

THE FREQUENCY AND FORMATION MECHANISM OF B2–B5 MAIN-SEQUENCE BINARIES

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ABSTRACT

We obtained about 20 coudé spectra of each of 74 B2–B5 IV or V stars and combined the results of their radial velocities with a previous study of 42 similar stars. We list new, improved, or published orbital elements for nine known double-lined and 26 single-lined (13 new, 13 known) spectroscopic binaries. In addition we list data for 49 visual companions (two with orbital elements, four showing orbital motion, six occultation or speckle companions, and 37 common proper motion pairs). Seven deletions are made because the systems met the selection criterion ($B \leq 6.00$ mag) only because they are double. Attempts are made to allow for undetected systems with secondary masses $\geq 1 M_{\odot}$.

We find that systems with periods of 10^{-2} to 10^5 yr have secondary frequencies that fit the Salpeter luminosity function (but not the van Rhijn function), and therefore the systems were formed primarily by capture. For systems with periods shorter than 10^{-2} yr = 3.6 days, the separations of components are only a few stellar radii, so they have probably undergone mass transfer and their secondary masses tell us nothing directly about the formation mechanism.

In the reduced sample of 109 stars we detected 32 spectroscopic and 49 visual companions, implying 0.7 observed companions per primary. After allowance for incompleteness, we find at least 0.8 companions of $M_2 \geq 2 M_{\odot}$ per primary or 1.9 companions of $M_2 > 1 M_{\odot}$ per primary. These are minimal values because new components are still being discovered, especially with speckle interferometry and occasionally among the remaining variable velocity stars.

Consideration of these results for the B2–B5 stars and published results on Am and F3–G2 stars show secondary luminosity or mass functions that can be explained entirely in terms of a capture mechanism for binary formation. That is, the widely spaced (visual) binaries in each case follow the Salpeter (or van Rhijn) function as one would expect in first- or early generation captures. For the closely spaced (spectroscopic) binaries with ages less than about one free-fall time (i.e., the B2–B5 stars), multiple capture processes have not had time to occur, so the secondary mass function is also a Salpeter function. But for the older stars (Am, F3–G2) that have probably existed in clusters for many free-fall times, the multiple captures have allowed the formation of hard binaries with mass ratios near 1. Thus binary formation by fission or bifurcation, which was proposed earlier but has been difficult to achieve theoretically for compressible viscous gases, may not occur frequently or ever.

Subject headings: stars: binaries — stars: early-type — stars: formation — stars: stellar statistics — stars: visual multiples

1. INTRODUCTION

There are two or more ways that have been proposed for the formation of binaries, and these lead to different secondary mass functions. Binary formation by fission or bifurcation of a contracting rotating protostar has predicted (classically for incompressible nonviscous gases) the formation of binaries with mass ratios near 1. But for capture in a cluster consisting primarily of low-mass stars, the first generations of binaries with high-mass primaries will mostly have low-mass companions. Thus observations of the frequencies of secondaries of various masses may distinguish between these two binary formation mechanisms.

An earlier study (Abt and Levy 1978, hereafter AL78) of spectroscopic binaries among B2–B5 IV or V (mostly field) stars seemed to show a decreasing number of secondaries

with decreasing secondary mass. Thus the conclusion of AL78 was that the B type binaries of orbital periods less than about 10 years formed by fission or bifurcation. For the longer periods the numbers of secondaries of various masses fit well the van Rhijn or Salpeter functions, implying a formation of those binaries by capture.

However the AL78 study was based on only 42 nonemission stars of which 23 had spectroscopic or visual companions. Such numbers are too small to derive accurately a secondary luminosity or mass function.³ Thus we planned a study done with similar equipment and methods of 74 more stars to produce more reliable results.

There have been more recent studies of B type binaries. One by Wolff (1978) of spectroscopic (i.e., short-period) binaries among late B type stars also showed a decreasing

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²Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

³However, it might be mentioned that AL78 was planned for another reason, namely a comparison of Be and B binary periods.

frequency of binaries with decreasing secondary mass, although with an apparent increase for secondary mass $< 10^{-1} M_1$. A study by Halbwachs (1987) of cataloged binaries showed no difference between short- and long-period binaries in the frequencies of various mass ratios, i.e., both showed increasing frequencies with decreasing masses down to a mass ratio $Q (= M_2/M_1) = 0.4$. However, one can argue that the cataloged binaries do not represent an unbiased sample because astronomers tend to obtain orbital elements for double-lined spectra and stars showing large velocity amplitudes but usually ignore the small-amplitude systems that are hard to measure and analyze.

In the following sections we define our new sample, list and describe the spectroscopic observations, analyze the stars for spectroscopic and visual duplicity, present and discuss the revised secondary mass function, and synthesize the results for early- and intermediate-type main-sequence stars.

II. OBSERVATIONS

The original AL78 study included all 42 of the B2–B5 IV or V stars brighter than $B = 5.00$ mag and north of -30° declination in the list by Slettebak and Howard (1955). Their spectral types are still consistent with more recent ones. The new sample included 74 stars with $5.00 \leq B \leq 6.00$ mag and $-20^\circ < \delta < +70^\circ$ from the list by Lesh (1968), which also has excellent spectral classification. The northern limit of the coudé feed telescope caused us to eliminate only HR 1289 at 83° . For each star we obtained approximately 20 coudé spectra, and we added (below) the published astrometric data.

The spectra were obtained with the 1 m aperture Kitt Peak coudé feed telescope and the coudé spectrograph built for the 2.1 m telescope. We used the 309×370 mm “B” Bausch & Lomb grating of 316 grooves mm^{-1} and the 622 mm focal length camera No. 2 to give a dispersion of $16.9 \text{ \AA mm}^{-1}$ in the third order blue-violet. This gives spectra 0.4 mm wide and $0.015 \text{ mm} = 18 \text{ km s}^{-1}$ in resolution on Kodak IIa-O emulsions. The stellar lines measured were the He I lines $\lambda\lambda 3819, 4009, 4026, 4143, 4387$, and 4471 and the Mg II line $\lambda 4481$.

The velocity standards observed for instrumental stability were HR 2943 = α CMi (13 spectra), HR 4054 = 40 Leo (11 spectra), HR 5340 = α Boo (19 spectra) and HR 8969 = ι Psc (42 spectra). The velocity corrections applied were $+1.7 \text{ km s}^{-1}$ during JD 2,443,296–2,443,676 and -1.5 km s^{-1} during JD 2,443,677–2,444,700. The break occurred at the time of change of measurers from Levy to Gomez.

The spectra were measured on a PDS microphotometer as described in the Appendix of AL78. The internal standard deviations were 1.3 km s^{-1} for $V \sin i = 0 \text{ km s}^{-1}$, 3.0 km s^{-1} for $V \sin i = 50 \text{ km s}^{-1}$, and flat at 4.0 km s^{-1} for $100 < V \sin i < 300 \text{ km s}^{-1}$. The external standard deviations for stars judged to have constant velocities were 1.4 times those values at each value of $V \sin i$. It is significant that the accuracies are essentially independent of $V \sin i$ for $V \sin i > 100 \text{ km s}^{-1}$ and only a factor of 2 smaller for the sharpest lined stars. Thus the results are not very sensitive to line broadening. These accuracies determine our sensitivities in detecting low-amplitude spectroscopic binaries.

The 74 stars observed are listed in Table 1. The first four columns give the number (HR) from the Bright Star Catalogue (Hoffleit and Jaschek 1982), the Henry Draper number, the constellation name, and the number of the system in Aitken’s Double Star Catalogue. The fifth column gives the MK classification by Lesh (1968), and the sixth column has the projected rotational velocity, if available, as cataloged by Uesugi (1976). The final column gives comments on published results, which are not all confirmed below. The published orbital elements are listed in Batten, Fletcher, and Mann (1978) or in Batten, Fletcher, and McCarthy (1989).

The new radial velocities are listed in Table 2, which lists the heliocentric Julian Dates, the radial velocities corrected for the instrumental corrections, and the internal standard errors computed from the scatter among the seven lines measured.

Table 3 gives our conclusions about the radial velocities, both for the current 74 stars and those in AL78 because the two samples will be considered together. The data for HR numbers footnoted “a” are taken from AL78, although our current interpretations are more conservative in view of the lack of confirmation by Morbey and Griffin (1987) of other marginal elements. Even if some of the AL78 marginal elements are valid, that information is not lost statistically because an assumed higher threshold for the discovery of spectroscopic binaries is included in the calculations for undetected binaries.

The remaining columns in Table 3 are described as follows. The second column gives the number of measures in AL78 or in Table 2. A zero implies that we assumed the well-determined published orbital elements quoted. The external (E) and internal (I) standard errors are given. If the former are less than twice the latter, we assumed that the velocities are constant within our accuracy. Some stars (e.g., HR 5902) have $E/I \gg 3$, but we were unable to discover their orbital elements. All of the 13 newly discovered binaries (SB1) have $E/I > 3.0$, and 11 have $E/I > 4.0$. The mean $V \sin i$ of the 13 new binaries is exactly the same (135 km s^{-1}) as the mean for all of the stars in Table 1, and the range of the former is $25\text{--}251 \text{ km s}^{-1}$, so we are discovering binaries of all line widths. Comments on selected systems follow Table 4.

The derived orbital elements are listed in Table 4 for 35 known, improved, or new sets of elements. Not included is one SB2 (HR 1764) with uncertain elements. All quoted errors are standard deviations. Comments about some of the individual systems follow the table. Velocity curves are shown in Figures 1–6 for 11 newly discovered systems and seven for which the published elements have been modified substantially. For each set of orbital elements we applied several least-squares modifications until the improvements were less than 0.5%.

III. DISCUSSION

a) Spatially Resolved Binaries

The visual binaries are the easiest to discuss because for those we have approximate magnitudes for both components, so from the mass-luminosity relation we can derive secondary masses, assuming that the secondaries are on the

TABLE 1
NEW OBSERVING LIST

HR	HD	Name	ADS	MK Type	$V \sin i$ (km s ⁻¹)	Published Information
91	1976	...	328	B5 IV	230	VB, SB1 (orbit), light variable (102323)
155	3379	53 Psc	...	B2.5 IV	...	Suspected light var. (5865)
189	4142	...	...	B4 V	177	
987	20365	29 Per	...	B3 V	156	
989	20418	31 Per	...	B5 IV	298	
1005	20756	τ Ari	...	B5 IV	20	
1011	20809	...	...	B4 V	244	
1029	21071	...	...	B5 IV	43	
1153	23466	29 Tau	2750	B3 V	142	SB1 (orbits)
1174	23793	30 Tau	2778	B3 V	52	Suspected light var. (100327)
1244	25340	35 Eri	...	B5 V	179	
1253	25558	40 Tau	...	B3 V	51	
1288	26326	...	...	B4 V	31	
1350	27396	53 Per	...	B4 IV	19	Suspected light var. (100379); non-rad. puls.
1574	31331	...	...	B5 V	200	(Buta & Smith 1979)
1646	32686	...	...	B5 IV	...	
1659	32990	103 Tau	3709	B2 V	98	SB1 (orbit)
1749	34759	ρ Aur	...	B5 V	102	SB1 (orbit)
1764	35007	...	3941	B3 V	150:	
1783	35337	8 Lep	...	B2 IV	23	
1803	35588	...	...	B2.5 V	150	SB1 (orbit); suspected light var. (100485)
1808	35671	115 Tau	4038	B5 V	155	
1833	36166	...	...	B2 V	175	
1864	36653	35 Ori	...	B3 V	224	
1875	36819	121 Tau	...	B2.5 IV	117	
1911	37209	...	4212	B2 IV	50	Suspected light var. (100638)
1913	37232	...	...	B2 IV-V	120	
1928	37438	125 Tau	...	B3 IV	65	SB1 (orbit)
1952	37756	...	...	B2 IV-V	77	SB2 (orbit); suspected light var. (100671)
1993	38622	133 Tau	4381	B2 IV-V	70	
2031	39291	55 Ori	...	B2 IV-V	164	
2052	39698	57 Ori	...	B2 V	121	SB2 (orbit)
2154	41692	...	4698	B5 IV	20	
2205	42690	...	...	B2 V	25	
2266	43955	...	...	B2 V	88	
2273	44112	7 Mon	...	B2.5 V	152	
2395	46487	...	...	B5 Vn	300	
2490	48879	42 Cam	...	B4 IV	126	
2494	48977	16 Mon	...	B2.5 V	...	
3194	67880	...	6632	B2.5 V	...	
3952	87015	...	...	B2.5 IV	...	
4456A	100600	90 Leo	8220	B4 V	117	
5764	138485	ζ Lib	...	B2 Vn	256	
5902	142096	λ Lib	...	B2.5 V	197	SB1 (orbit)
5915	142378	47 Lib	9834	B5 V	240	
5985	144218	β^2 Sco	9913	B2 IV-V	74	Suspected light var. (101548)
6502	158148	...	...	B5 V	251	
6684	163472	...	...	B2 IV-V	120	
6738	164852	96 Her	...	B3 IV	25:	SB2 (orbit)
6984	171780	...	...	B5 Vn	310	Occasionally a Be star (MWC 604)
7084	174237	...	...	B2.5 V	170	Occasionally a Be star (MWC 608)
7100	174585	8 Lyr	11732	B3 IV	...	Suspected light var. 7975
7166	176162	...	IDS	B5 IV	185	

TABLE 1—*Continued*

HR	HD	Name	ADS	MK Type	$V \sin i$ (km s^{-1})	Published Information
7202	176871	...	...	B5 V	296	
7210	177003	...	...	B2.5 IV	13	
7279	179406	20 Aql	...	B3 V	187	Suspected light var. (101808)
7486	185936	QS Aql	IDS	B5 V	58	Eclipsing binary; SB1 orbit)
7608	188665	23 Cyg	...	B5 V	145	
7613	188892	22 Cyg	...	B5 IV	85	
7620	189066	...	...	B5 IV	...	
7628	189178	...	IDS	B5 V	115	(SB1 orbit)
7647	189687	25 Cyg	...	B3 IV	229	Suspected light var. (8375); occasional Be
7688	190993	17 Vul	...	B3 V	214	star (MWC 624)
7894	196740	28 Vul	...	B5 IV	330	
7899	196775	...	14106	B3 V	...	
7929	197511	51 Cyg	14189	B2 V	40	
8215	204403	70 Cyg	...	B3 IV	135	
8356	208057	16 Peg	...	B3 V	152	Occasionally a Be star (MWC 644)
8439	210191	35 Aqr	...	B2.5 IV	...	
8513	211924	30 Peg	15847	B5 IV	32	Suspected light var. (102164)
8579	213420	6 Lac	...	B2 IV	74	SB1 orbit)
8725	216916	16 Lac	16381	B5 IV	23	SB1 orbit); β CMa var.
9005	223128	...	...	B2 IV	...	
9011	223229	...	17006	B3 IV	...	Suspected light var. (103134)

main sequence. That assumption would be violated if the current secondary is a white dwarf that was originally the more massive star. However, we know enough about these secondaries to be certain that this is not the case here.

A few visual binaries had to be deleted from the sample because of the Branch effect (Branch 1976), namely that if a binary falls within the magnitude limit ($B \leq 6.00$ mag) of the sample only because it is double, it should be deleted from the sample. An alternative phrasing is that the primary alone should be within the magnitude limit because otherwise we are favoring binaries in the sample. This caused us to drop HR 4456A, 5915, 7166, 7486, and 9011 from the sample, although HR 1946, dropped in AL78, could now be included because of the fainter magnitude limit.

We searched the literature, especially the new Bright Star Catalogue (Hoffleit and Jaschek 1982) and its background literature, for information about visual companions. However, new components, especially those discovered with speckle and occultation techniques that fill in the gap between spectroscopic and visual binaries, are being found annually so the full binary frequencies will eventually be substantially higher than our current estimates. The information on spatially resolved duplicity is given in Table 5 for the entire sample less the Branch effect deletions. In that table the third column ("Kind") needs explanation. "Orb" are visual systems with published orbital elements, "Vis" are visual systems that show binary motion, "Occ" means occultation or speckle (McAlister and Hartkopf 1984) doubles, and "CPM" means common proper motion binaries. If pairs have only one or two astrometric measures, they were not included. If the measures extend over too short a time interval, they were indicated by "CPM:." To be convincing as a physical pair, a CPM pair must have a constant separation for a longer interval than the component proper motions would allow. The periods (last column) were computed as-

suming that the current separations are the sum of the two semimajor axes. The largest separation among the CPMs is 41,000 AU, which is still allowed for physical systems containing B2–B5 stars (Abt 1988). In the period calculations we assumed luminosities given by Blaauw (1963) and stellar masses by Allen (1973).

The frequencies of various secondary masses are shown in Figure 7. The masses are binned on a logarithmic scale where, e.g., bin 4 $M_{\odot}$ ranges from $4(2)^{1/2}$ to $4(2)^{-1/2} M_{\odot}$. A comment should be made about incompleteness. Relative to the binaries with separations of 1"–100", those with separations $< 1''$ are deficient in binaries with $\Delta V > 5$ mag, whereas half of the systems with larger separations have $\Delta V > 5$ mag. Therefore the $M_2 = 1 M_{\odot}$ point is about 15 systems too low.

Two curves are shown in Figure 7, both normalized to the $M_2 = 2 M_{\odot}$ data point. The curve for a van Rhijn luminosity function (Allen 1973) fits the data poorly because the first two data points are too high by factors of 12 and 6, respectively, while the $1 M_{\odot}$ data point is too low by a factor of 4. However, the Salpeter initial luminosity function (Salpeter 1955) fits well (average factor of 1.4). Our estimate of the errors is the square roots of the numbers. The largest sources of error are the inaccuracies of the visual estimates of secondary magnitudes, and the next largest is the scatter in the mass-luminosity relation. Allowing for incompleteness as estimated above, the $1 M_{\odot}$ data point would be at about 39 secondaries, whereas the Salpeter function predicts 41 secondaries. That the Salpeter function is better is not surprising for this sample of early-type stars that show evolutionary effects quickly.

But the main result of Figure 7 is that the primaries and secondaries seem to be formed by capture within clusters because the numbers of secondaries of various masses are proportional to the numbers that exist within the clusters. This confirms the result of AL78 derived from fewer B2–B5

TABLE 2
RADIAL VELOCITY MEASURES

Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 244000+	ρ (km s ⁻¹)	σ
HR 91			4188.677	-73.4	+4.3	4187.798	+14.9	+1.8	4237.657	+ 9.6	+4.2
3411.860	-36.7	+5.0	4189.838	-64.6	3.0	4235.750	+15.0	3.4	4472.945	- 0.1	5.2
3459.731	-42.0	3.0	4229.688	-66.8	3.1	4236.653	+16.2	2.7	4495.894	+24.3	1.6
3460.730	-44.3	2.8	4231.627	-70.7	5.6	4237.639	+11.8	1.2	4496.879	+20.8	4.2
3461.679	-37.8	5.8	4235.738	-58.5	3.1	4471.949	+15.3	1.9	4522.917	+28.1	3.6
3462.790	-21.1	1.5				4472.929	+13.5	2.4	4523.832	+ 1.8	2.7
3508.748	-32.8	2.7	HR 987 = 29 Per			4495.879	+23.7	2.7	4524.842	+22.2	5.3
3726.972	+ 6.7	3.8	3411.933	- 1.3	4.9				4525.862	+26.4	3.7
3808.852	- 5.5	2.1	3459.849	- 5.5	4.2	HR 1011					
3809.896	-23.4	3.3	3460.753	- 4.7	4.2	3411.943	- 5.5	2.2	HR 1174 = 30 Tau		
3810.821	-14.4	2.1	3461.736	- 4.6	3.7	3460.828	- 6.2	3.4	3411.956	+23.8	3.6
3830.758	+ 3.1	3.8	3462.837	-10.7	2.7	3461.753	- 1.5	3.7	3460.840	+22.6	3.6
3831.648	- 2.0	1.8	3508.812	- 2.0	4.0	3462.868	- 2.5	2.7	3461.799	+26.5	4.4
3832.647	- 4.2	2.8	3521.659	+ 0.2	5.6	3508.839	-10.7	2.7	3462.882	+22.7	1.9
4068.973	-45.6	3.3	3726.984	- 4.4	5.8	3521.671	- 9.5	1.8	3521.803	+29.7	3.4
4116.922	-27.8	0.9	3808.931	- 4.6	2.5	3808.954	- 7.5	1.9	3809.007	+17.4	3.6
4187.697	+ 0.4	0.7	3810.016	- 7.8	3.3	3810.050	- 6.4	2.7	3810.962	+13.1	4.6
4188.666	+ 1.9	3.1	3810.892	-16.1	1.6	3810.919	+ 0.4	2.8	3830.979	+17.0	2.4
4189.825	- 2.0	1.8	3830.831	- 6.6	2.9	3830.847	- 0.4	3.0	3831.842	+25.4	3.0
4229.655	-16.0	3.0	3831.751	- 6.6	5.9	3831.822	- 1.3	3.0	4116.988	+14.7	3.0
4231.618	- 0.8	3.4	3832.750	- 6.7	3.6	4116.973	- 8.6	1.5	4235.772	+22.9	2.2
			4116.932	- 0.6	2.1	4235.754	+ 3.8	1.0	4236.683	+20.4	1.5
HR 155 = 53 Psc			4187.790	- 7.7	5.8	4236.659	- 5.9	2.2	4237.661	+19.9	2.4
3411.867	+ 0.1	4.2	4188.683	- 8.4	3.3	4237.643	-11.5	4.2	4472.951	+23.4	3.4
3459.745	- 1.5	2.5	4189.844	- 7.8	1.9	4471.953	- 3.2	2.1	4495.898	+19.2	1.5
3460.735	- 2.6	3.0	4229.675	- 2.6	4.6	4472.933	-11.2	3.4	4496.885	+ 5.7	1.5
3461.691	- 3.6	0.4	4231.638	- 7.7	4.0	4495.881	- 9.4	3.1	4522.920	+18.4	1.6
3462.828	- 4.7	0.9				4496.862	- 7.4	2.7	4523.835	+20.2	5.5
3508.770	- 6.7	4.6	HR 989 = 31 Per			4522.907	- 7.4	1.6	4524.846	+ 8.8	1.9
3726.979	-12.0	4.3	3411.936	- 3.8	3.4				4525.866	+21.3	3.3
3757.927	-17.2	1.8	3459.859	- 8.2	4.2	HR 1029					
3808.862	- 6.6	1.0	3460.822	- 2.3	4.8	3411.946	- 2.8	4.2	HR 1244 = 35 Eri		
3809.905	-10.3	3.3	3461.740	- 0.6	3.1	3460.832	-13.1	2.4	3411.960	+ 6.4	4.3
3810.835	-14.2	3.3	3462.859	+ 1.2	6.1	3461.783	- 4.0	4.9	3460.844	+19.3	2.7
3830.764	- 6.3	4.4	3508.818	- 4.9	4.6	3508.855	- 3.6	2.4	3461.806	+18.5	5.5
3831.655	-10.6	5.5	3521.663	- 9.1	1.8	3521.678	- 8.7	2.8	3462.886	+13.8	3.1
3832.684	-12.4	4.2	3726.988	- 4.8	1.6	3808.962	+ 1.4	5.2	3521.808	+15.7	5.3
4116.929	-12.2	2.4	3808.937	- 0.8	3.1	3810.059	- 4.6	3.7	3810.978	+17.0	0.7
4187.780	- 7.2	2.5	3810.022	- 5.8	3.0	3810.928	+ 3.1	4.0	3830.984	+20.1	4.4
4188.672	- 9.3	4.3	3810.897	- 7.5	3.9	3830.962	- 3.4	3.4	3831.859	+19.6	4.2
4189.832	- 7.1	3.6	3930.836	- 3.6	2.4	3831.830	- 5.7	3.1	4235.776	+25.6	4.7
4229.661	- 7.1	3.6	3831.756	+ 2.9	6.7	4116.978	+ 6.0	3.1	4236.688	+24.6	4.6
4231.622	-18.3	4.9	4116.935	- 6.2	3.1	4235.761	- 2.8	0.7	4237.688	+12.1	3.0
4525.831	-11.0	3.0	4187.793	- 8.3	3.0	4236.668	-11.2	1.9	4472.955	+13.6	4.4
4556.740	- 5.2	1.9	4189.848	- 2.2	2.1	4237.650	- 2.7	5.5	4495.904	+21.2	3.0
4557.702	- 6.4	2.1	4229.679	- 3.4	3.0	4471.960	+ 8.0	5.6	4496.901	+15.6	4.4
			4231.641	- 9.8	3.0	4472.939	- 4.7	3.7	4522.923	+19.8	2.7
HR 189			4235.746	- 5.5	4.0	4495.889	-10.5	3.1	4523.839	+10.8	3.3
3411.869	-69.2	5.9	4236.648	- 5.3	3.7	4496.871	+ 1.0	5.8	4524.851	+16.2	2.8
3459.750	-63.2	2.4				4522.911	+ 0.1	4.4	4525.870	+10.9	2.8
3459.755	-64.7	3.7	HR 1005 = τ Ari			4523.826	- 5.1	3.0	4556.881	+18.6	2.7
3460.739	-53.0	5.2	3411.941	+15.4	2.4				4557.741	+ 8.2	5.8
3461.705	-68.8	3.1	3459.899	+18.5	2.5	HR 1153 = 29 Tau					
3462.833	-64.6	1.8	3460.825	+ 3.1	1.3	3411.953	+18.3	5.6	HR 1253 = 40 Tau		
3508.781	-61.6	5.8	3461.747	+17.5	3.1	3460.837	+27.4	2.4	3411.964	+ 6.7	2.1
3726.982	-68.7	2.1	3462.864	+19.9	2.7	3461.793	+ 3.7	4.6	3460.848	+13.0	1.9
3808.869	-59.3	2.4	3508.826	+21.4	3.3	3462.877	+14.0	4.9	3461.814	+15.5	2.9
3809.911	-64.8	2.4	3521.666	+ 9.4	2.2	3521.797	+23.0	1.6	3462.891	+ 6.3	2.1
3810.840	-65.1	4.2	3808.944	+ 9.9	4.2	3810.955	+16.9	4.2	3521.813	+17.2	1.6
3830.823	-72.7	3.1	3810.029	+ 8.4	4.0	3830.973	- 7.1	4.3	3810.983	+21.2	3.1
3831.692	-67.9	2.8	3810.914	+21.4	2.4	3831.837	+25.6	2.4	3930.992	+13.3	2.7
3832.690	-68.5	2.7	3830.843	+12.6	2.1	4116.984	-22.6	2.5	3831.864	+18.5	2.5
4116.930	-72.8	3.7	3831.818	+12.9	1.8	4235.768	- 9.5	4.2	4235.780	+11.4	1.2
4187.785	-72.0	+4.9	4116.968	+20.8	+3.7	4236.676	+23.3	+3.0	4236.694	+20.3	+2.4

TABLE 2—Continued

Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 244000+	ρ (km s ⁻¹)	σ	Helio. JD 244000+	ρ (km s ⁻¹)	σ
4237.673	+13.0	+1.8	4522.943	- 8.3	+4.4	4525.943	-14.0	+1.8	4557.867	+71.4	+3.0
4472.959	+14.5	1.8	4523.861	-11.4	4.8	4556.912	+ 7.0	3.7	4589.795	+72.2	4.0
4495.908	+14.5	1.6	4524.868	- 9.9	3.0	4557.816	- 7.1	2.4	4590.752	-17.0	2.8
4496.903	+15.8	2.1	4525.890	- 1.6	1.9	4589.769	+15.0	3.3	4622.659	-31.7	2.4
4522.929	+19.8	1.5	4556.897	+35.3	2.8	4590.710	+13.9	5.5	4623.612	+ 6.0	3.6
4523.843	+ 9.2	1.8	4557.764	+36.4	3.0	4622.638	+23.2	3.9	4643.657	-16.7	4.2
4524.856	+12.2	1.3	4589.737	+22.4	0.7	4623.594	+22.2	3.4	4680.653	-38.3	3.6
4525.874	+17.1	2.4	4590.695	+21.5	2.4	4643.639	+20.2	4.9	4698.640	+ 2.5	2.1
4556.884	+20.6	2.5	4622.615	+11.0	3.3	4680.639	+39.8	4.8	4699.617	+66.0	3.6
4557.746	+ 7.3	0.9	4623.574	+10.9	3.9	4699.607	-15.9	3.1			
HR 1288			HR 1646			HR 1764			HR 1808 = 115 Tau		
3411.967	+25.6	4.2	3412.019	+31.2	2.2	3459.881	+21.6	1.8	3460.929	+ 8.9	2.5
3460.850	+25.7	1.8	3460.863	+18.9	5.8	3460.873	+ 7.2	2.2	3508.895	+ 8.4	5.6
3461.824	+20.0	2.8	3521.843	+32.8	5.3	3508.876	+ 0.4	5.2	3521.888	+12.3	5.1
3462.895	+22.8	1.8	3571.891	+39.9	4.2	3521.864	+52.7p	6.4	3831.990	+15.4	3.9
3521.819	+23.1	2.7	3831.952	+22.7	5.0		-47.9s	9.2	4237.802	+ 0.8	2.5
3571.677	+22.8	2.5	4235.805	+29.0	3.6	3831.970	+37.5p	4.6	4495.955	+15.5	1.9
3810.988	+19.9	1.0	4237.762	+28.0	4.6		-60.2s	2.2	4496.950	+19.9	5.8
3831.868	+20.2	2.4	4472.980	+30.1	2.8	4235.912	-31.9p	5.9	4522.988	+20.1	4.9
4235.784	+17.1	2.8	4495.931	+31.3	2.1		+113.1s	6.7	4523.898	+12.8	2.4
4236.700	+11.4	3.0	4496.923	+27.3	2.1	4237.780	+12.0	3.6	4524.898	+14.1	3.3
4237.677	+20.8	2.8	4522.947	+28.8	4.3	4525.951	+22.2	1.2	4556.928	+12.6	1.5
4472.966	+20.9	2.1	4523.867	+31.3	4.4	4556.916	-38.8p	5.2	4557.873	+16.7	3.3
4495.918	+18.9	1.6	4524.873	+31.3	5.0		+106.7s	5.3	4589.805	+17.1	3.4
4496.907	+10.7	1.3	4525.896	+33.2	5.2	4589.777	-23.2p	3.0	4590.783	+ 9.3	3.6
4522.933	+12.2	0.9	4556.902	+29.8	2.4		+97.6s	1.8	4622.695	+ 6.6	5.6
4523.851	+15.6	1.8	4557.805	+29.1	1.6	4590.740	+18.2	4.2	4623.619	+11.4	5.0
4524.859	+15.6	2.8	4589.749	+26.0	2.2	4622.648	+21.5	3.1	4643.661	+16.1	3.9
4525.877	+16.1	1.8	4590.700	+28.4	3.3	4623.600	+40.2p	3.4	4698.666	+ 9.6	4.2
4556.888	+11.9	2.5	4622.623	+26.6	5.3		-40.4s	7.1	4699.627	+25.2	3.1
4557.751	+18.9	1.2	4623.582	+28.2	2.8	4643.644	-10.6	2.1	4700.605	+12.8	5.2
HR 1350 = 53 Per			HR 1659 = 103 Tau			HR 1783 = 8 Lep			HR 1833		
3412.012	+ 5.0	1.0	3412.021	+41.3	2.5	3459.906	+14.9	1.8	3460.932	+19.6	3.6
3460.854	+16.2	1.5	3460.867	+27.6	3.3	3460.920	+11.7	1.9	3521.895	+20.7	3.6
3521.827	+15.9	2.4	3521.851	+38.1	3.1	3521.870	+25.2	1.2	3831.995	+ 6.0	3.1
3571.681	+10.9	3.0	3571.695	- 1.3	2.2	3831.975	+41.5	0.6	4189.013	+13.4	3.7
3831.938	+10.8	1.5	3831.959	+25.2	1.5	4235.920	+25.0	1.6	4237.806	+ 7.9	3.3
4235.792	+ 6.9	2.4	4235.811	+24.1	2.8	4237.784	+25.9	2.2	4495.968	+14.1	4.3
4236.707	+ 5.5	3.0	4237.769	+24.5	1.9	4495.947	+12.6	1.2	4496.955	+ 1.8	4.6
4237.683	+12.6	1.5	4472.985	+10.4	2.5	4496.939	+ 9.5	2.7	4522.992	+ 4.2	4.9
4472.969	+ 7.7	2.4	4495.935	-15.9	3.6	4522.963	+11.9	1.3	4523.904	+15.4	1.9
4495.920	+ 6.5	2.7	4496.928	-18.4	3.1	4523.886	+10.7	1.3	4524.904	+11.2	1.8
4496.910	+15.4	3.0	4522.954	+40.0	5.3	4524.890	+11.6	1.5	4556.976	+18.3	2.1
4522.937	+10.0	2.2	4523.872	+28.7	4.2	4556.919	+28.9	1.8	4557.876	+ 6.9	3.4
4523.856	+ 3.4	2.5	4524.878	+33.5	3.0	4557.824	+27.3	2.2	4589.824	+ 7.2	3.0
4524.864	+ 8.5	1.9	4525.901	+20.0	2.8	4622.652	+19.2	1.2	4590.786	+ 6.0	4.3
4525.885	+ 3.4	1.3	4556.906	-15.7	3.9	4623.605	+20.6	2.2	4622.700	+ 6.9	2.1
4556.892	- 1.6	3.6	4557.812	-12.1	1.5	4643.648	+21.6	1.6	4623.625	+ 8.5	3.1
4557.757	+14.6	2.4	4589.765	+16.6	3.3	4664.629	+20.0	2.4	4643.671	+ 2.8	4.6
4589.724	+ 7.6	2.5	4590.706	+ 8.3	3.6				4698.675	+18.8	2.1
4590.688	+ 3.3	1.8	4622.631	+ 5.2	3.0				4699.635	+24.5	1.8
4622.609	+ 7.2	2.2	4623.589	+13.6	4.4				4700.611	+20.0	4.2
HR 1574			HR 1749 = ρ Aur			HR 1803			HR 1864 = 35 Ori		
3412.015	- 8.5	4.9	3460.870	-15.3	3.6	3459.917	+39.3	4.6	3460.936	+21.2	2.4
3460.858	- 8.8	2.7	3521.857	+17.6	4.6	3460.925	+27.8	5.2	3571.799	+ 9.3	3.0
3521.834	+25.2	3.4	3831.964	+12.9	2.8	3521.879	+ 6.8	4.6	4188.000	+10.8	3.3
3571.685	+25.2	7.4	4235.815	+57.9	4.8	3831.983	-13.0	2.4	4189.019	+20.8	2.4
3831.944	+15.4	3.0	4237.774	+53.8	4.3	4237.796	+40.8	1.0	4237.837	+29.2	2.5
4235.798	- 5.8	2.4	4495.939	-19.8	2.4	4495.951	-46.2	2.4	4495.974	+14.4	3.7
4237.688	- 5.0	2.7	4496.931	- 8.7	5.8	4496.946	+43.1	3.4	4496.958	+ 7.2	1.9
4472.974	-16.5	4.0	4522.956	+ 4.6	4.2	4522.967	+47.7	2.7	4522.996	+21.3	3.4
4495.927	+ 8.8	3.4	4523.879	- 1.5	4.4	4523.893	+31.5	4.6	4523.908	+19.2	4.0
4496.915	- 8.7	+3.7	4524.881	-11.4	+4.4	4524.894	-42.5	4.2	4524.915	+15.0	3.6
						4556.924	-16.9	+4.4	4556.983	+11.6	+4.2

TABLE 2—Continued

Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ
4557.881	+17.4	+2.5	4557.896	+53.2	+3.0	4643.711	+28.4	+3.6	4496.012	+27.0	+1.9
4589.834	+13.9	4.2	4589.852	- 8.9	4.8	4700.673	+28.2	3.1	4496.999	+27.7	1.6
4590.797	+16.0	3.4	4590.818	+24.7	3.9				4523.032	+27.4	1.9
4622.706	+12.9	2.1	4622.725	+39.3	4.4	HR 2031 = 55 Ori			4523.951	+25.1	1.5
4623.634	+14.1	1.6	4623.651	+ 2.8	3.1	3460.961	+18.7	2.2	4524.957	+24.3	0.9
4643.677	+24.0	5.5	4643.694	- 2.3	3.7	4188.047	+ 9.6	5.5	4557.026	+25.0	1.5
4698.685	+ 6.8	4.4	4699.681	+ 7.8	5.5	4189.048	+15.1	3.6	4557.934	+26.0	1.3
4699.645	+13.8	2.7	4700.644	- 4.4	4.3	4237.928	+11.8	2.4	4589.921	+28.6	1.5
4700.618	+19.2	5.2				4496.002	+12.4	2.5	4590.860	+26.5	1.5
HR 1875 = 121 Tau			HR 1928 = 125 Tau			4496.988	- 5.2	3.6	4622.761	+28.3	1.5
3460.940	+ 3.9	4.2	3460.953	+30.5	3.0	4523.021	+ 7.5	4.3	4623.718	+30.3	1.9
3571.804	+14.6	4.8	4188.032	+20.8	4.2	4523.938	+12.2	4.4	4643.758	+28.7	1.8
4188.006	+21.3	2.8	4189.038	+19.7	2.2	4524.945	- 3.3	2.8	4680.676	+27.4	1.8
4189.023	+24.9	3.7	4237.858	+56.3	3.7	4557.013	+11.5	3.7	HR 2266		
4237.842	+ 7.0	2.7	4495.992	+16.4	2.1	4557.915	+14.1	2.2	3460.975	+22.7	4.3
4495.977	+ 1.8	2.7	4496.977	+13.5	4.0	4589.901	+ 0.2	3.7	4190.036	+11.1	4.4
4496.962	+11.8	4.2	4523.013	+18.5	3.9	4590.840	+15.7	4.4	4237.952	+24.6	3.0
4523.000	+15.6	5.5	4523.927	+16.8	2.4	4622.745	+ 3.4	4.4	4496.016	+33.9	4.6
4523.912	+ 4.0	3.9	4524.934	+15.3	1.3	4623.701	+17.0	5.6	4497.002	+33.4	4.3
4524.919	+ 9.2	3.6	4557.002	+ 1.6	1.8	4643.740	+12.8	2.4	4523.956	+18.9	5.8
4556.987	+18.1	2.5	4557.901	+14.6	4.2	4664.757	+ 9.4	4.9	4524.961	+20.0	3.9
4557.885	+ 7.6	4.6	4589.858	+10.7	2.4	HR 2052 = 57 Ori			4557.030	+ 1.5	3.4
4589.839	+10.9	2.7	4590.828	+ 5.3	2.7	3460.965	+29.5	3.6	4557.938	- 5.9	2.1
4590.811	+17.8	3.0	4622.732	+11.3	3.7	4190.025	-39.0	2.8	4589.931	+23.9	3.1
4622.711	+14.2	2.7	4623.656	+12.4	1.8	4235.928	+64.4	5.8	4590.884	+23.7	3.7
4623.639	+20.2	3.3	4643.704	+12.0	3.6	4237.935	-35.7	3.1	4622.765	+ 1.7	3.6
4643.682	+18.8	3.6	4699.693	+16.4	1.5	4496.005	-28.7	1.5	4623.722	+ 0.1	4.4
4698.694	+15.2	5.0	4700.654	+ 6.7	2.7	4496.992	+14.9	4.4	4643.763	+38.2	4.9
4699.654	+17.3	3.9	HR 1952			4523.025	+80.0	3.0	4664.644	+24.0	3.9
4700.624	+13.2	5.8	3460.955	-35.5	2.8	4523.942	+50.7	3.9	4680.685	+ 9.5	2.5
HR 1911			4188.037	+53.0	2.1	4524.949	+15.0	2.4	HR 2273 = 7 Mon		
3460.943	+22.1	1.2	4189.041	+62.0	3.3	4557.018	+13.3	2.8	3460.979	-16.3	5.3
4188.012	+32.6	1.2	4237.861	+41.3	4.4	4557.921	-36.3	2.7	3571.835	-24.5	5.2
4189.027	+31.8	3.4	4495.995	-11.8	3.9	4589.907	-42.4	3.1	4237.960	+ 3.7	3.7
4236.905	+30.1	2.7	4496.981	+ 0.1	3.6	4590.847	-58.9	3.1	4523.034	0.0	3.0
4237.846	+30.9	3.7	4523.016	- 9.2	3.6	4622.753	-61.8	3.6	4523.962	+25.4	3.7
4495.982	+31.9	3.6	4523.931	- 3.1	4.4	4623.707	-39.7	2.1	4524.965	+24.8	3.7
4496.968	+35.4	2.4	4524.938	- 1.8	3.9	4643.746	+74.7	5.5	4557.034	+33.6	2.5
4523.004	+31.3	2.4	4557.004	+18.2	2.8	HR 2154			4557.969	+50.9	5.5
4523.916	+31.4	2.8	4557.904	+21.1	3.1	3460.969	+24.8	2.2	4589.936	+45.1	1.5
4524.925	+27.1	2.7	4589.885	+28.8	3.3	4190.029	+22.4	1.9	4590.888	+55.9	4.9
4556.991	+26.8	2.1	4590.830	+34.4	4.2	4235.935	+19.8	1.6	4622.769	+54.9	5.0
4557.890	+30.1	1.6	4622.738	+51.3	3.6	4237.940	+21.1	1.6	4623.727	+60.5	1.8
4589.843	+29.9	2.5	4623.692	+56.3	4.2	4496.009	+16.7	1.6	4643.768	-20.9	3.4
4590.814	+32.5	2.4	4643.707	+32.1	5.3	4496.996	+22.0	2.4	4664.657	+ 9.0	2.8
4622.715	+28.3	2.7	4699.702	+41.6	3.3	4523.029	+21.9	1.5	4680.693	+13.3	3.4
4623.644	+24.1	3.0	4700.663	+42.2	2.8	4523.948	+19.6	1.2	4698.712	+27.7	3.3
4643.687	+29.0	2.2	HR 1993 = 133 Tau			4524.952	+19.3	1.3	HR 2395		
4664.769	+28.0	2.4	3460.959	+20.3	3.6	4557.022	+19.8	2.2	3460.982	+11.83.7	
4699.665	+27.0	2.2	4188.042	+24.1	1.8	4557.928	+20.6	1.3	4190.041	+16.7	1.8
4700.631	+34.4	4.8	4189.045	+23.2	2.8	4589.916	+24.1	3.4	4237.966	+16.5	1.3
HR 1913			4237.924	+20.2	3.4	4590.854	+23.2	1.5	4335.700	+18.3	3.0
3460.949	+12.4	2.1	4495.999	+29.2	3.4	4622.757	+20.9	2.2	4336.681	+20.8	2.7
4188.023	+61.9	2.8	4496.984	+26.8	2.8	4623.711	+20.1	1.3	4523.037	+20.5	3.3
4189.033	+10.1	2.7	4523.019	+31.3	3.3	4643.753	+20.3	1.5	4523.966	+15.6	3.4
4237.853	+40.4	2.5	4523.934	+18.1	3.4	4664.726	+22.0	3.1	4524.968	+20.0	2.7
4495.986	+37.4	2.7	4524.941	+20.7	3.3	4699.717	+19.7	1.8	4557.039	+18.3	3.0
4496.973	+52.0	4.8	4557.009	+26.8	3.9	HR 2205			4557.973	+15.2	1.3
4523.009	+54.3	5.3	4557.908	+23.2	1.9	3460.972	+31.1	1.2	4589.947	+21.7	3.3
4523.921	+25.4	3.9	4589.890	+20.7	4.2	4190.033	+30.5	1.2	4590.892	+21.4	2.2
4524.929	-15.0	1.8	4590.833	+17.6	3.6	4235.940	+30.1	0.6	4622.827	+27.6	3.4
4556.997	+55.9	+3.0	4622.742	+23.8	4.6	4237.946	+31.9	+0.9	4623.731	+25.4	+1.8
			4623.697	+20.0	+3.1						

TABLE 2—Continued

Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ
4643.772	+21.1	+1.8	HR 3952			HR 5902 = λ Lib			4059.659	+0.2	+2.7
4664.666	+29.3	3.3	3461.023	-3.8	+4.9	3296.781	-7.6	+1.8	4068.664	-11.8	4.6
4680.722	+21.2	2.4	3571.957	-3.2	3.1	3298.781	-24.8	3.1	4070.670	-6.7	4.9
4698.721	+22.8	1.5	3601.756	-5.1	3.6	3329.669	+15.6	1.2	HR 6502		
4699.730	+26.3	0.9	3648.748	0.0	2.4	3571.968	-35.2	4.9	3296.820	-39.1	3.0
HR 2490 = 42 Cam			3649.634	-7.2	3.7	3601.888	-4.5	2.4	3298.816	-27.1	2.7
3460.984	-2.5	3.4	3650.669	+3.1	4.2	3648.788	-48.7	1.8	3329.687	-26.8	4.9
4190.045	-0.4	4.3	3929.887	-9.6	3.6	3649.783	-21.4	3.7	3412.574	-48.4	1.9
4237.971	-8.6	4.6	3984.743	+0.6	3.1	3650.775	-5.1	2.8	3572.011	-32.8	4.2
4335.706	-15.6	2.8	3985.726	-8.6	2.7	3676.715	+10.7	5.9	3601.900	-37.4	4.2
4336.686	+0.7	4.2	3986.688	-2.7	2.7	3677.735	-5.5	1.9	3648.848	-21.3	3.3
4524.007	+2.0	5.3	4236.933	-3.8	3.7	3678.732	-7.0	5.9	3649.792	-7.2	3.7
4557.045	-0.9	3.6	4237.991	+5.3	5.3	3727.667	-5.8	4.1	3650.786	-18.5	2.4
4557.979	+3.3	3.7	4270.964	-5.7	1.3	3929.929	+3.8	1.5	3676.747	-7.5	4.4
4589.954	+7.9	4.8	4335.735	+0.6	3.9	3984.810	-11.3	2.8	3677.763	-17.3	3.3
4590.899	+4.6	5.5	4336.719	-12.7	3.3	3985.863	+1.4	1.6	3678.760	-24.9	4.4
4622.831	+1.0	3.7	4363.645	+2.8	3.3	3986.887	+9.6	2.4	3726.758	-38.5	1.6
4623.735	-0.8	3.4	4364.656	-5.8	2.1	4057.718	-19.7	3.9	3727.680	-36.6	0.7
4643.777	+5.8	2.2	4390.638	-1.0	3.1	4058.702	-22.6	3.0	3757.764	-6.4	4.3
4664.682	-1.0	3.3	4391.636	-7.3	4.9	4059.648	-21.9	3.4	3930.013	-28.3	3.6
4680.730	-0.7	3.3	HR 4456A = 60 Leo			4068.651	-16.4	2.7	3984.946	-45.9	1.6
4698.730	-2.6	4.4	3298.632	+20.7	2.8	4070.659	-25.9	3.3	3985.883	-45.1	2.2
4699.740	+6.7	5.4	3571.963	-19.2	5.8	HR 5915 = 47 Lib			3986.905	-44.3	2.8
4700.749	+7.4	5.4	3601.762	+8.4	5.3	3296.808	+7.5	4.7	4057.732	-40.6	4.0
HR 2494 = 16 Mon			3649.641	+1.8	3.6	3298.809	+11.8	3.6	4058.713	-40.0	3.6
3460.990	+19.5	2.1	3650.675	+38.9	3.1	3329.674	+5.7	4.2	4059.784	-28.6	3.0
4190.051	+36.4	3.4	3986.699	+29.2	1.9	3571.972	+6.9	4.6	HR 6684		
4237.979	+28.7	1.8	4237.994	+0.4	4.6	3601.894	+6.5	2.2	3296.826	-11.9	3.4
4335.715	+2.6	2.2	4270.973	-6.2	4.3	3648.791	+17.6	2.7	3298.821	-24.7	4.0
4336.693	+8.0	3.7	4334.782	+26.2	4.8	3649.787	+17.6	5.0	3329.695	-13.4	1.9
4524.011	+22.4	1.8	4335.741	+8.6	3.6	3650.779	-1.0	6.1	3412.581	-29.6	1.8
4557.051	+17.8	2.8	4336.728	-12.5	2.1	3676.722	-1.7	9.6	3572.016	-20.7	2.4
4557.985	+15.9	1.8	4363.652	-9.8	5.0	3677.742	+8.4	10.7	3601.938	-18.1	4.2
4589.967	+8.8	2.2	4364.663	+24.1	4.0	3678.740	+9.7	2.7	3648.858	-28.2	2.1
4590.907	+11.2	1.6	4390.663	-10.8	2.4	3727.673	+10.9	3.9	3649.875	-22.8	3.1
4622.839	+1.8	2.2	4391.644	+31.0	2.2	3929.944	-4.7	4.7	3650.865	-21.0	5.0
4623.744	-5.9	1.2	4392.633	+14.6	3.0	3984.819	+9.6	5.0	3676.795	-22.5	1.2
4643.784	+23.2	1.0	4589.998	+17.8	3.3	3985.873	+6.6	2.5	3677.810	-21.0	3.0
4664.712	+50.1	1.5	4590.920	+22.5	3.6	3986.895	+5.9	3.7	3678.812	-27.0	3.1
4680.740	+49.1	1.6	4622.851	-18.2	3.9	4057.724	+11.3	1.3	3726.765	-22.7	1.8
4698.740	+46.9	1.6	4623.892	+5.5	2.1	4058.706	+12.0	5.4	3727.685	-14.4	3.7
HR 5764 = ζ Lib			HR 3194			4059.653	+11.8	1.9	3757.773	-16.7	3.7
3296.802	+2.4	3.3	3461.021	+26.2	1.6	4068.655	-28.3	5.8	3930.022	-25.5	2.2
3298.776	+4.2	2.1	3571.852	+25.8	3.3	4070.664	-36.0	3.6	3985.947	-20.3	3.0
3329.663	+3.5	5.0	3601.749	+31.0	2.4	HR 5985 = β^2 Sco			3986.965	-31.3	2.7
3601.883	+5.9	4.3	3649.629	+23.7	3.4	3296.817	-6.3	2.2	4057.844	-11.2	3.1
3648.761	-1.0	5.0	3650.661	+23.4	3.6	3298.813	-6.2	5.3	4058.871	-24.7	3.7
3649.779	-1.2	5.0	3986.679	+30.6	2.4	3329.683	-11.7	3.0	4059.790	-11.7	3.0
3650.772	-2.2	2.1	3986.679	+30.6	2.4	3572.009	-1.3	5.8	HR 6738 = 96 Her		
3676.682	-11.1	6.8	4237.985	+27.9	2.4	3601.899	-16.5	5.0	3296.845	-20.7	4.4
3677.705	+4.8	11.6	4335.727	+31.3	1.9	3648.795	-0.9	3.1	3298.823	-37.8p	2.1
3678.700	-1.1	6.8	4336.710	+30.5	1.8	3649.791	-4.0	3.7	+15.0s		
3726.748	+1.4	5.2	4557.988	+18.8	2.2	3650.785	-8.3	3.4	3329.811	+31.7p	4.8
3727.662	-4.5	3.0	4589.971	+28.8	1.9	3676.727	+1.1	5.4	-37.3s		
3929.918	-10.7	5.9	4590.915	+30.7	2.7	3677.749	-18.2	3.1	3412.587	-38.4p	3.6
3984.803	+1.5	1.2	4622.845	+29.8	2.2	3678.747	-14.8	4.8	+11.2s		
3985.858	+4.5	4.6	4623.749	+29.8	2.5	3929.957	-3.5	2.5	3459.623	-24.4	2.8
3986.882	-13.2	3.9	4643.790	+26.0	2.1	3984.827	-0.6	3.4	3460.560	-30.1	2.7
4057.714	-0.4	4.4	4664.747	+25.0	1.8	3985.880	-13.3	4.0	3461.568	-28.1	2.8
4058.687	+2.7	1.8	4680.769	+26.4	4.3	3986.901	-9.3	4.0	3462.565	-35.6p	6.4
4059.644	-4.1	+3.3	4698.755	+32.8	1.5	4057.728	-1.3	3.6	+16.1s		
			4699.755	+28.0	+0.7	4058.682	-2.1	3.9	3572.021	-28.2	+3.1
						4058.710	-1.2	+5.2			

TABLE 2—Continued

Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ
3601.944	+ 8.0p	+2.4	3298.891	-41.0	+4.2	4058.882	-25.3	+2.8	3808.665	+ 5.0	+5.3
	-56.3s	5.3	3329.828	-28.7	2.5	4059.800	-23.7	2.5	3809.672	-57.2	4.4
3648.857	-28.2	2.8	3459.643	-32.7	4.6				3810.629	+29.0	2.8
3649.878	-38.1p	3.7	3460.575	-49.2	3.9	HR 7210			3830.652	+26.0	3.3
	+22.9s	3.0	3461.591	-27.8	2.4	3296.872	-14.0	1.5	3985.991	-23.6	3.3
3650.897	-22.1	3.3	3462.611	-23.8	3.7	3298.902	-17.1	1.0	3987.006	+ 6.5	1.8
3676.800	+26.6p	3.3	3601.961	-30.3	3.3	3329.849	-18.1	1.3			
	-52.7s	1.6	3649.886	-28.4	2.2	3459.671	-21.0	2.1	HR 7608 = 23 Cyg		
3677.815	-21.0	4.6	3650.906	-28.2	3.0	3460.614	-21.0	1.8	3296.890	-28.9	4.0
3678.818	-25.5	4.0	3676.843	-26.4	5.3	3462.667	-22.0	1.2	3298.915	- 9.9	3.9
3726.769	+36.0p	3.9	3677.862	-24.6	5.2	3601.977	-18.4	1.6	3329.863	-15.3	5.9
	-65.2s	4.0	3678.865	-23.6	6.5	3649.922	-20.7	2.7	3460.630	-20.9	2.1
3727.833	+34.8p	4.2	3726.801	-24.8	3.6	3650.918	-19.5	1.8	3462.685	-15.7	4.9
	-77.2s	6.7	3727.862	-26.8	4.2	3676.858	-18.8	1.5	3601.993	-45.9	4.7
3757.781	-19.6	3.9	3808.613	-21.4	4.3	3677.880	-22.4	3.0	3649.933	-43.7	4.4
3985.953	-43.4p	2.7	3809.614	-30.7	5.0	3678.883	-22.6	1.9	3650.927	-31.0	4.2
	+19.7s	0.9	3810.596	-25.0	5.0	3726.814	-22.8	2.8	3676.878	-41.4	5.6
3986.970	-31.4	1.5	3985.958	-24.9	4.8	3727.882	-20.3	2.7	3677.902	-37.8	2.5
			3986.975	-19.3	4.4	3808.645	-21.0	1.6	3678.911	-52.2	2.7
HR 6984						3809.640	-20.5	1.8	3726.860	-37.3	3.3
3296.849	-20.6	2.7	HR 7166			3810.617	-21.6	2.8	3727.898	-32.3	2.4
3298.878	-28.0	5.6	3296.866	-10.0	4.9	3985.977	-15.9	2.1	3808.679	-39.9	4.0
3329.814	-38.1	5.0	3298.897	-11.7	5.3	3986.992	-14.8	1.2	3809.680	-29.4	2.4
3412.591	-26.4	4.0	3329.836	- 9.4	3.0	4057.852	-17.4	2.7	3810.637	-46.0	4.0
3459.630	-27.0	6.2	3459.651	-21.0	5.0	4058.883	-19.3	2.1	3830.662	-37.4	2.2
3460.566	-28.7	4.4	3460.578	-13.8	4.0	4059.802	-19.9	2.2	3985.997	-32.5	3.1
3461.575	-29.7	4.8	3461.600	-13.4	4.3	HR 7279 = 20 Aql			4057.861	-42.5	5.5
3462.597	-19.7	3.1	3462.616	-15.8	5.3	3296.880	-21.3	3.6	4058.890	-33.2	4.7
3601.949	-39.0	5.8	3601.968	-10.2	4.0	3298.910	-15.3	2.2	4059.812	-26.5	4.3
3649.880	-14.5	4.4	3649.916	-11.6	1.8	3329.857	-15.3	4.4	HR 7613 = 22 Cyg		
3650.899	-18.8	5.3	3650.913	- 6.8	1.5	3460.616	-17.2	3.7	3296.895	- 0.5	1.9
3676.811	-13.0	7.1	3676.851	-11.8	6.7	3601.982	-21.3	2.5	3298.920	- 3.6	2.2
3677.831	-28.0	3.4	3677.871	-23.8	5.6	3649.929	-18.7	1.8	3329.870	- 0.1	1.3
3678.829	-22.7	10.8	3678.874	-29.5	9.2	3650.924	-18.4	3.7	3460.633	- 5.4	1.2
3726.773	-16.9	4.8	3726.807	-13.4	4.0	3676.870	-35.4	2.1	3462.689	- 6.1	1.0
3727.839	-25.8	3.4	3727.871	-14.9	1.9	3677.889	-23.4	5.7	3601.996	-19.8	2.1
3757.792	-25.6	2.1	3809.622	-16.0	2.1	3678.893	-15.4	7.0	3649.937	-19.0	1.8
3808.595	-29.9	4.6	3810.601	- 6.7	4.2	3726.854	-19.6	2.7	3650.935	-21.3	5.3
3809.598	-20.9	3.3	3985.965	-12.0	2.5	3727.891	-33.6	2.7	3676.885	-25.3	1.9
3810.575	-20.6	4.1	3986.982	- 6.1	5.3	3808.655	-26.8	5.0	3677.908	-17.7	3.9
HR 7084			4057.849	- 9.6	0.9	3809.653	-12.2	3.1	3678.919	-24.1	1.3
3296.852	-34.1	4.6	4058.875	- 8.6	1.9	3810.621	-17.2	3.4	3726.866	-23.8	3.1
3298.882	+10.8	5.9	4059.795	- 8.0	0.7	3830.639	-11.0	4.2	3727.905	-22.5	2.4
3329.819	-29.6	3.9	HR 7202			3985.985	-12.4	2.8	3808.685	-27.5	1.0
3412.595	+30.0	4.8	3296.869	-21.5	4.0	3987.000	-42.9	1.5	3809.686	-26.2	1.3
3459.638	+32.7	3.4	3298.900	-22.3	3.9	4057.859	-21.2	1.3	3810.641	-29.3	2.4
3460.572	+33.8	4.3	3329.846	-24.5	3.0	4058.891	-39.6	5.0	3930.666	-28.0	2.4
3461.584	+15.8	3.0	3459.663	-25.7	4.2	4059.813	-18.6	3.0	3986.002	-33.7	1.8
3462.606	-19.8	3.1	3460.609	-17.6	5.2	HR 7486 = QS Aql			4057.866	-33.4	1.6
3601.955	+12.5	4.2	3462.659	-25.2	5.3	3296.886	-60.1	2.7	4058.897	-32.1	2.4
3649.882	-18.1	3.6	3601.972	-18.2	2.2	3298.913	-40.8	4.2	4059.818	-36.8	1.5
3650.900	-46.9	3.6	3649.921	-28.8	3.1	3329.862	-33.4	2.1	HR 7620		
3676.834	-10.1	5.5	3650.916	-17.7	1.9	3459.677	-33.6	2.5	3296.900	-21.5	5.2
3677.854	-43.3	4.8	3676.855	-23.5	1.6	3460.623	-28.7	3.0	3298.924	-20.7	3.3
3678.856	-27.2	4.8	3677.876	-26.6	5.9	3462.674	-60.0	3.3	3329.875	-24.3	4.3
3726.793	+ 8.3	5.0	3678.879	-21.2	5.8	3601.987	+12.8	4.2	3460.637	-17.9	4.3
3727.849	+31.6	3.9	3726.811	-22.2	5.6	3649.931	+20.9	2.8	3462.696	-21.3	4.6
3757.799	-32.2	2.1	3727.878	-16.4	1.6	3650.926	-48.7	1.6	3602.001	-41.0	4.7
3808.605	+39.9	4.3	3808.636	-20.6	3.9	3676.875	-16.9	2.4	3649.956	-25.6	4.0
3809.607	+14.5	4.0	3809.632	-26.9	1.8	3677.899	+ 5.7	6.1	3650.942	-30.4	2.5
3810.590	+ 6.6	5.5	3810.610	-21.9	3.9	3678.901	-56.5	3.3	3676.890	-23.8	5.3
HR 7100 = 8 Lyr			3985.971	-23.4	2.1	3726.859	-43.9	2.8	3677.913	-31.7	4.7
3296.859	-26.1	+3.1	3986.987	-18.6	1.5	3727.896	+18.8	+1.3	3678.925	-23.1	+5.0
			4057.851	-21.5	+2.4						

TABLE 2—Continued

Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ
3726.870	-29.6	+1.9	3726.882	- 7.3	+2.5	3677.952	- 6.8	+3.7	3677.976	- 2.9	+3.1
3727.911	-18.9	3.0	3727.926	-13.6	1.9	3678.959	- 2.2	2.5	3678.983	- 8.2	4.0
3808.695	-26.0	3.6	3757.849	-10.8	3.4	3726.892	- 1.5	1.9	3726.908	- 5.9	1.5
3809.697	-18.3	3.0	3808.716	-18.6	4.0	3727.940	- 2.1	1.6	3727.987	- 8.0	1.5
3810.649	-16.8	3.0	3809.732	- 8.8	3.6	3757.863	- 2.0	1.5	3757.878	- 8.4	0.9
3830.674	-26.1	2.5	3810.671	- 4.3	5.3	3808.742	- 1.7	2.1	3809.770	- 8.5	1.8
4057.870	-20.3	2.2	4057.925	-16.8	5.8	3810.696	- 3.4	1.2	3810.722	-10.5	1.0
4058.900	-19.3	1.9	4058.912	- 9.2	1.0	4057.934	+ 0.5	1.3	3830.702	- 2.5	2.1
4059.822	-25.9	2.4	4059.904	- 9.4	1.3	4058.922	- 5.2	1.8	3831.608	-10.6	1.0
			4068.880	- 4.0	2.2	4059.916	- 3.5	2.4	3832.604	- 9.6	1.2
						4068.893	- 5.7	1.6	4057.957	- 8.9	1.0
HR 7628			HR 7894 = 28 Vul						4058.938	- 6.8	1.0
3296.905	- 1.3	2.4	3296.949	-27.2	4.2	HR 8215 = 70 Cyg			4059.932	- 8.3	1.0
3298.928	- 4.3	5.9	3298.938	-27.1	2.5	3296.963	-20.8	3.1	4068.901	- 2.2	2.5
3329.880	-57.5	2.8	3329.893	-24.2	2.7	3298.970	-23.2	4.7	4116.870	-12.5	1.9
3460.642	-54.8	3.0	3460.653	-21.3	2.5	3329.906	-20.5	3.4	4117.835	- 2.5	1.5
3462.705	-54.5	5.4	3462.722	-20.2	4.7	3459.691	-19.3	4.0			
3602.006	-34.2	3.0	3508.608	-35.6	4.2	3460.669	-17.7	3.9	HR 8513 = 30 Peg		
3649.950	-17.5	3.7	3649.970	-21.3	3.6	3650.966	-11.6	4.7	3296.980	-12.4	1.3
3650.938	-16.4	3.3	3650.957	-20.2	3.4	3676.948	-28.3	4.6	3298.982	-10.3	3.1
3676.896	-40.7	5.2	3676.915	-16.4	3.9	3677.962	-25.8	3.6	3459.698	+ 2.5	4.0
3677.917	-43.3	5.4	3677.936	-12.3	4.3	3678.972	-21.1	3.6	3460.682	-10.9	1.5
3678.931	-50.5	3.9	3678.950	-25.7	3.6	3726.898	-13.7	4.2	3462.760	- 4.3	3.3
3726.874	-35.5	4.2	3726.885	-20.0	2.8	3727.946	-22.2	2.4	3521.571	- 8.6	2.1
3727.917	-31.2	4.6	3727.930	-22.8	4.4	3757.868	-17.9	3.7	3676.966	+ 2.6	2.8
3808.703	-47.3	4.2	3757.853	-23.3	3.0	3809.750	-17.8	3.0	3677.981	-12.9	4.2
3809.705	-39.1	4.4	3808.724	-25.5	3.0	3810.703	-20.9	4.4	3678.989	- 2.1	3.6
3810.655	-40.2	4.6	3810.682	-19.2	1.9	3830.686	-18.4	3.1	3726.913	+ 5.8	4.0
4057.874	+ 4.6	1.6	4057.929	-22.5	2.7	3831.600	-14.3	2.2	3727.993	- 3.4	1.6
4058.904	- 9.1	1.9	4058.915	-21.9	2.1	3832.545	-18.6	3.7	3757.884	+ 0.8	1.2
4059.826	- 7.8	3.6	4059.906	-22.1	4.3	4057.941	-18.1	1.8	3809.832	+ 6.0	4.3
4068.871	-17.1	3.7	4068.883	-27.3	2.8	4058.926	-13.9	1.9	3810.729	+ 2.9	1.9
						4059.922	-18.8	2.2	3830.709	+ 2.4	1.9
HR 7647 = 25 Cyg			HR 7899			4188.566	-18.5	5.0	3831.615	+ 4.6	2.5
3296.909	+ 3.4	2.5	3296.954	-13.0	3.0	HR 8356 = 16 Peg			3832.612	- 3.7	1.0
3298.932	- 8.3	4.0	3298.964	- 2.0	3.1	3296.968	-27.1	2.5	4057.960	+ 2.1	2.7
3329.885	+ 1.4	3.7	3329.899	- 5.9	3.4	3298.973	-27.7	2.2	4058.942	0.0	3.0
3460.645	-28.8	4.3	3460.658	- 9.2	5.3	3329.910	-23.2	3.1	4059.935	+ 2.8	2.8
3462.712	-18.6	4.0	3462.730	- 5.0	1.9	3459.695	-12.9	4.2			
3602.010	- 0.3	2.4	3508.621	- 7.4	3.0	3460.672	- 7.8	2.8	HR 8579 = 6 Lac		
3649.962	- 5.9	7.6	3649.976	-13.9	1.8	3461.662	-19.7	1.8	3459.702	-19.0	3.6
3650.947	- 5.3	1.9	3650.961	- 2.9	2.4	3462.744	-22.0	3.4	3460.686	-16.4	4.9
3676.900	- 3.0	3.7	3676.922	- 7.2	6.2	3650.970	-32.5	3.9	3462.765	-21.0	3.4
3677.924	-11.2	5.0	3677.947	- 5.1	5.3	3676.953	-20.9	3.6	3508.664	-20.0	2.4
3678.936	-12.9	3.4	3678.956	- 3.6	4.6	3677.967	-33.8	1.3	3676.968	-24.1	1.5
3726.878	-13.4	1.8	3726.889	- 7.1	2.4	3678.976	-14.2	2.4	3677.982	-22.7	2.7
3727.922	-19.6	2.2	3727.936	+ 0.9	3.3	3726.902	-21.6	3.0	3678.991	-24.4	3.1
3808.710	-16.7	3.0	3757.859	- 3.3	5.9	3727.951	- 6.0	3.9	3726.914	-20.5	3.7
3809.725	-11.6	2.8	3808.732	-10.4	5.8	3757.873	-25.1	2.5	3727.994	-23.1	3.1
3810.667	-10.9	2.2	3810.688	-11.1	4.4	3809.762	-22.5	3.0	3757.886	-20.5	2.5
4057.878	-26.7	3.3	4057.933	- 5.9	4.9	3810.717	-29.0	1.9	3809.837	-25.2	2.7
4058.907	-36.4	2.7	4058.921	- 2.8	5.6	3830.693	-21.4	4.3	3810.734	-21.7	3.6
4059.899	-26.8	2.4	4059.915	+ 2.7	3.0	3831.604	-18.2	3.0	3830.715	- 9.7	5.5
4068.876	-33.9	2.7	4068.888	- 3.5	3.9	3832.550	-18.2	2.8	3831.620	-17.7	2.4
						4057.945	-17.9	3.6	3832.617	-14.8	2.5
HR 7688 = 17 Vul			HR 7929 = 51 Cyg			4058.933	-23.1	4.2	4057.964	-21.1	2.7
3296.914	- 8.5	6.5	3296.957	- 8.1	1.6	4059.925	-21.5	4.2	4058.945	-12.6	4.0
3298.936	- 9.6	2.8	3298.966	-10.2	2.4				4059.935	-16.8	2.7
3329.889	-11.9	4.2	3329.901	- 6.7	1.9	HR 8439 = 35 Aqr			4068.907	-15.2	2.8
3460.649	- 0.9	4.4	3459.687	-10.9	2.2	3296.975	- 7.8	0.9	4116.871	-26.3	3.1
3462.717	-10.9	2.2	3460.664	-12.9	3.4	3298.978	- 3.0	1.5	4117.837	-24.5	4.2
3649.966	- 9.8	3.7	3462.739	-12.6	1.3	3460.675	- 6.7	1.6			
3650.950	- 3.8	4.0	3649.978	- 2.6	2.7	3462.750	- 9.7	2.1	HR 8725 = 16 Lac		
3676.911	-13.9	0.9	3650.963	- 1.1	2.2	3676.961	-13.6	+2.4	3459.706	-31.1	1.2
3677.930	-11.7	5.3	3676.931	-12.2	+1.8				3460.690	-35.2	+1.5
3678.942	-11.5	+5.9									

TABLE 2—Continued

Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ	Helio. JD 2440000+	ρ (km s ⁻¹)	σ
3462.769	-22.6	+2.1	4187.677	-26.4	+1.6	3832.629	- 7.4	+1.5	3757.903	-11.9	+2.2
3508.670	-35.0	0.9	4188.659	-20.8	1.8	4057.971	- 5.0	1.9	3808.842	+ 5.5	3.1
3676.979	-19.7	1.3				4058.952	- 8.6	1.6	3809.872	- 9.1	2.5
3677.992	-38.7	2.5				4059.970	- 8.9	1.6	3810.766	+ 5.5	2.2
3726.918	-37.2	2.2	HR 9005			4068.914	- 6.4	1.6	3830.750	+11.7	3.4
3757.889	+ 7.8	0.7	3459.814	- 8.7	1.8	4116.877	-12.8	2.1	3831.642	- 3.7	2.8
3810.749	-24.0	1.8	3460.695	- 7.3	2.8	4117.847	- 7.9	1.9	3832.639	+ 2.5	3.7
3830.720	+19.4	2.1	3462.776	- 6.4	1.0	4187.684	-11.6	0.5	4057.977	- 8.3	2.4
3831.625	+ 2.6	1.0	3508.681	-11.9	1.5				4058.958	- 1.5	3.3
3832.622	-15.9	2.1	3676.984	- 7.0	1.9				4059.980	-12.0	4.0
4057.967	- 3.3	1.2	3726.921	-10.8	1.3	HR 9011			4068.968	+ 1.3	1.6
4058.948	+10.2	1.8	3757.894	-11.6	2.4	3459.728	- 2.2	1.5	4116.884	+10.5	2.2
4059.963	+12.2	1.8	3808.829	-10.1	2.2	3460.725	-12.5	3.7	4117.855	- 2.8	3.3
4068.911	- 7.8	1.8	3809.856	- 8.7	1.8	3462.784	- 8.8	3.1	4187.692	-31.8	+3.1
4116.875	-19.6	1.2	3810.758	-13.2	1.0	3508.689	- 4.6	3.6			
4117.842	- 9.4	+1.6	3830.729	- 4.2	1.8	3676.990	-19.0	4.7			
			3831.632	-10.9	+1.3	3726.928	-21.1	+3.6			

TABLE 3
RESULTS OF SPECTROSCOPIC SURVEYS

HR	n	$\langle\rho\rangle$ (km s ⁻¹)	σ (km s ⁻¹) E I	Conclusions and comments	
39 ^a	20	+ 3.3	+3.1	+1.8	Approximately constant velocity; β CMA variable
91	20	-15.8	17.9	2.8	Known SB1 (Blaauw and van Albada 1963); improved elements
153 ^a	20	+ 1.0	1.6	1.5	Constant velocity
154 ^a	0	+ 8.4	...	...	Known SB2 (Pearce 1936)
155	23	- 8.4	4.7	3.1	Constant velocity
179 ^a	20	-10.3	8.9	4.7	Probably variable
189	21	-66.2	5.2	3.6	Constant velocity
226 ^a	20	-23.5	51.3	3.7	Known SB2 (Jordan 1910); improved elements
779 ^a	20	+ 4.4	7.6	3.1	Constant velocity; β CMA variable
801 ^a	20	+12.4	7.6	4.4	Possibly variable
987	20	- 5.8	3.7	3.8	Constant velocity
989	20	- 4.4	3.4	3.6	Constant velocity
1005	20	+15.1	5.2	2.5	Constant velocity
1011	20	- 5.6	4.3	2.5	Constant velocity
1029	20	- 3.2	5.5	3.7	Constant velocity
1034 ^a	20	- 0.5	18.2	5.5	SB1
1044 ^a	20	- 5.0	8.6	4.5	Constant velocity
1153	19	+10.6	14.7	3.7	Known SB1 (Blaauw and van Albada 1963); corrected elements
1174	20	+19.7	5.8	3.0	Constant velocity
1239 ^a	0	+15.2	...	...	Known SB2 (Fekel and Tomkin 1982)
1244	20	+16.1	5.0	3.7	Constant velocity
1253	20	+14.4	4.6	1.9	Probably variable
1288	20	+18.5	4.6	2.2	Constant velocity
1320 ^a	20	+15.5	4.0	3.7	Constant velocity
1350	20	+ 8.5	4.7	2.2	Constant velocity
1497 ^a	20	+13.9	42.0	5.6	Known SB2 (Petrie and Ebbighausen 1961); improved elements
1520 ^a	0	+23.3	...	...	Known SB1 (Hill 1969)
1574	20	+15.0	16.9	3.4	SB1
1617 ^a	20	+17.9	2.8	3.4	Constant velocity
1641 ^a	23	+ 5.4	4.5	4.9	Constant velocity
1646	20	+29.2	4.2	3.7	Constant velocity
1659	20	+10.4	+19.3	+3.1	Known SB1 (Hill 1929); improved elements

TABLE 3—*Continued*

HR	n	$\langle \rho \rangle$ (km s ⁻¹)	σ (km s ⁻¹)		Conclusions and comments
			E	I	
1679 ^a	21	+ 1.0	+29.8	+10.1	Variable velocity
1749	20	+16.3	22.5	3.9	Known SB1 (Blaauw and van Albada 1963); improved elements
1764	14	+ 9.2	27.4	3.7	SB2; uncertain elements
1765 ^a	21	+28.2	3.0	1.6	Constant velocity
1783	19	+21.6	8.2	1.6	SB1; uncertain elements
1803	20	+13.4	38.8	3.4	Known SB1 (Dufloot 1953); improved elements
1808	20	+13.3	5.3	3.9	Constant velocity
1810 ^a	20	+15.2	2.2	2.4	Constant velocity
1811 ^a	20	+19.1	110.3	4.9	Known SB2 (Pearce 1953a); improved elements; apsidal motion
1833	20	+11.7	6.8	3.3	Possible variable
1839 ^a	20	+19.8	7.0	6.2	Constant velocity
1864	20	+15.9	5.6	3.3	Constant velocity
1875	20	+13.4	6.2	3.7	Constant velocity
1911	20	+29.7	3.3	2.7	Constant velocity
1913	18	+22.8	25.2	3.6	SB1
1928	18	+16.2	11.9	2.8	Known SB1 (Cannon 1916); improved elements
1946 ^a	20	+22.8	4.6	4.3	Constant velocity; possible β Cma variable
1952	18	+36.2	27.9	3.6	Known SB2 (Pearce 1953b); confirmed elements
1993	17	+23.7	4.2	3.3	Constant velocity
2031	17	+ 9.6	7.0	3.7	Constant velocity
2052	16	0.0	48.8	3.3	Known SB2 (Hill 1969); improved primary elements
2154	18	+21.0	1.9	1.9	Constant velocity
2159 ^a	0	+24.1	...	...	Known SB1 (Ebbighausen and Petrie 1959)
2198 ^a	20	+14.9	25.2	10.5	Possibly variable
2199 ^a	20	+22.4	19.1	4.9	SB1
2205	17	+28.0	2.2	1.5	Constant velocity
2266	16	+17.9	13.2	3.9	SB1
2273	16	+16.5	28.0	3.7	SB1
2344 ^a	20	+26.8	5.9	4.9	Constant velocity
2395	19	+20.6	4.4	2.4	Constant velocity
2490	18	+ 0.4	5.8	4.0	Constant velocity
2494	16	+17.9	17.3	2.1	SB1
3192 ^a	21	+20.7	6.1	4.6	Constant velocity
3194	20	+27.9	3.6	2.4	Constant velocity
3454 ^a	20	+11.6	5.5	5.0	Constant velocity
3849 ^a	20	+22.6	8.3	6.2	Constant velocity
3952	19	- 3.4	4.7	3.4	Constant velocity
4456A	20	+ 6.4	17.5	3.6	SB1
5191 ^a	20	-15.3	5.6	6.1	Constant velocity
5764	20	- 0.8	5.5	4.4	Constant velocity
5902	21	-11.5	15.9	3.1	Known SB1 (Levato et al. 1987)
5915	21	+ 5.0	14.1	4.4	Variable velocity
5985	21	- 6.5	5.9	4.0	Constant velocity
6092 ^a	24	-17.2	3.9	3.9	Constant velocity
6502	22	-28.4	12.9	3.1	SB1
6588 ^a	20	-19.9	4.2	1.6	Possibly variable
6684	21	-21.7	5.9	3.0	Known β Cma var.; confirmed velocity variations; var. γ -vel.?
6738	21	-16.0	25.7	3.4	Known SB2 (Koubsky 1985)
6787 ^a	19	-15.6	1.6	1.8	Constant velocity
6984	20	-24.7	6.8	4.7	Constant velocity
7084	20	- 2.1	29.1	4.2	SB1
7100	20	-28.2	6.7	4.0	Constant velocity
7166	22	-12.9	5.8	3.9	Constant velocity
7202	22	-22.4	+3.3	+3.4	Constant velocity

TABLE 3—*Continued*

HR	n	$\langle \rho \rangle$ (km s ⁻¹)	σ (km s ⁻¹)		Conclusions and comments
			E	I	
7210	22	-19.5	+2.5	+1.9	Constant velocity
7279	21	-21.8	9.0	3.4	Probably variable
7298 ^a	22	- 8.9	3.0	1.8	Constant velocity
7306 ^a	30	-27.2	8.6	4.7	Possible variable
7372 ^a	21	-25.0	11.0	5.0	Probably variable
7426 ^a	22	-19.5	1.9	1.9	Constant velocity
7486	20	-16.9	31.6	3.1	Known ecl. SB1 (Hill 1930); improved elements
7608	21	-33.3	11.1	3.9	Probably variable
7613	21	-14.8	11.3	2.1	SB1
7620	20	-24.1	5.8	3.6	Constant velocity
7628	20	-30.8	19.6	3.9	Known SB1 (Batten et al. 1982)
7647	20	-14.6	11.6	3.3	SB1
7688	20	- 9.8	4.3	3.6	Constant velocity
7739 ^a	21	- 9.2	8.6	5.9	Constant velocity
7844 ^a	21	-21.9	11.1	5.0	Possibly variable
7894	20	-22.8	4.7	3.3	Constant velocity
7899	20	- 5.8	4.3	4.0	Constant velocity
7929	20	- 5.5	4.3	2.1	Possible variable
8001 ^a	70	-17.6	69.7	5.6	Known SB2 (Hilditch 1973); improved elements; apsidal motion
8215	21	-19.1	4.0	3.6	Constant velocity
8301 ^a	20	-11.1	4.4	3.9	Constant velocity
8356	22	-21.2	7.0	3.1	Possibly variable
8439	21	- 7.5	3.3	1.6	Constant velocity
8513	20	-18.0	6.2	2.7	Possibly variable
8579	21	-19.9	4.4	3.1	Constant velocity
8725	20	-13.0	17.9	1.6	Known SB1 (Fitch 1969) and β CMa; confirmed elements
8858 ^a	21	- 4.2	25.6	10.8	Probably variable
8926 ^a	0	-13.4	...	...	Known SB1 (Gorza and Heard 1971)
9005	20	- 9.0	2.5	1.6	Constant velocity
9011	20	- 5.6	+10.8	+3.0	Possibly variable

^aData from Abt and Levy 1978, although the interpretation may be changed.

dwarfs and by Abt and Levy (1976) for F3–G2 dwarfs that for binary periods of about $10\text{--}10^6$ yr, the systems are formed by capture.

For the reduced sample of 109 primaries, 36 primaries (33%) have one or more companions, and there are 49 observed companions plus at least 15 undetected ones for a total of 64 companions of $M_2 > 1 M_\odot$ to 109 primaries or 0.6 visual companions per primary.

b) Spectroscopic Binaries

After considering the properties of the spectroscopic binaries listed in Table 4, we again have to drop one (HR 1803) because of the Branch effect. Also, the fourth edition of the Bright Star Catalogue has the apparently single star HR 1029 too faint for this study; the original observing list was based on the third edition photometry. Thus our sample of 42 (AL78)+74 = 116 primaries is now reduced to 109 primaries.

For the double-lined binaries (SB2), the secondary masses are derived directly from the primary masses, assumed typical for their types, and the ratios of the velocity amplitudes.

The determination of secondary masses for single-lined binaries (SB1) can be done in any of three ways described by Halbwachs (1987). We prefer the second, or “discrete distribution of mass ratios,” used previously (e.g., AL78 or de-

scribed better in Abt and Levy 1985). We assume a nominal $8 M_\odot$ for the primaries; although they range from 11.8 to 6.3 $M_\odot$. We used the numerical method that assumes statistically random orientations of orbital axes to derive simultaneously the numbers of systems with various inclinations and secondary masses. The results are given in Table 6 in the rows labeled “Observed.” The periods of the spectroscopic binaries range from 1.7 to 143 days, or within the bins 10^{-3} to 1 yr.

However, all real SB1’s are not detected because the rotationally broadened lines may not allow the measurement of small amplitudes or small inclinations (between the line of sight and orbital axes). We used empirical data to calculate how many binaries of each orbital period and secondary mass we are missing. For instance, for periods in the range 10^{-3} to 10^{-2} yr (average of 2.6 days) and $M_1 = M_2 = 8 M_\odot$, the sum of the maximum velocity amplitudes, $K_1 + K_2$, is 399 km s^{-1} . But because the mean rotational broadening, $V \sin i$, of these primaries is 137 km s^{-1} and if we assume the same for these identical secondaries, we will not detect the binaries with inclinations such that $\sin i < (2 \times 137) (399)^{-1}$, or $i < 43^\circ$. The frequencies of orbital inclinations $0 < i < 43^\circ$ is $\cos 0^\circ - \cos 43^\circ = 0.273$. Therefore the ratio of total systems of this period to the number of observed ones is

TABLE 4
SPECTROSCOPIC ORBITAL ELEMENTS

HR	Period (days)	T_0 2400000+	K (km s ⁻¹)	γ (km s ⁻¹)	e	ω	$a \sin i$ (10 ⁶ km)	$f(R/R_0)$ (R_0)	$\sin^3 i$ (R_0)	σ (km s ⁻¹)
91	25.44 +0.03	43840.3 +0.3	23.4 +1.9	-15.8 +1.3	0.14 +0.09	165 ⁰ +5	8.10	0.0329	...	4.5
154 ^a	143.61	27898.57	47.5 117.4	+ 8.4	0.56	349 169	77.7 192.	0.9086	27.1 11.0	
226 ^a	4.282728 +0.000006 assumed	18155.67 +0.01 18157.87 +0.03	71.7 +1.5 101.9 +2.5	-23.5 +1.0 -25.4 +4.0	0.03 +0.01 0.04 +0.04	25 +18 212 +40	4.22 6.00	0.1637	1.36 0.96	9.5 13.5
1034 ^a	21.659 +0.16	41946.0 +1.5	25.0 +3.0	-0.5 +2.5	0.17 +0.12	134 +33	7.34	0.0336	...	3.3
1153	1.69382 +0.00006	44062.84 +0.04	26.8 +3.3	+10.6 +1.2	0.40 +0.10	176 +10	0.572	0.00261	...	2.5
1239	3.95296	44658.4	56.9 215.6	+13.4	0.0	...	3.093 11.72	0.0754	7.18 1.89	...
1497 ^a	2.956548 +0.000013 assumed	36425.10 +0.47	52.8 +1.0 179. +12	+13.9 +0.9	0.02 +0.01	107 +58	2.146 7.277	0.0451	2.95 0.87	6.2
1520 ^a	7.35886 +0.00006	16392.46 +0.31	19.4 +1.3	+23.3 +1.0	0.26 +0.06	150 +11	1.90	0.00502	...	6.0
1574	24.10 +0.02	44280.0 +1.6	24.5 +4.1	+15.0 +2.8	0.33 +0.13	138 +34	7.66	0.031	...	5.8
1659	58.25 +0.07	44276.6 +2.6	30.5 +3.1	+10.4 +2.2	0.26 +0.10	296 +19	23.59	0.1547	...	3.9
1749	34.45 +0.03	44412.3 +0.6	36.6 +2.4	+16.3 +1.6	0.12 +0.06	31 +6	17.21	0.1718	...	4.2
1783	106.7 +0.4	44370.7 +6.7	14.9 +4.1	+21.6 +1.5	0.50 +0.20	45 +27	18.93	0.0238	...	4.2
1803	2.88843 +0.00004	44367.343 +0.007	53.8 +0.9	+13.4 +0.6	0.006 +0.016	...	2.137	0.04677	...	4.7
1811 ^a	2.52605 +0.00006 assumed	41949.51 +0.10 assumed	142.2 +2.4 229.	+19.1 +1.8	0.08 +0.01	356 +13	4.924	0.7471	8.19 5.09	6.5 24.9
1913	3.8110 +0.0006	44458.4 +0.3	34.4 +3.3	+22.8 +2.4	0.07 +0.12	...	1.798	0.01601	...	5.2
1928	27.8285 +0.0006	25147.5 +0.3	24.3 +2.2	+16.2 +1.0	0.65 +0.04	344 +7	7.066	0.1822	...	6.5
1952	27.1546 +0.0001 assumed	29991.10 +0.16 assumed	88.5 +5.5 137.9 +8.9	+36.2 +2.1	0.73 +0.04	85 +4 265 +4	22.59 35.19	0.6243	6.36 4.08	
2052	7.99687 +0.00007 assumed	16805.89 +0.07 assumed	70. +4 199. +7	0.0	0.01 +0.06	...	7.698 21.88	0.2848	12.0 4.2	10. 25.

TABLE 4—Continued

HR	Period (days)	T_0 2400000+ (km s ⁻¹)	K (km s ⁻¹)	γ (km s ⁻¹)	e	ω	$a \sin i$ (10 ⁶ km)	$f(R)$ ($M_\odot$)	$M \sin^3 i$ ($M_\odot$)	σ (km s ⁻¹)
2159 ^a	131.211 +0.004	36475.85 +0.33	33.3 +1.2	+24.1 +0.4	0.64 +0.01	7 +2	45.96	0.2252	...	...
2199 ^a	45.10 +0.09	41962.3 +4.0	22.4 +3.1	+19.3 +1.5	0.26 +0.13	205 +30	13.41	0.0474	...	2.8
2266	70.6 +0.3	44493.7 +1.9	20.7 +2.7	+17.9 +1.2	0.56 +0.10	269 +10	16.487	0.03597	...	1.9
2273	15.78 +0.03	44451.8 +1.5	40.4 +5.0	+16.5 +4.9	0.30 +0.12	75 +25	8.362	0.09392	...	4.6
2494	16.88 +0.01	44466.7 +0.3	20.3 +2.7	+17.9 +1.2	0.36 +0.10	269 +10	16.487	0.03597	...	1.9
4456A	3.8209 +0.0006	44181.8 +0.1	24.0 +2.4	+6.4 +1.6	0.02 +0.01	...	1.261	0.00549	...	4.3
5902	14.4829 +0.0004	35172.380 +0.164	28.5 +3.3	+3.3 +1.6	0.27 +0.09	217 +17	5.460	0.0308	...	...
6502	8.9560 +0.0037	43721.66 +0.12	17.1 +1.1	-28.4 +0.8	0.11 +0.06	...	2.093	0.00457	...	3.6
6738	12.4573	45895.41	57.6 57.5	-15.5	0.54	321	8.30 8.29	...	0.59 0.59	...
7084	6.692 +0.003	43594.30 +0.07	35.4 +2.1	-2.1 +1.6	0.054 +0.006	...	3.253	0.03075	...	6.5
7486	2.51330 +0.00003	43647.363 +0.003	40.8 +0.3	-16.9 +0.1	0.002 +0.007	...	1.410	0.01775	...	4.8
7613	78.2 +0.4	43734.5 +2.1	20.7 +3.1	-14.8 +1.8	0.17 +0.13	139 +11	21.93	0.06902	...	4.7
7628	70.22 +0.02	39762.1 +1.4	41.4 +1.6	-20.1 +0.9	0.34 +0.04	302 +6	37.1	0.43	...	...
7647	53.6 +0.5	43749.2 +3.3	20.1 +6.1	-14.6 +3.6	0.18 +0.24	...	14.57	0.04308	...	8.2
8001 ^a	2.854822	40019.82	108.5	-17.6	0.12	191	4.229	0.3702	1.93	8.8
	assumed	40019.84	123.7	-11.9	+0.03 +0.15 +0.03	+2 +25 +1	4.801		1.70	18.2
8725	12.097 +0.001	33841.3 +1.3	23.0 +0.6	-13.0 +0.4	0.035 +0.03	...	3.82	0.0152	...	...
8926 ^a	6.06633	40087.19 +0.02	56.7 +1.0	-13.4 +0.7	0.245 +0.018	34 +1	4.59	0.095	...	4.2

^aData from Abt and Levy 1978.

COMMENTS TO TABLES 3 AND 4

HR 91.—A suspected light variable, and Koch 1960 found small light variations when he used this star as a comparison for nearby AO Cas. The period quoted above fits the data of Plaskett and Pearce 1931, Blaauw and van Albada 1963, and Abt 1970, although only the current data are used in the determination of orbital elements.

HR 987; HR 989; HR 1011; and HR 1029.—These four stars are members of the α Persei (Per OB3) cluster.

HR 1034.—Weak secondary lines were reported by Gomez and Abt 1982.

HR 1153.—Blaauw and van Albada 1963 gave a period of 2.4079 days, but our period of 1.69382 days fits our observations and/or theirs better. The elements above are from our data only.

HR 1239.—We quote in Table 4 Fekel and Tomkin's 1982 orbital elements.

HR 1350.—The nonradial pulsations with periods of 1.74 and 2.04 days may account for the velocity scatter of $E/I = 2.1$.

HR 1574.—Pearce and Petrie 1951 found the velocity to be variable with a range of 60 km s⁻¹. Although a period of 24.10 days seems best, we cannot rule out 23.66 and 1.04 days.

HR 1659.—Our elements are not very different than those of Hill 1929, but the scatter is smaller.

HR 1764.—This star has faint secondary lines not previously reported, but they are difficult to measure because of rotational broadening. The period may be 5.344 days, $K_1 = 43$ km s⁻¹, and $K_2 = 107$ km s⁻¹.

HR 1783.—Reported variable in velocity by Frost, Barrett, and Struve 1926. Although the period of 106.7 days fits the data best, periods of 7.10, 13.47, 13.97, and 9.17 days give scatter that is larger by only factors of 1.1 to 1.3.

HR 1803.—We confirm the period derived by Dufloot 1953 and Blaauw and van Albada 1963, but our smaller scatter does not confirm their eccentricity and large amplitude.

HR 1875.—Kodaira 1971 published elements, but both he and Frost *et al.* 1926 found only one observation that deviated substantially from a constant velocity.

HR 1913.—Plaskett and Pearce's 1931 five measures show no evidence for this large-amplitude binary motion, but those five measures all fall at two phases of equal velocity. However, we cannot use their data to improve the period because of an uncertainty of one cycle for the interval between their and our observations.

HR 1928.—The elements given are derived from measures by Cannon 1916 and us because a lack of measures by us near periastron prevents an independent determination.

HR 1952.—The secondary lines are too difficult to measure. We confirm Pearce's (1953b) primary elements and simply quote his results.

HR 2052.—Known SB2 with revised elements by Hill 1969. Our measures confirm his primary elements, except for a change in γ -velocity, and we did not attempt to measure the secondary lines. We quote his elements.

HR 2266.—van Hoof 1973 found the velocity to be variable and suggested a period of 12 days. However, his two sets of measures taken in 3–5 successive days show no significant variations within those groups. His data fit our elements if the γ -velocity has decreased 5 km s^{-1} .

HR 2273.—A period of 15.56 days gives only 1.7 times the scatter for a period of 15.78 days.

HR 2494.—Known velocity variable (Plaskett 1924). A period of 15.89 days gives 3 times the scatter of the adopted 16.88 days, but Plaskett's measures fit neither period.

HR 4456A.—ADS 8220 is a north-south pair with a separation of $3''.6$ and $\Delta V = 1.3$ mag. Plaskett and Pearce 1931 observed the northern bright star to have a constant velocity on eight spectra but the southern fainter star to be variable in velocity on 10 spectra. We observed the primary (northern, brighter) star—our exposure times and spectra verify the identification—and found it to be variable in velocity. Our orbital elements are given. Furthermore, eight of the 10 velocities for the “southern” star observed by Plaskett and Pearce fit our velocity curve, so we question their identifications.

HR 5902.—Variable velocity according to Moore 1924, and van Hoof, Bertiau, and Deurinck 1963 suggested a period around 11.5 days. Levato *et al.* 1987 derived a period of 14.4829 days and orbital elements. We do not confirm those, but we cannot offer an alternative.

HR 5915.—Variable velocity according to Wilson and Joy 1950. Evidently the orbit is very eccentric because only two of our 21 measures deviate significantly from a constant value. Two of the four Wilson-Joy measures (Abt 1973) also deviate significantly. These four measures provide limitations on the period. The two best periods using all the observations are 25.2737 days ($\sigma = 5.8 \text{ km s}^{-1}$) and 25.2498 days ($\sigma = 5.9 \text{ km s}^{-1}$).

HR 6502.—Variable velocity according to Struve 1925.

HR 6684.— β Cep star with velocity and light curves published by Bolton, Percy, and Shemilt 1975; the period is 0.139890 days. Our velocities confirm their velocity curve except that our mean of -22 km s^{-1} is smaller than theirs of -16 km s^{-1} .

HR 6738.—Koubisky 1985 published elements for this SB2 with a period of 12.4573 days. The lines may be triple or quadruple. Our measures confirm his period, at least. We quote his elements. The published rotational velocity of 205 km s^{-1} must refer to unresolved double lines; the individual values of $V \sin i$ are less than 50 km s^{-1} .

HR 6984.—Our measures are based on hydrogen lines that give less scatter than the helium lines in this broad-lined spectrum. However, both sets show no evidence of variability.

HR 7084.—Plaskett *et al.* 1921 and Plaskett and Pearce 1931 reported a variable velocity.

HR 7100.—Wood and Walker 1960, using this star as a photometric comparison for β Lyrae, found a variation with $\Delta V = 0.025$ mag and period of $7\frac{1}{2}$ days. But that is the rotational period because $V \sin i$ is about 125 km s^{-1} . The velocity is constant within our accuracy.

HR 7166.—IDS 18538–1258. The spectrum has a superimposed shell spectrum.

HR 7486.—IDS 19365+1335. We list improved (smaller scatter) orbital elements compared with those published by Hill 1930. Guthnick 1934 found that the spectroscopic and photometric periods agree.

HR 7608.—As with HR 7279, we can find many periods that fit the data but are unable to decide which is the true one.

HR 7613.—Reported to be variable in velocity by Frost *et al.* 1926. A period of 32.45 days is a poor alternate choice. Faint secondary components of $\lambda 4481$ may be present at times.

HR 7628.—IDS 19538+4006. Millman (Plaskett and Pearce 1931) suggested a period of 71.80 days; Beardsley 1969 and Batten, Fisher, and Fletcher 1982 found 70.2 days. Fig. 6 shows our independent solution giving $P = 69.3$ days, $K = 23.7 \text{ km s}^{-1}$, $\gamma = -30.8 \text{ km s}^{-1}$, $e = 0.29$, and $\omega = 345^\circ$. However, the Batten *et al.* solution has better phase coverage and less scatter; their elements are given in Table 4.

HR 7647.—Variable velocity reported by Campbell and Moore (1928) and Kodaira (1971) suggested a period of 80.0 days. Batten, Fletcher and Mann (1978) rejected those elements. Less successful than 53.6 days, but possible periods, are 8.492 and 5.340 days.

HR 8215; 8356.—Kodaira 1971 suggested elements for both stars, but Batten, Fletcher, and Mann 1978 rejected them. We found little or no evidence for variability.

HR 8301.—There are marginal orbital elements by Fehrenbach 1948, but we cannot confirm variability.

HR 8579.—Our observations during 658 days do not show variability or confirm Beardsley's 1969 period of 880 days and $K = 9 \text{ km s}^{-1}$.

HR 8725.—This is a β CMa stars with $P_1 = 0.16916$ days and $K_1 = 4.5 \text{ km s}^{-1}$ plus $P_2 = 0.17085$ days and $K_2 = 14.8 \text{ km s}^{-1}$ (Struve *et al.* 1952) with a variation in γ -velocity in 12.097 days and $K = 23.4 \text{ km s}^{-1}$. The last is considered to be a binary period. Orbital elements are given by Struve *et al.* and Fitch 1969. Our data agree well with the previous data, and Fitch's are quoted above.

HR 9011.—Reported by Plaskett and Pearce 1931 to have a variable velocity. We could find elements that fit ours or their data, but not both.

$1/0.727 = 1.38$. This is the origin of the incompleteness factor I given in Table 6 (*upper left group*).

There is confirmation of the assumption made above because for all the detected SB2's in this study, $K_1 + K_2 > 2 (V \sin i)$ except for HR 1497, where the secondary was barely detected by Petrie and Ebbighausen (1961).

The detectability of SB1's has a different criterion. Inspection of the K s in Table 4 for the 21 SB1's shows 12 with $20 \leq K \leq 25 \text{ km s}^{-1}$, but only three smaller ones (and all in the range $15\text{--}19 \text{ km s}^{-1}$). Therefore $K = 20 \text{ km s}^{-1}$ is a

reasonable lower limit to our detectability of SB1's. That is because not all binaries have the same $V \sin i$, with better detectability for sharp-lined primaries, so the lower limit will not be sharp. In the case of periods 10^{-3} to 10^{-2} yr and $\mathcal{M}_2 = 1 \mathcal{M}_\odot$, $(K_1)_{\text{max}} = 34.2 \text{ km s}^{-1}$ and K_1 will not exceed 20 km s^{-1} if $i < 36^\circ$. Because $\cos 36^\circ = 0.81$, the incompleteness factor $I = 1.23$ (*upper right group*).

Table 6 gives the incompleteness factors for each bin; they are smaller for SB1's than SB2's. Thus for an observed total of 32 observed systems (29% of the sample of 109 stars), we

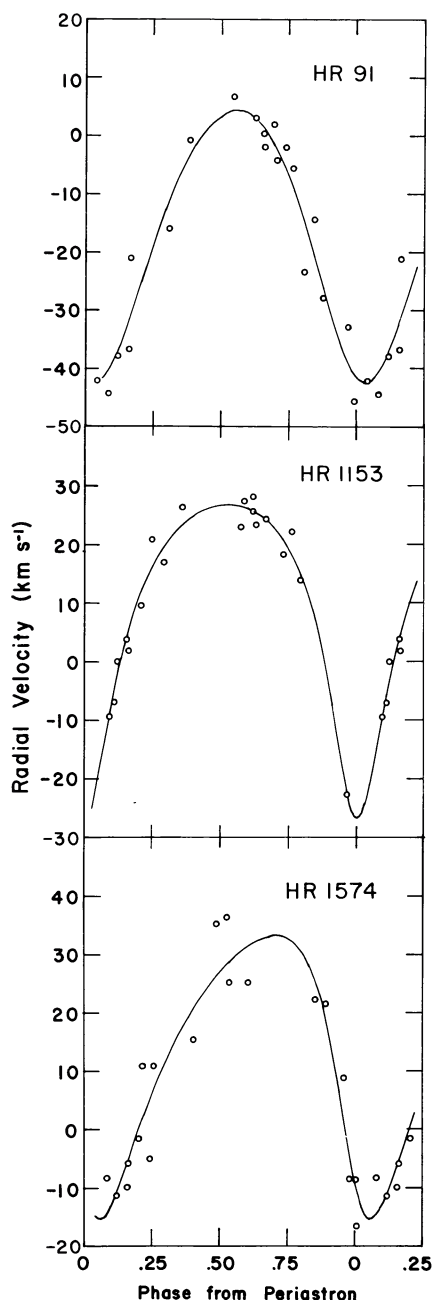


FIG. 1.—Radial velocity curves for two systems (HR 91 and 1153) with modified elements and one newly discovered binary (HR 1574). The curves are the result of numerous least-squares solutions, both here and in the other figures.

conclude that there must be at least 62 actual systems (57% of the sample). These are nearly all only for $M_2 \geq 2 M_\odot$ (secondaries earlier than F3 V) because we detect few secondaries of lower masses. When added to the 24 visual companions with $M_2 > 2 M_\odot$, there are 0.8 companions per primary, although some have several and some have none. For $M_2 > 1 M_\odot$, extrapolations with the Salpeter function indicate that there are about 1.9 companions per primary.

The total numbers of secondaries listed in Table 6 are plotted in Figure 8. The data for periods 10^{-3} to 10^{-2} yr show a roughly horizontal distribution, but the data for 10^{-2}

to 10^{-1} and 10^{-1} to 1 yr fit a Salpeter function within the square roots of the numbers of secondaries. We conclude that spectroscopic binaries of periods greater than 10^{-2} yr = 3.6 days are formed by capture in their original cluster environments. Periods less than 10^{-2} yr involve separations that are less than 2.5 times the sum of the radii of the components. Systems of such short periods probably have already exchanged mass and no longer have their original mass ratios; we are unable to give their mechanisms of origin.

An obvious question is why these data show so clearly the Salpeter distribution for periods 10^{-2} to 1 yr while the AL78

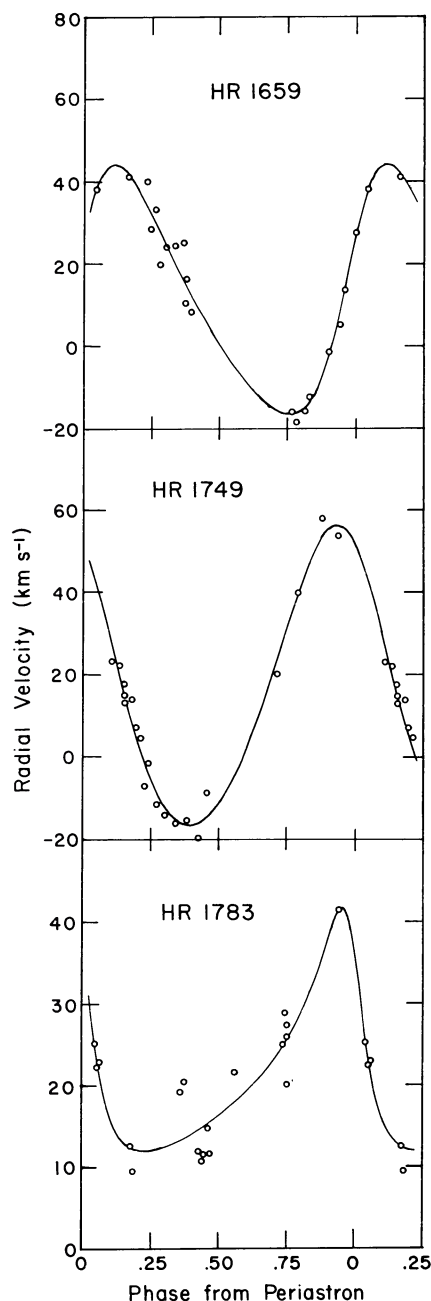


FIG. 2.—Radial velocity curves for two systems (HR 1659 and 1749) with modified elements and one newly discovered binary (HR 1783).

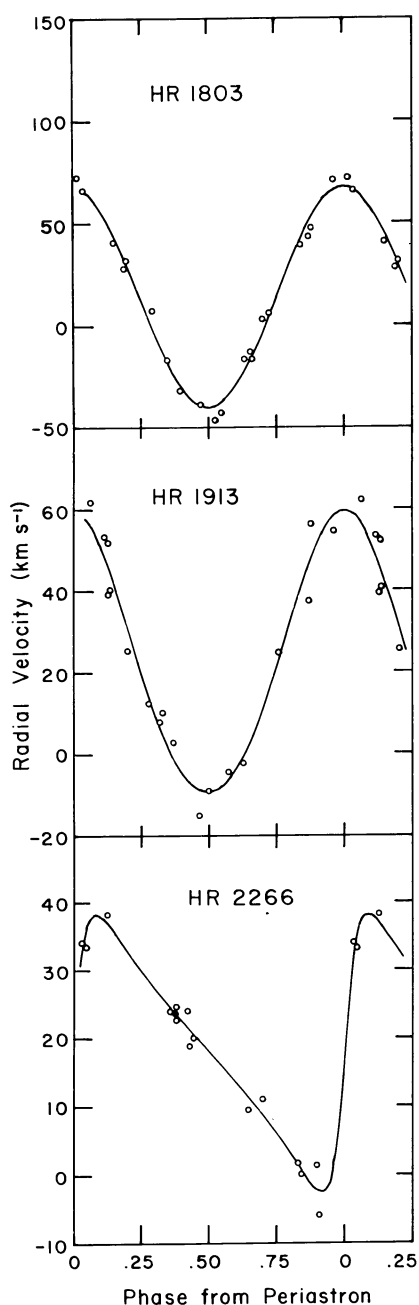


FIG. 3.—Radial velocity curves for one system (HR 1803) with modified elements and two newly discovered binaries (HR 1913 and 2266).

data showed a flat distribution for 10^{-3} to 10 yr. There are several reasons for this. One reason is that now we have enough data to separate the 10^{-3} to 10^{-2} yr periods (flat distribution) and 10^{-2} to 10^{-1} yr periods (Salpeter distribution). Another reason is that the entire AL78 study was based on 15 spectroscopic binaries while we now have 28 binaries. A third is that our more conservative estimate of the smallest detectable velocity amplitude ($K_1 = 20 \text{ km s}^{-1}$), compared with the previous 8.5 km s^{-1} , causes larger incompleteness factors, especially for low secondary masses. A fourth is that we no longer accept the orbital elements for

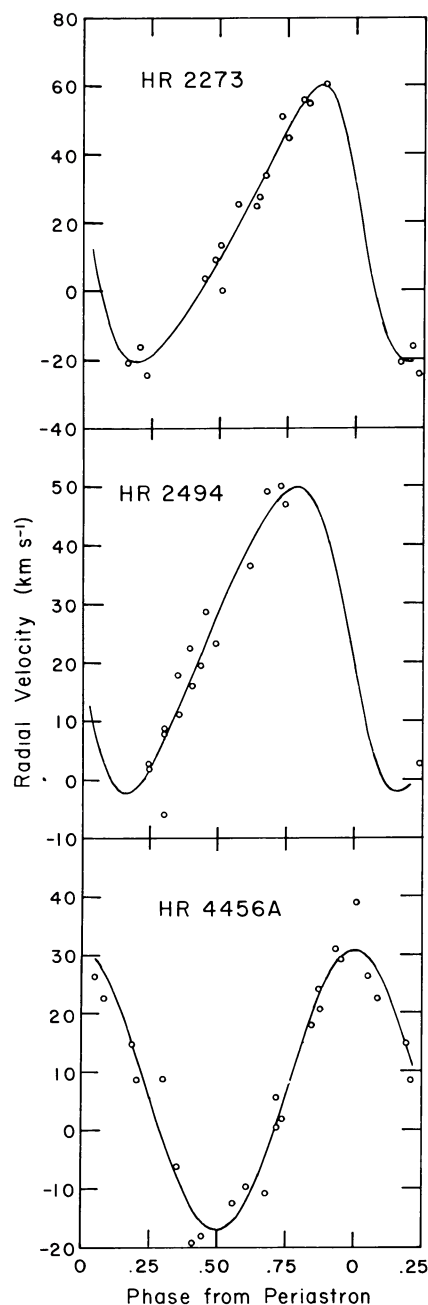


FIG. 4.—Radial velocity curves for three newly discovered binaries (HR 2273, 2494, and 4456A).

the two SB1's with periods 1–10 yr, so we have no binaries with periods between 143 days and 25 yr.

The period distribution of the spectroscopic and visual binaries is similar to that in previous studies except for a deficiency of systems with 10^{-1} to 10^3 yr (about $0''.002$ – $1''$), where the radial velocity amplitudes are too small to measure, and adequate occultation and speckle measurements have not yet been made.

We conclude the following:

1. For binaries with periods of 10^{-2} to 1 and 10 – 10^6 yr, the primary mechanism of formation is by capture; for peri-

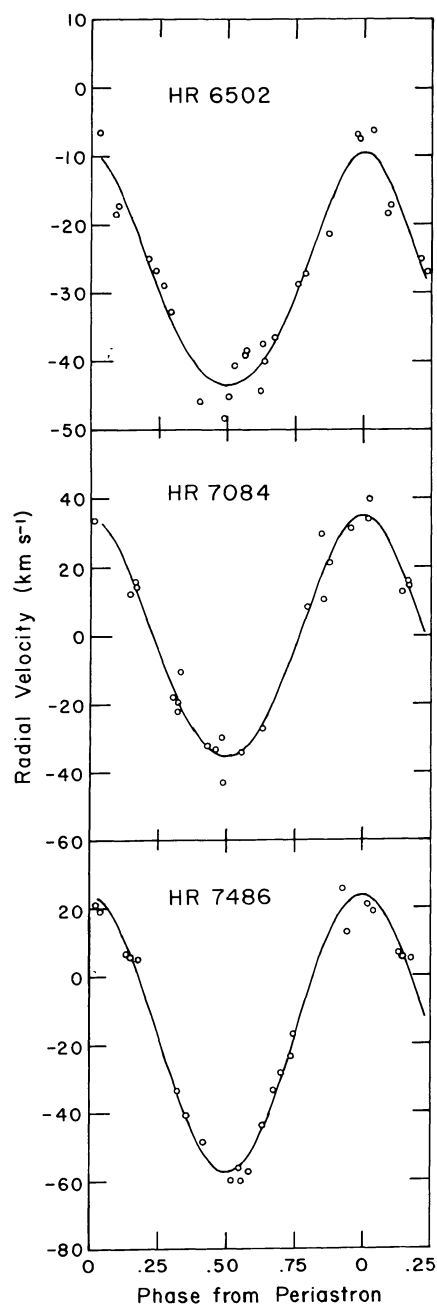


FIG. 5.—Radial velocity curves for two newly discovered binaries (HR 6502 and 7084) and modified elements for HR 7486.

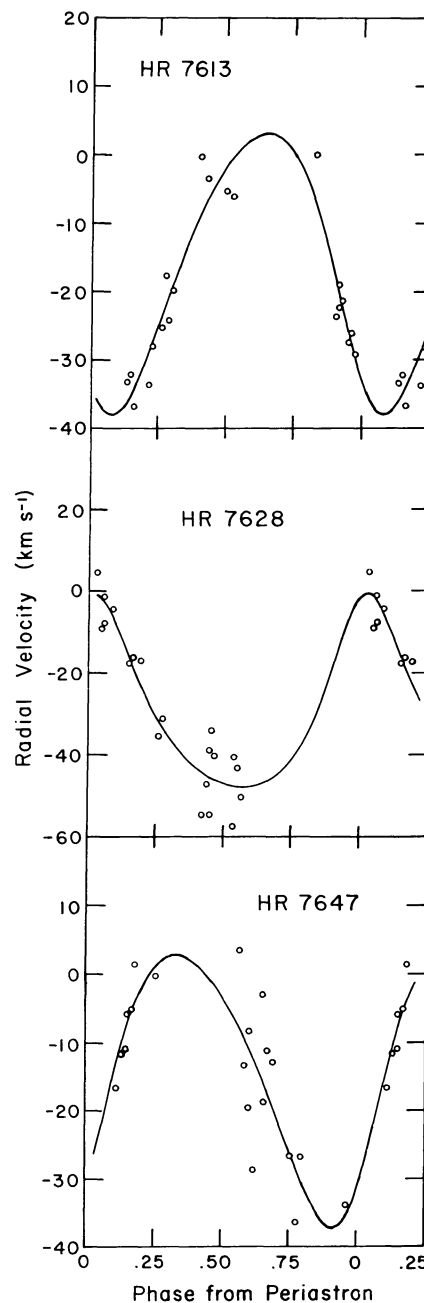


FIG. 6.—Radial velocity curves for two newly discovered binaries (HR 7613 and 7647) and one (HR 7628) with modified elements.

ods shorter than 10^{-2} yr, the mass ratios may have been modified by mass exchange and may not tell us anything about formation mechanism.

2. Binaries are still very prevalent; we observe 32 spectroscopic and 49 visual binaries in a sample of 109 stars for an observed frequency of 74%. If we make some allowance for incompleteness, we estimate that each primary has an average of 0.8 secondaries with $M_2 > 2 M_\odot$ or 1.9 secondaries with $M_2 > 1 M_\odot$.

c) Extension to Other Types

How can we reconcile this evidence that capture is the primary formation mechanism among B2-B5 stars with the evidence from spectroscopic binaries among later type stars that fission or bifurcation is the primary mechanism?

For spectroscopic binaries among later types, the observations generally show a decreasing frequency of secondaries with decreasing secondary mass. That was found by Abt and

TABLE 5
VISUAL BINARY COMPONENTS

HR	Identifications	Kind	V_1 (mag)	V_2	Separation or a	M_2 ($M_\odot$)	Period (yr)
91	ADS 328 AB	Vis	5.5	8.0	0.2	3.7	195
154	ADS 513 AB	CPM	4.0	8.9	35.9	1.3	103,000
1005	03155+2047 Aa	Occ	5.4	7.9	0.15	2.4	49
	AB	CPM	5.4	8.4	0.67	2.0	470
1044	ADS 2558 AB	Vis	4.8	6.8	0.8	4.3	550
1153	ADS 2750 AB	CPM:	5.4	11.6	64.7	1.2	906,000
1174	ADS 2778 AB	CPM	5.1	10.1	9.2	1.5	38,000
1497	IDS04362+2246 AB	Occ, CPM	4.3	8.9	0.17	1.5	43
	AC	CPM	4.3	7.3	62.8	2.6	290,000
1659	ADS 3709 AB	CPM	5.5	12.0	13.3	1.2	116,000
	AC	CPM	5.6	8.6	35.3	3.8	473,000
1764	ADS 3941 AB	CPM	5.6	11.3	32.7	1.3	383,000
	AC	CPM	5.6	10.8	37.6	1.4	473,000
1808	ADS 4038 Aa	Occ	5.4	6.5	0.09	4.2	25
	AB	CPM	5.3	10.1	10.1	1.2	25,600
	AC	CPM:	5.3	11.8	9.8	0.8	25,600
1810	ADS 4048 Aa	Occ	5.6	5.6	0.1	8.9	26
	AB	CPM	5.6	10.9	37.8	1.3	213,000
	AC	CPM	5.6	10.4	58.8	1.5	411,000
	AD	CPM	5.6	11.6	74.2	1.1	591,000
1811	ADS 4039 AB	CPM	4.7	10.3	2.7	1.8	9,000
	AC	CPM:	4.7	12.3	83.4	1.1	1,570,000
1839	ADS 4115 AB	Orb	4.5	5.8	1.293	5.3	586
1911	ADS 4212 AB	CPM	5.7	8.9	5.2	5.6	67,000
1928	05335+2550 Aa	Occ	5.2	8.5	0.32	3.2	310
1946	ADS 4265 AB	Orb	5.3	5.9	0.357	9.8	95.4
1993	ADS 4381 AB	CPM	5.2	12.2	17.8	1.2	217,000
	AC	CPM	5.2	11.5	24.9	1.4	362,000
2154	ADS 4698 AB	CPM	5.4	11.6	28.9	1.1	324,000
3194	ADS 6632 AB	CPM:	5.5	12.2	5.3	1.1	29,900
5985	ADS 9913 CE	Occ	4.9	7.4	0.12	4.3	54
6092	ADS 10010 AB	CPM	3.9	14.6	6.7	0.5	10,800
6787	ADS 11102 AB	CPM	4.3	11.8	23.4	0.9	118,000
7100	ADS 11732 AC	CPM	5.8	10.3	58.7	2.7	2,380,000
7298	ADS 12197 AB	CPM	4.5	9.2	28.1	2.5	258,000
7306	ADS 12243 AB	CPM	4.6	11.6	39.1	1.0	369,000
7628	IDS19538+4006 AB	CPM:	5.5	8.5	64.6	0.8	390,000
7739	ADS 13589 AB	Vis	4.8	8.9	0.8	1.8	680
7844	ADS 13932 AB	CPM	4.9	12.9	17.8	0.9	119,000
	AC	CPM	4.9	9.4	56.3	2.0	644,000
7929	ADS 14189 AB	CPM	5.4	12.4	3.0	1.1	12,400
	AC	CPM	5.4	11.4	25.7	1.4	309,000
	AD	CPM	5.4	11.4	32.8	1.4	496,000
8513	ADS 15847 AB	CPM	5.4	10.7	6.2	1.4	20,900
8725	ADS 16381 AB	CPM	5.5	11.5	27.6	1.1	291,000
	AC	CPM	5.6	8.6	62.8	1.2	994,000
8926 ^a	ADS 16795 AB	Vis	4.9	9.3	1.1	1.6	1,500
	AC	CPM	4.9	7.1	75.7	3.5	569,000
	AF	CPM	4.9	8.9	67.3	1.8	498,000

^a Plus additional companions to these secondaries; see Abt 1986.

Levy (1976) for F3–G2 stars (left panel of their Fig. 6). Also Abt and Levy (1985, Fig. 6) found that for metallic-line binaries, whose primaries have hydrogen types of A4–F1. For the B7–B9 sharp-lined stars, the results of Wolff (1978), as corrected by Abt (1983) for the Branch effect and for equal bin sizes, show a flat mass distribution. But the B2–B5

stars show a steeply rising (Salpeter) distribution. And Halbwach's (1987) results for stars of all types combined show a slowly rising distribution. These indicate a progression from rapidly rising mass functions for the early B stars (Fig. 8) to flat ones among the late Bs to slowly decreasing distributions for the As and Fs.

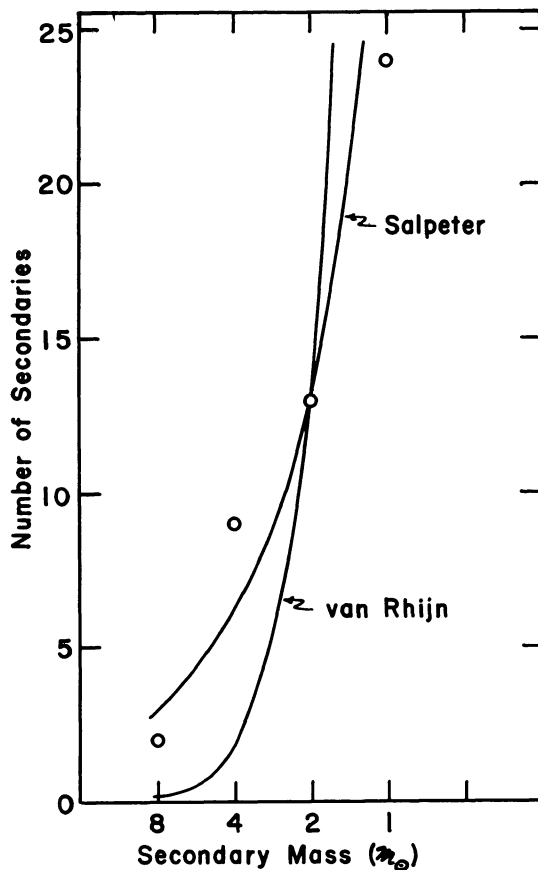


FIG. 7.—The frequencies of the 49 visual companions of various secondary masses, binned by factors of 2. As explained in the text, the van Rhijn function for an older stellar population fits poorly, but the Salpeter function for a young population fits within the estimated errors.

Let us consider in more detail what happens during successive captures. In the first few generations of captures in an open cluster, given the preponderance of low-mass stars, a massive star will probably acquire a low-mass companion. This causes a Salpeter or van Rhijn distribution of secondary masses. But during repeated captures and disruptions (Hills 1975), a steady state situation is approached in which massive stars will pair with other massive stars while the low-mass stars are ejected. This produces a secondary mass function roughly like that of the F3–G2 stars in which equal masses are favored.

This transition in secondary mass function is demonstrated in the n -body simulations reported by Aarseth and Hills (1972). They listed the pairing in 19 binaries with primaries up to 4.0 solar masses and formed at various times, measured in free-fall times. In Table 7 we have grouped those binaries in three time intervals. We see that the binaries formed in less than 0.4 free-fall times tend to have mass ratios around 0.25, i.e., like a truncated Salpeter function. During 0.4–0.8 free-fall times, the peak mass ratio is 0.5, and after 0.8 free-fall times the binaries of equal mass predominate, as among F3–G2 stars. The number of cases here is small, but the tendency toward an equal mass distribution after repeated encounters is shown.

How long does it take for this transition to occur? Let us consider a cluster such as the α Persei cluster that has stars as early as B0.5, a radius of 5 pc, and a total mass of roughly $400 M_{\odot}$. The free-fall time is about 7×10^6 yr, which is slightly less than its age. But is this comparison valid for the B2–B5 stars, which are mostly field stars? Do they come mostly from clusters that age or from younger clusters? Because many clusters have subclusterings, should the free-fall times be computed for the whole clusters or the subclusters? And the Aarseth-Hills simulations were made for late B type star masses, not early B stars. So all that we can

TABLE 6
NUMBERS OF SPECTROSCOPIC SECONDARIES OF VARIOUS MASSES

PERIOD RANGE (yr)	PARAMETER	SECONDARY MASS ($M_{\odot}$)				SUM OF OBSERVATIONS	SUM TOTAL
		8	4	2	1		
10^{-3} to 10^{-2}	Observed	1	2	0	1	4	5.7
	Kind	SB2	SB2	...	SB1		
	I	1.38	1.54	1.05	1.23		
	Total	1.4	3.1	0	1.2		
10^{-2} to 10^{-1}	Observed	2	2+2	1+9	3	19	34.4
	Kind	SB2	SB2 SB1	SB2 SB1	SB1		
	I	2.52	2.52 1.05	2.62 1.19	3.01		
	Total	5.0	5.0 2.1	2.6 10.7	9.0		
10^{-1} to 1	Observed	1	4	4	0	9	21.8
	Kind	SB2	SB1	SB1	...		
	I	3.71	1.18	3.34	...		
	Total	3.7	4.7	13.4	...		
Sum						32	61.9

TABLE 7
HISTORIES OF 19 BINARIES

$T(\tau_{\text{ff}})$	M_2/M_1			
	1	0.5	0.25	0.125
$< 0.4 \dots$	0	2	4	2
$0.4-0.8 \dots$	2	4	0	0
$> 0.8 \dots$	3	1	0	1

conclude is that in roughly a free-fall time, a transition should occur for binary secondaries from a Salpeter function to one that favors equal component masses. This is consistent with the observations of the spectroscopic binaries.

How can we interpret the visual binaries, which all show Salpeter-like secondary mass distributions? But visual binaries are loosely coupled systems that have not become "hard" (short-period) systems through repeated encounters. They are effectively first-generation encounters that should follow the Salpeter function.

There are two possible objections to this model for binary formation. For the first one, consider Figure 8. The binaries of periods 10^{-2} to 10^{-1} yr follow a Salpeter function. But those binaries of 3.6–36 days include some hard binaries. Can we have hard binaries formed in just a few encounters? Presumably n -body simulations will tell us, but if hard binaries cannot be formed in a few encounters, there is a problem with our model or an additional binary formation mechanism other than capture will be needed. The second objection is due to Robert Mathieu, who points out that because most of the B2–B5 stars in this study are field stars, they have left their cluster environments and further stellar encounters will be rare. That is not a problem for the B stars, but it implies that perhaps the F and G stars in the same clusters have also left the clusters so that repeated encounters will not occur for them either. In other words, do clusters such as the Hyades and Coma clusters that persist to ages of 10^8 – 10^9 yr represent the norm for F and G type stars or do such stars leave their cluster environments at much earlier times, terminating the effects of repeated three-body encounters?

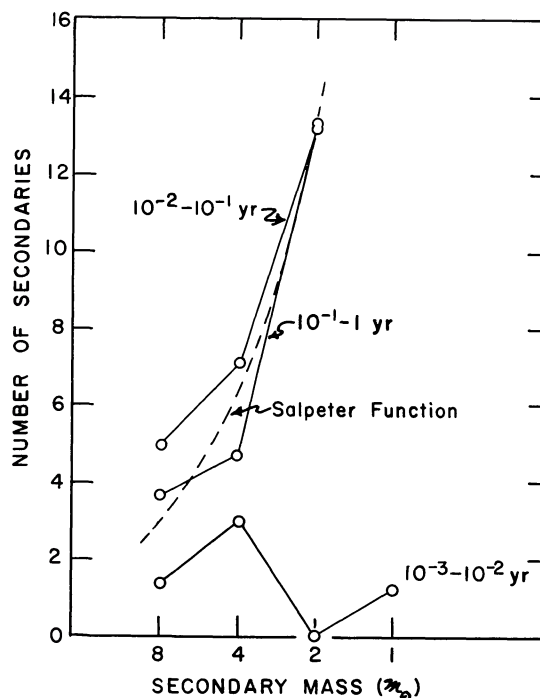


FIG. 8.—The frequencies of spectroscopic secondaries of various masses, corrected for incompleteness. The systems are grouped in three ranges of orbital periods, and the two longest period ranges are compared with a Salpeter function.

We provisionally come to the conclusion that most or all binaries were formed in capture processes (including initial star formation in bound systems) and that bifurcation or fission need not have occurred frequently. That may be encouraging because Gingold and Monaghan (1978, 1979) and Durisen and Tohline (1985) found that once compressibility and viscosity are included in calculations, it is very difficult to produce binaries by fission and only under special circumstances. In view of the high frequency of spectroscopic binaries, the formation mechanism must be a frequent one, not a rare occurrence.

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