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THE AGES AND DIMENSIONS OF TRAPEZIUM SYSTEMS

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ABSTRACT

We have obtained MK spectral types and hence memberships of 120 stars in 31 systems thought to be Trapezium systems, i.e., multiple-star systems with several similar separations. We found 28 optical components; after their removal, 17 systems are hierarchical and three have no companions. All but one of the 11 remaining Trapezium systems are the same age or younger than the Hyades. The exception is explained statistically as a hierarchical triple that, when projected on the sky, only appears to be a Trapezium system. Hence the dynamically-unstable Trapezium systems are less than $10^{8.9}$ yr old. The maximum radii of Trapezium plus hierarchical systems show a pronounced decrease with primary spectral type or age T, ranging from roughly 50,000 AU for OB primaries to 1000 AU for G dwarfs. The systems evolve and lose outer components such that the maximum separations decrease as $T^{-0.3}$. These results agree roughly with published calculations that give maximum binary separations of roughly 10,000–20,000 AU for old binaries in the solar vicinity, and the data are consistent with data by Öpik.

If stars of the solar age have an observed maximum binary separation of roughly 5000 AU, the likelihood of the Sun having a stellar companion (Nemesis) at 92,000 AU is extremely small.

We call attention to a newly discovered Ba II star with a physical companion, a star with strong double Ca II emission lines, and a chance projection of a nearby quadruple hierarchical system on a distant triple hierarchical system.

Subject headings: stars: evolution — stars: spectral classification — stars: stellar dynamics — stars: visual multiples

I. INTRODUCTION

Trapezium systems, named after the Trapezium in the Orion Nebula, are groups of three or more stars whose separations are roughly equal. As such, they are dynamically unstable and must evolve either into hierarchical systems or into hard binaries with outer components lost to the systems. The hierarchical systems are typically a close pair associated with a distant third star, a close pair and another close pair far away, two close pairs widely separated and a far more distant fifth star, etc. That is, hierarchical systems are ones in which the successive separations increase by large factors. Such systems are dynamically stable and should be present among systems of all ages. However, Trapezium systems, being unstable, should be young. To determine exactly how young is one goal of this study.

Ambartsumian (1954) compiled a list of 108 Trapezium systems found in Aitken's Double Star Catalogue (1932). He found some of those (mostly early-type systems) to have dimensions of roughly 100,000 AU = 0.5 pc (without correction for interstellar absorption). He also computed that stable systems in the solar vicinity should have maximum dimensions of 10,000–20,000 AU because of interactions with passing stars. He therefore concluded that the large Trapezium systems are young.

An unpublished list of 968 likely Trapezium systems has been compiled and described by Allen, Tapia, and Parrao (1977). They scanned an updated and augmented tape version of the IDS (Jeffers, van den Bos, and Greeby 1963) compiled at the US Naval Observatory. They looked for systems of three or more stars in which the relative separations differ by less than a factor of 3. In the process they deleted components for which the probabilities of their being field stars of those magnitudes are more than 1%, based on the mean distribution of stars by Galactic latitude and longitude; this is their "1% filter." As one would expect, the primary stars in many of these systems are young OB stars, but surprisingly 75% of the systems have primaries, where their spectral types are known, of types later than B (but of unknown luminosities). If those late-type primaries are not supergiants and giants, the existence of those systems would be inconsistent with the expectation that all Trapezium systems must be young.

In this study we collected spectra for classification of a random sample from the Allen *et al.* catalog to learn (1) whether optical companions (foreground or background stars) occur in a significant fraction of the systems to make some hierarchical systems appear to be Trapezium systems, and (2) the ages of the true Trapezium systems, as judged by their H-R diagrams.

An important consideration is the effect of projection of the three-dimensional systems on the plane of the sky, because in this study we will be unable to measure accurately the dimensions along the lines of sight. In principle, a distant third star in a hierarchical system could be projected to be close to the pair and make it look like a Trapezium system. This confusion is independent of whether these systems are coplanar (Worley 1967) or spherical (Batten 1973). We shall see below that in a statistical sense this confusion between true Trapezium systems and merely projected hierarchical systems is small—not trivial, but also not dominating.

Our random sample from the Allen *et al.* catalog was made independent of primary types, separations, or numbers of components, except that we avoided subgroups of clusters and

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associations. Specifically, we observed all systems north of declination $-25°$ with three or more components that are all brighter than $V = 11.0$ mag. However, as we shall document below, the fainter IDS magnitudes are systematically too bright and randomly poor, so some systems that seem to fulfill the above criteria could not be observed.

The technique used is to obtain two-dimensional MK types for the components to see if their individual distance moduli are compatible with membership in the systems. Then we will see what fraction of the systems are Trapezium systems and what their ages and dimensions are.

II. SPECTRAL CLASSIFICATION AND SYSTEM MEMBERSHIPS

The spectra were obtained with the 2.1 m Cassegrain spectrograph. They have a reciprocal dispersion of 39 Å mm^{-1} and resolution of 1 Å. We used Eastman Kodak IIa-O emulsions that were overexposed and then underdeveloped in D76 to minimize grain. For the stars brighter than $B = 9.0$ mag, we used a spectrum width of 1.2 mm; for $B = 9$–10 mag, 0.6 mm; and for stars fainter than $B = 10$, 0.3 mm. Thus the classification accuracy and the ability to identify peculiarities is a function of brightness. The spectra were compared on a Boller & Chivens Spectra Comparator against early-type standards by Morgan, Abt, and Tapscott (1978) and late-type standards by Morgan and Keenan (1973) and Keenan and McNeil (1976). The classification accuracy is typically ± 1 spectral subclasses and ± 0.7 luminosity classes for the brightest stars ($B < 9.0$) and nearly twice those numbers for the faintest stars.

Table 1 gives the data and conclusions on individual stars. The first column gives the numbers in the unpublished Allen *et al.* catalog; those numbers are convenient to use because of the diversity of names. The names and epoch 1900 positions are given in the second column. Those are followed by the components observed. The separations in seconds of arc from component A (with two exceptions as marked) are listed in the fourth column. Our types are in the next column; the footnotes indicate a few published sources or further details about the types. We call attention to two stars: Trap. 446A is a newly discovered Ba II star with one physical companion, and Trap. 588C has strong double Ca II emission lines.

In eight cases listed in Table 1 we observed two close stars simultaneously, e.g., Trap. 13 AB. In five of those cases the secondary is 2.0 mag or more fainter than the primary, so the types refer to the primary. In three cases (Trap. 581, 588, and 641), the components differ by less than 2.0 mag in brightness and the spectral types represent blends of the unknown individual types, although among such pairs in general the components are usually similar in type.

The visual magnitudes in the sixth column require some explanation. Those with two decimal places are photoelectric ones, mostly from the compilation by Blanco *et al.* (1968), to which the principal contributor is Eggen (1963, 1965). Magnitudes with one decimal place were computed from the relative exposure-meter counts at the spectrograph and should be valid to ± 0.3 mag. Magnitudes in parentheses are taken from the IDS and have systematic and random errors described below. The next column gives the distance moduli, $V_0 - M_V$. In the cases where we have no knowledge of the color(s) for one or more components, we could not correct for interstellar absorption, and the distance moduli are given in parentheses; they are generally upper limits. In the remaining cases the intrinsic colors appropriate for the spectral types are taken from Johnson (1963) or Harris (1963). The absolute magnitudes appropriate for the spectral types are taken from Blaauw (1963).

How well should the distance moduli of the primaries and secondaries in a system agree for us to conclude that they are physically associated? One source of error is the luminosity width of roughly ± 1 mag in the luminosity classes (smaller among the earlier types and larger among the later ones). Another is our average errors of about ± 1.0 luminosity class in classifying the spectra. A third is an average error (see below) of ± 0.75 mag in the apparent brightnesses of these stars. A fourth is intrinsic spread in the main sequence and the occurrence of undetected companions. All together, we will assume that if the derived distance moduli of the secondaries differ by more than 2.0 mag from that of the primary, we will question their physical association. Thus in the eighth column of Table 1 we identify the physical and optical companions. In several cases where we have no spectroscopic information or the spectral types are compatible with physical membership, we have evidence from the IDS that the relative (astrometric) motion is too large for orbital motion; those are labeled as not having common proper motions (Non-CPM) and hence are optical companions. Finally, the last column of Table 1 gives our conclusions about the kinds of systems represented.

An interesting system is Trap. 588, which consists of a hierarchical quadruple at 32 pc superposed on another hierarchical triple at 150 pc, although the latter distance has not been corrected for interstellar absorption. Although such a superposition is rare, it should not be unknown. The IDS contains about 50,000 double and multiple systems, or one per square degree. Since the average sizes of these double- and multiple-star systems is roughly 15″, there could be cases of overlap, preferably among the systems that are largest in angular sizes.

In summary, we have studied 31 systems. We observed the 31 primaries and 89 companions. Of the latter, 61 are apparently physical companions, and 28 are optical superpositions.

The evidence that 31% of the companions observed are optical is disturbing in view of the attempts by Allen *et al.* to eliminate optical companions through the use of their 1% filter. Our proposed explanation is as follows. We compared the IDS magnitudes with photoelectric ones by Eggen (1963). The results are given in Table 2. We see that for stars brighter than $V = 8.0$ mag, the agreement of the IDS and photoelectric magnitudes is good. In $V = 8.0$–8.9 mag, they agree systematically but the scatter is large (± 0.75 mag). In the $V = 9.0$–12.9 mag range, the IDS magnitudes are too bright by 0.5 mag, and for a few 13th mag stars the systematic errors are much larger. Similar errors exist among variable stars (Kinman 1965), probably for the same reason, namely that the magnitudes were tied into the BD and CD system. For the 28 optical companions in Table 1, $\langle V \rangle = 9.9$ mag, and 75% of those stars are fainter than $V = 9.0$ mag. Therefore, if the 1% filter is based on an incorrect (and brighter) magnitude system for the multiple stars relative to that of field stars, too many optical companions will slip through the 1% filter. It would be interesting to correct the IDS magnitudes by the amounts given in Tabe 2 before applying the 1% filter and see whether the occurrence of optical companions is diminished significantly.

In the 31 systems, three (10%) consist purely of optical superpositions. In 17 systems (55%), the occurrence of one or more optical companions made an intrinsic hierarchical system look like a Trapezium system. A good example is Trap. 306 with secondaries at 4″.2, 38″.6, and 78″.3; because the last is found to be an optical companion, the primary plus the

TABLE 1

SPECTRAL CLASSIFICATION AND SYSTEM MEMBERSHIPS

Trap. No.	Names and 1900 Position	Comp.	Separ-ation	Type	V (mag)	V_0-M_V	Conclu-sion	System
13	ADS 719	AB	1".4	O5 V	7.76	12.5	Physical	ABCD
	A=HD 5005	C	4.0	O9 V	8.5	(12.1)	Physical	Trap.
	00470+5605	D	9.0	O9 V	8.3	(11.9)	Physical	
24	ADS 1040	AB	0.6	B9.5 V[a]	7.13	6.3	Physical	ABC
	A=HD 7710	C	10.0	Am(A6/A9/F2)	9.00	6.4	Physical	Hier.
	01119+4829	D	var.	....	(10.8)	...	Non-CPM	
34	BUP	A	...	F9 V	9.7	(5.5)	....	AC
	C=HD 9365	B	60.0	G8 III	8.4	(8.0)	Optical	Hier.
	01268+6006	C	44.3	F1 V	8.2	(5.6)	Physical	
42	H 69	A	...	F0 III-IV[b]	4.98	3.7	....	Opt.
	A,C=HD 13174,52	B	93.2	K0 III	9.8	(8.9)	Optical	
	02037+2528	C	105.9	(F2)[c]	8.7[c]	(5.8)	Optical	
306	ADS 6746	AB	4.2	F7 V	8.55	4.5	Physical	ABCc
	AB,D=HD 69894,65	C	38.6[d]	G7 V	9.84	4.2	Physical	Hier.
	08140+4743	D	78.3	G8 IV	8.22	3.7	Optical[e]	
320	BUP	A	...	G8 III	6.39	6.0	....	ABPQ
	A,B=HD 73665,6	B	149.8	A1 Vs	6.61	5.6	Physical	Trap.
	08344+2022	P	134.1	F2 V	9.22	6.4	Physical	
		Q	135.0	F2 V[f]	8.81	6.0	Physical	
351	HJ 1166	A	...	G9 III	5.85	5.0	....	ABC
	A=HD 82087	B	62.8	G8 IV-V	9.5	(5.2)	Physical	Trap.
	09247+3406	C	97.8	G5 V	10.9	(5.8)	Physical	
357	STT 103	A	...	Am(A2/F0/F3)	8.0	(6.0)	....	ABC
	A=HD 85216	B	78.2	F2 Vs	9.2	(6.8)	Physical	Trap.
	09453+1947	C	95.7	G2 V	10.9	(6.8)	Physical	
410	ADS 8162	A	...	G9 IV-V	6.50	2.2	....	AB
	A,B=HD 99491,2	B	40.8	K4 V	7.58	0.8	Physical	Hier.
	11217+0333	C	90.3	F5 V	11.1	(7.9)	Optical	
427	ADS 8413	A	...	K1 III	7.35	6.5	....	AB
	A,E=HD 105028,9	B	10.2	G0 V	10.98	6.5	Physical	Hier.
	12005+6921	D	127.	G8 III	9.0	8.5	Optical	
		E	var.	M4 III	7.3	(7.7)	Non-CPM	
445	HJ 217	A	...	K1 IV	9.4	(6.4)	....	AC
	12409+1042	B	33.6	G5 V	9.7	(4.6)	Optical	Hier.
		C	42.7	G3 IV	10.1	(7.2)	Physical	
446	HJ 2621	A	...	G7 III[g]	10.0	(9.6)	....	AB
	A=HD 119008	B	34.7	K5 III	9.6	(9.9)	Physical	Hier.
	12474+0745	C	38.5	F6 V	11.3	(7.8)	Optical	
448	HJ 2639	A	...	K7 III	7.4	(7.7)	....	ABC
	A=HD 113892	B	31.4	G5 V	11.8	(6.7)	Physical	Trap.
	13016+4128	C	57.2	F8 V	10.6	(6.6)	Physical	
456	STF 1773	A	...	F7 V	9.7	(6.0)	....	AC
	B=HD 119181	B	28.7	K1 III	9.5	(8.7)	Optical	Hier.
	13367+0807	C	57.0	G2 V	10.1	(5.4)	Physical	
457	ADS 8997	A	...	A7 V	6.6	(4.6)	....	Opt.
	A=HD 119702	B	26.3	K0 IV	9.6	(6.6)	Optical	
	13397+7721	C	var.	F7 V	8.9	(5.2)	Optical	
488	STT 138	A	...	F0 IV	7.4	(5.6)	....	AB
	A,B=HD 136882,48	B	150".5	F4 V	7.7	(4.6)	Physical	Hier.
	15180+6044[h]	C	82.0	K2 III	8.5	(7.7)	Optical	
511	ADS 10049	A	...	B2 V	5.02	6.0	....	ABCDE
	A,B,C,D=HD 147933,	B	3.1	B2 IV	5.87	7.7	Physical	Trap.
	934,932,888	C	151.0	B7 V	7.13	(6.1)	Physical	
	16196-2313	D	156.0	B3 V	6.76	7.0	Physical	
		E	DE:0.7	....	8.1	...	Physical	
527	STF 2090	A	...	K7 III	8.1	(8.4)	....	AC
	A=HD 151088	C	66.9	F5 V	10.8	(7.6)	Physical	Hier.
	16401+1008	D	92.9	G3 V	10.1	(5.3)	Optical	

TABLE 1—*Continued*

Trap. No.	Names and 1900 Position	Comp.	Separation	Type	V (mag)	V_0-M_V	Conclusion	System
581	ADS 10987	AB	0.7	B8.5 V	8.4	(8.6)	Physical	ABE
	A,E=HD 164529,57	C	104.1	F8 V	10.0	(6.0)	Optical	
	17566+0332	E	90.2	B7 III	8.0	(9.6)	Physical	
588	ADS 11060	AB[i]	0.27[i]	G1 V	7.07	2.5	Physical	AaBC
	A,G=HD 165590,69	C	28.2	K7: V[j]	10.62	2.5	Physical	Hier.
	18016+2126	D	37.9	F7 V	10.2	(6.4)	Optical[k]	
		E	63.1	F8 V	9.6	(5.6)	Optical[k]	DEG
		G	135.9	A7 V	7.8	(5.8)	Optical[k]	Hier.
593	S 700	A	...	B1 III[l]	8.46	11.4	....	ABC
	A=HD 166286	B	18.7	B2 IV:	10.7	(12.5)	Physical	Trap.
	18048-1647	C	28.7	B2 V	10.5	(11.5)	Physical	
600[m]	ADS 11169	Aa[m]	0.011	B9 Ia	3.86	10.3	Physical	Aaa'DE
	A=HD 166937	B	16.9	....	11.5	...	....	Prob.
	18078-2105	D	48.5	B2 IV[n]	9.61	(12.2)	Physical?	Trap.
		E	50.0	B2.5 V[n]	9.23	(10.6)	Physical	
603	ADS 11168	A	...	B3 III	8.9	(11.8)	....	AC
	A=HD 166934	B	7.6	B1 V	10.3	(13.9)	Optical:	Hier.
	18079-1849	C	13.5	B5 V	10.0	(11.0)	Physical	
641	ADS 11579	AB	0.25[o]	G5 III-IV	6.94	5.6	Physical	ABC
	A=HD 172865	C	14.2	F7 V	8.83	5.0	Physical	Hier.
	18374+3012	D	22.9	....	(11.9)	...	....	
650	STF 2388	A	...	B2 V	7.6	(10.1)	....	AB
	A=HD 174069	B	53.7	B9 V	10.6	(10.0)	Physical	Hier.
	18435-0835	C	21.4	K0: III	10.1	(9.3)	Optical[p]	
657[q]	ADS 11745	Aa	0.0	B8.5 Ib-II	3.45	7.8	Physical	AaBF
	A=HD 174638,9=β Lyr	B	45.7	B7 V	7.22		Physical	Trap.
	B=HD 174664	C	46.3	...	13.43		Optical	
	18464+3315	D	64.3	...	15.15		Optical	
		E	67.0	Am(A5/F2/F2)	9.81		Optical	
		F	85.8	Am(A7/F1/F3)	10.16		Physical	
714	STT 187	A	...	B9 IVs	8.3	(8.5)	....	Opt.
	A=HD 185116	B	64.3	F5 IV-V	9.3	(6.5)	Optical	
	19325+4613	C	129.2	G2 V	9.0	(4.3)	Optical	
740	ADS 13117	A	...	B7 V	6.54	6.8	....	AB
	A=HD 188651	B	9.7	A3 V	9.3	(7.8)	Physical	Hier.
	19519+2956	C	16.4	G0: III	11.1	(10.4)	Optical	
751	ADS 13312	A	...	O5 If	6.63	11.2	....	ABC
	A=HD 190429	B	1.7	O9.5 III	7.3	(11.3)	Physical	Hier.
	19598+3545	C	42.5	B1 IIIs	8.6	(11.6)	Physical	
		D	29.0	...	(11.0)	...	....	
857	ADS 15184	A	...	O7 V	5.62	9.5	....	ABCD
	A=HD 206267	B	1″6	...	(13.3)	...	Physical	Trap.
	21355+4116	C	11.7	B1.5 V	8.10	9.7	Physical	
		D	19.9	B1 V	8.02	10.1	Physical	
951	ADS 16795	Aa[r]	0.0	B3 V[s]	4.91	6.3	Physical	AaBCDFG
	A,B=HD 221253,37	B	1.1	...	9.3	...	Physical	Trap.
	23254+5800	C	75.7	B8 Vn[s]	7.07	6.96	Physical	
		D	CD:1.4	...	9.1	...	Physical	
		E	43.4	A3: V	11.28	(9.8)	Optical	
		F	67.3	F7 IV-V[s]	11.06	7.90	Physical	
		G	67.0	F9 V	11.11	6.60	Physical	

[a] (Trap. 24) Abt 1985.
[b] (42) Slettebak 1955: F2 III.
[c] (42) HD type and magnitude.
[d] (306) Cc: separation, 0″44; orbital period, 180.6 yr.
[e] (306 D not CPM with A; D has a reddening of 0.52 mag, while ABC have 0.09 mag.
[f] (320) Lutz and Lutz 1977.
[g] (446) G7 III (Ba II, Sc II very strong, Sr II, CN, CH strong).
[h] (488) IDS gives a declination of 60°36′.
[i] (588) Orbital period, 20.25 yr; Aa period, 0.8795 days (Batten *et al.* 1979).
[j] (588) K7: V (Ca II double emission), velocity difference, 110 km s^{-1}.
[k] (588) This evidently consists of two superposed hierarchical systems, one at 32 pc and one at roughly 150 pc.
[l] (593) Morgan, Code, and Whitford 1955 give B1 II.
[m] (600) Member Sgr OB1. Aa is an occultation double with a separation of 18.6×10^8 km; A is an SB1 with $a \sin i = 1.29 \times 10^8$ km. These are probably different companions unless $i < 4°0$.
[n] (600) Abt and Cardona 1983.
[o] (641) Orbital period, 90 yr (Baize 1950).
[p] (650) Component C is too late for membership.
[q] (657) See Abt *et al.* 1962, Abt and Levy 1976, and Dobias and Plavec 1985 for details. A is an SB1 with period 12.9349 days.
[r] A is an eclipsing binary (AR Cas) with period 6.0663 days.
[s] (951) Abt and Cardona 1983.

TABLE 2

MEAN ERRORS IN IDS MAGNITUDES

IDS V (mag)	NUMBER OF STARS	$V_{IDS} - V_{pe}$ (mag) Mean	σ
3.0–7.9	70	+0.07	±0.19
8.0–8.9	23	−0.13	0.75
9.0–12.9.........	64	−0.50	0.77
13.0–13.9.........	5	−1.67	±0.74

first two companions consitute a typical hierarchical multiple system. Only in 11 systems (35%) do we agree that the systems are Trapezium systems, at least in projection.

III. THE AGES OF TRAPEZIUM SYSTEMS

In Table 3 we summarize the results for all the observed systems; they are arranged in the order of the earliest spectral type in each system (second column). Apparent exceptions are Trap. 351, 446, and 448; those have only late-type giants and late-type main-sequence stars, which do not immediately indicate the evolutionary state of those systems. However, isochrones fitted to these systems (see below) show main-sequence turnoff points at A1, and so that is given (in parentheses) as the earliest spectral type. The third column gives the number of physical components and the next two columns are taken from Table 1.

Figure 1 shows the H-R diagram of the 11 Trapezium systems. The open circles represent the brightest star in each system, and the dots represent the companions. The Trapezium numbers are given to the right of each primary. The evolutionary track for a $\mathscr{M} = 2.4\ \mathscr{M}_{\odot}$ star of $Y = 0.25$ and $Z = 0.0169$ is taken from VandenBerg (1985). The four crosses represent the four Hyades giants; those plus the primaries in Trap. 448, 320, and 351 approximately fit the evolutionary track illustrated. The main-sequence turnoff for this isochrone is spectral type A1.

There is only one Trapezium system among the 11 that is older than the Hyades, whose age is about $10^{8.9}$ yr (van den Heuvel 1969). That exception is Trap. 357, a triple system with companions at 78.″2 and 95.″7. If, in three dimensions, that system is really a hierarchical system with AC being three times the separation of AB, then the angle of AC with the line of sight is 24° or less, assuming the orbit of AB to be perpendicular to the line of sight. The probability of that angle occurring is 0.087 or less. Therefore, among the dozen multiple systems older than the Hyades, roughly one should be a hierarchical system that projects to look like a Trapezium system and that can account for Trap. 357. This single calculation is, admittedly, a crude approximation to a Monte Carlo simulation of the distributions (some of which are still unknown, such as the

TABLE 3

SUMMARY OF DATA ON PHYSICAL SYSTEMS

TRAPEZIUM NUMBER	EARLIEST TYPE	PHYSICAL COMPONENTS	KIND	$V_0 - M_V$	MAXIMUM SEPARATION (arcsec)	(AU)
13.........	O5 V	4	Trap.	12.5	9.″0	28500
857.........	O7 V	4	Trap.	9.8	19.9	17900
751.........	O9.5 III	3	Hier.	11.2	42.5	73900
603.........	B1 V	2	Hier.	(11.4)	13.5	(26000)
593.........	B1 III	3	Trap.	11.4	28.7	54400
511.........	B2 V	5	Trap.	6.9	156.0	37600
650.........	B2 V	2	Hier.	(10.1)	53.7	(56000)
600.........	B2 IV	5	Trap.	10.3	50.0	56600
951.........	B3 V	7	Trap.	6.9	76.6	18700
657.........	57 V	4	Trap.	7.8	85.8	31200
740.........	B7 V	2	Hier.	6.8	9.7	2200
581.........	B7 III	3	Hier.	(9.1)	90.2	(60000)
714.........	B9 IVs	1	Opt.	(8.5)	...	...
24.........	B9.5 V	3	Hier.	6.4	10.0	1900
320.........	A1 Vs	4	Trap.	6.0	149.8	23700
351.........	(A1)[a]	3	Trap.	5.0	97.8	9800
446.........	(A1)[a]	2	Hier.	(9.8)	34.7	(32000)
448.........	(A1)[a]	3	Trap.	(7.0)	57.2	(14000)
457.........	A7 V	1	Opt.	(4.6)	...	...
357.........	Am (F0)	3	Trap.	(6.0)	95.7	(15000)
488.........	F0 IV	2	Hier.	(5.1)	150.5	(16000)
42.........	F0 III–IV	1	Opt.	3.7	...	...
34.........	F1 V	2	Hier.	(5.6)	44.3	(5700)
527.........	F5 V	2	Hier.	(8.0)	66.9	(27000)
306.........	F7 V	4	Hier.	4.4	38.6	2900
456.........	F7 V	2	Hier.	(5.7)	57.0	(7900)
641.........	F7 V	3	Hier.	5.3	14.2	1600
427.........	G0 V	2	Hier.	6.5	10.2	2000
588.........	G1 V	4	Hier.	2.5	28.2	900
	A7 V	3	Hier.	(5.9)	135.9	(21000)
445.........	G3 IV	2	Hier.	(6.8)	42.7	(9800)
410.........	G9 IV–V	2	Hier.	1.5	40.8	800

[a] "A1" is the main-sequence turnoff point for these giant branches.

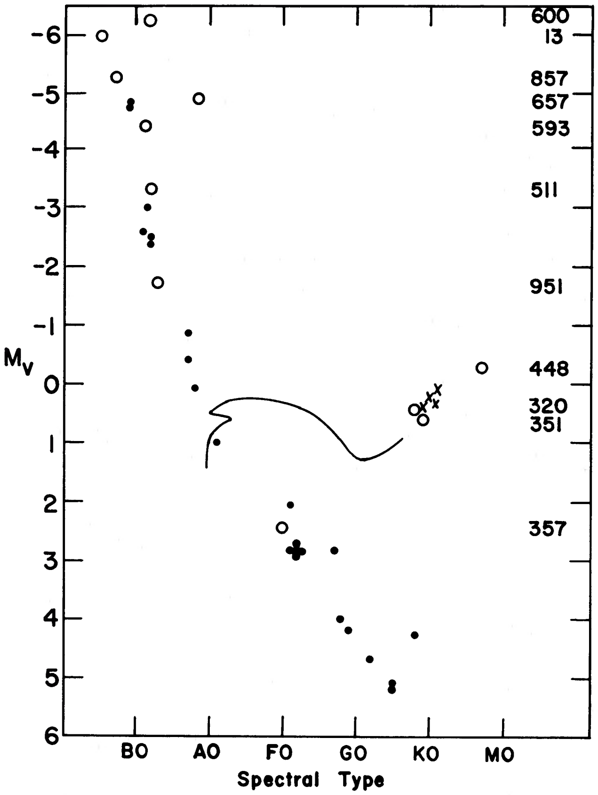

FIG. 1.—H-R diagram for 11 Trapezium systems. The absolute magnitudes are taken from the MK types and the calibration by Blaauw (1963). The most luminous star in each system is indicated with a circle, and the Trapezium numbers are given to the right; the companions are represented with dots. The four Hyades giants are indicated with crosses. The evolutionary track for a 2.4 $\mathscr{M}_{\odot}$ star is taken from VandenBerg (1985).

shapes of multiple-star systems) in seven orbital elements for each secondary in a multiple system. The full calculation is far beyond the scope of this study, but (1) the crude example shows that at least one hierarchical system could be masquerading as a Trapezium system, (2) the results would not change if several more were doing the same thing, and (3) 11 systems is too small a sample for a full statistical treatment.

We conclude that the maximum age of Trapezium systems is that of the Hyades. That may be consistent with estimates of dynamical ages: Allen and Poveda (1974) computed that after 10^6 yr, two-thirds of the O-type Trapezium systems would still exist; the remainder became hierarchical systems or binaries with the remaining components lost to the systems. Smaller mass systems would have longer crossing times and would take longer to come into dynamical equilibrium or dissolve.

IV. DIMENSIONS OF HIERARCHICAL AND TRAPEZIUM SYSTEMS

For each system in Table 3, Trapezium or hierarchical, we give in the last columns the maximum separation from the primary, expressed in seconds of arc and in astronomical units. For systems with unknown reddening and absorption, the dimensions in AU are placed in parentheses; they are generally upper limits. For the remaining systems with better distances, we plot in Figure 2 the maximum separations as a function of the most luminous main-sequence type (again, for the systems with only late-type giants and late-type dwarfs, we use the main-sequence turnoff type of A1). We see that many OB systems have maximum separations of roughly 50,000 AU, whereas for the late-type systems the maximum dimensions are roughly 2000 AU. This shows that the larger multiple-star systems form smaller hierarchical systems or lose outlying companions in encounters with passing stars, or both.

There may be reservations, at least initially, about these results because of two selection criteria. First, the sample is limited by apparent magnitude ($V \lesssim 11$), so that the more luminous early-type systems will tend to be farther away. For instance, the OB systems with reddening-corrected distances are 10 times farther away on the average than the FG V systems. Therefore a given separation in seconds of arc will translate to larger separations in AU among the OB than among the FG stars. Seemingly, that could explain the limiting curve in Figure 2. It is generally true that the discoverers of these multiple systems were unaware of the spectral types and distances of the stars at the times of discovery. A second selection effect is that the discoverers rarely record companions at more than 150″ separation (see Table 1). Let us see in two areas whether these two selection effects and the above characteristic of discovery will explain or confirm as real the results in Figure 2.

Note in Table 3 that for the systems with reddening-corrected distance moduli greater than 9 or 10, there are none with maximum separations greater than 50″, whereas among nearer systems there are many in the range 50″–150″. Since the observers did not know the distances to these systems, they would have recorded the 50″–150″ companions among the former if they existed. That is why we believe that the upper limits of 20,000–80,000 AU among the early-type systems are real upper limits. Second, consider the systems with primaries later than F0 V; none, either with or without good determinations of distance, have separations greater than 70″, whereas

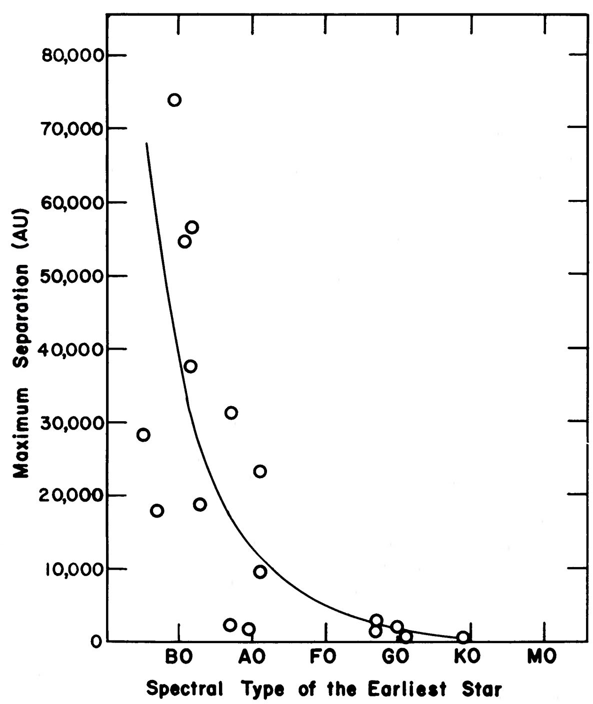

FIG. 2.—For 17 multiple-star systems, both Trapezium and hierarchical, the maximum component separations from the primaries vs. the spectral type of the earliest main-sequence stars. The mean least-squares power-law curve gives a maximum separation proportional to $T^{-0.3}$.

among the remaining systems in Table 3 nearly half (nine of 20) have larger maximum separations. That is why we believe that for late-type systems the upper limit of less than 10,000 AU is real.

However, obviously further work on these and other Trapezium and hierarchical systems is badly needed, especially (1) more spectral classsfications to get luminosities and ages; (2) photoelectric photometry to get distances and reddening; (3) astrometric measures to obtain information on membership, because many of the companions have only one measure obtained early this century; and (4) radial velocities for membership information and the discovery of spectroscopic companions.

We have fitted the data in Figure 2 to a power-law decrease of separation with increasing spectral type or age. We would be tempted to use the upper envelope of the data points except for the following reason: the distance moduli for the systems are known only to roughly ± 1 mag for the reasons given above, and consequently the distance and separations in AU are good only to a factor of 1.6. Therefore the upper envelope probably represents the systems with distance errors such as to make them unusually large. Instead we will use the mean maximum separations. The primary types are converted to ages, T, with sufficient accuracy with the relations given by Sandage (1958). A least-squares solution gives the mean maximum separation, $3.9 \times 10^6\ T^{-0.3}$, where the separations are in AU and the ages are in years. That is, for every increase in age by a factor of 10 the maximum separation decreases by a factor of 2. However, recall that these are dimensions projected on the plane of the sky. The actual separations in three dimensions will be larger by a factor of $\sim 4/\pi$.

Various people have discussed the maximum sizes of double- or multiple-star systems. On the theoretical and simulation side, Ambartsumian (1954), Heggie (1975, 1977), and Retterer and King (1982) agree that due to the effects of many passing stars during the lifetime of the Galaxy, the maximum dimensions of binaries in the solar vicinity should be 10,000–20,000 AU. On the observational side, Ambartsumian (1954), Bahcall and Soneira (1981), Retterer and King (1982), and Latham *et al.* (1984) found systems with maximum dimensions up to 20,000–100,000 AU. In the cases where the ages are known, those limits seem to be consistent with the results shown in Figure 2. It remains to be seen whether the systems whose ages are currently unknown will also be consistent with Figure 2.

Perhaps the most interesting reference is to the work of Öpik (1924) that showed maximum double-star separations (computed without knowledge of interstellar absorption) of 1700 AU for dwarf G and K stars, 7000 AU for dwarf F stars, 14,000 AU for dwarf A and giant G, K, and M stars, 28,000 AU for dwarf B stars, and 112,000 AU for O stars and supergiants. Our results are in agreement with Öpik's after some allowance is made for interstellar absorption to the latter. Thus he derived the basic data shown in Figure 2 when people still interpreted the H-R diagram as stars evolving through the supergiant region toward the left and then down the main sequence.

These new observations, indicating a reduced upper limit of roughly 5000 AU for binary- and multiple-star dimensions among dwarfs of solar age, make it extremely unlikely that the Sun has a stellar companion (Nemesis) with an orbital semimajor axis of 92,000 AU. Lower mass companions would be perturbed even more easily because they are bound less strongly, and they would also be unlikely.

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