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INTERNAL MOTIONS OF TRAPEZIUM SYSTEMS

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RESUMEN

Estudiamos las separaciones entre las componentes, como función del tiempo, para 44 trapecios, aprovechando observaciones recientes de alta precisión. Un estudio anterior reveló que algunos de estos sistemas tienen componentes en movimiento, con velocidades superiores a la velocidad de escape (Allen et al. 1974). El presente trabajo actualiza nuestro estudio anterior, extendiendo 30 años las observaciones y permitiendo así una mejor determinación de las velocidades transversales relativas de las componentes. El análisis de los nuevos datos nos permite confirmar las conclusiones del trabajo anterior: la mayor parte de los trapecios muestra los movimientos internos esperados para cúmulos pequeños ligados y virializados, pero algunos de ellos tienen componentes que se escapan. Los datos disponibles apoyan el concepto de que los trapecios son sistemas inestables con vidas medias del orden de unos cuantos millones de años.

ABSTRACT

The separations of the various components of 44 trapezia as a function of time are studied, taking advantage of many new, high precision observations for these objects. A previous study revealed that some systems have components moving with velocities larger than the escape velocity (Allen et al. 1974). The present work updates our previous study, extending the observations by about 30 years, and thus allowing an improved determination of the relative transverse motions of the components. The analysis of the new data confirms the conclusions we reached in our previous work: most of the trapezia show the internal motions expected for bound, virialized small clusters, but a few have escaping components. The available observational material lends support to the concept that trapezia are unstable systems with lifetimes of the order of a few million years.

Key Words: **STARS: KINEMATICS — OPEN CLUSTERS AND ASSOCIATIONS**

1. INTRODUCTION

Small stellar systems of the trapezium type are known to be dynamically unstable. The dynamical evolution of trapezia depends critically on their internal motions. Thus, if internal motions are large, the system is unbound, and it will expand indefinitely (Ambartsumian 1954). If the motions are small, the system will be bound, and will evolve dynamically either by transferring one or more components into wide orbits with negative energy, thus transforming itself into a hierarchical configuration, or, alternatively, by ejecting one or more components into hyperbolic trajectories, until only a close pair is left (Allen & Poveda 1974).

A study of the separations of the various components of 44 trapezia as a function of time (Allen, Poveda, & Worley 1974, henceforth APW) showed no evidence for systematic expansion or contraction in any of the systems. In fact, the small motions detected were fully consistent with the expectations for systems in virial equilibrium. However, some trapezia appeared to have components moving with velocities larger than the escape velocity. That investigation was based on data gathered by various observers of visual binaries spanning a period of time of up to 130 years for many cases. The present work takes advantage of modern observations of these trapezia. Thanks to data contained in the WDS Catalogue of Observations we have been able to complement and extend by about 30 years the material that we investigated in 1974, allowing an improved determination of the relative transverse motions of the components.

2. ANALYSIS OF THE NEW OBSERVATIONAL MATERIAL

The analysis of the new data was carried out in a way similar to that in APW, extending to some 160 years the time covered by the observations. To proceed in a systematic way, we re-examined all systems found in APW to be "well observed systems". By a "well observed system" we mean a system having more than four different observations listed in the the catalogues. By an "observation" we understand a measurement, at a given epoch, of the position angles and separations of at least three stars in the system. For the search of recent observations

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TABLE 1

ERRORS FOR THE MOST RELIABLE OBSERVERS (APW 1974) [a]

Best		Good (0.12″)
W. Struve	0.07″	O. Struve
Burnham	0.07″	Hall
Barnard	0.08″	Dembowsky
Aitken	0.10″	Comstock
van den Bos	0.10″	Baize ($t > 1935$)
Finsen	0.10″	Hussey
van Biesbroeck	0.10″	Couteau
USNO ($t > 1960$)	0.04″	Heintz
		Worley
		Voute
All others:> 0.20″		

[a] Errors for modern observers ($t > 1990$) range from about 0.01″to 0.12″, depending on instrument and technique.

we worked with the lists from the Washington Double Star Catalogs (WDS) kindly provided to us for the requested systems by Dr. B. Mason. We found recent observations for the majority of the systems.

For each of the 44 original "well-observed trapezia" , we plotted the new observations, along with the old ones, as a function of time. We thus obtained a number of graphs like that shown in Figure 1. In order to combine modern observations of position angles and separations with old ones it is important to assign realistic error bars to the old observers. Fortunately, we still had the error bars assigned to the old observers by C. Worley, which we used in APW. Since these were based on a lifetime of experience of C. Worley, they were adopted here without modification. They are listed in Table 1. For the modern observations we determined the error bars from the dispersion of the measurements of the same object, by the same observer, at nearly equal epochs. In the cases where many nearly simultaneous observations by the same observer were available we used mean values.

Most modern observations have a very good internal consistency, and thus very small error bars. Interesting exceptions are the observations made by Hipparcos and Tycho, which were found to be, at times, very discrepant, and on other occasions, quite coincident, with other observations made at nearly equal epochs. Since the reduction procedures of these catalogues were not really designed to deal with multiple systems, it should not come as a surprise that results are sometimes ambiguous. Therefore, the Hipparcos and Tycho points are plotted with a special symbol (a diamond) and without error bars.

In this way we ended up with over a hundred graphs. An example is shown in Figure 1. Each graph was carefully examined for any possible changes in the separations as a function of time. In most cases, we found no discernible motion, in complete agreement with our early study. Therefore, we confirm the first conclusion reached in APW: trapezia show no evidence of a systematic expansion or contraction.

A few systems, however, did show components with relative motions. We would like to draw attention to the Orion Trapezium, by far the best studied system. We confirm the slight decrease in the separation AC, as well as the increase shown by AE. We find, however, that the separation AB also shows a slight but definite increase, a result that APW considered marginal.

Another system showing relative motion of two components is ADS 2843. Figure 1 shows the increase of separation of components AD.

An important matter follows, namely to ascertain whether the relative motion stars are merely field stars, which generally would show a proper motion relative to the trapezium, or whether they are physical members of the trapezium, which would show the small motions expected for bound systems, or the larger motions of stars that have acquired, through encounters, larger velocities, up to or exceeding the escape velocity.

In order to clarify the nature of the relative-motion stars we subjected them to three tests: a statistical test, a proper-motion test and a luminosity-function proper-motion test. A brief description of these tests follows. A fuller discussion of the first two is given in APW. The third test will be described in detail in a forthcoming paper.

The statistical test is carried out as follows. Let the separation of the moving star from the primary be s; if s is larger than $r(m)$ the moving star is rejected as an optical member; $r(m)$ is given by

$$N_{b,l}(m)\pi r^2(m) = 10^{-2}, \qquad (1)$$

where $N_{b,l}(m)$ is the number of field stars per unit area brighter than magnitude m in the direction (l,b) of the system under study, and m is the apparent magnitude of the moving star.

The application of this test proceeds as in APW. Moving components that do not pass this test were rejected.

Because of random fluctuations in the distribu-

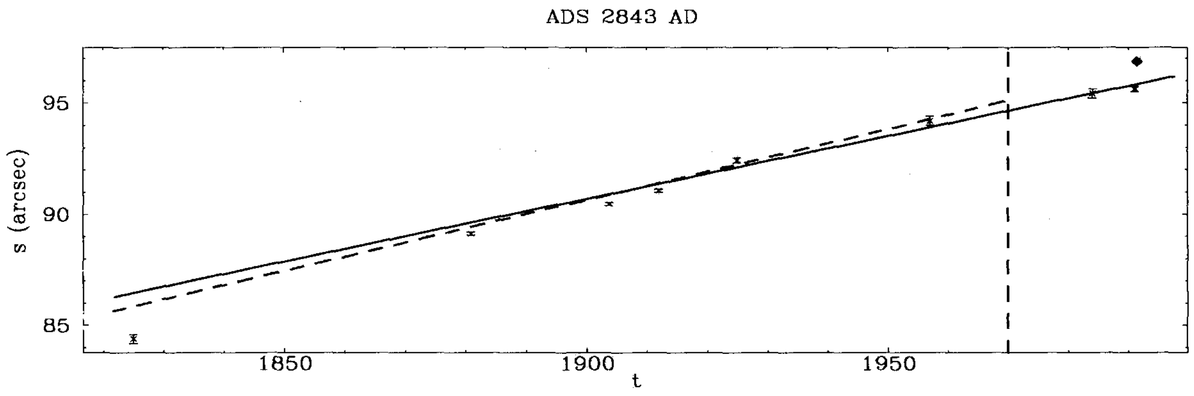

Fig. 1. Separation as a function of time for ADS 2843 AD. The dashed line represents the result obtained in APW, the full line refers to the present study. Note the slight change in the slope, which corresponds to a somewhat smaller transverse velocity. The vertical dashed line represents the limit of the observations considered in APW.

tion of field stars, or errors in the estimated magnitudes of the moving stars, it is possible that among the 44 well-observed trapezia one or two optical companions may survive the statistical test. One would expect such optical survivors to have a proper motion different from that of the trapezium. Our second test consists, therefore, of a comparison of the vector ds_i/dt of the moving component i relative to component A, against the displacement of component A due to its proper motion during the time the trapezium has been observed. When the vector ds_i/dt is approximately opposite to, and of the same magnitude as, the displacement vector of component A, we reject the moving component as a distant field star, because its apparent motion is only a reflection of the proper motion of star A. We conducted this test for all trapezia with sufficient data, and eliminated all components with equal and opposite proper motions as possible opticals. In this way, and due to improved data on the proper motion of ADS 14831, component C, which in APW had passed this test, was rejected as optical. Note however that the proper motion test may eliminate some physical systems.

Our third test, the luminosity-function proper-motion test proceeds as follows. Given the proper motion μ_A of the primary and the relative motion ds_C/dt of the moving companion C, we can compute the proper motion μ_C of component C, which in most cases turns out to be larger than that of the primary, ie., $\mu_C > \mu_A$. This means that component C, if optical, is likely to be a foreground star. We now estimate the expected number of foreground stars *E(for)* projected on the trapezium, that is, within a circle with radius s_{AC}, with an apparent magnitude brighter than $m_v(C)$, and out to a distance d. In other words, we compute the number of field stars inside a cone with vertex at the observer and base at the trapezium, centered on component A and with a height equal to the distance to the trapezium. Note that by taking the height of the cone equal to the distance, we are overestimating its volume and hence also the number of field stars projected onto the system. Finally, we convert the apparent magnitude of the moving component into an absolute magnitude and, using Wielen, Jahreiss, & Kruger's (1983) luminosity function, we estimate the number of foreground stars that are expected to be projected onto the Trapezium, that is, within the cone and with magnitude brighter than $m_v(C)$. To take into account the fact that the visual magnitudes of the faint companions are listed in the catalogues brighter by up to 1.1 magnitude (Abt & Corbally 2000) the corresponding absolute magnitudes were made 1.5 mag fainter. In this way, we overestimate *E(for)* for each trapezium with a moving component. Multiplying the largest value of *E(for)* by 44 (the total number of well-observed trapezia), we obtain the total expected number of foreground stars in this sample to be less than about 0.4.

The relative-motion stars that survive these three tests are expected to be physical members of their trapezia. They are listed in Table 2, along with the relevant information on their distances and on the transverse velocities of the moving components.

3. DISCUSSION AND CONCLUSIONS

A re-examination of the internal motions of 44 trapezium systems based on the combination of old

TABLE 2

TRAPEZIA WITH PROBABLE MEMBERS SHOWING RELATIVE MOTION

ADS	Moving Star	ds/dt ″/100 y	Spectrum	Distance[a] pc	v_t km s^{-1}
2843	AB;AD	+0.24;+6.60	B1 Iab	301[2]	3.6; 99.0
4186	AB;AC	+0.18; −0.11	O7	470[3]	4.1; −2.5
	AE	+0.36			8.4
4728	AB;AD	+0.10; −0.15	B1 V	794[1]	4.0; −6.0
13374	AC	3.24	WN5+ O9.5 III	1600[4]	259.0
14831	AC	0.40	B2 Vne	276[2]	5.5
15834	AB	0.36	O9 V	3467[1]	62.4
15847	AC	5.90	B5 IV	392[2]	115.0

[a] References for distances: (1) Abt & Corbally (2000); (2) Hipparcos (ESA 1997); (3) Jones & Walker (1988); (4) Rubin et al. (1962); van der Hucht (2000).

and modern data on the position angles and separations of their components largely confirms the results arrived at in our previous study (APW). We find no evidence for either contraction or expansion of these systems. However, we find again some components that appear to have large transverse motions.

In order to establish the physical membership of their trapezia the moving components were subjected to three tests. Only moving components that have passed all three tests are listed in Table 2 as probable physical members. In some cases, the transverse velocities are small. However, a few stars, such as ADS 15834 B appear to have velocities comparable to those of the runaway stars. If such stars were in fact expelled from their parent trapezia, they would constitute a good example of the formation of runaway stars by dynamical interactions in small clusters, as originally proposed by Poveda, Ruiz, & Allen (1967).

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DISCUSSION

Griffin – There were some cases in your graphs where some of the modern and supposedly very accurate measurements disagreed with one another. In the case of ADS 4186E, for example, the last two points disagreed by about ten standard deviations. Are they showing real changes of motion?

Allen – This is indeed something to worry about, but I do not believe the discrepancies indicate motion. In the case of ADS 4186E the observations are nearly simultaneous. The last two points refer to measures by Mauray, using CCD astrometry and Mason, using speckle interferometry. Both points are single measurements. This example highlights the need for many more high quality observations, which will also contribute to a better understanding of different modern observational methods.

Mathieu – Velocities of tens of km/sec would remove a star from a trapezium system in very short timescales. Is it plausible to find such stars still associated with their companions in a sample of 44 trapezia?

Allen – Yes, when you consider (a) the small ages of most of these trapezia; (b) the possibility that their bright components may be undetected multiple stars (as seems to be the case of the main components of the Orion trapezium). These considerations suggest the possibility that a given trapezium may eject several low-mass stars throughout its lifetime.

Scarfe – Are there stars near some of your groups that have not been included in your discussion? If so, there may be some observational selection in your results in that the groups were chosen for proximity on the sky, and it is more likely that stars will be seen to leave them than to approach them.

Allen – Observers usually include as trapezium members all stars near the main group. But we did put all such stars through the statistical tests to eliminate - as far as possible - all optical companions.

Abt – There are other data that can help to tell if possible escaping stars are group members, data such as photometry, spectral types, and radial velocities.

Allen – Yes, of course, but at present the data one would like to have are not available. Perhaps you would like to put some of these stars in your observing program, as you did before with our unpublished list of possible trapezia.

Tokovinin – Some moving components of trapezia may be members of the same star-forming groups that project onto the system but do not belong to it. Did you check this possibility?

Allen – In almost all cases the proper-motion vectors of the "moving companions" point away from the main component of the trapezium. It is very unlikely – but not impossible – that a member of another star-forming region would have its proper motion directed away from the trapezium as well as appear projected within the very small area of the system. The statistical tests we have performed apply to this case as well, and they give a very small probability for this to happen.

Mardling – It is possible for a star in a bound system to have a much higher velocity than the escape velocity but still remain bound. Example: a close pair moving around a wide pair, all four forming a bound system. The V at periastron would be 30 km/s or higher. However, such a V would make the periastron distance $\sim$ 1 AU. Very close!

Allen – I agree. In the example you propose the "high velocity star" will not be resolved as a "visual" binary member of the trapezium and hence its separation will not be measurable ("visually").

Zinnecker – What about radial velocities of the members of the Orion Trapezium systems? Do you have any information on these?

Allen – Yes, there are radial velocities for the brightest members of the Orion trapezium. However, their close duplicity (or even multiplicity) makes uncertain the analysis of their kinematics.