Revista Mexicana de Astronomía y Astrofísica, Volumen 3, Mayo 1977

TRAPEZIA AND INFRARED SOURCES

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RESUMEN

Con base en consideraciones dinámicas se espera que una fracción apreciable de los sistemas múltiples de tipo trapecio sean muy jóvenes. Se ha efectuado una búsqueda de las coincidencias en posición entre trapecios de varios catálogos y fuentes infrarojas en 2.2 micras. Se encuentra que del 12 al 20% de los trapecios pueden ser asociados con fuentes infrarojas. Varias pruebas estadísticas indican que no es probable que estas coincidencias sean casuales. Se discute brevemente la naturaleza de las fuentes infrarojas asociadas a trapecios.

ABSTRACT

From dynamical considerations, a significant fraction of multiple systems of trapezium type is expected to be quite young. A search for positional coincidences between trapezia from various catalogues and infrared sources at 2.2 microns was undertaken. It was found that between 12% and 20% of the trapezia can be associated with infrared sources. Various statistical tests indicate that these coincidences are not likely to be accidental. The nature of the infrared sources associated with trapezia is briefly discussed.

I. INTRODUCTION

Studies on the dynamical evolution of trapezium-type systems (Allen and Poveda 1974, 1975) have shown that these configurations are rather unstable. In fact, their half-lives are around 8×10^5 to 10^6 years. Assuming that there exists a steady-state situation (i.e., that continuous formation of trapezia is taking place) one would expect a fraction of these (about 10%) to have ages of the order of 10^5 years. Clearly, trapezium-type systems should contain a significant number of stars which are very young from the point of view of nuclear evolution.

On the other hand, it is known that very young objects like T-Tauri stars, stars associated with cometary nebulae, etc., show large infrared excesses. Therefore, a connection should exist between trapezia and infrared sources. In fact, the best-known trapezium, θ^1 Orionis, is a well-known infrared source; this trapezium should be very young, because gas dynamical considerations indicate that the H II region excited by it (the Orion nebula) is younger than 20000 years. Not only is the Orion trapezium an infrared source but the whole region surrounding it contains several other sources, as pointed out (e.g.) by Wynn-Williams and Becklin (1974). It would seem, then, that in order to understand better the physical nature of trapezia, one should try to find out how many of them are associated with infrared sources, and under what circumstances.

II. A SEARCH FOR INFRARED TRAPEZIA

A search was made for positional coincidences between several groups of trapezia and the infrared sources contained in the Two Micron Sky Survey (Neugebauer and Leighton 1969). This survey, which covers the whole sky north of declination $\delta = -33°$, is complete up to magnitude $K = 3$, and contains approximately 5500 sources. The criterion for positional coincidence used was the same as the one used by the authors of the Two Micron Sky Survey for purposes of identification; that is, two sources were considered to be identified with each other if they were within 3′ north-south and 3′ east-west.

Three groups of trapezia were chosen for the search: a list studied by Sharpless (1954) containing 25 objects, Ambartsumian's (1954) catalogue containing 108 objects, and the new catalogue of trapezia by Allen *et al.* (1977), containing 915 objects. One should notice that these three groups are not mutually exclusive. Obviously, only those trapezia with $\delta \geqslant -33°$ were considered. We will call these "northern trapezia".

For purposes of control, several groups of northern objects were submitted to the same process of search for positional coincidences with the sources in the Two Micron Sky Survey. The chosen control groups were:

i) the 100 brightest O-type stars,
ii) 100 random positions on the celestial sphere,
iii) 100 random positions distributed like the OB stars, and
iv) a random sample of 240 hierarchical multiple systems.

The first group was chosen from the Catalogue of Galactic O-Stars (Cruz-González *et al.* 1974). The fourth group was obtained from the IDS catalogue after filtering out optical companions (Allen *et al.* 1977).

III. RESULTS

Table 1 summarizes the results of the search for coincidences among different groups of objects. Column 1 lists the spectral types; columns 2, 3 and 4 give percentages of coincidences found among the trapezia of Sharpless, Ambartsumian and Allen *et al.* respectively. Columns 5 to 8 give percentages of coincidences for the control groups.

A comparison of columns 2, 3 and 4 with columns 6, 7 and 8 rules out the possibility that the coincidences between trapezia and infrared sources are accidental. If that were the case, percentages in these columns would be comparable, whereas, in fact, there are significant differences.

We notice that the percentage of coincidences of trapezia with two-micron sources is very similar for the catalogues of Ambartsumian and of Allen *et al.* The trapezia of Sharpless do show more coincidences; this could be due to the fact that all of these trapezia are associated with emission nebulae, and are thus, presumably, quite young.

On the other hand, while hierarchical multiples (column 5) do show some coincidences with infrared sources, we shall see below that most of these coincidences are not significant.

It is of interest to consider the influence of the spectral types of the trapezia in our analysis. Ambartsumian (1954) computed the probability of a hierarchical multiple system appearing as a trapezium due to projection effects. This probability is approxi-

TABLE 1

COINCIDENCES WITH INFRARED SOURCES

	Systems						
	Trapezia			Non-Trapezia			
Spectral Type	Sharpless	Ambartsumian	Allen *et al.*	Hierarchical Multiples	Random positions on Galactic Plane	Random positions on Celestial Sphere	Brightest O-Stars
All types	—	—	5%	2%	1%	0%	0%
O + B + K + M	—	—	14%	8%			
O + B + M	20%	12%	14%	4%			
K	—	—	18%	10%			
Number of northern objects in sample	25	108	707	240	100	100	100

mately 9%. One can then compare, for each spectral type, the expected number of such "pseudo-trapezia" with the number of trapezia of the given spectral type present in the sample. If those two numbers are comparable, one could suspect that most trapezia of that spectral type are, in fact, pseudo-trapezia. Using this argument, Ambartsumian retained in his catalogue trapezia mostly of spectral types O, B and M. A similar analysis carried out for the trapezia in the catalogue of Allen *et al.* indicates that for trapezia of spectral types A, F and G, the expected number of pseudo-trapezia is only about one-third to one-half of the observed number of trapezia.

These results are useful in understanding the statistics of coincidences with infrared sources. Indeed, comparing columns 2, 3 and 4 with column 5, we notice that when all spectral types are considered, the percentage of coincidences among trapezia is only slightly larger than the percentage among hierarchical systems. On the other hand, if we look only at systems of spectral types O, B and M, trapezia show a markedly larger percentage of coincidences than do hierarchical systems.

A different situation occurs for spectral type K. The percentage of trapezia showing coincidences remains the same whether we include the K-systems or whether we do not. However, the percentage of hierarchical multiples showing coincidences decreases appreciably when the K-multiples are taken out. Finally, looking only at spectral type K, we notice that trapezia again show more coincidences than do hierarchical multiples.

The above behavior is consistent with the idea that trapezia are young objects, some of them having infrared excesses; when we look at a sample of trapezia containing few pseudo-trapezia the full effect is observed; if the sample contains a significant fraction of pseudo-trapezia the effect becomes diluted.

On the other hand, if one examines the contents of the Two Micron Sky Survey according to spectral type, one notices a strong predominance of objects of types K and M. It is not surprising, therefore, that a number of hierarchical multiples of these types appear among the positional coincidences; for a given visual magnitude, it is more probable for a K-type star to appear in the survey than for an O or B-type star. A similar effect on the statistics for the coincidences is undoubtedly present for M-type objects, since these are subject to the same selection effects as the K-type objects of the survey. However, statistical studies (Allen *et al.* 1977) show that the expected number of pseudo-trapezia is smaller for type M than for type K; in addition, the total number of M-multiples is small. For both these reasons, M-type systems were treated together with the OB systems.

In summary, we have discussed up till now two factors (random effects and spectral types) affecting the relative percentage of trapezia and hierarchical systems that show coincidences with infrared sources. In this light, we believe that the most significant percentages are those given for objects of types O, B and M.

There is a further effect, not yet discussed, that will probably increase the number of significant coincidences for trapezia and decrease it for hierarchical multiples. It is that some trapezia will appear as hierarchical systems due to projection effects, and vice versa.

There is still another effect that has to be considered. In order to appear in the Two Micron Sky Survey, an object does not have to display abnormal properties in the infrared. It need only be sufficiently bright. In fact, all but three of the one hundred visually brightest northern stars do appear in the survey (the three stars that do not appear are variables of type B). Clearly, it is of interest to try to distinguish, among the trapezia that show coincidences, those that are simply bright enough to appear in the survey even if their infrared emission is normal, from those that effectively display an abnormal behavior in the infrared. We will call the latter "Infrared Systems". We have computed, for each spectral type, the visual magnitude that a star should have in order to have a K-magnitude brighter than or equal to 3, which is the limiting magnitude of the survey. The relation is simply

$$m_v = 3 + (V - K).$$

The color index $(V - K)$ for each spectral type was taken from Johnson (1966). The above relation is shown graphically in Figure 1 (lower continuous curve). In drawing the lower boundary in Figure 1, we took, for each spectral type, the largest value of $(V - K)$ available in Johnson's tables. The shaded area represents an allowance of 1.0 mag upwards, since the visual magnitudes for some trapezia and hierarchical multiples were obtained from the IDS catalogue and are therefore somewhat uncertain. In Figure 1, we expect the least interesting objects to appear below the shaded area; these will be stars that appear in the Two Micron Sky Survey simply because they are bright. However, objects appearing above the shaded area are "Infrared Systems"; that is, objects whose apparent magnitude and spectral type would have excluded them from the infrared catalogue, and whose presence therein indicates anomalous behavior at two microns.

We notice that most of the coincidences for trapezia (crosses in Figure 1) lie above the curve, whereas all but one of the coincidences for hierarchical multiples lie below the curve. In fact, the sole hierarchical multiple that lies well above the curve appears to be a rather interesting system. We suggest that this system might be a true trapezium that appears as a hierarchical multiple system due to projection effects.

We do not wish to imply that the infrared source is necessarily one of the visible stars of the associated trapezium. The two-micron source may be either an "unseen" member of the trapezium or a neighboring source; the Orion Trapezium, with its surroundings, is a good example of this.

The above results are summarized in Table 2. If we look at all northern trapezia of spectral types O, B, K and M from the catalogue of Allen *et al.* we find that 14% of them show a positional coincidence with a source of the Two Micron Sky Survey, and 5% of them are "Infrared Systems". Thus an infrared coincidence from a sample of trapezia of types O, B, K and M has a 36% probability of being an "Infrared System". A similar sample of hierarchical multiple systems of the same spectral types gave only 8% of infrared coincidences and less than 1% of "Infrared Systems". Hence an infrared coincidence from a sample of hierarchical systems has a 7% probability of being an "Infrared System". This shows that for multiple stars of tra-

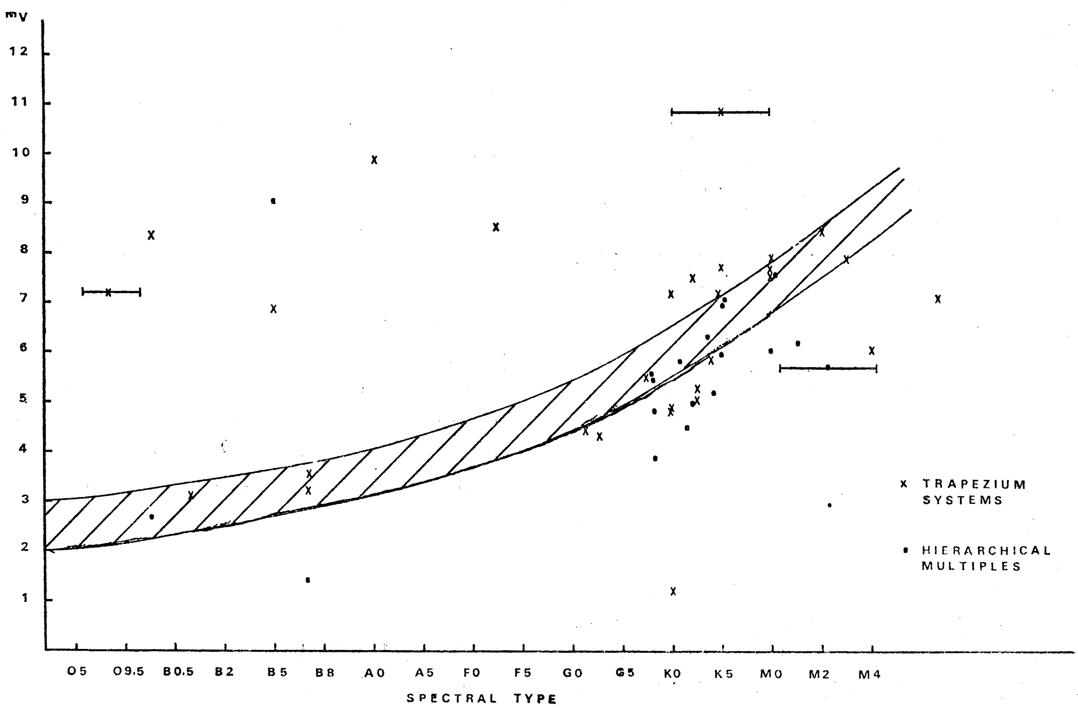

FIG. 1. Plot of visual magnitudes versus spectral types for trapezia and hierarchical multiples. Points lying above the shaded area are "Infrared Systems".

TABLE 2

INFRARED SYSTEMS

Object	Coinci-dences (%)	Infrared Systems (%)	IR Systems Coinci-dences (%)
'rapezia ıll types)	5	2	33
'rapezia ϽϽ + B + K + M)	14	5	36
ːierarchical Multiples Ͻ + B + K + M)	8	1/2	7

ezium type the probability of being an "Infrared ystem" is much larger than for multiple stars of ierarchical type.

From this analysis, we have obtained a list of ·apezia of particular interest. This is shown in 'able 3. Column 1 gives the ADS number of the ·stem. Column 2 gives its catalogue number in ıe Two Micron Sky Survey. Columns 3 to 7 give, :spectively, visual magnitudes, spectral types, K-ıagnitudes, $(I-K)$ colors and $(I-K)$ excesses. Ve notice, finally, the large $(I-K)$ excesses for ıese trapezia.

IV. DISCUSSION AND CONCLUSIONS

From a sample of 707 trapezia with declination $\delta \geqslant -33°$, it was found that 5% of the trapezia exhibit positional coincidence with an infrared source in the 2.2 micron catalogue. Statistical tests indicate that these coincidences are not likely to be accidental. We have also shown that 36% of the trapezia of types O, B, K and M exhibiting infrared coincidences are "Infrared Systems", i.e., are brighter in the infrared than would be expected for normal stars of their visual magnitudes and spectral types.

These particular trapezia could be explained in any of the following ways:

(*a*) They are subject to a large amount of interstellar absorption which will make them visually faint without greatly affecting their K-magnitudes. In the absence of this absorption such systems would fall below the shaded area in Figure 1.

(*b*) They are very young systems containing stars still surrounded by circumstellar clouds which radiate in the infrared. These stars may be faint in the visual, or not visible at all, but bright in the infrared, like the Becklin-Neugebauer star in Orion.

TABLE 3

INFRARED SYSTEMS

ADS (1)	2μ (2)	m_V (3)	Sp. Type (4)	K (5)	I − K (6)	E(I − K) (7)
1918	+50067*	9.9	A0	2.89	4.22	4.25
4186	−10093	6.8	B5	1.58	1.72	1.97
6033	−30087	7.5	M0	−0.69	5.56	4.15
6087‡	+20179	6.9	K5	2.59	2.67	1.54
8413	+70111*	7.7	K5	2.54	2.63	1.50
HJ2616	+10257*	10.5	—	2.62	3.35	—
11078†	−20431	9.0	B5	−0.37	4.76	5.01
11193	−20453	8.3	B0	2.38	3.32	3.83
12283	−10500	7.4	K2	2.94	3.07	2.14
13312	+40376	7.2	Oe	2.77	4.23	(4.70)
14338	+30456	10.7	K	2.57	4.52	(3.50)
15460	+50410	8.4	F2	2.29	3.85	3.47
16982	+60421	7.1	K0	1.79	3.55	2.78

* Our identification is different from that of the Two Micron Sky Survey.
† Proposed interpretation: trapezium seen as hierarchical system (see text).
‡ Marginal trapezium, not considered in the sample of 707 systems nor in the statistics, but included here for reference.

(*c*) The infrared source, although not physically associated with the trapezium, may lie in its immediate neighborhood. Because of their small ages, these trapezia might be regarded as tracers of regions of present star formation.

If case (*a*) holds true, then we would expect trapezia to be systematically fainter in the visual than hierarchical systems. We have studied the distribution of apparent magnitudes as a function of spectral type for both trapezia and hierarchical systems; no significant differences were found. Therefore, we regard (*a*) as the most unlikely of the three explanations.

The Orion trapezium seems to be a combination of cases (*b*) and (*c*), since the trapezium itself is an infrared source, while within one minute of arc there are several other infrared sources, of which the Becklin-Neugebauer star and the Kleinmann-Low nebula are the most conspicuous.

From the above discussion we may suspect the "Infrared Trapezia" listed in Table 3 of containing, or of being close neighbors of, very young peculiar objects radiating significantly in the infrared. It is of the greatest interest to study these trapezia, and their surroundings, as extensively as possible.

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DISCUSSION

Carrasco: The presence of "infrared" sources may or may not be connected at all with youth of the trapezia. A star that appears in the IRC may do so due to at least one of three causes: a) The star is intrinsically bright, b) the star has a high interstellar reddening, c) the star has an intrinsic IR excess.

Poveda: Indeed, a trapezium may appear in the IRC because it is visually bright, because of interstellar reddening or because it is anomalous in the infrared; these three possibilities are discussed in the text.

Pişmiş: You showed us, as a typical case, the Orion trapezium with the IR sources in the region. It is quite tempting to ask whether in your list of trapezia with IR sources there are some that resemble the Orion trapezium: How many of the trapezia have associated HII regions, compact or otherwise?

Poveda: We have looked at each one of these 13 trapezia in the Palomar charts trying to find "peculiar" nebulae associated with them, but we did not find anything unusual. In fact, the Orion trapezium is the one associated with the brightest HII region.