2, which is untrue.

HD 197076: CPM pair. B (m_v 13.4) at 175°, 125″. BS: m_v(B) = 11.6 at 94″. COR: Comp. A: constant velocity; comp. B: marginally variable, but classified as constant velocity. Hyades group (BS).

HD 202275: ADS 14773. VBO, $P = 5.7$ yr, $a = 0''.26$ (WH). IM. The components are indistinguishable. Spectroscopic elements (Bat 1290). COR: Additional SB2 orbit by DM. ADS 14773–C: m_v 9.5 (BS), m_v 11.0 (W) at 50″(*, **) optical (BS).

HD 207966: ADS 15400. CPM pair. B (m_v 12.3) at 87°, 10″.5 (1886–1911). COR: Comp. A: constant velocity; comp. B: not measurable. ADS 15400–(m_v 12.3, *): 52°, 51″.7 (1895), 55°, 55″ (1911) probably optical.

HD 213429: VR noted V? in BS. COR: SB2O, $P = 633$ d (Duquennoy et al. 1988).

HD 214615: ADS 16145. Triple, and probably quadruple. AB: CPM pair, 148°, 4″.7 (1830), 118°, 3″.6 (1960). Comp. C (m_v 14.7) at 139″, CPM. COR: proximity and similar magnitudes of the components AB give somewhat difficult interpretation of the measures. Tentatively, we have: comp. A: SB?, comp. B: constant velocity; comp. C: not measurable. W: AB: position angles differ by 180° from those given by Gl. A and B: Ca II Em. ADS 16145–C (m_v 12.0): 245°, 98″.2 (1908–1912) optical.

HD 216777: CPM pair. B (m_v 16.5) at 43″. 61 Cyg group. COR: Comp. A: constant velocity; comp. B not measurable.

HD 219834: ADS 16672. Triple. AB: 345°, 13″.4 (1830), 350°, 13″.0 (1958). Comp. A: SB1O, $P = 2323$ d. (Bat 1438); classed as G5IV, G81V–V or dG4. IM. Analysis of the spectroscopic/interferometric orbit is given by McAlister & Hartkopf (1982, PASP 94, 832). Sarma (1961, ApJ 135, 301) suggested some additional cause of velocity variation is acting, that McAlister & Hartkopf attribute to possible instrumental effects. COR: Comp. A: additional SB1 orbit, somewhat longer period, but eccentricity confirmed to be higher than found by Sarma; comp. B: constant velocity, which does not support the hypothesis rised by McAlister & Hartkopf that comp. B may be a close binary containing 2 nearly equal K dwarfs.

HD 224930: ADS 17175. VBO, $P = 26.3$ yr, $a = 0''.83$ (WH). IM. A third star has been detected by IR interferometry (McCarthy 1983), but not quoted in IM, considered as uncertain. Spectroscopic elements of the VB by Underhill (1963, PDAO 12, 159): $K_1 = 5.1\,\mathrm{km\,s^{-1}}$(Bat 1468). COR: Other preliminary SB1 orbit. Two companions listed in ADS (*, **): C (m_v 8.6) at 1′.2, D (m_v 13.0) at 9″.8. BS: Comp. C and D probably optical; C is K7V. NLTT: both optical.

4.4. Variable stars without orbit

Adopting a variability criterion of $P(\chi^2) < 0.01$, 16 stars in our complete sample show velocity variations whose origin is not known. The choice of the severe criterion of 0.01 is justified by the discontinuity in the distribution of $P(\chi^2)$ at this level (see Fig. 3). Among these 16 stars without orbit, two may be false alarm detections (1% of the sample). These apparently variable stars have r.m.s dispersions of their radial velocities mostly between 0.4 and 0.6 km s^{-1}. Maybe a few of them have variability related to other causes than duplicity: micropulsations, spots, etc. For example, HD 42807 is a probable photometric microvariable ($\sigma_{\mathrm{mv}} = 0.019$ mag) according to the criterion used by Rufener (1988), but the star also has velocity residuals which suggest long-period binarity.

Some of these stars probably contain one or more discordant measures due to bad observing conditions. At this level of precision, the quality of the focusing, guiding problems, etc. can influence the velocity determination. For example HD 102870 with a $\sigma = 0.32\,\mathrm{km\,s^{-1}}$ is, due to its large number of measurements (IAU standard star), below the 1% level for $P(\chi^2)$ but is certainly not a variable star with such an amplitude, if we consider the observations of this star by Campbell et al. (1988). However, two years ago, two stars (HD 18445 and 89707) had been suspected in this way to be variable (with similar low rms values) and do have now computed orbits ($M_{2_{\min}} = 0.058$ and $0.059\,M_{\odot}$). In 1985 HD 114762 was announced as a probable spectroscopic binary (Mayor & Maurice 1985) due to its abnormal rms and now is known to be a SB1 with $M_{2_{\min}}$ as low as 11 Jupiter masses (Latham et al. 1989).

So very probably some unknown fraction of these 14 stars with $P(\chi^2) < 0.01$ (after subtraction of the two statistically false alarms) are low amplitude spectroscopic binaries resulting from very low sin i, or very low mass companions, or extremely long period. Note that the stars with $P(\chi^2) > 0.01$ may also include some binaries. In Sect. 7.4, we shall use these $P(\chi^2)$-variables only as a constraint to estimate an upper limit to the number of very low mass companions ($M_2/M_1 < 0.1$).

5. Summary of observational data

5.1. The spectroscopic binaries

The available orbital elements for all the SBs in the complete sample are listed in Table 2 (stars without asterisk in this table). Complementary information can be found in the *Notes* (Sect. 4.3).

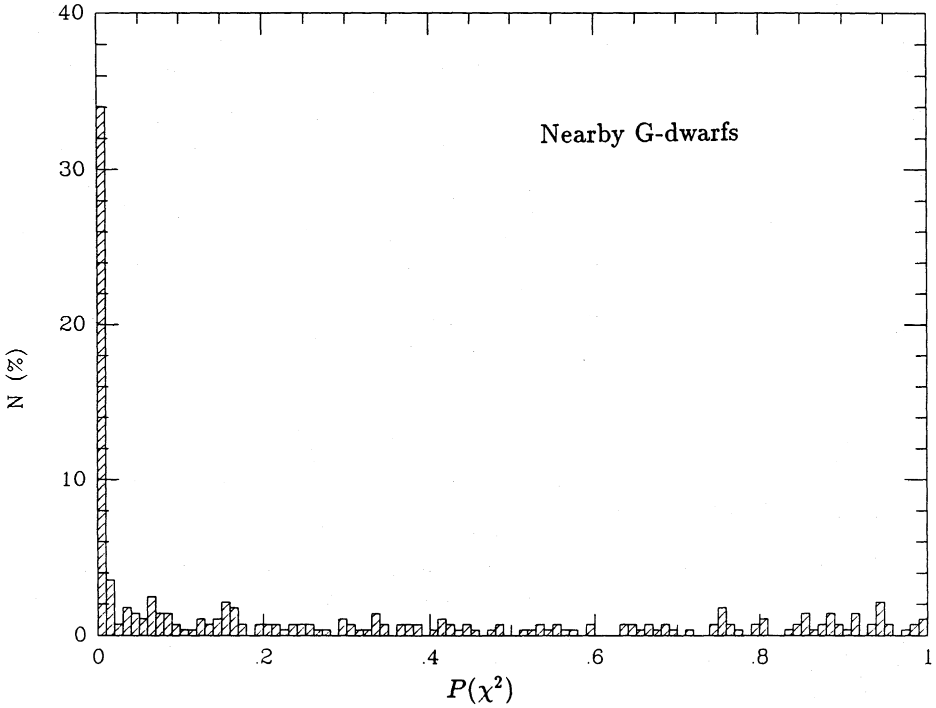

Fig. 3. Distribution of the variability criterion $P(\chi^2)$ among the nearby G-dwarfs, showing the clear discontinuity at $P(\chi^2) = 0.01$. The distribution remains essentially flat for larger values, as expected in a sample of constant velocity stars

5.2. The visual binaries

A rather large intersection is present between SBs and VBs (about 18 stars, see Table 5). Consequently, the orbital elements ($P, e, q = M_2/M_1$) whose distribution will be studied in the next sections of this paper can be derived from Table 2 for a majority of the VBs. We list in Table 3 the elements for the VBs in the complete sample with $P > 10^4$ d, corresponding to the cut-off adopted in Sect. 6 for the kind of method used for the analyses of detection biases.

Table 3. The visual binaries with $P > 10^4$ d in the complete sample, with the physical parameters used for the derivation of the distributions of orbital elements and for the estimation of the detection biases. Spectral types and magnitudes are taken from Gliese (1969), orbital elements are taken from Worley & Heintz (1974)

HD (primary)	Sp	m_1 *mag*	Δm_v *mag*	P *yrs*	e	a "
123	dG4, dG8	6.43	0.77	106.8	0.45	1.43
4614	G0V, M0V	3.45	4.06	480.0	0.50	11.99
16895	F7V, M1V	4.13	5.74	2720.0	0.13	22.29
78154	F7IV-V, K5	4.85	3.59	1067.1	0.81	6.20
82885	G8IV-V, (M6)	5.41	7.60	201.0	0.88	3.84
98231	G0V, G0V	4.33	0.48	59.8	0.41	2.53
108799	G0V, (K8)	6.41	3.80	161.5	0.73	1.39
131156	G8V, K5V	4.68	2.16	151.5	0.51	4.90
133640	G0V, G2	5.25	0.60	225.0	0.43	3.77
137107	G0V, (G8)	5.61	0.25	41.6	0.28	0.91
146361	G0V, G1V	5.69	1.03	1000.0	0.78	6.60
158614	G8IV-V, G8IV-V	6.00	0.10	46.4	0.17	1.02
160269	G1V, M0.5	5.33	2.73	76.0	0.16	1.52
165908	F7V, K5V	5.09	3.35	55.8	0.74	1.00
176051	G0V, (K3)	5.34	2.40	61.2	0.25	1.24
191854	G4V, G8V	8.00	0.42	86.2	0.48	0.46

5.3. The CPM pairs

A search in the literature using the SIMBAD data base at Strasbourg, as well as appropriate catalogues published since the Gliese's catalogue such as BSC (Hoffleit & Jaschek 1982) and NLTT (Luyten 1979a,b, 1980a,b) has been made for complementary information on the common proper motion pairs. The results of this search are included in the Notes (Sect. 4.3). The CPM pairs accessible to CORAVEL (i.e. with $m_v \leq 12.5$) have been measured and their physical binding was confirmed, except for component C of the HD 90839 system (see *Notes* to Table 1). Their velocities have also been listed in Paper I.

With a view to studying the orbital period distribution in our complete sample, we estimated the period of the CPM pairs as follow: the semi-major axis is estimated from the apparent observed separation, by the statistical relation $\log a'' = \log \rho'' + c$. We used $c = 0.13$, the average value between the determinations of Kuiper (1935) and Couteau (1960). Note that AL used $c = \log(\pi/2) \simeq 0.20$. Using a'' with the trigonometric parallax and with an estimate of the individual masses from the observed spectral types of the components, we derive an estimate of the orbital period from Kepler's law. This estimate is likely to be right to within 1/2 dex. We adopted a cut-off for the gravitational binding of the pairs slightly greater than the separation limit used in AL's study. Estimates of this cut-off by several authors (Chandrasekhar 1944; Bahcall et al. 1985) place it between $2\,10^3$ and $2\,10^4$ AU or at an orbital period of about 10^6 yr. We adopted a cut-off of about 10^{10} d (see discussion below) in our study, to show the appearance of the upper tail of the period distribution presented in Sect. 7.3. As the number of stars in the last bin is only 1, this cut-off has no influence on the other orbital element distributions, in particular on the results found for the mass-ratio

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Table 4. The common proper motion pairs in the complete sample. Spectral types are taken from Gliese (1969) and Gliese & Jahreiss (1978) except those in parenthesis which are estimates from the magnitudes. Stellar masses are estimated from a mass/spectral type relation and taking into account the fact that one of the components is sometime double itself. Orbital periods are estimated from a statistical law (see text). An asterisk indicates a CPM too faint and/or too close to be observed with CORAVEL. For the other CPMs, the physical bounding is confirmed by the common radial velocity found by CORAVEL. HD 68146 B and 91889 B are probably SB. HD 140538 shows slow relative motion but is not known to have a visual orbit yet. HD 149414 is discussed in the text

HD (primary)	Sp	log P *days*	Masses $\mathcal{M}_\odot$	
11964	G5, (M2)	6.84	0.9	0.4
13612	dF9, dG4	6.43	2.1	0.9
*19994	F8V, (M1)	5.31	1.2	0.4
35296	F8Ve, dK5	8.74	1.2	0.6
43587	dG0, (M5)	7.56	1.1	0.2
68146	dF7, M3	7.60	1.3	0.3
75732	G8V, M5	7.33	0.9	0.2
*90508	G1V, (M4)	5.64	1.0	0.2
90839	F8V, K7Ve	7.37	1.2	0.6
91889	F8V, (M0)	6.44	1.2	0.5
101177	G0V, K2V	6.13	1.1	0.7
*103095	G8VI, (M5)	4.64	0.7	0.2
103432	dG6, dG7	7.71	0.9	0.8
*115383	G0V, (M6)	6.77	1.0	0.1
118576	(G3, K0)	6.56	1.0	0.7
119124	dF9, (K9)	6.56	1.1	0.5
*120136	F7V, dM2	5.55	1.3	0.4
126660	F7V, M3.5	7.16	1.2	0.3
*140538	dG5, (M3)	5.64	0.9	0.3
*144579	G8V, (M6)	7.18	0.8	0.1
*146361	G0,G1, dM3	8.77	3.1	0.3
*149414	G5Ve, (M4)	9.23	1.2	0.2
160269	G1,M0, M1	8.60	1.5	0.5
187691	F8V, dM4	6.56	1.2	0.2
*190360	G8IV-V, dM6	7.98	1.0	0.1
197076	dG2, (M5)	7.82	1.0	0.2
*207966	G5, (M3)	6.23	0.9	0.3
214615	dG9e, dG9e	5.68	0.8	0.8
*214615	G9,G9, dM	8.02	1.6	0.4
*216777	G6V, (M7)	7.45	0.9	0.1

distribution. This search found 30 CPM pairs in our complete sample, which are displayed in Table 4.13 of them were too faint and/or too close to the primary to be observed with CORAVEL and are assumed to be real physical pairs. An interesting case is HD 189340 which was not known to have any orbital elements before this study, for which the estimated period was only 20 yr and which has now a preliminary set of orbital elements with $P = 4.6$ yr (see Fig. 2 and the Notes in Sect. 4.3).

Another interesting case is HD 149414, relative to our adopted cut-off period. It has a faint CPM companion ($m_v = 15.1$) at 19′.5. Its semi-major axis is estimated by the above approximation as $a \simeq 3\,10^4$ AU $= 0.15$ pc if we use the trigonometric parallax as required for our complete sample, or $a \simeq 0.51$ pc if we use the spectral or photometric parallax. These values are above the currently admitted limit of 0.1 pc for the gravitational binding of binary components. Although the parallax is poorly known, possibly due to the inner spectroscopic binary system of the primary with $P = 133.3$ d (Mayor & Turon 1982) which implies an apparent inner semi-major axis equivalent to half the parallax, it may be worthwhile to look further at the characteristics of that system. HD 149414 is actually a high W-velocity halo star, so this long-lived pair should have had time to disrupt under the effect of cumulative gravitational perturbations after 10^{10} yr (see the results of Retterer & King 1982). But its high W-velocity ($W = -100$ to $-120\,\mathrm{km\,s^{-1}}$ depending on the parallax) obliges it to spend much of its time off the galactic plane, in regions where the stellar density is roughly one tenth that in the disk, reducing the number of possible perturbers. Moreover, the high W-velocity acts to reduce the interaction time with the perturbers. Both of these properties reduce the cumulative effects of the perturbers during the lifetime of the system and make it still observable as a (probably very loosely) bound system despite its large separation. Indeed Eq. 11 of Weinberg (1990) shows that the characteristic time of the process is proportional to the ratio of the relative velocity of the perturbers to their space density. This ratio is about 30 times larger in the case of HD 149414 than for a normal old-disk G-dwarf star. Note that at present the gravitational binding of HD 149414 is not fully confirmed because CORAVEL is not able to measure the very faint companion. This measurement should be done with an appropriate instrument.

Note that there exist three other CPM pairs in our sample with estimated separation between 0.07 and 0.10 pc: HD 35296, 146361 and 160269. All have a low W-velocity, and two have their radial velocities measured with CORAVEL for both components. One (HD 35296) has a velocity difference of $\Delta RV = 0.17 \pm 0.28\,\mathrm{km\,s^{-1}}$ between the components, which confirms their physical binding; another (HD 160269) has a $\Delta RV \simeq 2.3\,\mathrm{km\,s^{-1}}$ with its 738″ distant companion, but the primary is itself a 80 yr period visual binary whose exact γ-velocity is still unknown, so that there is at present no inconsistency in physical binding of the large pair.

5.4. *Observed frequencies of multiple systems*

The complete sample contains 164 primary stars. The secondaries observed with CORAVEL include 17 CPM companions and 17 secondary components of VBs or SB2s. Among the systems with derivable orbital period, we count 62 double, 7 triple and 2 quadruple systems, making a total of 82 orbits, among which 52 have known orbital elements. The observed number of multiple systems appears rather low, compared to their expected high proportion (25 to 50%) among binary systems, according to other studies (Mayor & Mazeh 1987; Mazeh 1990). It is highly probable that some additional multiple systems can still be detected among the nearby G-dwarf binary systems. Such higher multiplicities could be detected through periodic radial velocity residuals of the inner pair, or through the nodal precession effect (Mayor & Mazeh 1987), or by direct imaging of a third star. In fact the method used in the next section to study the incompleteness among each kind of binary probably encompasses the multiple systems that still could be discovered.

The total number of stars implicated in the complete sample is at least 246, so that each primary star has actually 0.5 companion, on the average. The ratios of observed

Table 5. Classification of the binaries in the G-dwarf complete sample according to their nature: SB wO: spectroscopic binary without orbit; SB1O nVB: single-lined spectroscopic binary with orbit, not known as visual binary; SB2O nVB: double-lined spectroscopic binary with orbit, not known as visual binary; VBO SB1: visual binary with orbit and known as single-lined spectroscopic binary; VBO SB2: visual binary with orbit and known as double-lined spectroscopic binary; VB wO: visual binary without orbit; CPM: common proper motion pair

SB wO	SB1O nVB	SB2O nVB	VBO SB1	VBO SB2	VBO nSB	VB wO	CPM
(15)	16	6	7	11	11	1	29

single:double:triple:quadruple systems are 57:38:4:1. This indicates significantly more single stars than in the study of AL, but is in agreement with it if the frequencies found by AL are corrected from the 21 spurious binaries (among 132 primaries) found by Morbey & Griffin (1987). If we use all the stars with $P(\chi^2) < 0.01$ and without orbit as additional multiple systems, the relative observed frequencies become 51:40:7:2 in our sample. The classification of the systems according to the nature of binarity is given in Table 5.

6. Incompleteness study

How many binaries have we missed in our survey? How can we estimate the actual distributions of orbital elements? One has to take into account the detection biases due to instrumental limitations (radial-velocity precision) and to the observational procedure (number of measurements, timespan) which affect particular ranges of orbital elements (high eccentricity, long period, low amplitude, or a combination of these). To derive the correct distributions of mass ratios, one will have also to correct the mass function of the SB1s which depends on the distribution of the orbital inclinations.

The detection effects can be treated in two steps: one concerning the SBs observed with CORAVEL (this work), the other concerning the VBs studied by visual observers. The cut-off period between the two steps may be set at $P_c \simeq 10$ yr, since this is the approximate mean timespan of CORAVEL observations. In fact the simulations of spectroscopic binary detection made below show that we can reliably estimate the detection biases up to $P_c \simeq 10^4$ d. This relatively high value of P_c is important because it means that CORAVEL observations overlap the somewhat less controlled domains (in terms of incompleteness numbers) of the astrometric and interferometric binaries: to our knowledge, no systematic surveys have been done yet with these techniques. This also permits direct contact with the domain of visual binaries for which incompleteness studies have already been made (AL, Halbwachs 1986).

6.1. The spectroscopic binaries

AL used three assumptions to predict the number of unseen spectroscopic binaries:

– A: Random distribution of orbital axes, even within multiple systems.

– B: Failure to detect any SB1 with $K_1 < 2.0\,\mathrm{km\,s^{-1}}$.

– C: Failure to detect any SB2 with $K_1 < 20.0\,\mathrm{km\,s^{-1}}$.

The method we use here is supposed to incorporate these three biases, plus the assumptions D and first part of E of AL which concern primarily the astrometric and interferometric binaries:

– D: Failure to detect any VBs with $a < 0\farcs03$ and $\Delta V > 0.4$ mag.

– E: Failure to measure half of the VBs with $0\farcs3 < a < 1\farcs0$ and $2.0 < \Delta V \leq 3.5$ mag, and essentially all of those with $\Delta V > 3.5$ mag.

Our method consists in simulating the spectroscopic binary detection with CORAVEL, using a sample of fictious binaries with various ranges of orbital elements, and using the actual observational procedure used in our survey. This procedure includes, for each star, the real set of internal velocity error, number of measures and observing dates. We must exclude from this incompleteness study both detected SBs and IAU standards which have received a large number of measures in our survey, and concentrate only on the 101 other stars which were less frequently measured (about 11 observations per star). For each set of fixed (M_2, P), we generate a sample of N binaries. In our tests we used $N = 63125$. The orbital elements (T, ω, i) of these binaries are chosen to be randomly distributed, while the eccentricity is assumed to satisfy the following distribution (see Sect. 7.2 for a discussion of these distributions):

– for $P < 10$ d: $e \equiv 0$.

– for $10 < P < 1000$ d: e follows the eccentricity distribution obtained for the Hyades dwarfs (Mayor & Mermilliod 1983, 1984, hereafter MM; and Burki & Mayor 1985, hereafter BM).

– for $P > 1000$ d: $f(e) = 2e$.

The radial velocity RV is computed from these elements for each of the 101 a priori single stars in our sample. For each star, we compute the RV at the same observing dates as in the real sample, and we add to this RV a random error generated from a Gaussian-like distribution centered on zero and with a sigma equal to the mean measuring error for each star. Then we compute the variability criterion $P(\chi^2)$ as defined in Paper I and if $P(\chi^2) < 0.01$, the binary is declared detected. The results of these simulations in the plane (M_2, P) are shown in Fig. 4 as iso-probabilities of detection. We see for example that we have a 50% probability of detecting a secondary of mass $0.05\,M_\odot$ with a period of 4 yr if the solar-type primary has been observed 11 times with CORAVEL in 3000 d. Note that this probability is higher for IAU velocity standards which received many more measurements ($\simeq 100$ to 200). This is an important point for the discussion of the very low mass companions in Sect. 8.

From Fig. 4 we also deduce that the detection biases are quite negligible for $q > 0.1$ and $\log P < 3$, while for $\log P = 3$ to 4 the detection probabilities vary from 0.75 to 0.95 for $q = 0.1$ to 0.6 and are negligible for $q > 0.6$. For $q < 0.1$, (say for $\overline{q} = 0.06$), the detection probability averaged on orbital periods from $\log P = -1$ to 4 is about 0.75, which means that the real number of objects in this class differs from the observed one by an incompleteness factor of about 1.33.

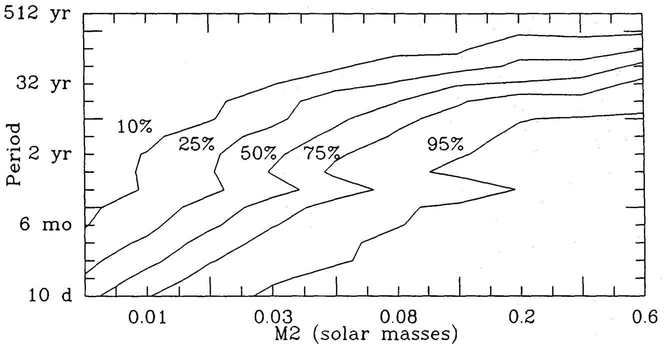

Fig. 4. Detection probabilities for a given orbital period and secondary mass observed with CORAVEL, for typical nearby G-dwarfs primaries observed on average 11 times with a timespan of 8 years. Periods are in logarithmic scale except between 6 months and 2 yr where they follow the sequence 6, 9, 12, 18, 24 months in order to surround the 1 yr period which is affected by seasonal effects. The detection criterion used is $P(\chi^2) < 0.01$

6.2. The visual binaries and the common proper motion pairs

The visual and CPM binaries are treated using two slightly different methods: firstly the method of AL was used with the same incompleteness factors which are functions of the apparent separation ρ and magnitude difference Δm_v between the stars. In particular, this method does not take explicitly into account the occurrence of possible WD components. Secondly we used the method of Halbwachs (1987b), with the same completeness cut-off as function of $(\Delta m_v, \rho)$, and $(m_1, \Delta m_v)$ where m_1 is the magnitude of the primary. But in addition we used a 50% detection probability in order to define the incompleteness after the cut-off, from examination of the Tables 2.3 and 2.4 of Halbwachs' thesis. The adopted detection probabilities are as follow:

100% if $\Delta m_v < \Delta m_1$
50% if $\Delta m_1 < \Delta m_v < \Delta m_2$
0% if $\Delta m_2 < \Delta m_v$

with, for the bias depending on $(\Delta m_v, \rho)$:

$$\Delta m_1 = 2.45\rho^{0.6} - 0.5$$

$$\Delta m_2 = 2.45\rho^{0.6} + 1.5$$

and, for the bias depending on $(m_1, \Delta m_v)$:

if $m_1 < 6.5$: $\Delta m_1 = 12.5 - m_1$
$\Delta m_2 = 13.5 - m_1$
if $m_1 > 6.5$: $\Delta m_1 = 5$
$\Delta m_2 = 7$

Halbwachs (1987b) examined in addition the occurrence of WDs in the sample. The WDs may be treated in 2 ways: either they are added as undetected binaries with a G-type primary, but the WD was thus originally a B, A, or early F-type primary and so the mass-distribution derived will be the present-day distribution of secondaries around present G-type primaries. Or they are discarded from the complete sample in order to deal with the primitive secondary distribution. In both cases, the relative proportion of binaries increases. But in the second case we should also add the few initially late F-type primaries which are now evolved and so do not appear in our complete sample. The second case also addresses the problem of mass-transfer during stellar evolution in close binaries. To simplify, we shall use the first way to deal with the WDs. From statistical considerations of the evolutionary time-scales of A and early F-type stars and from their observed numbers in the solar neighbourhood (thus neglecting B stars), we expect about 2 WDs per decade of period, in agreement with the estimations of Halbwachs (1987b).

7. Corrected distributions of orbital elements

7.1. The eccentricity-period relation

The eccentricity distribution in the complete sample is found to be strongly dependent on the orbital period, as shown in Fig. 5. Therefore this distribution will be discussed in detail in the next paragraph, within each of the 3 period ranges that we propose. We also note here the particuliar position of the multiple systems, specially the triple systems which seem to populate the largest eccentricities for $P > 10$ d. In particular the newly found inner system HD 13612 Aa–Ab which has been rejected from the complete sample due to its probably falsified parallax, appears to have a unusual high eccentricity ($e = 0.69$) for a period of less than 100 d. Similarly, the present highest reliably-known eccentricity for any kind of binary belongs to the nearby triple system HD 137763 ($P = 890$ d, $e = 0.975$, CORAVEL orbit to be published; CPM with HD 137778). Several questions arise such as: are purely double systems (multiplicity strictly equal to 2) with $10 < P < 1000$ d and high eccentricity so rare? Are there preferential orbital elements for triple systems? Are such high eccentricities for inner systems of triple systems indications of their formation process, for example by evolution of small stellar systems (van Albada 1968a,b; Harrington 1975)?

7.2. The eccentricity distribution

As suggested by Fig. 5 and following the idea of division of the orbital periods in three classes, as proposed by MM and BM for the distribution of the eccentricities in open clusters, we find for the sample of nearby G-dwarfs:

i) For P less than a certain value identified as the circularization period $P_{\rm circ}$, all the orbits are circularized due to tidal interactions that occurred either in the pre-main sequence stage, or on the main sequence where $P_{\rm circ}$ would then depend on the age (see e.g. Zahn 1977, 1989; Zahn & Bouchet 1990; and with a different approach Tassoul 1987, 1988). In our sample, the period of the last circularized binary (HD 13974, GOVe) and that of the first eccentric binary (HD 17433, G9Ve) are respectively 10.02 and 13.20 days, which situates $P_{\rm circ}$ around 11.6 d. We reject the case of HD 110010 with $P > 3000$ d whose orbit is not completely covered and can tolerate an eccentricity range of 0 to 0.3 (see Notes in Sect. 4.3) without changing significantly the present (O–C) values.

One could use the value of $P_{\rm circ}$ to derive an estimate of the absolute age of the galactic disk (to which our sample statistically belong), from the circularization theories. Unfortunately, the circularization time $t_{\rm circ}$ appears to depend drastically on the factor $(R/a)^8$ (Zahn 1989), equivalent to a dependence as $P^{16/3}$. It depends basically on the knowledge of the convection in the stellar interior which is still limited and prevents a reliable absolute determination of $t_{\rm circ}$. The limitations and uncertainties of this kind of clock for age determination are reviewed by Mathieu &

Mazeh (1988). We emphasise however that one should be careful in using such a clock, especially if we consider the study of Hut (1981) showing the great variety of combined evolutions of the parameters (a, e) (or P, e) with time, under the effects of tidal forces in short period binaries. Such evolution may alter substantially the initial distribution of these elements and lead to spurious ages. As an indication, Eq. (8) of Mazeh & Shaham (1979), also derivable from Eq. (4.3) of Zahn (1977) after some assumptions, suggests that the orbital period generally decreases with e^2, i.e. much more rapidly in eccentric orbits, and this in turn accelerates the circularization process although the initial period was relatively large. Furthermore, the observed cut-off in the $(e, \log P)$ plane is not only a function of age but also of the distribution of orbital eccentricities. Let us also recall the recent analysis of Zahn & Bouchet (1989), who argue that the orbital circularization is essentially achieved during the pre-main sequence phase up to orbital periods of about 7.5 days for low-mass stars, and who reject the use of such a clock for stars on the main sequence.

However, in the context of Mathieu and Mazeh's clock hypothesis, a relative age may be proposed, using the different values of $P_{\rm circ}$ obtained in several studies (see Table 6). We find that the $P_{\rm circ} \simeq 11.6$ d proposed here is statistically in agreement with the expected mean age of the galactic disk. However, two kinds of stars could have polluted this result due to the age mixing in our sample:

– Young stars (e.g. with age $\simeq 5\,10^8$ yr, statistically about 20% of our sample) could have exhibited binaries with $P < 11$ d not circularized yet; the relevant binary to be used in that case for disk-age determination would be the binary with the highest period around 10 d with $e = 0$.

– Old stars could have produced a SB1 with $P \simeq 1000$ d and circular orbit, provided the present secondary is a degenerate star (white dwarf, or WD). Such a secondary was initially a primary B or A star, which during the giant phase of its evolution has circularized the orbit of its solar-type companion, now observed as SB1 primary. This could be the case of HD 110010 if further observations yield a circular orbit for this binary. But Barry (1988) gives an age of only $2\,10^8$ yr for HD 110010 which then probably does not contain an evolved star. It is thus expected that further determinations of the eccentricity will yield $e \neq 0$ as adopted in Table 2.

In fact the eccentric binary with the shortest period is HD 17433 whose classification is controversial. A discussion of this star by Duquennoy & Mayor (DM, 1988) tentatively concludes that its spectral-type is near KOIV–V, while it is classified G9e by Gliese (1969). According to their model of spectral type, the star now appears about 0.8 mag above the main sequence. Taking the tables of evolutionary star models of Maeder & Meynet (1988) for the low-mass stars, we derive ages from 8.4 to 13.6 Gyr if the initial mass of HD 17433 ranged from 1 to 0.85 $M_\odot$. However, HD 17433 is classified as Ge-type and the space velocity distribution of Ge stars in the solar neighbourhood is similar to that of A stars (Mayor 1972), giving a maximum kinematical age of about 1 Gyr for HD 17433. Such an estimation is also in agreement with the expected number of young G dwarfs. Note that stellar activity may as well be supported (but not increased) by short period binarity (Basri 1987; Young et al. 1987). The rotational velocity of HD 17433 is $V \sin i = 9.5 \pm 1.0\,{\rm km\,s^{-1}}$. DM explored the possibility of reconciling such a high rotation with the hypothesis of an old, evolved primary. If it were as old as 5 Gyr, such a large $V \sin i$ would be in complete disagreement with the observed decay of stellar rotation with age (for example Barri 1988; Mayor & Mermilliod 1990). In fact the relatively large rotation, the high level of chromospheric activity and the kinematics of HD 17433 are probably more in agreement with a young, unevolved star.

Table 6. Circularization periods due to tidal forces as a function of the sample age, and eccentricities observed in the period range $P_{\rm circ} < P < 10^3$ d. Sources: (1) MM, BM; (2) Mathieu & Mazeh 1988; (3) Latham et al. 1988; Jasniewicz & Mayor 1988; (4) This work; (5) Maeder and Mermilliod, from fitting isochrones; (6) Liebert et al. (1988) from cooling times of white dwarfs, and Grenon (1989) from maximum limiting isochrones

Sample	P_{circ} *days*	Age $10^9 yrs$	$\bar{e}$ $P_{circ} < P < 10^3 d$
Hyades and Praesepe	5.7 (1)	0.7 (5)	0.33 ± 0.03
M 67	10-11 (2)	5 (5)	0.37 ± 0.06
Old disk	> 10 (4)	7 – 11 (6)	0.31 ± 0.04
Halo	12-19 (3)	≃ 15	0.33 ± 0.03

There is a third method to estimate low-mass star ages, which uses their rotational period and the magnetic braking law. Kawaler (1989) derives a mean age of $4.5\,10^8$ yr for the Hyades with this method. CORAVEL observations yielded also the $V \sin i$ for our programme stars, but not directly the rotation periods. Careful statistical analysis of this material could be done in a further paper.

ii) For stars with $P_{\rm circ} \leq P_{\rm orb} \leq 1000$ d, called tight binaries, the eccentricity distribution is 'bell shaped' (see Fig. 6a) with a maximum for $e \simeq 0.3$, as in the case of open clusters (MM, BM). The mean eccentricity is $\bar{e} = 0.31 \pm 0.04$ for the nearby G-dwarfs, to be compared with $\bar{e} = 0.33 \pm 0.03$ for young open clusters and also $\bar{e} = 0.33 \pm 0.03$ for halo SB stars in the same period range (see Table 6). Moreover, in advance of the discussion presented in Sect. 8 we find $\bar{e} = 0.34 \pm 0.07$ for tight binaries with very low mass secondaries ($M_{2_{\rm min}} \leq 0.1\,M_\odot$). These striking results show that the mean eccentricity of non-evolved tight binaries ($P_{\rm circ} \leq P_{\rm orb} \leq 1000$ d):

– is independent of the population (halo or disk);

– is independent of the mass of the companion.

Thus, keeping in mind the possible influence of age mixing invoked above, this class of binary may reflect the initial binary formation process. In this hypothesis, binary stars formed with a near-zero eccentricity would be rare. Note that the limiting period of 1000 d is somewhat arbitrary and appears at present only as an ad hoc cut-off. Note also that out of the limits of our so-called complete sample, exist two exception cases with HD 89707 ($P \simeq 298$ d, $e \simeq 0.93$) and HD 114260 ($P = 20.5$ d, $e = 0.56$) which substantially populate the upper tail of the eccentricity distribution. As they are not found to belong to triple systems, at least at present, they prove that binaries may form with simultaneous short period and high eccentricity, in response to one of the questions of Sect. 7.1

iii) For $P_{\rm orb} > 1000$ d, larger eccentricities are found in the sample and one has to take into account detection biases. According to simulations made by Harrington & Miranian (1977), we expect incompleteness factors of about 1.2 and 2.0 for the bins $e = 0.60$–0.75 and 0.75–0.90 respectively. Figure 6b shows that the corrected eccentricity distribution tends reasonably toward the normalized $f(e) = 2e$ (see Fig. 6b) which is expected if that

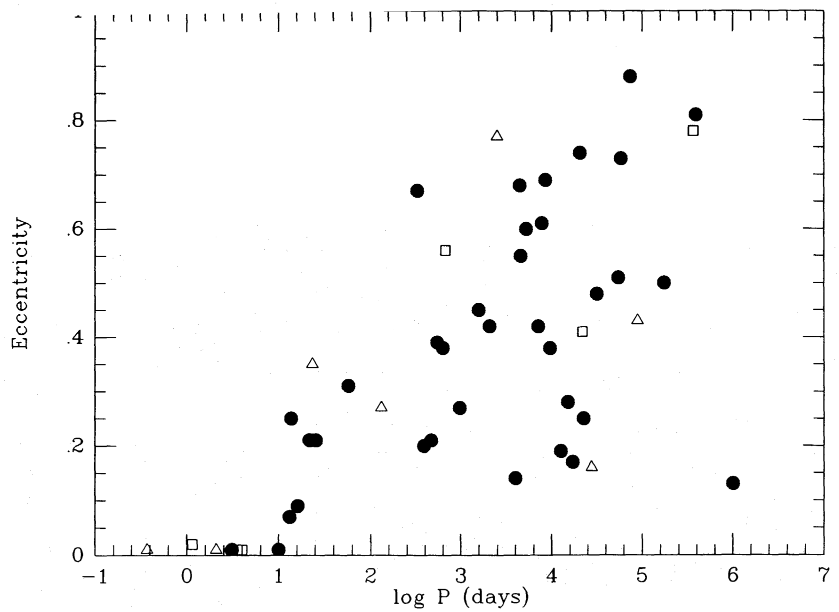

Fig. 5. Diagram eccentricity versus period for the complete nearby G-dwarf sample. Note the strong circularization effect due to tidal stresses for short periods binaries. The symbols are according to the multiplicity of the system: ● double, △ triple, ☐ quadruple

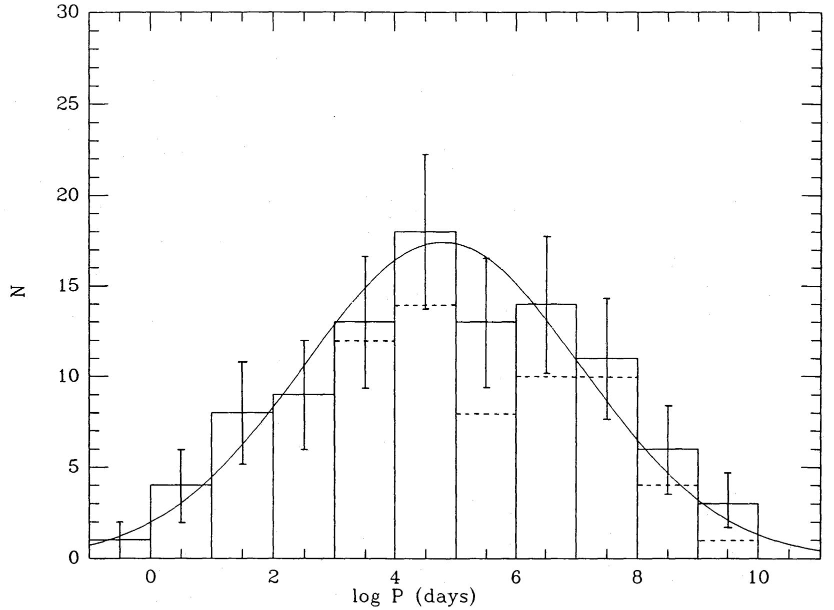

Fig. 7. Period distribution in the complete nearby G-dwarf sample, without (dashed line) and with (continuous line) correction for detection biases. A Gaussian-like curve is represented whose parameters are given in the text

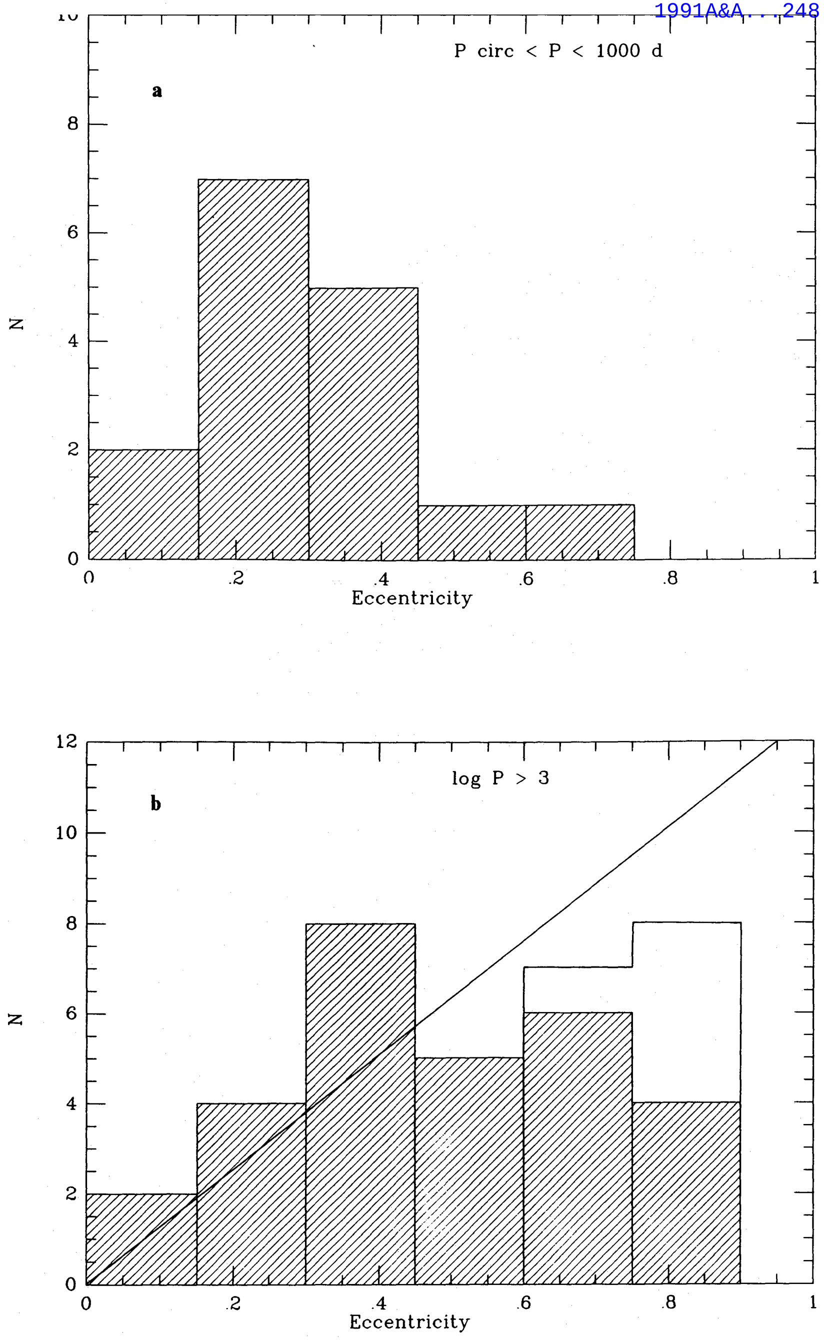

Fig. 6a and b. Eccentricity distributions in the complete nearby G-dwarf sample. **a** For $P_{\mathrm{circ}} < P < 1000\,\mathrm{d}$, the distribution is bell-shaped. **b** For $P > 1000\,\mathrm{d}$ without (hatched) and with (white) correction for detection biases. The distribution $f(e) = 2e$ here normalized to $N = 34$ systems is represented with a continuous line distribution is a function of energy only (Ambartsumian 1937). We note in particular the scarcity of circularized binaries in that period range. The same result is obtained by MM for young open clusters. Such a distribution can result from the dynamical disruption of small stellar systems (Van Albada 1968a,b; Harrington 1975). Note that Harrington (1975) finds a distribution which is flatter at high eccentricities. See also the distributions found by Anosova (1989) for various dynamical processes concerning unstable triples.

7.3. The period distribution

With all known spectroscopic, visual and cpm pairs in our G-dwarf sample of 164 primaries, the resulting period distribution for 82 systems is shown in Fig. 7 (dashed lines). It has been corrected from detection biases according to the methods described in Sect. 6 applied to each decade of period, and we found that a total of about 19 undetected systems (mostly visual) are expected in our complete sample. The corrected distribution also shown in Fig. 7 presents a single maximum for $P_{\max} \simeq P_{\text{median}} \simeq \overline{P_{\text{orb}}} \simeq 180$ yr. This value is to be compared with the much smaller value of 14 yr found by AL in their survey of solar-type bright stars. The difference between the two results may have two sources:

i) The magnitude-limited sample of AL tends to favour the inclusion of SB2s, brighter than single stars of same type, and these SB2s have apparently often short periods because of the difficulty in resolving the components of low amplitude (i.e. usually long period) binaries, which then appear only as SB1.

ii) The over-interpretation of the velocity data by AL, which led them to include a number of spurious short period binaries (Morbey & Griffin 1987; Duquennoy & Mayor 1988). The dangers are deriving semi-amplitudes too close to the velocity precision of each measurement or eccentricities based on one single discordant velocity or based on poor orbital coverage.

The distribution of the orbital periods in our sample appear remarkably symmetrical and may be approximated by the following Gaussian-type relation (see representation in Fig. 7):

$$f(\log P) = Cst\exp\left\{\frac{-(\log P - \overline{\log P})^2}{2\sigma^2_{\log P}}\right\}$$

where $\overline{\log P} = 4.8$, $\sigma_{\log P} = 2.3$, and P is in days.

It is interesting to compare this distribution with that obtained by Griffin (1985) for two different samples (see Fig. 8). The first one, the sample of binaries among giant stars, show some depletion at low value of the period ($\log P < 2$ or 2.5). This could be explained by the fact that these systems suffered mass-transfer when evolving through helium-flash, if the primaries have masses below about 1.8 $M_{\odot}$. The second one, the sample of dwarf stars in the Hyades field, seems to show an excess of short period binaries ($\log P = 0$ to 1) compared to our G-dwarf sample, but agrees perfectly for the larger periods. This comparison suggests a possible evolutionary effect in the distribution of the periods, since the Hyades sample is statistically younger than our sample. The origin of such an effect is not explained yet: could combined variations of (P, e) under tidal effects as discussed in Sect. 7.2, followed eventually by coalescence (Webbink 1976) of some systems, explain this difference between the two period distributions? Or could it be the mechanism which is invoked to produce W UMa-type systems, known as AMLOSC (Angular Momentum Loss in Orbit-Spin Coupled binaries, see Huang 1966; van't Veer & Maceroni 1989, for $P = 4$–5 d)? Indeed the characteristic time scales of this later mechanism are the following: i) less than 10^9 yr for the approach time, ii) about 10^8 yr for the contact phase and iii) about 10^7 yr for the coalescence. So for orbital periods less than 4–5 d, some of which possibly come from periods initially around 7–8 d and decreased through tidal processes mentioned above, the timescales seem even smaller than the age of young star samples such as the Hyades. This means that some of the short period Hyades binaries could be affected by this mechanism, producing a temporary excess of short period binaries which may disappear later due to coalescence.

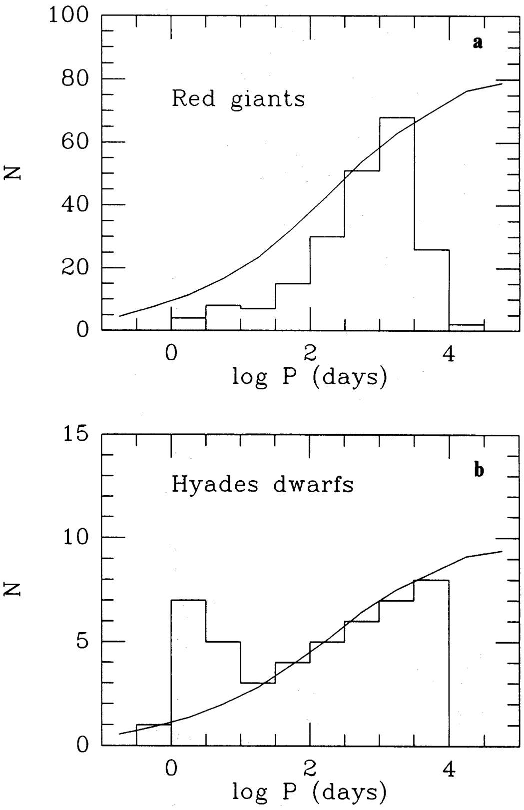

Fig. 8a and b. Comparison of the Gaussian-like curve fitting the nearby G-dwarf sample period distribution with 2 observed period distributions studied by Griffin (1985). **a** Red giants. **b** Hyades dwarfs

Anyway, the prediction of Griffin (1985) that the frequency of binaries as a function of $\log P$ is a monotonically rising function valid to period larger than 3000 d is fully confirmed by the present study.

7.4. The mass ratio distribution

7.4.1. The detection biases

To examinate the biases affecting the mass-ratio distribution, we must once again consider the various aspects under which the binaries appear:

i) The visual and CPM binaries are treated using the two methods described in Sect. 6. Comparing the results given by the two methods, we find that without consideration of the white dwarfs (WDs), the global numbers of undetected binaries for $\log P = 4$ to 10 are 12.5 and 13 for the AL (1985) and Halbwachs

(1987b) methods respectively, and thus are very similar. If we take into account the WDs, we expect about 2 WDs per decade of period (see Sect. 6). Some of these WDs must exist among the SB detected in our sample and are subject to the same detection biases as the SB1s treated in ii). The remaining about 8 WDs expected for $\log P = 4$ to 8 affect the range q = 0.4 to 0.8, if we assume a mean WD mass of $0.6\,M_\odot$ around a F7–G9 primary. They will be equally distributed in this period range. The number of undetected binaries with $\log P = 4$ to 10 in the complete sample increases the total number of VB and CPM with $q > 0.1$ from 47 to 67 (see some details in Table 7), in reasonable agreement with the 19 undetected binaries expected in the period distribution discussed in Sect. 7.3. This relatively high number of undetected visual binaries may be related to the finding of Upgren et al. (1986) that stars down to $M_\mathrm{v} = 14$ are completed only out to 13 pc.

ii) For the SBs ($\log P = -1$ to 4), we also estimated the unbiased q-distribution from two similar methods. For given observational conditions (velocity precision, timespan, number of measurements), the SB detection depends on the semi-amplitude K_1, which decreases with increasing P and decreasing M_2, sin i and e. The simulations made in Sect. 6 allow correction for the simultaneous action of these parameters on the observed distribution of the mass function. Using these mass functions, with the mass of the primary estimated by the mass/spectral-type relation, gives minimum mass ratios which can be distributed among larger mass ratios according to the probabilities of different orbital inclinations. The second method is the one used both by Abt & Levy (1985) and Halbwachs (1987a), who used directly the mass function distributions for SB1s and SB2s to derive the true q-distribution. In the case of the SBs in our sample, the incompleteness factors in each bin of q are generally small and the difference between the two methods never exceeds 10%. This confirms the argument of Trimble (1990) that the incompleteness studies are little dependent on the method used, and rather much more dependent on the star sample selected.

7.4.2. Number of binaries with $q < 0.1$: upper limits

The advantage of the second method is that it estimates the number of expected low-inclination binaries (that we may call VLI SBs) in our sample. We find, to a precision of 0.1 SB, that all the observed SB1s with smallest mass-functions (indicative of $q < 0.2$ if they had sin $i = 1$), may be statistically considered as due to the SBs with $q > 0.2$ with unfavourable sin i, if orbital inclinations are randomly distributed (see Table 7). In other terms, this means that the VLIs have all been detected down to $q = 0.2$. It means also that the low-amplitude SB candidates (without orbit) that we observe in our sample are not due to low-inclination orbits with $q > 0.2$, but due primarily to a combination of long period and $q < 0.2$ SBs, or due only to low q if long periods can be ruled out from examination of the (O–C) velocity residuals which can be of two types: oscillations (long periods ruled out) or long-term velocity gradient. From the detection probabilities shown in Fig. 4, very few of these candidates (less than 10%) are expected to have both $q > 0.2$ and $\log P = 3$ to 4.

In our sample, 16 stars among the primaries have $P(\chi^2) < 0.01$. After subtraction of the expected number of false alarms (2 stars), we still have 14 SB candidates. Although among these 14 candidates there may be a certain fraction of non-binaries (see Sect. 4.4), we can use them to estimate an upper limit to the number of very low mass companions (VLMCs) in our sample. About half of them can be attributed to binaries with $q = 0.1$–0.2, and the other half to $q = 0$–0.1. Taking into account the detection probabilities for $q = 0 - 0.1$ and assuming that VLMCs have a period distribution similar to that of companions with $q > 0.1$, we estimate the number of VLMCs as 23, or 13.9% of the primaries, in the period range $\log P = -1$ to 10. This corresponds

Table 7. Correction of detection biases for the mass-ratio distribution among G-dwarf binaries as a function of the orbital parameters (P, i, M_2). Numbers between brackets are less certain. Lines 1 to 3 concern SB1 and SB2 stars: (1): observed distribution for systems with orbits, obtained as if sin $i = 1$. (2): same as (1) but corrected from a sine distribution of the orbital inclinations (2a), plus observed VLMC candidates discussed in the text (2b). (3): same as (2) but corrected from SB detection probabilities with CORAVEL. For VB and CPM systems: (4): observed distribution. (5): same as (4) but corrected from the detection biases as described in the text (white dwarfs included). Line (6): merge of both sets of binaries; the bin $q = 0$–0.1 is obtained from the average between the upper and lower limits derived from CORAVEL observations of SBs, extended to the domain of VBs and CPMs (see text)

q_{max}	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
	$P < 10^4 days$										
(1)	1	4	7	6	5	4	2	1	1	2	1
(2a)	-0.3	1.1	5.6	5.5	5.5	5.9	3.0	0.9	1.2	1.6	2.9
(2b)	[4.3]	[6.0]									
(3)	[5.6]	[7.6]	6.1	5.9	5.7	6.0	3.0	0.9	1.2	1.6	2.9
	$P > 10^4 days$										
(4)	0	7	9	8	5	6	3	3	3	3	0
(5)	[8.4]	9	14	12	8	8.5	5	5	3	3	0
(6)	[14.0]	[16.6]	20.1	17.9	13.7	14.5	8.0	5.9	4.2	4.6	2.9

(roughly) to the proportion we gave in a previous preliminary study (Duquennoy & Mayor 1990). The difference is that we use here the criterion $P(\chi^2) < 0.01$ to define our VLMC candidates, instead of $P(\chi^2) < 0.05$ previously. We stress that this upper limit of about 14% for VLMCs is for the whole range of periods, less than half of them having periods smaller than $\log P = 4$.

On the other hand, Campbell et al. (1988), with much better velocity precision (typical rms of about 0.020 km s^{-1}), have measured a sample of 16 dwarfs for six years. They have detected two SBs with rather large amplitudes (HD 39587 and 222404), but they found no velocity variations corresponding to VLMC with $q = 0.01$–0.10. However, they have detected variations corresponding to possible companions with much lower masses ($< 0.01\ M_\odot$). We can use this absence of detection to estimate an independent upper limit for the fraction of VLMCs. If we suppose that the fraction of VLMCs orbiting around G-dwarf stars is x, we can estimate the probability of having no VLMC discovery in a sample of 16 stars. Due to the high precision of Campbell's technique, we assume 100% detection probability. We find that we have a less than 5% chance to detect less than 1 VLMC if the fraction x is 17%, and that we have a less than 10% chance to detect less than 1 VLMC if $x = 13\%$. This fraction x does not include the full range of possible periods. To correct for the whole range of periods, we must increase these upper limits by a factor of at least 1.5. So the Campbell et al. survey at a level of 10% of probability sets an upper limit of about 20% for the fraction of (sub-)stellar companions in the range $q = 0.01$–0.10.

7.4.3. Number of binaries with $q < 0.1$: lower limits

We try now to derive a lower limit to the number of probable brown dwarf companions. It is interesting to consider here the cases of HD 18445, 89707 and 114260 which all have computed orbits with $M_{2_{\min}} < 0.1$. They all are out of the limits of the complete sample studied here, but the purpose of this complete sample was essentially to avoid an over-representation of the SB2s, which are different from the objects discussed here. Moreover they have declination $\delta < -15°$ and their spectral types are still in the range F7–G9. The only important bias affecting these three systems is orbital inclination, and we still expect from its distribution the $q = 0$–0.1 bin to contain 2.6 stars. Correcting for the CORAVEL detection probabilities of Sect. 6.1 by a factor of 1.3 for these objects, we have then 3 to 4 such systems with $\log P = -1$ to 4, and about 9 over the whole period range if they follow the same period distribution as the systems with $q > 0.1$, out of an extended sample (down to $\delta = -25°$) of 188 F7–G9 primaries. The lower limit to the proportion of 'soft brown dwarf' (since the calculation is actually based on candidates of mass above $0.058\ M_\odot$) companions among nearby G-dwarfs then appears to be about 4.7% of the primaries, which is low but definitely not zero. Taking into account the very small number of detected objects, the true lower limit is about 1.9%. This value corresponds to the lowest fraction of VLMCs compatible with our estimation of 9 VLMCs among 188 stars at the 5% confidence level.

With the same candidates and assuming a random distribution of orbital inclinations, we can also compute the probability that there exists no companion below a certain mass M in the G-dwarf sample. This is equivalent to saying that our VLMC candidates have all a mass above M. For $M = 0.10\ M_\odot$ we find that this probability is 0.014 and for $M = 0.08\ M_\odot$ it is 0.113 (see Table 9).

Finally, an interesting remark can be made: our simulations of SB detection with CORAVEL as a function of M_2 and P made in Sect. 6.1 can be convolved with the real frequency distribution of the orbital periods to give the expected shape of the observed (detection-biased) period distribution for each fixed secondary mass. This gives an indication of the period range where a given secondary mass can be detected through the CORAVEL process. The results are given by Fig. 9, which shows that the 6 VLMC

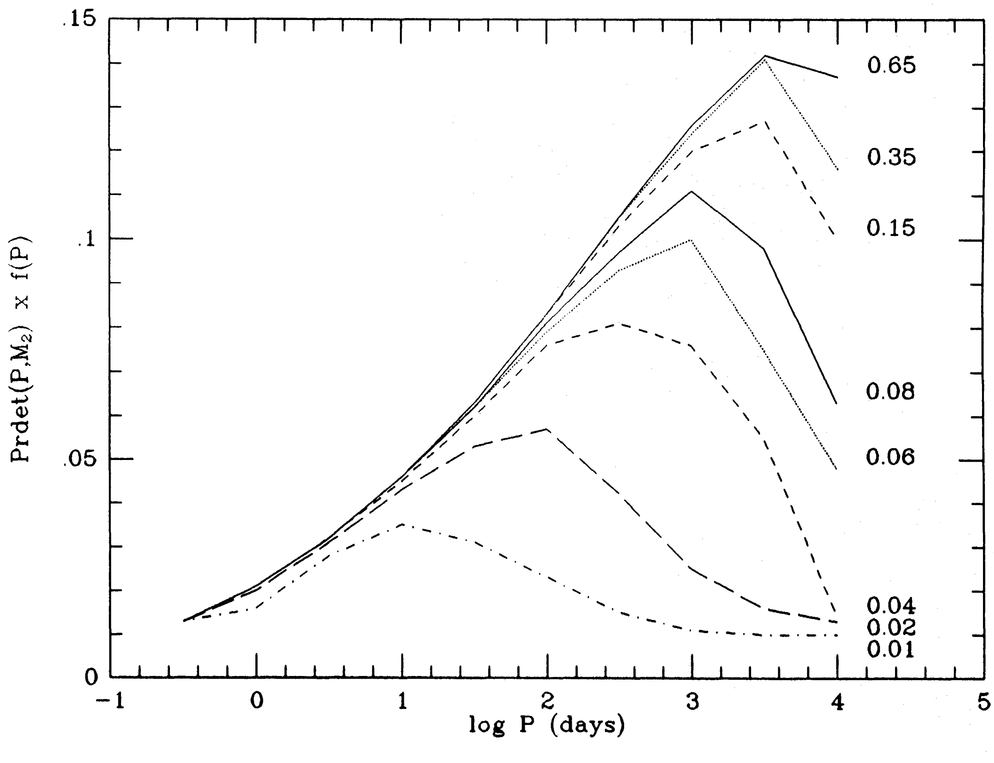

Fig. 9. CORAVEL secondary detection probabilities combined with the observed period distribution, showing the zones of best detection conditions in orbital periods for a given secondary mass (given in solar masses in the right margin)

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candidates (with $q \sim 0.05$) statistically expected with $\log P < 4$ in the complete sample should (again statistically) fall in the period range 1–10, 10–10^2, 10^2–10^3 and 10^3–10^4 days in the proportions 0.7, 1.4, 2.1 and 1.8. This means that we have the highest chance to detect VLMCs in the period range 10^2–10^3 days. Note that in practice in our survey, deriving orbits of systems belonging to the last bin of $\log P = 3$–4 would be unwise (mean P of 3000 d, hardly one cycle covered, very low velocity amplitude, and a mean of 11 measurements), although we can find a couple of such candidates in our sample (HD 4813, 20630, 42807). We also recall that the semi-amplitude K_1 of an SB may be expressed by

$$K_1 \propto f(M)P^{-1}(1-e^2)^{-3/2}$$

which means that the detection is also favoured among high-eccentricity orbits, if the number of observations is large enough. Both period and eccentricity characteristics of HD 18445, 89707 and 114260 fill the conditions of best detection probabilities, and this could explain why they are the first VLMC candidates to be found. Of course it would be of great interest to observe HD 18445 and HD 89707 with both visible and IR speckle interferometry, these stars having a sufficiently long period to search for the visibility of their secondary, in order to check the validity of the suggestion that they contain VLMCs.

7.4.4. Modelling of $\xi(q)$ and discussion

To summarize, the mass-ratio distribution in our G-dwarf sample is shown in Table 7 and Fig. 10. The important features are:

i) There is no maximum for $q = M_2/M_1 = 1$.

ii) The shape of the distribution is well fitted by one of the models derived by Kroupa et al. (1990) for the field mass function of low mass stars. They used the result of a recent study on the stellar luminosity function and a mass/luminosity relation derived from both theoretical models and observational points obtained from binary stars. The mass function called 'GS' in their paper, with the same value of the adjusted parameters (μ, σ,) is represented by a dashed line in Fig. 10:

$$\xi(q) = k\exp\left\{\frac{-(q-\mu)^2}{2\sigma_q^2}\right\}$$

where $q = M_2/M_1$, $\mu = 0.23$, $\sigma_{\rm q} = 0.42$, (and $k = 18$ for our G-dwarf sample). We note that the Miller and Scalo law is also admissible. The distribution below $q = 0.23$ could also be flat but probably not increasing after a plateau, the observed distribution in that range being still very uncertain. For comparison, the dashed curves corresponding to the models called 'MS' (Miller & Scalo law) and 'SL' (Salpeter power law) are also shown in Fig. 10. Of course, we are unable to state anything below $q = 0.01$, a domain which is not accessible with CORAVEL, where probably the fragmentation process stops (Boss 1987) and where other mechanisms such as fission followed by accretion may become dominant to form planetary-size objects.

The similarity of the mass functions for low-mass field stars and for secondary masses of nearby G-dwarf stars agrees with the idea of a binary star formation by random association of two stars formed with the same IMF. If such a scenario is acceptable for very long period binaries, probably for tight binaries the agreement between the observed $\xi(q)$ and the hypothesis of random association is fortuitous. We thus have examined the possibility of a difference in $\xi(q)$ as a function of the orbital period and computed the probabilities for the parent distributions to be different (see Fig. 11). With the dividing period of 100 yr suggested by AL applied to our G-dwarf sample, we find only a marginal 70% probability that the difference between the two populations of binaries above and below 100 yr is not fortuitous. Besides, the same probability is found to be 99% for the bright field stars, according to the data given by AL, and about 75% for K dwarf stars studied by Halbwachs (1987). The latter result seems consistent with our result for G-dwarf stars, while the difference with AL's result may come from the selection biases already discussed.

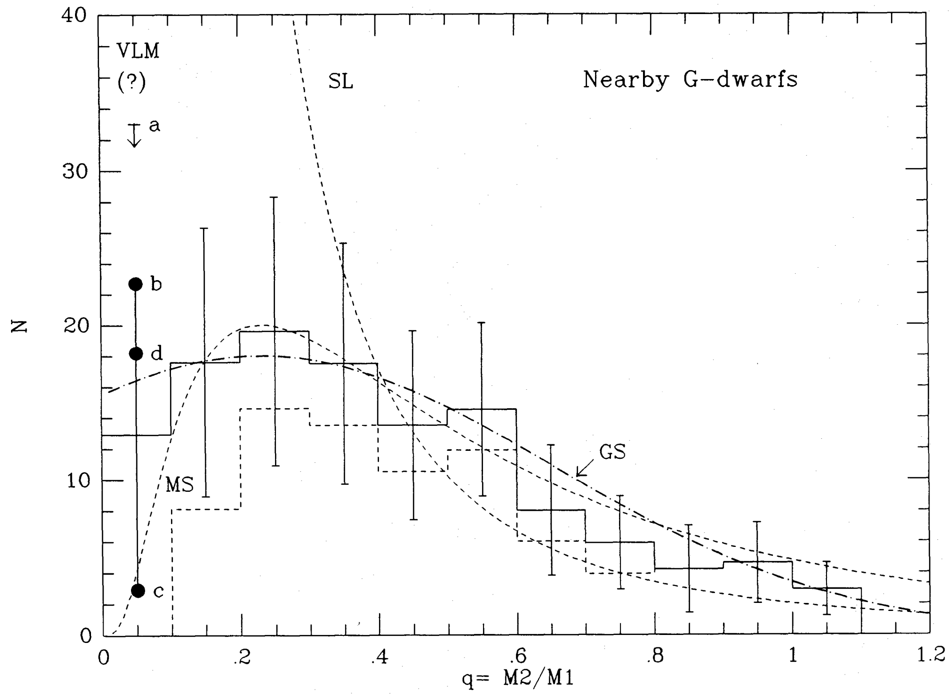

Fig. 10. Mean mass-ratio distribution in the complete nearby G-dwarf sample binaries. Histograms: dashed = observed, continuous = corrected for detection biases. Dashed curves: set of IMFs given by Kroupa et al. (1990) for field single stars: MS = Miller and Scalo, SL = Salpeter, as in their paper. The Gaussian curve (GS) seems to represent the best fit, although large uncertainties remain for the bin $q = 0$–0.1 of very low mass companions, as it result from the present observational constraints: (a) upper limit from the study of Campbell (1988), (b) and (c) resp. upper and lower limit in the nearby G-dwarf sample (this work), (d) estimated proportion among IAU velocity standards (this work)

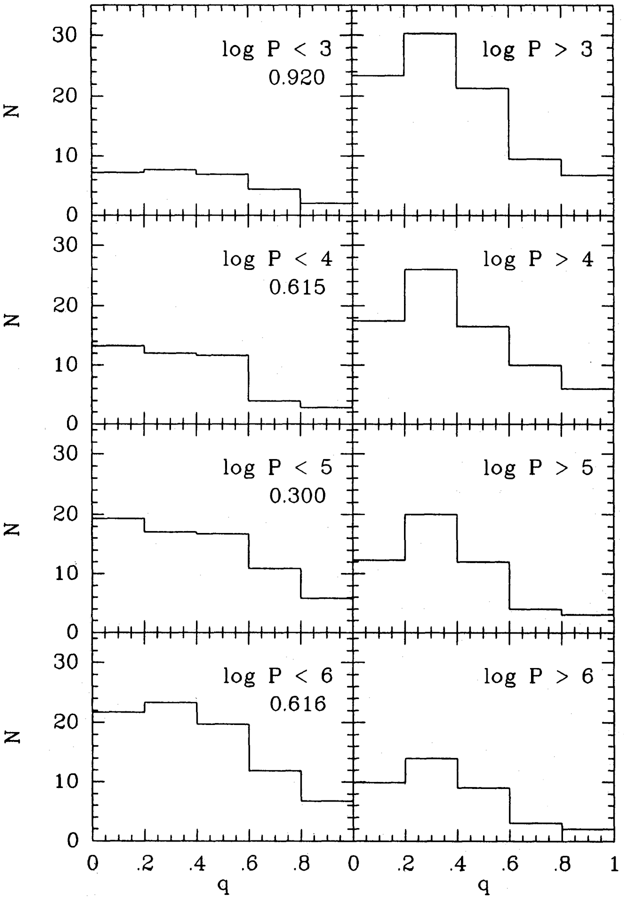

Fig. 11. Aspects of the mass-ratio distribution in the complete nearby G-dwarf sample for various period ranges. $\log P$ is in days, the second number is the probability that the difference between the two parent distributions below and above the limiting period is due to chance. No significant changes are seen in the shapes of the distribution

In a preliminary report (Duquennoy & Mayor 1990), we had found in our sample a statistically much more significant change for a dividing period of 1000 d in the distribution $\xi(q)$. We stated in this report: "if for $P > 1000$ d the distribution remains close to the mean observed $\xi(q)$, on the contrary for $P < 1000$ d the distribution seems to be quite constant for all values of q". However in the present paper, we find this early result too fragile, due to the small numbers of stars for large values of q and for $P < 1000$ d. We have seen in particular the importance of the parallax determination for stars at the edge of the sample. A few uncertain determinations around $\pi = 0''.045$ may considerably falsify the true distribution of q by inclusion in the complete sample of actually remote SB2 (such as HD 13612) or SB1 with $P \simeq 1$ yr (such as HD 20727) (see Sect. 3). In conclusion, we think that it is still premature to speculate on a possible deviation to the mean mass-ratio distribution for a given cut-off period (although it may exist), until more accurate parallaxes become available.

However a firm result from this study is that large q binaries among nearby G-dwarf stars are definitely not preponderant, even for low-P binaries. Such a distribution confirms the recent evaluations of Halbwachs (1986, 1987a), Scarfe (1986), and Trimble (1987, 1990). However the various samples used by these authors were initially affected by rather larger selection effects than ours, and the q-distribution obtained in our study appears somewhat more straightforward at least for $q = 0.1$–1.0. This consideration strengthens the merit of these authors to deal successfully with the selection effects, and also seems to establish definitely the character of the real q-distribution, essentially decreasing when q increase.

This confirmation should arise new interests in the binary formation theories which have some difficulties to form preferentially binaries with q close to 1, both by fragmentation (Boss 1987, 1988; Pringle 1989) and by fission (Lucy 1977).

8. The very low mass companions and the real multiplicities

By very low mass companions (VLMCs) we mean here $M_2 \leq 0.1\,M_\odot$ or $M_{2_{\rm min}} \leq 0.1\,M_\odot$. Some fundamental astrophysical issues in this domain are:

i) the behaviour of $\xi(q)$ for $q \leq 0.1$;
ii) what fraction of solar type stars are really single?
iii) is there a lower limit to the mass M_2 of the companion?
iv) the study of the transition from stars to brown dwarfs and to giant planets.

Point i) has been investigated in some details in the previous section. In particular we showed that according to the method we used for correcting detection biases, the number of expected SBs in the bin $q = 0$–0.1 may be comparable to that observed in the bin $q = 0.1$–0.2. We recall that we have no certain detection (i.e. with orbit) yet in the complete sample, but only candidates. Extending the sample to declination $\delta = -25°$, we have 3 SBs with orbit and $M_{2_{\rm min}} < 0.1\,M_\odot$ (HD 18445, 89707 and HD 114260). In the complete sample we expect between 3 and 23 VLMC with a mean secondary mass of $0.06\,M_\odot$ over the whole range of orbital periods ($\log P = -1$ to 10), or an average of $(8 \pm 6)\%$ of the primaries. This result is not necessary in contradiction with the study of Campbell et al. (1988) who find no brown dwarf candidates in a similar type of stars, given the small number of stars (16) observed in his sample (see Sect. 7).

8.1. *Comparison with the IAU standard stars sample*

It could be interesting to check the result we obtain for the G-dwarf stars by searching another sample of stars for which we could also estimate the proportion of VLMCs. The IAU (and other) velocity standard stars observed with CORAVEL provide more than 100 stars with 8000 velocity measurements, a $\Delta T \simeq 4500$ d and a precision of 0.2 to 0.3 km s^{-1}. These stars have typical masses close to one solar mass. From this extremely well measured sample, we extracted 6 SB with derivable orbits (and several other candidates, to be published in a further paper) and $M_{2_{\rm min}} \leq 0.10\,M_\odot$. Among these SBs (see Table 8), 5 are giant stars, of which 3 have derived periods around 500 d (one of these, HD 3346, has an orbit published by McClure et al. 1985 including CORAVEL observations), and only 1 is a dwarf (HD 114762, see Latham et al. 1989 for an orbit also including CORAVEL observations). We are aware of the paper of Walker et al. (1989, WYCI below) who suggest the possible existence of a new class of velocity variables among 'yellow' (K-type) giants. These variables would have characteristic periods and amplitudes of about 1 yr and 0.03–0.3 km s^{-1} respectively. However, two main differences exist in the data between the two samples:

Table 8. Photometry of very low amplitude spectroscopic binary candidates detected among velocity standards with CORAVEL and discussed in the text. σ_v and σ_c respectively are the visual and colour magnitude dispersions in 0.001 mag. P_{orb}, K_1, e and $f(m)$ are preliminary orbital elements from CORAVEL observations

Stars		Photometry			CORAVEL			
		BSC 1982	Rufener 1988		P_{orb}	K_1	e	$f(m)$
HD	Sp		σ_v	σ_c	*days*	kms^{-1}		$\mathcal{M}_\odot$
3346	K5-M0III	-	5	10	572	0.69	0.07	$1.4\ 10^{-5}$
35410	K0III	-	5	2	1492	1.88	0.62	$6.0\ 10^{-4}$
44131	M1III	var	4	4	3393	1.18	0.31	$5.0\ 10^{-4}$
114762	dF7	-	7	6	84	0.57	0.25	$1.4\ 10^{-6}$
115521	M2IIIa	var	12	26	509	1.54	0.36	$1.3\ 10^{-4}$
123782	M1.5III	var	-	-	494	0.87	0.21	$1.8\ 10^{-5}$

– The variations of 5 out of the 6 K-giants studied by WYCI have velocity amplitudes of 0.1 km s^{-1} or less, while the amplitudes found for our 5 K and M-type giants all exceed 0.7 km s^{-1}.

– The variations of the former seem to be more randomly distributed than those of the latter, although no strong affirmation about periodicity can be made due to the relatively small number and sparsity of the former data. All our giants except HD 115521 allow relatively well-determined period and orbital elements if binarity is assumed.

Three mechanisms are usually invoked to explain the observed velocity variations among cool giants: pulsation, binarity, and surface features (spots, flares, convection cells). In the first and last cases, one would expect photometric variations accompanying the velocity variations. This is the case for all WYCI's giants, as reported by them and according to the Bright Star Catalogue (Hoffleit 1982). In addition, no clear periodicity, but at best a characteristic time-scale, can be observed among both photometric and velocity variations for WYCI's giants. Some of them may have rotation periods of the order of 1 yr, corresponding to the time-scale of the life-time of large convective cells expected in the atmosphere of red giants ($\simeq$200 d, see e.g. Schwarzschild 1975). But the data of WYCI are still too sparse to give a continuous view of the phenomenon. In our sample, only 3 out of the 5 giants are possible or suspected photometric variables according to the BSC. They all are M-giants, not K-giants, and 1 of these 3 (HD 44131) is not confirmed as variable according to the variability threshold of the Geneva photometric system. Moreover, the period, amplitude and phase coverage for HD 44131 exclude the possibility of surface features. HD 115521 in our sample may be the least credible case for a SB, because the phase coverage is somewhat poor. But HD 123782, although being a known photometric variable, may be rejected as having velocity variations due to surface features because the velocity variations appear reasonably regular over several cycles (the descending branch is observed at least 5 times). This is also the case for HD 3346 which has same characteristics but with still better phase coverage.

Now we examine the case of pulsation. The K-giants are found in the HR-diagram between 2 classical variability regions: Cepheids and RR-Lyrae on the 'blue' side (instability strip) and Miras on the red side. But as quoted by WYCI we would not expect periods greater than about 100 d for Cepheids or RR Lyrae-type pulsations. Furthermore, all K and M-giants have surface temperature quite far from the temperature which define the variability strip of Pop. I Cepheids (about 5950 K if we use relations given by Iben & Tuggle 1975). HD 3346 is the star closest to this instability strip with an estimated $T_e \simeq 4040\,K$ and $P \simeq 570$ d. We analyzed its velocity curve with a computer program for pulsation analysis (Burki & Meylan 1984). We find that if pulsation occurs in HD 3346 with a 570 d period, the stellar radius variation would reach $10\,R_\odot$ comparable to the giant's radius, which would have been detected with other techniques. On another hand, Miratype pulsation is also excluded because of the lack of observed large photometric variations. Consequently, we believe that at least 5 out of the 6 velocity variables among our standard star sample are strong candidates for SBs with VLMCs, i.e. all except maybe HD 115521.

This sample of standard stars can be considered as being extracted from a larger sample (say $\sim$140 stars) of various luminosity class objects of roughly one solar-mass, whose large amplitude binaries (in same proportion $\simeq$ 30% as that observed for the nearby G-dwarf stars) have been removed. With 5 certain detections (i.e. with orbits, but several other candidates exist without orbits yet) among 100 stars, and rejecting 0.6 probable false VLM due to low $\sin i$ ($i < 29°$ means the averaged secondary is actually above $0.1\,M_\odot$), we have again 4.4 candidates in three dex of $\log P$. We use detection probabilities similar to those in Fig. 4 but adapted to the different observational procedure for standard stars (large numbers of measures), and to the lower mean minimum secondary mass detected (0.048 instead of $0.066\,M_\odot$). We assume that the period distribution found in Sect. 7.4 is valid for the standard stars, giving a correction factor of about 2.5. We thus expect 14 VLM or 10% of the initial sample, which agrees reasonably with the proportion of (8 ± 6)% estimated for the nearby G-dwarfs. Moreover, the VLMC candidates among the standard star sample are distributed in period in the same proportions as those statistically expected from detection simulations in the G-dwarfs sample (see Sect. 7.4) and assuming the period distribution found in Sect. 7.3 is valid. Conversely, we can use this interesting agreement as an indication that VLMCs among velocity standards follow the same period distribution as the G-dwarfs.

Finally, we can compute the probability that there exists no companion below a certain mass M in the IAU standard stars sample, as we did for the G-dwarfs. If we reject the star HD 114762 (which is the strongest candidate and biases the calculation of probabilities), these probabilities are 0.001 for $M = 0.10\,M_\odot$ and still 0.005 for $M = 0.08\,M_\odot$. These probabilities are summarized in Table 9 for both star samples. Including HD 114762, the probability for $M = 0.08\,M_\odot$ is less than 6.10^{-5}.

Table 9. Summary of VLMC candidates among 1) nearby G-dwarfs, 2) IAU velocity standards, and probabilities that there is no companion below a given mass $M_{\odot}$, assuming a random distribution of the inclinations. *: HD 114762 excluded

	Star	$\mathcal{M}_1(\mathcal{M}_{\odot})$	$\mathcal{M}_2(\mathcal{M}_{\odot})$		Probabilities that	
	HD	assumed	minimum	probable	$\mathcal{M}_2 > \mathcal{M}(\mathcal{M}_{\odot})$	
			(i=90°)	(i=57°)	$\mathcal{M} = 0.10$	$\mathcal{M} = 0.08$
1)	18445	0.92	0.058	0.070	0.199	0.327
	89707	1.19	0.059	0.072	0.162	0.345
	114260	0.87	0.082	0.099	0.442	1
	cumulated				0.014	0.113
2)	3346	1.2	0.027	0.033	0.042	0.065
	35410	1.1	0.088	0.114	0.695	1
	44131	1.2	0.083	0.113	0.674	1
	114762	1.0	0.013	0.014	0.006	0.011
	123782	1.2	0.030	0.036	0.050	0.078
	cumulated				0.001 *	0.005 *

8.2. *The real multiplicities and implications for the missing mass*

Let us come back to our sample of 164 nearby G-dwarf primaries. Among them, an observed percentage of 44% have a companion with $M_2/M_1 \geq 0.1$. The incompleteness study made on the mass ratio distribution indicates that probably 22 systems with $q > 0.1$ remain undetected, mainly with long orbital periods. Thus the corrected proportion of multiple systems, with a number of components more than or equal to 2 and $q > 0.1$, is probably close to 57%. Their companions represent 30% of the total mass of the primaries. Among the 43% apparently single remaining stars, a significant large proportion, maybe about 20%, or $(8 \pm 6)\%$ of the total sample of primaries, could have a VLMC in the mass range 0.01–0.10 $M_{\odot}$. Consequently, about one third of the G-dwarfs primaries may be real single stars, i.e. with no companion above 0.01 $M_{\odot}$. This result is a rather high percentage compared to recent standards, for example that found by AL who claimed that 100% of the G-dwarf primaries may have a stellar or degenerate binary companion. However their result is based partly on spurious SBs which probably led to overestimate the real multiplicities (see Sect. 2).

What are the consequence of this estimated number of VLMCs for the local missing mass? If we assume that the mass function of the field VLM primary stars is the same as for the secondaries around the G-dwarf stars, their expected number in the solar neighbourhood is about 3 times the number of G-dwarfs. We should then have about 1000 VLM primaries in a sphere of radius 22.5 pc. If we assume a mass ratio distribution independent of the spectral type of the primary, the number of VLM secondaries around F to M dwarf stars in the same sphere is less than 500. The mass density of all VLM degenerate stars (0.01–0.10 $M_{\odot}$) is then less than 0.002 $M_{\odot}\,\mathrm{pc}^{-3}$ and is a negligible contribution to the local mass density. We may recall here the recent works of Kuijken & Gilmore (1989 and references therein), whose conclusion is that there is no dynamically significant missing mass in the galactic disk near the Sun.

8.3. *Is there an orbital distinction between stars and planets?*

Now we consider the following 3 sets of stars:

i) The IAU (and other) standard stars observed with CORAVEL and examined in detail above. In this sample we derived 5 orbits of SBs with probable VLM secondaries (Table 8).

ii) Among published astrometric studies, we selected 7 astrometric binaries that seemed to have reliable with orbits and $M_2 \leq 0.10\,M_{\odot}$ (Table 10).

iii) Inspecting a sample of dM stars observed with CORAVEL for 12 years, we found another 7 SB with derivable orbits and $M_{2_{\min}} \leq 0.10\,M_{\odot}$ (Table 10, velocities to be published except for Gl 319).

These three sets give a VLM sample of 19 binaries with $\overline{M_{2_{\min}}} = 0.057\,M_{\odot}$. Their companions may thus be considered as probable 'soft' brown dwarfs, in the sense that they statistically appear below the usual hydrogen burning mass limit, but not too far from it. Fig. 12 is a plot of e vs $\log(M_{2_{\min}})$ for the nearby G-dwarf sample (SBs with $P \leq P_{\mathrm{circ}}$), the VLM sample, and the 4 giant planets of the solar system.

The mean eccentricities for the three sets are 0.31 ± 0.04, 0.34 ± 0.07 and 0.04 ± 0.01 respectively. This visually provocative result addresses the problem of the transition from stars and brown dwarfs to planets. The planets in the left part of the diagram represent in fact only one system, but at present it is the only one known. However the striking difference in the eccentricities strongly suggests one formation process for stars and 'soft' brown dwarfs, and another for the planets. Boss (1987), and Pringle (1989), find that the fragmentation process may explain many of the observed properties of binary and multiple stars, but is an unlikely source of brown dwarf companions and planetary systems less massive than 0.01 $M_{\odot}$. Instead, fission is known to favour the formation of disks or debris around a central star (Lucy 1977; Durissen et al. 1986) which may in turn favour planetary formation by accretion. Keeping in mind that the present lower limit to our secondary mass detection is similar to Boss' (1987) lower mass limit for fragmentation, the following questions arise:

i) Can we find any companion in the mass range 0.001–0.010 $M_{\odot}$?

ii) If yes, what is the eccentricity of its orbit?

The possible planetary companion to HD 222404 found by Campbell et al. (1988) could soon give an answer. But clearly one would need more such candidates in this fascinating range of masses.

Table 10. Sample of VLM secondaries among astrometric binaries from various sources and among spectroscopic binaries among K- and M-dwarfs observed with CORAVEL. For the latter, only preliminary orbital elements and the minimum secondary mass are given; in some cases more observations are needed to confirm the orbit. Catalogue names: Gl = Gliese (1969), GJ = Gliese & Jahreiss (1978)

Star	Sp	P_{orb} days	e	$\mathcal{M}_2$ $\mathcal{M}_\odot$	Source
GJ 1005	M4.5	1680	0.10	0.055	Ianna et al. 1988, A.J. 95, 1226
Gl 234	dM4.5	6100	0.38	0.06	Lippincott and Herschey 1972, A.J. 77, 679
Gl 301	dM0	195	0.17	0.10	CORAVEL
Gl 319	dM0	21	0.23	0.09	Duquennoy and Mayor 1988, A.A. 200, 135
Gl 473	dM6	5900	0.28	0.05	Heintz 1989, A.A. 217, 145
Gl 489	dK6	2530	0.63	0.09	CORAVEL
Gl 494	dM2e	1348	0.25	0.04	CORAVEL
Gl 623	M3.5V	1350	0.58	0.07-0.09	Marcy and Moore 1989, Ap.J. 341, 961
Gl 687	M3.5V	9500	0.90	0.01-0.07	Lippincott 1977, A.J. 82, 925
Gl 696	dM2	628?	0.27	0.03	CORAVEL
Gl 748	dM4	878	0.59	0.09	CORAVEL
GJ 1245	M6Ve	5480	0.33	0.10	McCarthy et al. 1988, Ap.J. 333, 943
Gl 806	dM3	2300	0.50	0.02-0.08	Lippincott 1979, P.A.S.P. 91, 784
Gl 873	M4.5	10600	0.44	0.01-0.02	van de Kamp and Worth 1972, A.J. 77, 762
Gl 886	K4V	458	0.66	0.08	CORAVEL

9. Conclusions

We have studied an unbiased sample of 164 primary G-dwarf stars in the solar neighbourhood with the help of 4200 radial velocities obtained in almost 13 yr. We have derived several present-day distributions of the orbital elements. For the systems with $M_2/M_1 > 0.1$ in the nearby G-dwarf sample, we find the following results:

i) The orbital period distribution is unimodal and can be approximated by a Gaussian-type relation with a median period of 180 yr.

ii) The short period binaries are circularized up to orbital periods of ~11 d due to the tidal evolution effects, a result compatible with the mean age of the galactic disk.

iii) The tight binaries not affected by tidal effects ($11 < P < 1000$ d) may reflect the initial binary formation process, and they have a mean eccentricity $\bar{e} = 0.31 \pm 0.04$.

iv) The remaining binaries ($P > 1000$ d) have an observed distribution, when corrected from detection biases, which tends smoothly toward $f(e) = 2e$.

v) The mass-ratio distribution shows no maximum for $q = 1$, but rather an increase toward small secondary masses, at least up to $q \simeq 0.3$. This result is similar to those of the most recent studies made by Halbwachs (1986, 1987a), Scarfe (1986) and Trimble (1987, 1990). We find that this distribution is well represented by a Gaussian-like relation similar to that found by Kroupa et al. (1990) for field low-mass stars, with a maximum for $q \simeq 0.23$. We think premature to see a difference in the distribution for some cut-off period of 100 yr or less.

Concerning the systems with $M_2/M_1 \leq 0.1$, we have studied the chances of detecting them with CORAVEL. Using the simulations of Sect. 6 for the nearby G-dwarf sample, we tentatively derived the proportion of $(8 \pm 6)\%$ VLM secondaries mentioned above. We emphasize that we have yet no firm detection (i.e. with orbit) in the complete sample, but that we have three candidates in the extended sample. Only a high precision and long term radial velocity study of a large sample will clarify the observed percentage of brown dwarf companions to cool dwarf stars. Such a study is in progress with CORAVEL for a special subsample of about 100 'constant velocity' G–K stars, observed each month with long integrations yielding a mean precision of 0.1 km s^{-1} for each measurement.

Among two other samples, the IAU velocity standards and the dM stars, CORAVEL detected and derived the orbits for 11 SB (some of them reported by Duquennoy & Mayor 1990) with probable VLM secondaries ($M_{2_{\rm min}} \leq 0.1\,M_\odot$), around low mass primary stars. In addition, we found in the literature 7 astrometric binaries with VLM secondary candidates. We note however that none of them is definitely below the hydrogen burning mass-limit, if error bars are taken into account (see for example Fig. 5 of McCarthy et al. 1988). These 18 stars lead to the following results:

i) The proportion of brown dwarf companions among the IAU velocity standards is estimated at 10% of the primaries, a value in rather good agreement with that found in the G-dwarf sample.

ii) The brown dwarfs (from 0.01 to 0.1 $M\odot$) among the three samples may not be as rare as quoted by Campbell et al. (1988) around solar mass stars, or by Marcy & Benitz (1989) around M-dwarf stars. But they do not seem to be numerous enough to contribute significantly to the local missing mass.

iii) The mean eccentricity for these VLM secondary binaries with $11 < P < 1000$ d is $\bar{e} = 0.34 \pm 0.07$. We preliminarily conclude that the binary formation process (by fragmentation ?) seems to be the same for stars and for brown dwarfs, and different from the process that produces the very small eccentricities observed for the giant planets of the solar system.

According to the present study and from the recent theoretical views, we find some consistency in the idea of a dominant formation process for all the binaries with $M_2 > 0.01\,M_\odot$ inde-

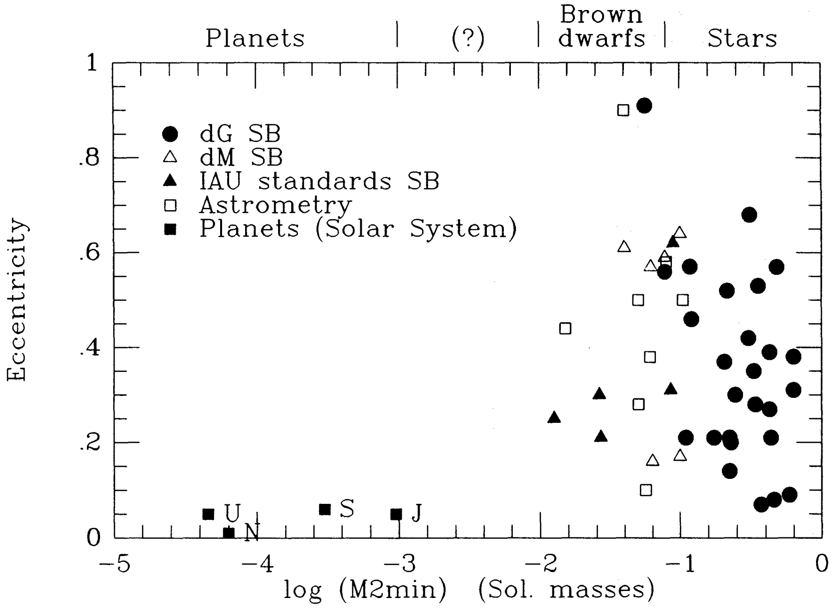

Fig. 12. Diagram eccentricity versus secondary masses for various kind of secondary object, from stars to brown dwarfs and planets. This diagram may be an indicator of the different modes of formation of multiple systems at the two edges of the mass spectrum between 0.001 and 1 $M_\odot$, and also shows the present missing link in the mass range 0.001–0.010 $M_\odot$

pendent of the orbital period (see Figs. 10 and 11 of this paper) which would be fragmentation (Boss 1987; Pringle 1989), and of a different formation process for objects below 0 001 $M_\odot$ (see Fig. 12) which could be fission (Lucy 1977; Durissen et al. 1986).

Finally, we ask the question if orbits of companions in the mass range 0.001–0.010 $M_\odot$ can be found around G-dwarf primaries, and if yes, whether their eccentricities are different from zero. The latter could be information about their formation process and could become a test to distinguish if we deal with stars (or brown dwarfs) or real extra solar system planets.

Similar studies on duplicity remain to be done with K and M stars in the solar neighbourhood, to allow direct comparisons with the nearby G-dwarfs. This question is of great importance since K and M dwarfs represent respectively about 10 and 60% of the total number of stars in our galaxy. Important contributions (e.g. Tokovinin 1988; Marcy & Benitz 1989) have been published recently but do not include yet a full description of the orbital elements among low-mass stars. We hope to be in position to discuss the K and M part of our survey in the near future.

Acknowledgements. We are deeply indebted to the CORAVEL observers who participated in this survey, and whose names have been listed in Paper I. Thanks are given to M. Imbert for providing 5 unpublished measures made by him with the CORAVEL, used in the calculation of the mean velocities quoted in Table 1 for HD 89125B, 119124B, 187691C and 215648B. 30 measurements obtained for 17 stars in common with a Danish-Swiss collaboration, not published in Table 1, have also been used to compute the mean velocities for these stars. We thank here J. Andersen and B. Nordström for allowing the use of these unpublished measurements. We thank again the Toulouse observers J.-M. Carquillat an N. Ginestet for the use of some of their measurements published in Paper I, and the technical staff E. Ischi and B. Tartarat who ensured a perfect maintenance of both CORAVELs during the whole 13 years necessary to achieve this survey. We also thank Bruce Campbell, Roger Griffin and David Latham for valuable comments and discussions, and V. Trimble for her kind help and acting as the referee. This work has been partly supported by the Fonds National de la Recherche Suisse.

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Note added in proof. Dr. H. Jahreiss has kindly made the following remarks on Table 1:

1. The spectral types of Gl 54.2 A and B should be exchanged.
2. Gl 398.1 is only an optical companion according to NLTT.
3. There are two records for Gl 392.1 with different HD numbers and RV's.

The authors wish to thank Dr. Jahreiss for his remarks and would like to answer them as follows:

1. Yes (misprint).
2. Overlooked. The effect on the general conclusion of our paper is of course negligible.
3. In fact the star HD 89862 has no Gliese number and should have a spectral type K0IV in Table 1. This star was among our programme stars in accordance with the note on HD 90839.