THE FREQUENCY OF SPECTROSCOPIC BINARIES IN THE PLEIADES*

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ABSTRACT

From 585 radial-velocity measures of the forty-seven brightest Pleiades stars and from measures published previously, orbital elements are derived for five newly discovered spectroscopic binaries. Among the thirteen B6–B9 stars no short-period ($P < 100$ days) binaries were found, and it is suggested that the unusually rapid rotational velocities in these stars are due to an absence of tidal interaction in close binaries. Among the twenty B9.5 V–A3 V stars the frequency of short-period binaries seems normal and the rotational velocities are normal compared to similar field stars. Among the fourteen A4 V–A9 V stars no good examples of metallic-line (Am) stars are known and no short-period binaries have been found. It is suggested that, since Am stars are generally members of close binary systems and the Pleiades has none in that spectral range, the cluster will never have Am stars.

I. INTRODUCTION

Data in a paper by Abt and Hunter (1962) showed that galactic clusters differ from each other in the mean axial rotational velocities of stars of the same spectral type and, probably, in the frequencies of spectroscopic binaries among those stars. Furthermore, there seemed to be a correlation between these characteristics in the sense that the larger the mean rotational velocity, the smaller the binary frequency. Such a correlation is understandable if tidal interaction, particularly during the slower contracting phases of stars, is effective in slowing the rotational speeds in close binaries, whereas such a mechanism is not present in single stars, leaving them to rotate rapidly.

The above-mentioned paper presented or quoted rotational velocities for numerous stars in nine clusters or associations, but the results on the frequencies of spectroscopic binaries depended only on a survey of published radial velocities; those velocities were insufficient in number to instil confidence in the tentative conclusion. Projects were therefore initiated to make intensive surveys of the frequencies of spectroscopic binaries in at least two extreme groups, namely, the Pleiades and the I Orion association. This paper presents the data and results of the first of these projects. In addition, a study (Abt and Snowden 1964) of the galactic cluster IC 4665 showed the existence of a somewhat high binary frequency and a somewhat low mean rotational velocity.

In the Pleiades the brightest star have a mean rotational velocity that is unusually large compared with that of field stars of the same spectral types or, for that matter, with any known group of stars having those types, whereas the fainter stars have a normal or nearly normal mean rotational velocity. The data given below on the binary frequencies are accordingly discussed separately for these two categories of stars.

The Pleiades cluster has another peculiarity, namely, the absence of any metallic-line stars, that is probably relevant to the frequency of spectroscopic binaries in that cluster. Recent work on field stars (Abt 1961, 1965) has shown that among the normal A4–F2 IV,

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V and the metallic-line (Am) stars, which occupy the same region of the color-magnitude diagram of population I stars, the Am stars are usually or always members of spectroscopic binaries with a most frequent period of 4 days whereas the normal stars seem never to occur in binaries with periods less than 100 days. The explanation advanced for this odd correlation is that members of binaries with periods less than 100 days would have encountered sufficient tidal interaction to have slowed their equatorial rotational speeds to less than 100 km/sec, and that for reasons not yet understood, it is the slowly rotating stars that have abnormal spectra. There are hopes of understanding the latter correlation in terms of a lack of convective mixing inward of abnormal surface material in slowly rotating stars or in the destruction in rapidly rotating stars of an atmospheric magnetic field, which might cause abnormal spectra through a magnetic support of an extended atmosphere.

According to the spectral classification work of Pleiades stars by Mendoza (1956) and Morgan (Abt 1963), there are no good examples of Am stars in that cluster, whereas numerous such stars exist in older groups such as the Hyades, Praesepe, and Coma clusters. This evident correlation between the occurrence of Am stars and age has led some observers (Jaschek and Jaschek 1959) to suggest that this spectral peculiarity will develop only at a certain age, which happens to be greater than the age of the Pleiades. We now have a chance to test this suggestion because it is very unlikely that single stars or widely spaced binaries can change into relatively closely spaced binaries in intervals of approximately the age of the Hyades. In other words, if there are no late A-type spectroscopic binaries with periods less than 100 days in the Pleiades now, we will conclude that that cluster never will have Am stars, while if such binaries are found, we will conclude that they will eventually develop the spectral characteristics of Am stars.

II. SPECTROSCOPIC DATA

The brighter Pleiades B-type stars were included in the extensive radial-velocity programs of the Lick, Dominion Astrophysical, and Mount Wilson Observatories in the interval 1900–1940, but the radial velocities of the remaining B- and A-type stars have generally been measured only by Smith and Struve (1944). Those authors obtained 237 spectra, generally of 55-Å/mm dispersion, of 71 stars, using the McDonald Observatory's 82-inch Cassegrain spectrograph. Most of those stars are now recognized as cluster members. After measuring those spectra they wrote: "The scarcity in the Pleiades of binaries with large amplitudes in the principal conclusion of our investigation." For only five members of types B or A was possible evidence found for velocity variations; those stars are HD 23157, 23512, 23629, 23642, and 23964. The fourth of these was found independently by Pearce (1957) and Abt (1958) to be a double-lined spectroscopic binary and those two astronomers obtained similar orbital elements.

The stars observed in the present study are listed in order of spectral type in Table 1, whose successive columns give the (1) serial number in this study, (2) *Henry Draper* number, (3) Hertzsprung number, "Hz" (Hertzsprung 1923), (4) Trumpler number, "Tr" (Trumpler 1921), (5) spectral type by Mendoza (1956), (6) projected rotational velocity by Abt and Hunter (1962), (7) number, *n*, of new radial velocities, (8) mean radial velocity from the present measures only, except γ-velocities are given in the cases of binaries with orbital elements, (9) the scatter in the present velocities only, expressed as a probable error per spectrum, (10) the mean internal probable error per spectrum, and (11) references, "R," to remarks in the footnotes and identifications of spectroscopic binaries. The stars are separated into three groups for convenient discussion below.

The results here are based on 585 spectra of the 47 B- and A-type members of the Pleiades, although no additional spectra of HD 23642 were obtained. Of these spectra, 564 were obtained with the Meinel spectrograph of the Kitt Peak 36-inch reflector, using Bausch & Lomb gratings giving dispersions of 63 Å/mm (269 spectra) or 128 Å/mm (295 spectra). That spectrograph was generally used on the 36-inch telescope, for which it

TABLE 1

SUMMARY OF DATA ON PLEIADES STARS

No.	HD	Hz	Tr	Spectral Type	V sin i	n	Mean Radial Velocity (km/sec)	p e	Mean Int p e	Remarks
6	23302	126	148	B6 III	230	14	− 0 3	7 4	2 4	Spec. binary; P= 100 46; R
19	23480	323	286	B6 IV	320	12	+ 0 3	6 0	5 4	
9	23338	156	170	B6 V	140	12	+ 5 9	5 5	4 2	Spec. binary; P= 1313.; R
13.	23408	242	231	B7 III	35	11	+ 7 3	6 7	3 8	R
28	23630	542	414	B7 III	215	11	+ 0 9	3 6	3 6	
5	23288	117	139	B7 IV	235	12	− 1 5	5 9	5 6	
37..	23850	870	594	B8 III	185	13	− 0 4	7 2	3 2	Spec. binary; P= 1254 68; R
7	23324	150	166	B8 V	235	11	+ 0 3	7 5	5 3	R
16	23432	255	240	B8 V	210	12	+ 0 2	5 6	5 3	
34	23753	722	506	B8 V	305	10	0 0	4 1	5 6	
38	23862	878	602	B8 p	380:	9	− 2 5	5 1	5 2	
17	23441	265	247	B9 V	295	13	− 0 3	6 2	5 1	
43	23923	977	671	B9 V	300:	11	− 3 5	6 2	6 8	
23	23568	436	354	B9 5 V	280	16	− 7 7	5 1	3 0	
41	23873	910	622	B9 5 V	85	11	+ 2 4	3 9	4 9	
15	23410	248	234	A0 V	185	13	−23 0	24 8	.	Spec. binary; P= 7 1538; R
21	23512	371	311	A0 V	155	11	− 4 4	6 9	4 3	R
27	23629	508	395	A0 V	155	10	− 1 1	7 7	5 9	R
31	23642	540	413	A0 V	30:	0	+ 4 99	.	.	Spec. binary; P= 2 46113; R
46 .	23964	1003	697	A0 V	20	11	+ 1 7	15 8	3 0	Spec. binary; P= 16 7258; R
12 .	23387	216	215	A1 V	20	16	+10 7	9 8	5 0	R
30 .	23632	510	397	A1 V	260:	13	− 7 3	7 6	6 4	
35	23763	742	518	A1 V	100	15	− 7 6	9 2	4 9	R
14	23409	251	235	A2 V	. .	12	− 8 7	5 9	4 6	
20	23489	341	295	A2 V	. .	15	− 0 6	7 9	3 7	R
29	23631	520	402	A2 V		13	− 5 8	8 9	4 8	
40	23872	891	613	A2 V	. . .	16	− 6 0	8 4	6 1	
45	23948	996	688	A2 V		16	+ 1 2	5 9	4 5	
47	24076	1129	791	A2 V	. .	16	− 7 3	11 3	6 3	
10	23361	187	195	A3 V		12	+ 9 3	9 7	6 8	
18 .	23479	313	281	A3 V		10	−13 7	6 2	6 0	
32 .	23643	534	410	A3 V	..	12	−11 6	9 8	5 6	
42 .	23886	924	629	A3 V		14	− 5 5	8 4	4 8	
26	23628	513	399	A4 V	.	14	− 9 8	7 5	6 6	
3	23194	43	74	A5 V	.	14	+11 7	7 8	4 3	R
1	23156	28	51	A7 V		12	− 4 7	6 4	4 6	
25	23607	501	390	A7 V	.	12	+ 2 3	7 5	4 2	
39 .	23863	885	607	A7 V		12	− 8 1	9 6	4 0	R
44	23924	975	670	A7 V	. . .	15	− 4 4	5 7	3 8	
4	23246	92	121	A8 V		14	+ 1 4	6 2	4 7	
36 .	23791	792	551	A8 V	..	13	− 7 0	7 1	4 8	
2	23157	27	50	A9 V	.	13	+ 2 7	6 8	4 9	R
11	23375	206	208	A9 V	.	12	− 6 6	4 5	5 5	
22.	23567	447	359	A9 V	..	13	− 9 2	7 0	6 1	
24	23585	457	365	A9 V	..	11	−10 1	6 7	3 6	
33	23733	693	493	A9 V	. .	13	−19 6	8 7	7.2	R
8	23325	146	162	Am ?	....	14	− 0 3	6 8	5 0	

NOTES TO TABLE 1

2 HD 23157 Although Smith and Struve suspected this star to be variable in velocity, the present measures do not confirm this suspicion.

3 HD 23194. The velocity may vary slowly with time.

6. HD 23302 = 17 Tauri = Electra. The orbit is based on four 1925–1926 Lick velocities (Campbell and Moore 1928), three 1941–1942 McDonald velocities (Smith and Struve 1944), three 1957 McDonald coudé velocities, and eleven 1962–1964 Kitt Peak velocities The orbit is not well determined.

7. HD 23324. Double lines are suspected to be present but not measurable at two times (JD 2436142, 2438006).

9. HD 23338 = 19 Tauri = Taygeta This small amplitude binary orbit is based on four 1925–1926 Lick velocities (Campbell and Moore 1928), two 1921–1922 Victoria velocities (Plaskett and Pearce 1931), three 1941–1942 McDonald velocities (Smith and Struve 1944), one 1957 McDonald coudé velocity, and eleven 1962–1964 Kitt Peak velocities The velocity variation, which is not completely convincing, undoubtedly is not due to the 8th mag. companion at 69″ (Jeffers, van den Bos, and Greeby 1963).

12. HD 23387. The scatter in the present velocities is unusually large but no periodic variation could be found.

13 HD 23408 = 20 Tauri = Maia. There have been reports (Struve 1945) of rapid velocity variations with a possible period of 4 hours, due undoubtedly to pulsation, but no evidence of binary motion. This pulsation may account for the large scatter in the present velocities

15. HD 23410. In this A0 V star only the K-line is seen to be double and the orbital elements are based on measures of that line alone. The components are of nearly the same intensity, leading to confusion and uncertainty in deriving the orbital elements. If these orbital elements are approximately correct, the system is not quite an eclipsing one.

20 HD 23489. See note for 12 HD 23387.

21. HD 23512 See note for 2. HD 23157.

27. HD 23629. See note for 2 HD 23157.

29. HD 23631. See note for 12 HD 23387.

31. HD 23642. Smith and Struve suspected this star to be variable in velocity but they did not detect its double lines. Pearce (1957) and Abt (1958) derived similar elements; Abt found a detectable eccentricity. The period and epoch of periastron from the combined material with other orbital elements by Abt are given in Table 3

33. HD 23733. The present mean velocity (−19 6 km/sec) is very different than the mean (+7.8 km/sec) obtained by Smith and Struve.

35. HD 23763 See note for 12 HD 23387.

37. HD 23850 = 27 Tauri = Atlas = ADS 2786. The orbital elements are based on four 1903–1904 Yerkes velocities (Frost, Barrett, and Struve 1926), five 1921–1924 Lick velocities (Campbell and Moore 1928), two 1942 McDonald velocities (Smith and Struve 1944), one 1957 McDonald coudé velocity, and twelve 1962–1965 Kitt Peak velocities. The observations are not well distributed in phase. There are scattered reports of a companion 4 mag fainter at about 0″.4 (Aitken 1932). However, this separation is 10 times the maximum separation in this spectroscopic binary.

39. HD 23863. See note for 12. HD 23387.

46. HD 23964. This star was suspected by Smith and Struve to be variable in velocity. The orbital elements are based on five 1941–1943 McDonald measures (Smith and Struve 1944), one 1957 McDonald coudé measure, and ten 1962–1963 Kitt Peak measures The velocity-curve is fairly well determined considering that the amplitude corresponds to only 7.5 μ on the Kitt Peak spectra of highest dispersion.

was designed, but pending the completion of the Kitt Peak 84-inch Cassegrain spectrograph, the spectrograph was used on the 84-inch telescope with a negative lens before the slit to change the Cassegrain f/7.5 beam to match the f/13.6 spectrograph collimator. The 96 spectra obtained on JD 2438368, 393, 397, 404, 411, and 778 were obtained with the 84-inch telescope. In addition, 21 spectra of 18 stars were obtained in 1957 with the C camera (18 Å/mm) of the McDonald Observatory's 82-inch coudé spectrograph; these were the spectra Abt and Hunter used to measure rotational velocities of Pleiades stars. Eastman Kodak IIa-O emulsions were used throughout. The Kitt Peak observations generally spanned an interval of 2 years.

The spectrograms were measured on an oscilloscope-type comparator made by Grant Instruments, Inc., of Oakland, California and the digitized output was reduced on the Observatory's CDC 160-A computer. The stellar lines used were Hγ, Hδ, H8, H9, H10, and, among the A-type stars, the Ca II K and Mg II λ 4481 lines. Table 2 gives the individual velocities and their internal probable errors.

RADIAL VELOCITIES OF PLEIADES STARS

1. HD 23156

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
7718 718	0	±5.0
7947.781	- 4	4.6
7948 799	- 16	3 5
7949 933	- 6	2 4
8013.624	- 2	4.9
8045 603	- 7	5.9
8046.826	+ 8	6 0
8047 593	- 27	6.1
8068 625	- 12	4 2
8302 747	+ 5	7 7
8368 643	+ 3	2 7
8397.687	+ 2	2.5

2. HD 23157

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
7718 726	+ 6	5 0
7947 802	+ 13	7 8
7948 821	+ 1	7 6
7949 969	- 8	3 8
8012 614	+ 3	4 8
8013.649	+ 3	3 3
8045 628	+ 2	3 6
8046 836	+ 28	5 2
8047.583	+ 10	7.2
8068 617	- 14	4 2
8302 757	- 3	3 3
8368 684	0	5.1
8404 680	- 6	3 3

3. HD 23194

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
7718 735	+ 20	7.6
7947 811	+ 29	2 7
7948 806	+ 17	6.3
7949 940	+ 16	4 0
8012 600	+ 12	7 8
8013 632	+ 14	1.7
8045 612	+ 11	4 4
8046.819	+ 13	5 9
8047 603	+ 29	5 2
8068 632	+ 27	2 2
8302 768	+ 4	2 4
8368 653	+ 2	3.4
8397 891	- 6	3 7
8404 694	- 6	2 5

4. HD 23246

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
7718 744	- 14	4 3
7947 819	+ 9	5 4
7948 812	+ 10	4 1
7949 947	- 2	3 5
8012 614	- 7	3 0
8013 640	- 7	4 6
8045 619	+ 2	6 9
8046 811	+ 12	8 0
8047 624	+ 13	6 2
8068 690	- 2	6 1
8302 777	- 1	2 5
8368 675	- 8	3 4
8387 880	- 11	4.1
8404 201	- 12	3.7

5. HD 23288

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
6142.873	+ 10	5 4
7668 837	+ 5	6 3
7684.795	- 2	±7.3
7950 890	+ 16	7 6
7951 817	+ 2	2 8
7984 819	- 13	5.6
8006.617	- 10	5 0
8011 712	- 5	6 8
8048 599	- 7	3 3
8239.833	- 4	4 4
8342 873	- 14	9.1
8356 976	+ 3	3.8

6. HD 23302

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
6142 815	- 3	1.6
6143 856	0	1.2
6153 765	- 5	1.0
7684 832	- 12	4.9
7950.894	- 1	2 0
7951 820	- 7	2 1
7984 822	- 18	4 3
7985 583	- 24	2.2
8006 586	+ 2	2 1
8011 710	- 1	1 3
8048.684	+ 2	1 5
8342 967	+ 26	3 9
8356 978	- 3	2 3
8426 781	- 3	3 3

7. HD 23324

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
6142.896	- 20	2 0
7668 839	+ 14	7 5
7684 840	- 5	3 6
7950 899	+ 13	7 3
7951.853	+ 7	3.3
7984 856	+ 2	12 5
8006 621	- 13	3.5
8011.720	+ 11	4.2
8048 605	+ 10	4 6
8342 878	- 4	4 5
8356 981	- 13	5 4

8. HD 23325

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
7718 749	+ 10	5 0
7947.827	+ 12	5 6
7949 765	- 6	5 2
7949 981	- 13	4.7
8012 673	0	3 6
8013 658	+ 2	4 1
8045 637	+ 15	2 5
8046 792	+ 11	6 1
8047 638	- 3	5 3
8068 649	+ 7	5 7
8302 788	- 5	4 0
8368 694	- 6	6 5
8397 868	- 22	6.3
8404 708	- 7	4 9

9. HD 23338

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
6142 802	- 2	0 7
7672 838	+ 5	12 0
7950 902	+ 13	3 5
7950 948	+ 15	2.4
7951 850	+ 12	3.4
7984 841	+ 21	6 0
8006 896	+ 23	±3.9
8011.715	+ 16	3.2
8048 602	+ 5	4.6
8342.970	+ 22	2.2
8356 983	+ 4	3.0
8426.784	+ 2	6.0

10. HD 23361

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
7947.836	+ 9	5.8
7949 774	+ 27	3 0
7949 988	+ 6	9.6
8012.631	+ 5	8.3
8013 667	+ 24	7 9
8045 644	+ 10	7.3
8046.783	+ 42	8.2
8047 657	- 10	11.6
8068 656	+ 6	5.2
8302 810	- 10	5.5
8368 704	+ 5	4.3
8404.751	0	5.4

11. HD 23375

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
7947 846	- 14	7.9
7949 787	- 17	6.3
8012 655	- 2	7.6
8013.693	+ 8	6.4
8045.666	- 9	2.2
8046 758	+ 1	9 8
8047.678	- 12	3 6
8068.687	- 9	2 1
8302.823	- 2	4 9
8368.763	- 4	6 1
8397.855	- 12	5.0
8404 717	- 8	4.1

12. HD 23387

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
6185 679	- 8	4.6
7668 844	+ 21	3 6
7684.802	+ 36	3 4
7947 853	+ 20	5.6
7949.793	+ 21	6.0
7951.917	+ 8	7 1
8012.662	- 3	6 6
8013.698	+ 5	4 8
8045 672	+ 21	3 7
8046 756	+ 30	5.9
8047 687	+ 29	5 7
8068 694	+ 2	4.9
8302.837	0	5 3
8368.756	+ 10	3 9
8397 846	- 12	4.9
8404.722	- 8	4.5

13. HD 23408

JD 2430000+	Radial Velocity (km/sec)	Internal p.e. (km/sec)
6142.831	+ 4	0.7
7950 908	+ 21	6 3
7951.846	+ 7	1 8
7984 837	0	5 9
8006.592	+ 18	2.1
8011.724	+ 10	4 4
8048.688	+ 16	4.5
8342.977	+ 6	1.6
8356 985	- 16	1.3

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
8426 788	+ 4	±3 9
8433 782	+ 12	3 9

14. HD 23409

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
7684 725	+ 4	5 3
7947 870	+ 2	3 9
7949 780	- 7	6 2
8012 638	- 17	4 7
8013 672	+ 4	2 2
8045 651	- 11	4 7
8046 726	- 1	6 9
8047 668	- 10	4 8
8068 679	- 20	6 4
8302 841	- 16	2 9
8368 713	- 11	3 0
8404 758	- 21	4.0

15. HD 23410

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
6185 725	-22, +56	
7684 791	- 6	.
7950 917	-54, +56	.
7951 826	+ 8	
7984 829	-64, +51	
8006 667	+ 20	
8011 750	-56, +83	
8045 618	+ 1	
8240 976	-69, +112	
8342 884	+ 28	
8356 989	- 15	
8782 660	-15, +79	

16. HD 23432

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
6143 869	- 3	0 6
7668 677	+ 11	5 4
7684 805	- 5	3 8
7950 924	- 5	1 5
7951 856	- 9	3 8
7984.859	- 4	4 6
8006 627	+ 20	7 2
8011 729	- 5	5 2
8048.609	+ 1	4 0
8239.958	- 7	2 2
8342.888	0	5.6
8357 941	+ 8	5 8

17. HD 23441

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
6143 890	- 15	3 0
7668.863	- 4	5 1
7684 508	0	4 8
7950 929	+ 6	5 7
7951 860	+ 2	2 6
7984 865	- 9	9.4
8006 631	+ 5	3 9
8011 773	+ 1	1 3
8048.613	+ 18	6.8
8223 978	- 15	5 5
8239 964	- 6	6.6
8342 896	+ 5	5 0
8357 744	+ 8	6.8

18. HD 23479

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
7947 885	- 18	5 0
7949.810	- 15	6.8
8013 706	- 1	7.1
8045.679	- 15	5 5
8046.744	- 7	7 6
8047.770	- 7	3 6
8068.747	- 13	8 1
8302 850	- 32	±5.8
8368 742	- 4	5 6
8404 743	- 25	5 3

19. HD 23480

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
6143 939	- 2	1 6
7684 844	+ 19	4 8
7950 951	- 6	4 8
7951 830	+ 4	7 1
7984 834	+ 4	4 4
8006 590	+ 6	3 0
8011 754	+ 5	7 8
8048 633	- 16	4 9
8239 968	+ 1	3 2
8342 981	+ 6	6 7
8357 748	- 6	8 7
8426 792	- 12	8 0

20. HD 23489

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
7668 867	+ 22	5 5
7684 812	+ 10	4 9
7947 891	+ 7	2 7
7949 819	+ 3	4 6
7952 882	- 4	2 6
8012 686	+ 1	5 0
8013 712	- 12	2 2
8045 687	+ 19	2 6
8046 838	- 7	6 6
8068 698	- 12	4 1
8301.975	+ 1	3 4
8302 856	- 6	2 3
8343 001	- 3	3 2
8368 750	- 5	2 9
8404 737	- 25	3 3

21. HD 23512

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
7668.575	+ 11	3 6
7684 860	- 17	8.3
7947 497	- 2	2.4
7949 919	- 16	6 2
8012 753	- 7	3.1
8013.765	+ 7	3 9
8045.740	+ 12	3 6
8046 699	- 10	3 8
8302 863	- 3	3 7
8368.721	- 15	3 2
8404 764	- 9	5 6

22. HD 23567

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
7947.906	- 30	6 7
7949 826	- 21	8 6
8012.694	- 2	6.2
8013.719	- 4	7 5
8045 694	- 8	5 0
8046 731	+ 2	3 6
8047 710	- 25	7.5
8068 715	- 2	4 8
8302.888	- 1	7 2
8368 782	- 3	6.6
8393.759	- 2	6 4
8397.690	- 4	4.5
8404 815	- 20	4 6

23. HD 23568

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
6155 931	- 19	5.0
6156.787	- 4	3 4
7684.731	+ 3	2.6
7950.935	- 3	4.5
7951 865	- 6	±3.9
7984 871	+ 4	4.0
8006 635	0	2 7
8011 760	- 16	2 6
8048 639	- 15	2 5
8068 725	- 15	1.9
8239 976	- 16	1 7
8240 987	- 11	1.3
8301 970	- 5	2.7
8302 874	- 18	2.1
8342 933	- 4	5 9
8357.752	0	1 8

24. HD 23585

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
7947 924	- 11	4 6
7949 847	- 3	3.9
8012 726	- 12	3 5
8013 747	0	3 8
8045 721	- 9	4 3
8046.705	- 6	2.9
8047 791	+ 3	2.7
8302 909	- 36	3 0
8368 844	- 8	5.4
8397 725	- 17	3 2
8404.792	- 12	2 3

25. HD 23607

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
7947.936	+ 16	4 9
7949 839	+ 16	5.4
8012 717	- 12	4.3
8013.733	+ 11	4 7
8045 712	+ 11	0 6
8046 717	- 1	5 0
8047 780	+ 17	3.3
8302 900	- 14	6 9
8368 835	- 12	3 1
8393 813	- 2	3.4
8397 714	- 2	4 4
8404 800	0	4 1

26. HD 23628

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
7947 913	- 13	6 7
7949.833	- 30	4.7
7951 936	- 18	5.8
8012 701	+ 4	7.0
8013 726	- 1	10 0
8045 744	- 2	5.9
8046 738	- 10	5 9
8047 692	- 14	9 7
8067 738	- 24	8.0
8302.880	+ 4	5.6
8368 773	- 9	5 9
8393.801	- 2	3.1
8397.701	- 13	8 4
8404 807	- 8	5.6

27. HD 23629

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
6185 705	- 1	3 2
7684 783	+ 17	8 1
7950 940	- 23	5.1
7951 870	+ 9	6.0
7984.876	- 16	9.9
8006 640	+ 6	7 5
8011 765	- 3	5.1
8048 644	- 7	3 3
8342 900	+ 6	7.4
8357 757	0	3.6

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JD 2430000+	Radial Velocity (km/sec)	Internal p.e (km/sec)
28. HD 23630		
6154.931	+ 2	±1.4
7684 848	+ 12	3.2
7950.948	+ 8	3.4
7951.878	- 2	1.0
7984.880	+ 3	5 3
8011.763	- 1	1.9
8048 701	- 8	2 8
8342.984	- 4	1 0
8357 759	+ 2	9 2
8426.799	- 3	6 6
8433.787	0	3 1
29. HD 23631		
7684 738	- 18	5 0
7947.943	- 36	6 0
7949.853	+ 3	4 3
7951.946	+ 9	2.6
8012 733	- 15	4 2
8013.752	+ 4	3.2
8045.727	+ 16	4 7
8046.699	- 11	8 6
8302 916	+ 3	5 8
8368.851	- 16	6.3
8393.824	- 2	2.6
8397 735	- 7	3.5
8404 785	- 6	4 8
30. HD 23632		
7684 735	- 3	1.0
7947.946	- 23	5 7
7949.857	+ 1	5.6
7951 953	- 6	8 0
8012.747	- 24	6.1
8013.759	- 2	6 2
8045 730	+ 18	3 7
8046 696	- 7	11 8
8302 928	- 18	6 9
8342 942	+ 3	8 4
8368.856	- 12	7 8
8393 830	- 20	7 6
8404.775	- 2	5 0
32. HD 23643		
7947.951	+ 2	6 8
7949 864	+ 1	4 6
7951 962	- 19	7 9
8012 747	- 26	5 5
8013 759	- 17	4 4
8045 733	0	4 8
8046 691	- 1	5 9
8301 964	- 1	6 7
8302 933	- 8	6 2
8368 861	- 18	2.4
8393 837	- 35	10 0
8404 770	- 19	1 6
33. HD 23733		
7947 958	- 21	7 7
7949 907	- 42	10 4
8012 801	- 29	4.4
8013 812	+ 4	7 3
8045 781	+ 2	9 3
8046 635	- 16	5 8
8047 857	- 8	9.6
8301 956	- 27	10 6
8302 941	- 13	5 9
8368 870	- 34	8 0
8393.742	- 29	±3.4
8397 673	- 21	4 6
8404 826	- 22	6 3
34. HD 23753		
6170 753	- 6	3 5
7684.741	+ 9	3 6
7950 955	+ 2	5 0
7951.882	- 4	9 2
7984.883	- 2	9.6
8006 644	+ 10	3 6
8011.768	- 6	11 1
8048 647	- 5	4 5
8342.903	+ 7	3 6
8357 764	- 4	2 8
35. HD 23763		
7684 745	+ 6	6 2
7947 963	- 32	9 5
7949 915	- 17	3.7
7951 971	- 11	4 2
8012 808	- 4	3 4
8013 818	+ 20	7 5
8045 792	+ 12	6 3
8046 629	+ 5	4 0
8301 950	- 6	1 9
8302 947	- 24	5 7
8342 950	- 11	2 9
8368 888	- 6	4 3
8393 733	- 5	3 3
8397 665	- 25	4 6
8404 832	- 16	5 4
36. HD 23791		
7947 972	- 28	6 3
7949 878	- 19	7 0
8012 763	- 10	4 8
8013 772	0	4 0
8045 748	+ 9	6 1
8046 677	+ 6	5 1
8047.819	- 14	4 5
8301 924	- 6	4 6
8302 984	- 1	2 9
8368 941	- 15	4.0
8393 662	+ 6	4 6
8397 591	- 15	6 2
8411.799	- 5	2 3
37. HD 23850		
6154 938	+ 4	2 8
7684 852	+ 13	5 9
7950 973	+ 8	3 4
7951 894	+ 4	1 9
7984 908	+ 1	3 3
8006 602	+ 13	2 2
8011 826	- 4	2 8
8342 986	- 15	2 7
8357.772	- 19	3 4
8778 633	+ 9	2 7
8778 638	+ 10	2.2
8782 665	+ 12	2 2
8782 666	+ 3	2 5
38. HD 23862		
6169 690	0	3 4
7950 976	- 10	3 8
7951 897	- 16	±4 4
7984.910	- 4	10 5
8006 658	- 4	5.6
8011 829	+ 8	4 6
8048 620	+ 6	4 6
8342 892	+ 4	8 0
8357 774	- 7	3.2
39. HD 23863		
7947 980	- 1	4.7
7949.892	- 30	7 2
8012.789	- 6	5 2
8013 790	- 32	2 6
8045 776	+ 1	4 0
8046 649	- 25	2 2
8266 923	+ 14	4 7
8273 846	+ 5	3 8
8301 931	- 2	5 9
8302 970	+ 5	2 5
8393 686	- 17	2 5
8397 615	- 9	2 2
40. HD 23872		
7684 760	0	8 2
7947 990	- 6	4.2
7949 919	- 13	5 2
7951 983	- 21	3 5
8012 812	0	6 7
8013 822	+ 19	7 9
8045 795	- 3	8 0
8046 626	- 13	7 0
8266 916	+ 16	1 9
8273 878	+ 12	8 0
8301 937	- 5	7 9
8302 950	- 13	4 8
8368 896	- 16	4 1
8393 847	- 19	5 6
8397 647	- 7	7 3
8404 843	- 24	8 1
41. HD 23873		
7684 765	+ 8	3 5
7950 981	- 2	3 0
7951 901	0	7 4
7984 915	+ 3	7 4
8006.662	- 3	4 2
8011 833	+ 4	4 6
8048 672	- 6	4 4
8273 875	+ 19	5 6
8342 917	+ 1	3 8
8357 777	0	2 6
8393 726	+ 3	4 2
42. HD 23886		
7947 986	- 32	2 0
7949 899	0	8 6
8012 795	- 17	4 8
8013 806	+ 7	3 6
8045 782	+ 2	5 2
8046 642	- 8	7 8
8047 847	- 1	7 8
8266 910	+ 12	3 6
8273 864	- 9	2 6
8301 945	- 12	4 1
8302 962	- 20	4 4
8368 910	- 16	3 1
8393 710	- 2	6 8
8397 631	+ 17	5 9

JD 2430000+	Radial Velocity (km/sec)	Internal p e (km/sec)
43. HD 23923		
6169 677	- 3	±3 7
7684 767	- 5	8 7
7950 965	+ 14	7 4
7951 887	- 4	6 2
7984 892	+ 1	10 0
8006 651	- 13	3 1
8011 772	- 14	6 2
8048 651	- 21	6 1
8273 840	+ 3	12 8
8342 907	+ 5	3 7
8357 781	- 1	7 3
44. HD 23924		
7948 003	- 3	4 0
7949 886	- 14	4 8
8012 782	- 30	3 0
8013 780	+ 9	3 2
8045 769	- 15	5 3
8046 669	- 21	3 8
8047 830	+ 7	2 1
8266 901	+ 18	5 4
8273 886	+ 2	6 9
9301 917	+ 1	3 0
8302 977	+ 6	2 6
8368 934	- 19	4 4
8393 675	+ 2	3 6
8397 604	- 3	±2 1
8411 810	- 3	1 9
45. HD 23948		
7684 772	- 4	5 8
7947 994	0	4 8
7949 922	- 11	2 3
7951 993	- 5	5 4
8012 816	+ 13	4 6
8013 827	+ 21	4 7
8045 800	+ 7	2 3
8046 622	- 5	7 2
8266 894	+ 14	5 8
8273 871	+ 5	3 5
8301 910	+ 4	4 3
8302 954	- 2	6 8
8368 903	- 4	3 0
8393 719	+ 2	4 0
8397 639	- 11	3 2
8404 851	- 5	3 7
46. HD 23964		
6185 650	+ 11	2 2
7684 776	+ 20	6 0
7950 969	- 11	2 5
7951 892	- 3	±1 8
7984 902	- 4	3 2
8006 654	+ 40	2 8
8011 824	- 23	1 5
8048 654	- 30	2 6
8273 835	+ 37	2 7
8342 912	+ 27	4 9
8357 768	+ 32	2 6
47. HD 24076		
7684 780	+ 12	3 9
7947 999	- 26	6 8
7949 927	- 18	3 4
7952 000	- 40	6 7
8012 835	- 25	7 3
8013 830	+ 6	5 3
8045 804	+ 2	9 3
8046 618	- 24	5 4
8266 889	+ 30	9 0
8273 830	+ 2	9 0
8301 906	- 5	7 8
9302 966	- 12	4 0
8342 958	+ 5	3 6
8368 917	- 2	9 4
8393 703	- 20	5 7
8397 623	- 4	4 3

Each of the four authors measured many or all of the spectra of the radial velocity standard stars, which were generally observed twice nightly. The results of fifty-four such 63-Å/mm spectra of Procyon, Vega, and 9 Aurigae taken between October, 1962, and February, 1964, indicated a correction to the measured velocities of $+0.3 \pm 5.3$ (p.e. per spectrum) km/sec. Since this probable error does not greatly exceed the usual measuring error, we conclude that the correction was essentially constant with time. For fifty 128-Å/mm spectra of the same stars taken between January, 1962, and September, 1963, the mean correction was $+11.6 \pm 9.2$ (p.e. per spectrum) km/sec. Although this scatter significantly exceeds that usually obtained, namely, ± 4.2 km/sec,

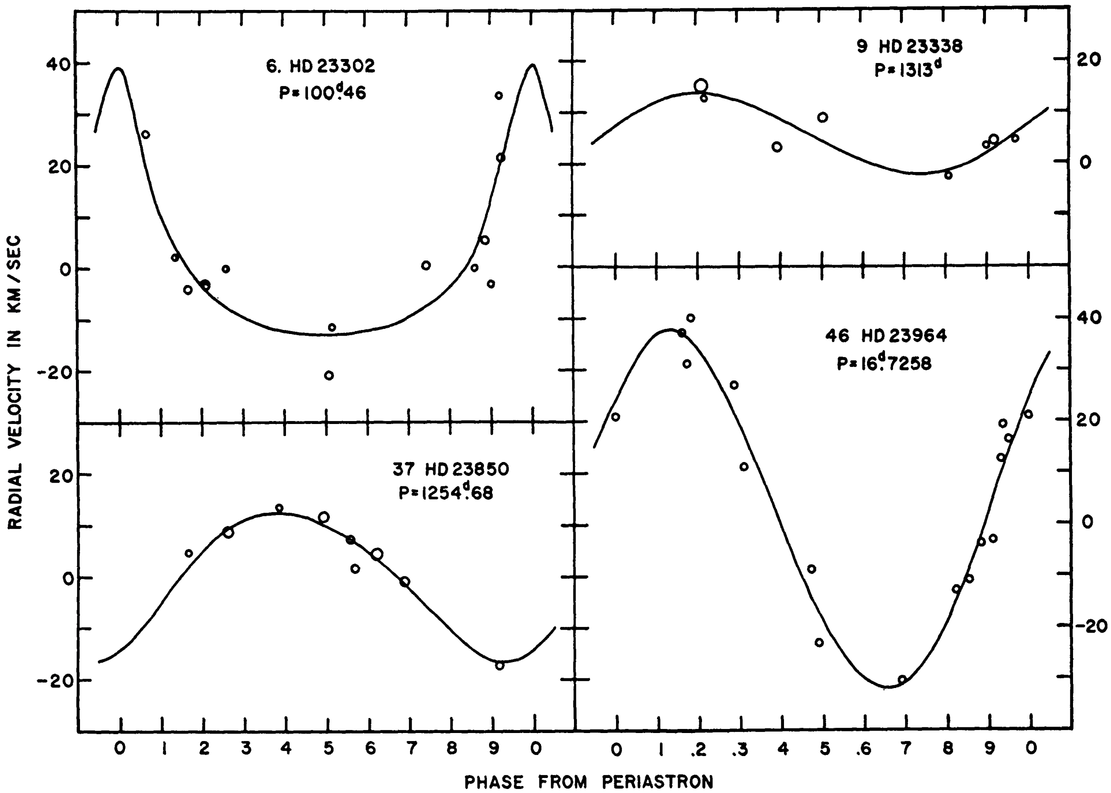

FIG. 1.—Computed radial velocity-curves and measured velocities for four newly discovered spectroscopic binaries in the Pleiades. The sizes of the circles indicate approximately the number of measures (1–7) included in the mean radial velocities. Other names for the stars are Electra (*upper left*), Taygeta (*upper right*), and Atlas (*lower left*).

it is not clear how this correction varies with time, and a constant correction was assumed. It is also not known why the instrumental error should differ by a mere substitution of gratings. The velocities listed in Table 2 include these corrections. No corrections were applied to the McDonald Observatory coudé spectrograms.

The spectroscopic binaries are generally those stars in Table 1 in which the scatter in the velocity measures appreciably exceeds the mean internal probable error, or in which the present measures differ significantly from the older published measures. Orbital elements were derived for five newly discovered binaries. The velocity-curves are given in Figures 1 and 2, while the orbital elements are listed in Table 3. A few other stars, as indicated in the notes to Table 1, also appear to be variable in velocity but orbital elements were not found for them.

The orbital elements, as derived from these spectra of relatively low dispersions, are not well defined, but the aim of this investigation is modest, namely, to determine whether short or long periods are present, rather than to determine definitive velocity-curves. An additional qualification is that the velocities reported here seem to be systematically low compared to those published by others.

III. DUPLICITY, ROTATION, AND METALLIC-LINE STARS

a) B-Type Stars

The first group (B6–B9) of stars in Table 1 has thirteen members. Although three of these stars are members of long-period ($P > 100$ days) binaries, no short-period binaries were discovered.

The distribution of binary periods in a random sample of B stars is not known. However, for the present we may combine the following evidence: (1) Petrie (1960) finds that

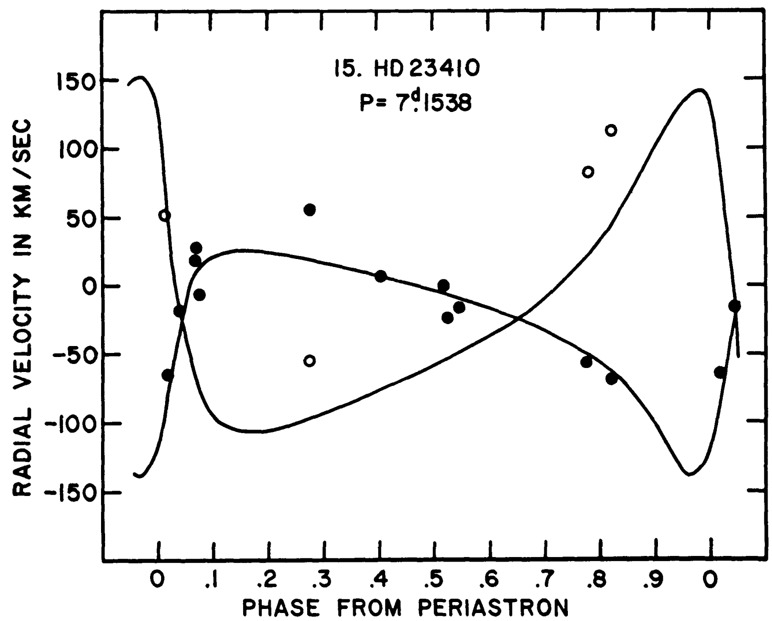

FIG. 2.—Computed radial velocity-curve and measured velocities for a double-lined A0 V binary in the Pleiades. The measures, all of single plates, are based on the Ca II K-line only.

TABLE 3

ORBITAL ELEMENTS OF SPECTROSCOPIC BINARIES

No	HD	Period (days)	T_0 2400000+	ω	e	K (km/sec)	γ (km/sec)	$a \sin i$ (10^6 km)	$f(\mathfrak{M})$ (☉)	$\mathfrak{M} \sin^3 i$ (☉)
6	23302	100 46	24472 86	0 0	0 522	26 0	− 0 3	30 64	0 114	.
9	23338	1313	23268 4	279 9	073	8 0	+ 5 9	144 0	069	.
15	23410	7 1538	36181 97	228	631	{86 2 {144 :	−23 0	{6 58 {12 3		2 66 1 59
31	23642	2 46113	3104 408	107 7	018	{98 1 {140 6	+ 4 99	{3 32 {4 76	. ..	2 05 1 43
37	23850	1254 68	15870 6	213	137	14 5	− 0 4	247 8	386	.
46	23964	16 7258	30293 0	309 0	0 055	35 0	+ 1 7	8 04	0 074	....

51 per cent of field O9–B5 stars and 54 per cent of field A stars have variable velocities, usually due to binary motion. Therefore, up to 50 per cent of the field late B-type stars could be expected to be found to be members of binaries in a study similar to the present one. (2) The distribution of binary periods is not known for a random sample of B stars, but the data (Abt 1961) in the *Fifth Catalogue of the Orbital Elements of Spectroscopic Binary Stars* (Moore and Neubauer 1948) indicate that the distribution is similar to that for A stars with the maximum frequency shifted from 6 days for the A's to 3 days for the B's. (3) Among the metallic-line stars (Abt 1965) there are 1.8 short-period ($P < 100$ days) binaries for every long-period binary. Therefore in a sample of thirteen

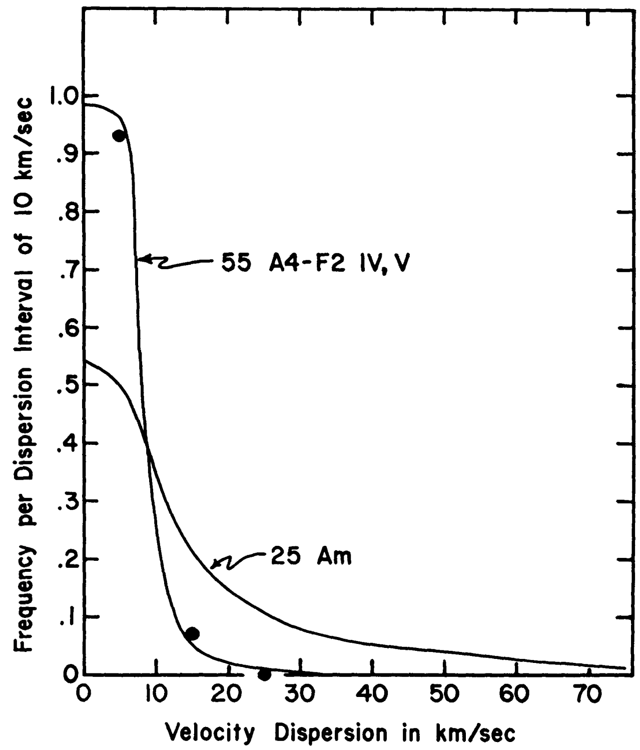

FIG. 3.—The frequencies of various radial velocity dispersions per star for a sample of fifty-five normal A-type field stars, twenty-five field Am stars, and the fourteen A4–A9 Pleiades members (*three dots*). The velocity dispersions for the Pleiades stars fit those of normal, rather than Am, field stars.

field B stars we would expect to detect approximately $13 \times 0.50 \times 1.8/(1.8 + 1) = 4.2$ short-period binaries and $13 \times 0.50 \times 1/(1.8 + 1) = 2.3$ long-period binaries. In comparison, among the Pleiades B stars we find no short-period binaries and three long-period binaries. There appears to be a deficiency of short-period binaries and the consequent absence of appreciable tidal interaction is blamed for the large mean rotational velocity observed in these stars.

b) Early A-Type Stars

The second group (B9.5–A3) of stars in Table 1 has twenty members, of which three are short-period binary systems with known orbital elements and four additional stars (Nos. 12, 35, 20, 29) are probably also binaries of unknown periods. By the same reasoning as above, we would have expected 6.4 short-period and 3.6 long-period binaries in this group, for a total of 10 binaries. The deficiency of three binaries may well be explained by the fact that the dispersions used here are somewhat lower than those used in the data leading to Petrie's conclusions of about 50 per cent detectable binaries. The mean projected rotational velocity, $V \sin i$, for the first ten stars (B9.5 V–A1 V) in this group is 129 km/sec, whereas for eighty-seven field stars of types B8 V–A2 V Slettebak (1955) finds a mean velocity of 139 km/sec. We conclude that the stars in this Pleiades group have an approximately normal binary frequency and normal mean rotational velocity. In contrast to the previous group, the occurrence of numerous short-period binaries evidentally has, by tidal interaction, reduced the mean rotational velocity to the normally observed value.

c) Late A-Type Stars

The third group (A4 V–A9 V) of stars in Table 1 has fourteen members of unknown rotational velocities. No spectroscopic binaries were discovered, and only two stars (Nos. 39 and 24) show excessive scatter in their velocities. The star HD 23325 (Am?), with estimated spectral types from the K-line, metallic lines, and hydrogen lines of A5, A6, and A4, respectively, is a borderline Am star of the kind discussed by Weaver (1952) in the Coma Cluster. The binary characteristics of such stars are not known; this star shows no evidence of duplicity.

Perhaps a more effective way to compare the binary frequency in this group with the distinctive binary frequencies in the normal A4–F2 main-sequence and Am stars is to compare velocity dispersions per star. The Am stars are often (about 56 per cent) members of short-period binary systems (Abt 1961) and therefore exhibit large velocity dispersions in the measures per star. The normal A-type stars are always single (constant-velocity) stars or members of long-period (small-amplitude) binaries (Abt 1965); their velocity dispersions per star are invariably small. Figure 3 shows the frequencies of velocity dispersions in 10-km/sec intervals for these two groups of field stars; the measured scatter in the velocities of each star has been reduced by the mean internal error, assuming both distributions to be Gaussian in shape. The data for the fourteen A4–A9 stars in the Pleiades have been treated in the same way, giving the three dots in Figure 3. The three dots fit, as well as can be expected, the curve for the normal field stars. We conclude that statistically the Pleiades has no short-period binaries among its A4–A9 stars and therefore in the future will have few or no Am stars.

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