THE ASTROPHYSICAL JOURNAL, 541:841–848, 2000 October 1
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THE MAXIMUM AGE OF TRAPEZIUM SYSTEMS

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Received 1999 December 29; accepted 2000 April 10

ABSTRACT

We sought to determine the maximum age of Trapezium systems by studying possible trapezium systems that were selected independently of their occurrence in H II regions. We started with the unpublished catalog by Allen, Tapia, & Parrao of all the known visual systems having three or more stars in which the maximum separation is less than 3.0 times the minimum separation. Their catalog has 968 such systems whose most frequent primary type is F, which does not describe young systems. With a CCD on the Kitt Peak 0.9 m telescope we obtained *UBV* frames for 265 systems accessible with our equipment on Kitt Peak. The frames were used to obtain *UBV* photometry for about 1500 stars with an accuracy of ± 0.04 mag between $V = 7$ and 14 mag. Also these frames were used to obtain astrometry with an accuracy of $\pm 0^\circ.015$ in position angle and $\pm 0''.01$ in separation. For the brightest star in each system we obtained a spectral type to determine the distance and reddening to the system. The measures were used to determine physical membership from stars that (1) fit a single color-magnitude diagram, (2) fit a common color-color diagram, and (3) show no astrometric motion compared to visual measures made (mostly) a century ago. Combining the results with spectroscopic data for 20 additional Allen et al. systems by Abt, we found that 126 systems had only optical companions to the primaries, 116 systems contained only a single physical pair, 13 were hierarchical systems with 3–6 members and having separation ratios of more than a factor of 10, two were small clusters, and only 28 fitted the criteria of Trapezium systems. However, as shown by Ambartsumian, about 9% of the hierarchical systems should appear to be Trapezium systems in projection. Those, like other hierarchical systems, have a broad distribution of primary spectral types. We isolated 14 systems that seem to be true Trapezium systems. They have primary types of B3 or earlier, indicating a maximum age of about 5×10^7 yr. This upper limit is consistent with the estimate made by Allen & Poveda for an age of several million years for these dynamically unstable systems. These Trapezia are also large with a median radius of 0.2 pc and a maximum radius of 2.6 pc. We asked why the sample of 285 possible Trapezium systems yielded only 14 true ones, despite the attempt made by Allen et al. to eliminate optical companions with a "1% filter," i.e., demanding that each companion have less than a 1% chance of being a field star of that magnitude within a circle of its radius from the primary. The explanation seems to be that the double star catalogs are based mostly on BD magnitudes that, fainter than $V = 12$ mag, are systematically too faint by 1 mag.

Subject headings: binaries: visual — open clusters and associations: general — stars: fundamental parameters

On-line material: additional figures, machine-readable tables

1. INTRODUCTION

Trapezium systems are physical systems of three or more stars with roughly equal separations. An arbitrary working rule is that the largest separation in a Trapezium system is no more than 3 times the smallest separation. In contrast, hierarchical systems have factors of at least 10 between the largest and the smallest separations. Typically, a hierarchical system will consist of a close pair and a distant third star, or a close pair and distant close pair.

Of course we see these multiple-star systems only in projection against the plane of the sky. Multiple-star systems tend to be spherical, rather than coplanar (Worley 1967). Therefore, a hierarchical system consisting of two close pairs widely separated could, if they lay nearly along our line of sight, simulate a Trapezium system. Ambartsumian (1954) called those "pseudo-Trapezium systems" and estimated in a statistical analysis that about 9% of a sample of hierarchical systems would appear to be such pseudo-Trapezium systems.

Trapezium systems are dynamically unstable: the orbits of their component stars are not closed, and they will evolve into hierarchical systems or disperse. Through extensive numerical computer simulations, Allen & Poveda (1974, 1975) have estimated that their maximum ages should be a few million years.

Trapezium systems, of course, were named after the Trapezium in the Orion Nebula Cluster. The reported expansion (Strand 1957) of the Orion Nebula cluster proved to be spurious. Allen & Poveda (1974) showed from observations that no Trapezia in their sample of 33 systems showed any measurable expansion.

Trapezia have been found in gaseous nebulae (Ambartsumian 1954; Sharpless 1954). Ambartsumian pro-

[1] Operated by AURA, Inc., under contract with the NSF.

vided a catalog of 108 such systems. Their association with gaseous clouds added evidence that Trapezia are young. But there is a logical dilemma here. If one looks at young gaseous nebulae and sees Trapezium systems, that does not imply that all Trapezia are young. There are many apparent Trapezia listed in the catalogs of visual double or multiple stars that are not imbedded in gas clouds.

One goal of this study is to see if physical Trapezia can occur among old stars that are not in gaseous clouds. What we did was to study a large sample of possible Trapezium systems gleaned from visual multiple star catalogs and to see if there are physical Trapezium systems among old stars. The second goal is to determine from observational data the maximum age of Trapezium systems.

Part of this Trapezia search independent of age was done by Allen, Tapia, & Parrao (1977). They searched through an early version of the IDS Catalogue (Jeffers, van den Bos, & Greeby 1963) that had 53,836 systems listed and isolated 968 possible Trapezia. Those were ones with the following characteristics: each system had three or more stars with a ratio of the largest to smallest separation within the system of not more than 3.0. Also they attempted to eliminate systems that were contaminated with optical components through the use of a conservative "1% filter." That is, they required that for each star in the system, the chances of finding a field star at that Galactic latitude and longitude and of that magnitude within the area of the system is less than 1%.

That catalog of 968 possible Trapezia was never published because of the unexpected characteristics of those systems, e.g., a most frequent primary type of F. They realized that a detailed study of those systems needed to be made before the reality of all the 968 possible Trapezia could be believed. This project describes such a study.

We studied as many of the 968 systems as could be observed from our location and with certain limitations of magnitudes and separations. To establish the physical reality of each system we required that each of the following criteria be met: (1) astrometric measurements with CCD frames compared to older visual measures must show no relative proper motions (beyond those that would be compatible with orbital motions); (2) the members of each system should fit a single color-magnitude diagram for stars at the same distance; (3) the stars should fit a single color-color diagram for stars with the same reddening. These tests required CCD frames in three colors (U, B, and V); those frames could also be used for the astrometry. We also needed at least one MK spectral type in each system to determine the distance and reddening to the system.

2. OBSERVATIONS AND DATA

Of the 968 possible Trapezium systems, we eliminated those south of $-20°$ declination because their minimal zenith distances of 52° would be too large for good photometric measurements. Our CCD equipment with a 0.9 m telescope had a minimum shutter duration of 1 s, so stars brighter than $V = 7$ saturated the system. Therefore, we eliminated all systems containing stars brighter than that limit. For systems in which all the stars were fainter than $V = 11$ mag, we felt that the older observations might not be very reliable. Because the seeing tended to be 1″–2″, we eliminated systems having more than one separation smaller than 2″. For some systems it was obvious from the published visual measures that the components were mostly optical ones, so those optical systems were not measured. Finally, 31 of these systems had been studied earlier (Abt 1986) with MK spectra of each of the components, so it was not felt to be necessary to obtain the CCD measurements for those. We observed 265 systems (see Fig. 1).

The UBV observations were made with the No. 1 0.9 m telescope at the Kitt Peak National Observatory. At the f/13.5 focus an RCA 512 × 300 pixel CCD chip gave a field of 4′.1 (E-W) by 2′.5 (N-S), which is a convenient size for most visual multiple star systems. The scale was 0″.48 pixel^{-1}. We used 10 moonlit nights distributed during nine months. Eight of the nights were fully or partially photometric. A red and a blue equatorial standard (Landolt 1973, 1983) was observed every hour. Generally, each night such a pair of stars was observed from low to high air mass and one from high to low air mass. Both the standard stars and the Trapezia fields were observed sequentially through the U, B, and V filters. Exposure times ranged from 1 s to several minutes (for the U frames).

The journal of observations is given in Table 1. The large number of CCD frames obtained each night shows both the efficiency of this program and the need for a batch approach to the reductions. The last column of Table 1 gives the sky quality.

2.1. *Photometric Data*

Aperture photometry was performed on each CCD frame with the IRAF[2] data reduction package APPHOT. This requires an input of starting star coordinates and the FWHM of the images. The latter was determined by plot-

[2] IRAF is distributed by the National Optical Astronomy Observatories, which is operated by Aura, Inc., under contract with the National Science Foundation.

TABLE 1

JOURNAL OF OBSERVATIONS

Night	UT Date	⟨FWHM⟩ (pixels)	Frames	Conditions
1.......	1987 Sep 6	4.0	66	Clouds early
2.......	1987 Sep 7	4.6	145	Clear
3.......	1987 Sep 8	4.6	174	Clear
4.......	1987 Dec 3	4.0	159	Clear
5.......	1987 Dec 6	4.2	105	Clouds first half
6.......	1987 Dec 7	3.2	208	Clear
7.......	1988 May 27	5.0	123	Clear
8.......	1988 May 28	5.0	136	Windy, var. seeing
9.......	1988 May 29	5.5	76	First half only; poor seeing
10......	1988 May 31	4.5	133	Clear

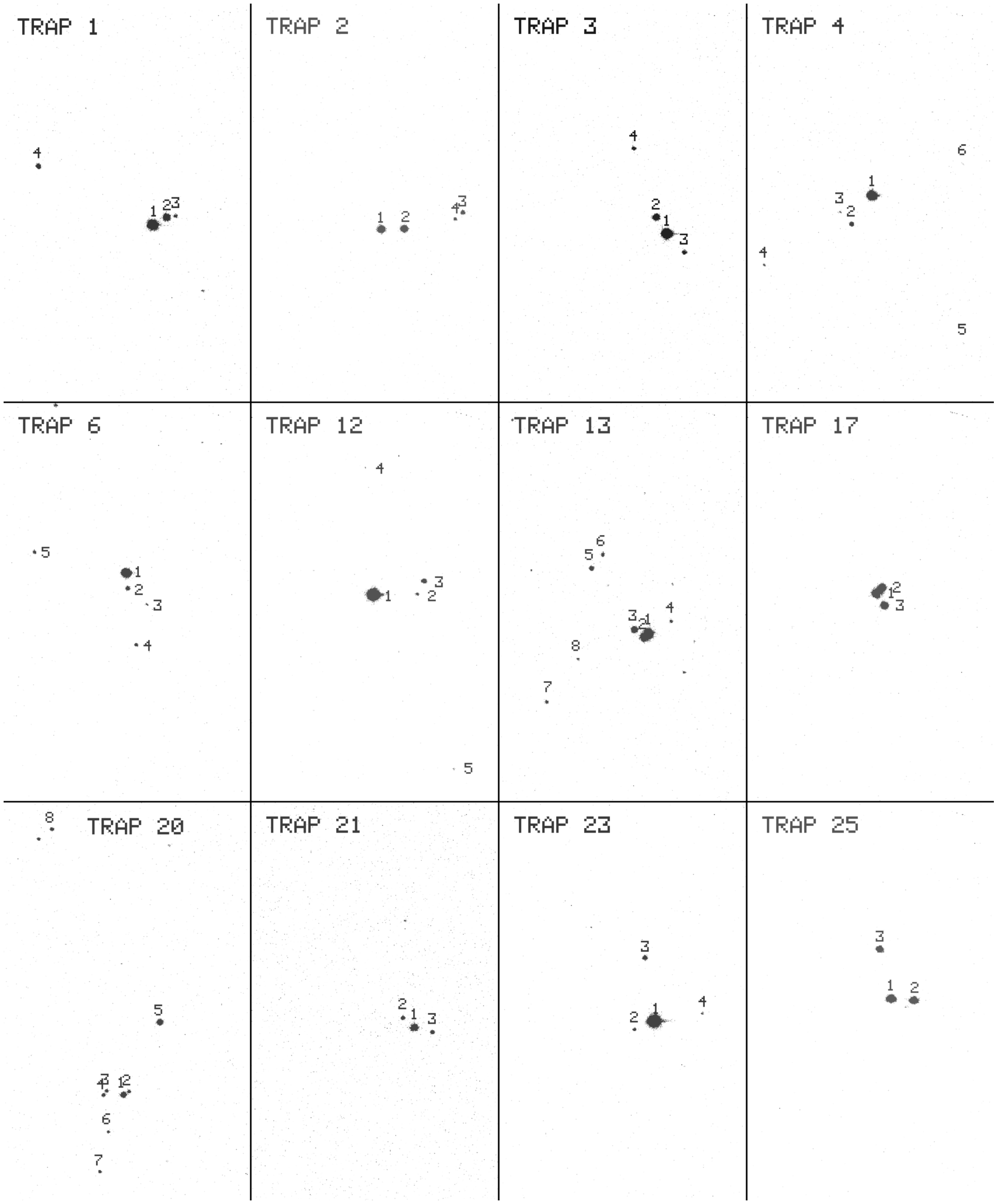

FIG. 1.—Copies of the *V* magnitude CCD frames for 266 Trapezium fields. The stellar designations or our arbitrary ones correspond to the first column entries in Table 3. A few fields, e.g., Trap 156, have moonlight contamination. Additional panels of this figure appear in the electronic edition of *The Astrophysical Journal.*

ting a selection of stellar image profiles and settling on a mean FWHM for each. That mean is a measure of the average seeing and the values are listed in Table 1. Then APPHOT computed accurate centers, sky background values, and magnitudes and errors, whose computational details are in the package specifications (Davis 1987). A series of apertures in units of the FWHM were used and a corresponding series of magnitudes were generated. We determined that an aperture of 1.5 times the FWHM was the best compromise between the goals of maximizing the number of star pixels processed while separating the occasional crowded images. Some images were still too blended to be separable. This had to be accepted because procedures such as DAOPHOT (Stetson 1987), which use the point spread function to deblend images, either would be too labor intensive or lacked sufficient images to be applied.

The aperture of choice, 1.5 times the FWHM, proved to give magnitudes just a factor of 1.0042 ± 0.0015 fainter than a wide aperture of 4 times the FWHM. Therefore, a zero-point correction from a finite to an infinitely wide aperture was not necessary for our desired accuracy. This decision is confirmed by Massey et al. (1989), who found that a fixed-size CCD aperture, extended beyond a certain size, merely excluded the same fraction of light. The chosen aperture was also insensitive to air mass between 1.1 and 2.0 at about half this level (1.0019 ± 0.0007). This implies that differences in seeing resulting from different air masses would have negligible effects on the photometry. These conclusions were confirmed during the reduction of the magnitudes to the *UBV* system when residuals from different apertures were compared. Somewhat surprisingly, when taking the first three nights and all three colors together, the mean of the residuals doubled from ±0.013 mag for the 1.5 FWHM aperture to ±0.026 mag for the 3.0 FWHM one. The increasing sky counts (in moonlight) with the larger aperture may have offset the increased star counts.

The reduction of instrumental magnitudes to the *UBV* system was accomplished by Peter Stetson's CCD photometry calibration package, CCDCAL, whose characteristics are described by Massey et al. (1989) and by Cook & Aaronson (1989). Because the programs were devised for a single field, we modified them for the multiple fields of the Trapezium systems while retaining the integrity of the calculations. P. Massey (1999, private communication) expressed some caution with using the residuals calculated in the program that produces the transformation equations, CCDSTD. Therefore, the same standard stars were run through the program to process the program stars, CCDCAL. Only a minor disparity was detected in the residuals from either program, one which grew for nights when fewer standards were observed. The programs have two special features: one is to reduce the observational data in the form of magnitudes, rather than photometric indicies, which suits CCD integration times; the other is to leave the forms of the transformation equations open to definition, and so different effects can be explored. The general form of the transformations were

$$u = U + A_0 + A_1(U - B) + A_2 X + A_3 T + A_4 T^2 , \quad (1)$$

$$b = B + B_0 + B_1(B - V) + B_2 X + B_3 T + B_4 T^2 , \quad (2)$$

$$v = V + C_0 + C_1(B - V) + C_2 X + C_3 T + C_4 T^2 , \quad (3)$$

where X is the air mass and T is the time of the observation (in decimal hours) since the start of the night.

Initially, the time of observation was not used as a parameter in the transformation equations. However, on seven nights the calculated residuals showed a drift with time, often with a more rapid drift at the beginning of the night. This has been noticed at Kitt Peak by Stetson & Harris (1988). First- or second-order terms in time were significant in improving the transformations for seven nights.

Massey (1985) has described the error in the timing of CCD shutters which will affect the short exposure frames. For KPNO shutters that error is about 1% for our shortest, 1 s *V* exposures. We also explored this during our reductions by including a term for exposure time but that gave negligible improvements.

The SIMBAD database was searched for *UBV* photometry of stars within the fields of the observed Trapezium systems. While the SIMBAD data are of variable quality and authorships, our agreement with the published photometry gives an external check. The differences (CCD-SIMBAD) are −0.014 ± 0.043 in V, +0.013 ± 0.034 in $B-V$, and −0.034 ± 0.064 in $U-B$. The systematic differences are smaller than the errors and the errors should be considered as the sums (added as squares) in our photometry plus that in SIMBAD.

Another way to estimate the photometric accuracy is to compare the 89 program stars that were measured more than once. Such a comparison is independent of errors in SIMBAD. They show that for stars brighter than $V = 14$, the dispersions in V are independent of brightness at $\Delta V = \pm 0.043$; for $B-V$ they are nearly constant at $\Delta(B-V) = \pm 0.022$ and $U-B$ they are nearly constant at $\Delta(U-B) = \pm 0.041$. A sample graph is shown in Abt & Corbally (1997). However, fainter than $V = 14$ the errors grow rapidly to ±0.2 at $V = 15$. Therefore, in the data listed in Table 3 (below), we have quoted values to only one decimal place between $V = 14.0$ and 16.0, and we have deleted all photometric data for stars fainter than $V = 16.0$.

2.2. *Astrometric Data*

The APPHOT reduction process produced (x, y) coordinates in terms of pixel positions in each frame and color. We searched the SIMBAD database for 20 wide visual pairs having various accurate separations (range of 11″–82″) and orientations; these were observed fairly evenly through the observing runs. These allowed us to determine the scale and orientation of the pixel frames. We used the method of Bertiau & De Graeve (1967) as summarized in Bertiau & Fierens (1977). The resulting scale was 0″.482 ± 0″.011 pixel^{-1} for all three filters, all nights, and all separations.

We used two ways to determine the orientation angle of the frames with respect to the celestial axes. First, during two runs we double exposed a Trapezium field with a right ascension shift between the exposures. Pairs of images for the same star define a chord perpendicular to the declination axis, providing that the telescope is accurately aligned. The second method involved using the same material as for the scale determination. The first method gave an error of ±0.002 radians or ±0°.1. It was found that this first method was about 10 times more sensitive than the second method.

With the pixel scale and rotation angles determined, the position angles and separations of all images in our fields were calculated. These were done for the components listed in the IDS so that changes in position angles and separations would be apparent. We generally averaged the results from all three filter frames, unless the stellar brightness (generally for faint stars) through one of the filters gave deviant results.

For 69 pairs of stars that were observed on two nights, we compared the differences in position angles and separations. For stars brighter than $V = 10$, the mean error in position angle was ±0°.015; it was less than ±0°.1 to $V = 14$. The mean error in separation was ±0″.01 for stars brighter than $V = 11$ and remained less than ±0″.05 to $V = 14$. The error dependence upon stellar magnitudes is shown in Abt & Corbally (1997).

We compare in Table 2 the accuracy of these CCD astrometric measures with those of experienced double-star observers. We selected a random sample of 20 double stars with separations between 3″ and 12″ measured visually 81 times by Van Biesbroeck (1974). His mean accuracy was ±1°.5 in position angle and ±0″.10 in separation. We also collected data for 20 pairs with separations of 3″ to 7″ and measured visually 63 times by Worley (1989). His accuracy in position angle was ±0°.99 and in separation it was ±0″.08. For repeated visual measures in Burnham's com-

TABLE 2

ACCURACIES OF ASTROMETRIC MEASUREMENTS

		Accuracy	
Source	Technique	Position Angle (deg)	Separation (arcsec)
Van Biesbroeck 1974......	Visual	±1.5	±0.10
Worley 1989	Visual	±0.99	±0.08
Burnham 1906	Visual	±0.67	±0.41
Josties et al. 1978	Photographic	±0.053	±0.069
This study	CCD	±0.015	±0.01

pilation (Burnham 1906) by various observers for stars with separations greater than 3″ but with an average of 36″, the accuracy in position angle is ±0°.67 and ±0″.41 in separations. Finally, we note the accuracy of photographic measures by Josties et al. (1978). Their mean accuracy were ±0°.053 in position angle and ±0″.069 in separation. The purpose of this comparison is not simply to show that the CCD measures were 10–100 more accurate than the visual measures or 3–7 times more accurate than the photographic measures, but to determine to what extent we can trust older astrometric measures with which we compare the new ones.

2.3. *Spectral Classification*

The spectral types for the stars brighter than $B = 11$ were observed photographically by the first author with the Kitt Peak 2.1 m telescope and Cassegrain spectrograph as described by Abt (1986). The early-type standard stars were selected from Morgan, Abt, & Tapscott (1978) and the late-type ones by Morgan & Keenan (1973) and Keenan & McNeil (1976). The classification accuracy was about ±1 spectral subclass and ±0.7 luminosity classes.

The stars fainter than $B = 12$ were observed by the second author with a CCD on the Steward Observatory 2.3 m telescope and Cassegrain spectrograph. He compared visual scans with those of standard stars from the same sources. Between $B = 11$ and 12, at least eight stars were observed with both telescopes and the small differences in results were reconciled.

3. FINAL DATA AND INTERPRETATIONS

Our procedure involved classifying at least one star in each group to obtain the approximate distance and the reddening to each group. We compared for those stars our photometry with Blaauw's (1963) absolute magnitudes and FitzGerald's (1970) colors for stars of the same MK types. The distance moduli are good only to roughly ±1 mag because of the intrinsic width of the main sequence (or scatter in absolute magnitudes for each luminosity class). The reddening values are probably valid to ±0.03 mag.

Then with those distance moduli and reddening, we fitted the observed color-magnitude diagram [V vs. $(B-V)_0$] and color-color diagram [$(U-B)_0$ vs $(B-V)_0$] with those of FitzGerald (1970). Stars that were more than 1.5 mag low (or high) in the color-magnitude diagrams were considered to be background (or foreground) optical companions. Stars that fell more than ±0.1 mag off in the color-color diagrams were considered to have significantly different reddening and were thought to be background or foreground optical companions. Illustrations of such sample diagrams are shown in Abt & Corbally (1993). Finally, we compared the current position angles and separations with the published ones in the Worley's Washington Catalog (US Naval Observatory), the on-line successor to the IDS. Those measurements were typically made a century ago. Stars that showed a motion more than 1° in position angle or more than 0″.5 in separation were considered to be nonmembers except for very nearby systems where the orbital motions in a century may be that large.

The data and results for each group are given in Tables 3A and 3B, which are given in full only in the electronic edition of this journal. These tables are complex and need explanation. In Table 3A we give for each group the group name (e.g., Trap. 1) and the 1900 right ascension and declination of the central star (e.g., $00^h06^m.0$ and 43°46′). The assumed values are taken from the Washington Catalog or IDS. That is followed by the ADS number (e.g., ADS 137), if it has one. That is followed by the conclusions about the group, e.g., components 1 and 2 form a physical pair, the reddening $R = (B-V)-(B-V)_0 = 0.06$ mag, and the distance modulus $d = V_0 - M = 8.8$ mag.

The data in Table 3B contain the following information. First is the Trapezium group number with the star number and the identifying letter in the ADS catalog or elsewhere. Then we list our value of the visual magnitude to two significant figures. For stars between $V = 14.0$ and 16.0 we include only one decimal place, and no photometry is given for stars fainter than $V = 16.0$. Then we give our $B-V$ and $U-B$ colors, again truncating to one decimal place for stars fainter than $V = 14.0$. Following that is our MK classification. That is followed by the date of the published astrometric data where the separation is given in arcseconds and the position angle in degrees. Each set of measures refer to the star designated on that line relative to the first star or the one marked "A," e.g., in Trap 1 star 2 = B has a separation of 9″.6 from A and at a position angle of 332 deg. A "v" following any entry indicates that the old measures show that quantity to be variable. That information is followed by the new measures where the time is in decimal years. The measures of separations in arcseconds and position angles in degrees are given to two decimal places each. The final entry gives our conclusion about the physical association of each component with, usually, the first star or the one marked "A." If the star deviated in the color-magnitude diagrams, we could identify it as a background ("backgr.") or foreground (foregr.") optical companion. If it deviated in the astrometric measures or color-color diagrams, we called it a "nonmember." A few marginal cases were called possible members ("poss mem").

TABLE 3A

Conclusions about the Possible Trapezium Systems

Trap Number	R.A. (1900)	Decl. (1900)	ID	Conclusions	Reddening	Distance
Trap 1	00 06.0	43 46	ADS 137	1, 2 physical pair	0.06	8.8
Trap 2	00 06.3	29 15	ADS 141	1, 2 physical pair	0.06	5.0
Trap 3	00 06.6	19 19	BD+19 15	1, 2 poss phys pair	0.09	10.2
Trap 4	00 09.9	59 13	ADS 192	1, 2 physical pair	0.54	10.5
Trap 6	00 17.4	61 41	ADS 307	All optical	0.40	10.5
Trap 12	00 40.1	31 06	HD 4279	1, 2 physical pair	0.23	7.9
Trap 13	00 47.0	56 05	ADS 719	1A, 1B, 2, 3 trap system	0.36	10.9
Trap 17	00 59.9	12 18	ADS 893	1, 2 physical pair	0.03	6.6
Trap 20	01 05.2	51 46	ADS 970	1, 2, 7 hierarchical	0.25	6.6
Trap 21	01 06.4	62 07	ADS 984	All optical	0.36	8.9
Trap 23	01 10.9	13 12	HD 7604	All optical	0.01	9.0
Trap 25	01 17.1	−26 16	CD−26445	1, 2 physical pair	−0.08	11.6
Trap 27	01 18.9	27 04	ADS 1119	1, 3 physical pair	0.03	4.4
Trap 29	01 23.4	05 43	HD 8989	All optical	0.60	6.1
Trap 31	01 23.8	24 30	BD+24 221	All optical	0.15	9.0
Trap 38	01 40.5	−02 54	BD−03 251	1, 2 physical pair	0.02	5.7

Note.—Table 3A is published in its entirety in the electronic edition of *The Astrophysical Journal*. A portion is shown here for guidance regarding its form and content.

To these results for 265 systems, we will add the results from Abt (1986) that used no modern photometry or new astrometric measures, but that used MK classifications for all the stars in each group. Of the 31 stars in that program, 11 were measured this time but we include the results for 20 other systems in the Allen et al. (1977) catalog that included stars that were too bright to measure with the CCD system.

Nearly half (44%) of the 285 systems were ones in which the primary star had no physical companions ("all optical"), although it is possible that there was a physical pair among the fainter stars; we did not search carefully for such possible pairs. The reason why so many of these proposed Trapezium systems turn out to be optical systems, despite the use of the 1% filter, will be discussed below. Nearly half (41%) of the remaining systems have only a single physical pair (or possible physical pair ("poss phys pair") and therefore also are not Trapezium systems. The results for all 285 systems are as follows: 126 systems have only optical companions to the primaries, 116 systems contain only one physical pair, although one (Trap. 619) has two pairs at very different distances, 13 systems are hierarchical ones of 3–6 members with separations ranging over more than a factor of 10, two systems are small clusters with 8 and 12 members, and 28 systems are apparent Trapezium systems according to the above definition.

The primaries of the 126 optical systems have a distribution of primary types (without regard to luminosity classes) that resembles that of the Henry Draper stars (Allen 1973) within the errors involved. That is to be expected because these are random stars that, by chance, happened to have three or four background or foreground stars along the same lines of sight. The mean spectral type is F4 ± 1 for the optical primaries compared with about F7 for the HD stars.

The primaries of the 116 systems having only one physical pair have a distribution of primary types that again resembles the HD distribution; the mean type is F4 ± 1.

TABLE 3B

Observational Data

Star	*V*	*B−V*	*U−B*	Type	Old Dates		Sep.	P.A.	New Date	Sep.	P.A.	Member?
Trap 1 1 A	9.26	0.23	0.13	A5 III(n)	1893	1938			1987.683			
Trap 1 2 B	11.04	0.28	0.10		1893	1938	9.6	332.0	1987.683	9.80	332.78	Member
Trap 1 3 C	13.89	0.50	0.08		1893	1938 BC	4.8	349.0	1987.683	5.58	350.57	Backgr.
Trap 1 4	12.98	0.31	0.08		1893	1938			1987.683	79.20	207.70	Backgr.
Trap 2 1 A	10.04	0.68	0.05	G1 V	1926	1935			1987.683			
Trap 2 2 B	10.33	0.73	0.13		1926	1935	14.5	359.0	1987.683	14.23	359.03	Member
Trap 2 3 C	12.60	0.55	−0.16		1926	1935 BC	38.4	351.0	1987.683	37.28	344.28	Backgr.
Trap 2 4 D	13.49	0.81	−0.15		1926	1935 CD	5.2	141.0	1987.683	6.11	139.61	Backgr.
Trap 3 1 A	9.86	1.62	2.02	K7 III	1912	1926			1987.683			
Trap 3 2 B	11.58	1.08	0.75		1912	1926	12.5	236.0	1987.683	12.24	237.81	Member
Trap 3 3 C	14.4	0.6	0.1		1912	1926	14.0	50.0	1987.683	15.64	46.78	Nonmem.
Trap 3 4	13.97	0.32	0.04		1912	1926			1987.683	56.20	249.18	Backgr.
Trap 4 1 A	8.06	0.63	0.32	A4 II	1876	1928			1987.686			
Trap 4 2 B	11.62	0.45	0.26		1876	1928	20.9	125.0	1987.686	21.77	125.63	Member
Trap 4 3	13.48	0.94	0.01		1876	1928 BC	10.0	333.0	1987.686	10.26	226.84	Foregr.
Trap 4 4	13.08	0.98	−0.29		1876	1928			1987.686	78.86	147.66	Foregr.

Note.—Table 3B is published in its entirety in the electronic edition of *The Astrophysical Journal*. A portion is shown here for guidance regarding its form and content.

Similarly, the primary types for the 13 hierarchical systems and two clusters again has the same distribution, although the sample size is rather small for statistics, as the HD stars and a mean type of A9 $\pm$ 4. However, the 28 apparent Trapezium systems differ markedly in that two-thirds of the primaries are of types O and B, and the mean is A1 $\pm$ 3.

Table 4 gives a list of the 28 apparent Trapezium systems arranged in order of their primary types. One star (Trap. 837A) lacks a spectral type but its colors and reddening indicate that it is of type A2.

However, we must remember that some hierarchical systems will appear to be Trapezium systems in projection. Ambartsumian (1954) estimated that 9% of a sample of hierarchical systems will be such "pseudo Trapezium systems." For the 285 proposed systems minus the 126 optical systems, the sample of 159 should have 14 pseudo Trapezium systems. But which 14 of the stars listed in Table 4 are the pseudo systems and which are the true Trapezium systems?

As we found above for other hierarchical systems, the 14 pseudo systems should have a spectral type distribution similar to the Henry Draper stars. Thus, we would expect zero O stars, two Bs, three As, three Fs, two Gs, four Ks, and zero Ms. In fact, a random sampling of 2200 HD stars shows that nearly all the listed B stars are B8 or B9; statistically the two B stars should be late Bs. Within the statistical accuracy of these small numbers, the pseudo Trapezium systems easily account for all the systems listed in Table 4 with primaries later than B plus three of the B stars, and those should be the late B stars.

The last five B star systems in Table 4 are off the main sequence. Let us trace them backward to their main-sequence origins by assuming the absolute magnitudes by Blaauw (1963) and assuming 1.5 mag brightening in bolometric magnitude since the main sequence. Then the original main-sequence types were B7, B3, B1, B4, and B4, respectively. Therefore, by deleting the three latest B stars (B7, B4, and B4), we find that all of the true Trapezium stars have main-sequence types of B3 or earlier. The list of true Trapezium systems are the first 12 systems in Table 4 plus Trap. 657 and 600.

Thus, the main-sequence age of a B3 star is the maximum observed age of a Trapezium system. The Trapezia may be younger because the B3 V primaries may be near the zero-age main-sequence, rather than at the maximum age for main-sequence B3 stars.

What is the maximum age of a B3 V star? An early calibration (Sandage 1958) gave 3×10^7 yr. For the alpha Persei cluster with an earliest type of B3 V, Mermilliod (1981) derived 5×10^7 yr and Prosser (1992) derived 8×10^7 yr. The models by Maeder & Meynet (1988) and Bertelli et al. (1994) give ages of $3\text{–}7 \times 10^7$ yr. A reasonable maximum age for a B3 V star seems to be about $5 \pm 2 \times 10^7$ yr. This maximum age is consistent with the age of a few millions years derived by Allen & Poveda (1974, 1975) from numerical simulations of the dynamical lifetime of these unstable systems. We know of no more recent or more detailed simulations for Trapezia.

In summary, we have looked at many multiple-star systems that looked like Trapezia, rather than hierarchical systems, and showed that the observations are consistent with the expectation from numerical simulations that these systems must be young.

These Trapezium systems are large in size as we can expect from their relatively faint apparent brightnesses, high intrinsic brightnesses for OB stars, and systems with dimensions of the order of 1′. The 14 true Trapezium systems have a median radius to the farthest outlying member of 40,000 AU = 0.2 pc and a maximum radius of 535,000 AU = 2.6 pc. This maximum is approximately the dimension of an open cluster. These dimensions are also consistent with values derived earlier (Abt 1988).

Finally, why did we find only 14 true Trapezium systems out of an original sample of 285 systems proposed by Allen et al. (1977), despite their serious attempt to eliminate optical companions with their 1% filter? The answer seems to be that the Bonner Durchmusterung visual estimates of magnitudes used in the Washington Catalog are systematically in error.

A comparison for the first 300 stars between our CCD V magnitudes and the BD V magnitudes shows systematic

TABLE 4

APPARENT TRAPEZIUM SYSTEMS

Trap. Number	Primary Spectral Type	Number of Members
13	O5 V	4
857	O7 V	4
900	O8 V	6
870	O9 V	3
761	B0 Ib	3
593	B0.5 III	3
177	B1 V	4
748	B1 Vn	6
754	B1 Vn	3
49	B2 Vn	3 + 6 hier.
511	B2 V	5
951	B3 V	7
133	B6 IIIp	5
657	B8.5 Ib–II	4
600	B9 Ia	5
120	B9 IIa?	4
239	B9 II	3 + 3 hier.
305	A0–2 III	3 + 2 hier.
130	A2 Vb	3
837	(A2)	3
655	A5 V	4
357	Am(H:F0)	3
840	F2 III	4
687	F2 V	3
110	G7 III	3
320	G8 III	4
351	G9 III	3
756	K1 III	3

TABLE 5

SYSTEMATIC ERRORS IN BONNER DURCHMUSTERUNG MAGNITUDES

		Standard Error		
V_{CCD}	V_{BD}	Per Star	Per Mean	Number of Stars
7.52	7.12	±0.37	±0.10	14
8.51	8.38	±0.36	±0.06	34
9.54	9.58	±0.51	±0.08	42
10.48	10.76	±0.46	±0.07	51
11.49	12.08	±0.75	±0.11	49
12.45	13.35	±0.86	±0.11	64
13.42	14.60	±1.06	±0.17	39
14.29	16.21	±1.10	±0.45	7

differences that have been graphed by Abt & Corbally (1997). The numerical values are given in Table 5. The table shows that for magnitudes 7 and 8, the BD magnitudes average several tenths of a mag too bright. At $V = 9$ the magnitudes are correct but with a large scatter of ± 0.5 mag. However, for fainter magnitudes the BD values are about 1 mag too faint. That means that when Allen et al. (1977) used contemporary statistics on the numbers of stars of, say, $V = 13$, within a given area of the sky to apply their 1% filter, they were allowing too many companions of $V_{BD} = 14$ to get through.

We thank C. Allen and A. Poveda for providing a copy of their unpublished catalog and for suggesting that we explore the nature and ages of an unbiased sample of Trapezium systems. We appreciate much help with the photometric reductions from Lindsey Davis, Phillip Massey, and Nigel Sharpe.

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