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MULTIPLICITY AMONG VISUAL BINARIES

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RESUMEN

Una breve reseña de la historia del descubrimiento de estrellas múltiples está seguida de una discusión de los efectos de selección, de la probabilidad de descubrimiento y las técnicas de detección de las mismas. Se investiga la incidencia de multiplicidad y las propiedades de las componentes múltiples en varias muestras de binarias.

ABSTRACT

A brief review of the history of multiple-star discovery is followed by a discussion of selection effects, discovery probability, and detection techniques. The incidence of multiplicity and the properties of multiples in various samples of binaries are investigated.

Not so long ago, multiple stars seem to have been considered rare objects by most of the astronomical profession. Thus, in his classical book *The Binary Stars*, Aitken (1935) devotes only a few pages to multiple stars, remarking that, even allowing for astrometric and spectroscopic companions, multiple stars constituted only 4 or 5 percent of the number of binary systems. Yet even in 1935 it was known that no less than nine of the fifty brightest stars were multiple, suggesting that if equally intensive observations of fainter groups of stars were to be made, the fraction of multiple systems might well turn out to be substantial. Such has proved to be the case, and it is the purpose of this paper to review the current evidence concerning multiplicity among visual binaries. The discussion will be limited to "hierarchical" systems as defined by Evans (1968), since the other kind of system, the trapezium, is much rarer in the solar neighborhood, and, in any event, has not been studied in much detail.

Is is an interesting historical coincidence that the first double star to be discovered with the aid of a telescope, Mizar, was later to become the first spectroscopic binary. In fact, both visual components are now known spectroscopic binaries, so that, excluding the distant companion Alcor, which may be only another member of the Ursa Major group, the system of Mizar contains at least four stars. Another famous multiple star, Castor, was the first example cited by William Herschel when he proved that true binary motion existed in double star systems. The nearest star, Alpha Centauri, was shown to have a third component as long ago as 1915. Despite these striking examples of multiple systems, systematic work on multiples seems to have begun only a few decades ago. One of the reasons for this state of affairs is obvious: as the degree of multiplicity increases, the discovery probability decreases drastically. Therefore, many companions were not found until observational techniques were improved and observations made over longer time intervals. Selection effects are specially severe in the discovery of multiple stars, and there was the additional fact that many observational programs were designed to specifically avoid multiplicity.

Examination of a visual double star catalogue such as the IDS shows that literally thousands of "multiple" stars are listed. Many of the companions are distant. Some were picked up during the great systematic surveys, but many were noted rather casually and unsystematically by an observer intent upon measuring the close pair. Often, no subsequent measures have been made and rarely is there any proper motion, spectroscopic, or other type of data which may aid in establishing the nature of the companion or system. This is true even for some of the brightest stars in the sky: Deneb has a 75″ companion of unknown nature.

For close visual pairs, completeness of discovery is a function of separation (ρ), magnitude difference (Δm), and magnitude (m). If m is not large, then completeness is a function of ρ and Δm only. In a diagram plotting Δm (ordinate) against separation (abscissa) there is a region bounded by two more-or-less straight lines in which current discoveries can be made, and this constitutes the range of partial completeness. To the right of this region "completeness" has already been attained, while to the left no discoveries have yet been made. Adopting numerical limits for the completeness factor, and further making the assumption that the distribution function for mass-ratios is known, it is then possible to estimate the number of undetected visual companions. Öpik (1924) and Heintz (1969) have made studies of the completeness factor. Of course, their numerical results for completeness would have to be modified in the case of multiple stars to allow for the lessened chance of discovery.

The role of observational selection in the discovery of spectroscopic and photometric sub-systems among the visual binaries is a complex one. Detectability is some obscure function of the periods, inclinations, light and mass-ratios, spectral types, and the quantity, quality, and time distribution of the observations. For example, the observed frequency of spectroscopic multiples is much higher for pairs of spectral type F, and it is not known whether this is inherent or simply reflects the fact that type F is the optimum range for discovery. Photometric detection of additional components in a binary system is also apt to be rare. Heintz applied the observed mass-ratio distribution to the observed color-magnitude array of clusters, and showed that the probability was only 0.03 that the masses would be so nearly equal that Δ [(mag. pri.) − (total light)] $>$ 0.75 mag. For multicolor photometry, however, there is a real possibility that red companions could be detected by use of a wide-base-line system.

Astrometric detection of companion stars is of great importance for objects closer than 20-30 parsecs. Beyond this limit the displacements generally become too small to be reliable. However, great caution needs to be exercised in the interpretation of some of the small (1-2 micron) perturbations reported for nearby stars; while these may be real, there is also the possibility that they are caused merely by systematic instrumental errors. For acceptance of such perturbations as real, it seems reasonable to require confirmation by a second investigator.

New techniques, including lunar occultations and the various interferometer methods under development, will also detect multiple stars. Each of these methods will also suffer its own peculiar selection effects. The importance of these techniques can hardly be overemphasized, since they permit us for the first time to bridge the gap between the very close spectroscopic binaries and the much wider visual pairs, and will therefore aid us in evaluating the roles played by fission and/or coeval evolution in the formation of binary and multiple systems.

With the above caveats about observational selection in mind, let us now look at the known proportion of multiple stars in various samples. Although an early statistical study (Öpik 1924) had indicated high multiplicity, this result does not seem to have been generally accepted, as mentioned earlier. Perhaps this was due to the rather heterogeneous and sparse nature of the observational material available to Öpik. Kuiper (1942) was one of the first to remark on the high incidence of multiplicity in a discrete sample, noting that of 73 nearby A-K stars, 19 of a total of 109 stars were bound up in multiple systems.

Several years later, Wallenquist (1944) considered visual systems where the combined visual magnitude was $<$9.0. In that study, photometric, spectroscopic, and composite-spectrum companions were included. although he did not use the term explicitly, Wallenquist was in fact responsible for the concept of hierarchical systems as distinct from trapezia. Wierzbinski (1964) did a similar study of multiplicity, considering only visual systems. Unfortunately, both these studies are flawed by the failure to remove optical companions, and this may account for one of their major conclusions, viz, that there is an in-

TABLE 1

FRACTION x_n, OF ALL SYSTEMS CONTAINING AT LEAST n STARS THAT CONTAIN AT LEAST (n + 1) STARS

n	Heintz	Wallenquist	Wierzbinski
1	0.70		
2	0.33		
3	0.33	0.22	0.28
4		0.30	0.40

creasing galactic concentration with increasing multiplicity. More recently, Heintz (1969) examined multiple systems of separations less than 12 seconds tabulated in the IDS, taking care to eliminate optical systems. He found only 590 certain physical multiples, with about the same number of probables. The salient features concerning the statistics of multiplicity for these three studies are presented in Table 1, in a form suggested by Batten (1973).

There exist a number of studies of multiplicity where smaller, but perhaps more physically meaningful, samples have been used. Also, these samples have been more intensively investigated in general, since there is more information for each individual object. Thus, Petrie and Batten (1965) studied 234 visual binaries for which spectroscopic observations had been made at Victoria. Batten (1967) examined the objects contained in his catalog of spectroscopic binaries. The writer has investigated samples of M-dwarfs and nearby stars (Worley 1969), as well as the apparently brightest stars (Worley 1962), and stars where one pair in the multiple systems possessed a visual orbit (Worley 1967). The latter two samples have been reinvestigated for this review. For the brightest stars, all objects with a combined $m_{vis} < 2.0$ were used, while for the stars with orbits, the Finsen-Worley (1970) catalog was the source. Results for these various samples are presented in Tables 2 and 3. Another intriguing re-

TABLE 1

MULTIPLICITY OF BINARIES IN THREE SAMPLES

	Spectroscopic Companions to Visual Binaries (Petrie and Batten)			Spectroscopic Binaries (Batten)			Visual Binaries with Orbits (Finsen and Worley)		
No. of Components	No. of Systems	No. of Stars	% of Stars	No. of Systems	No. of Stars	% of Stars	No. of Systems	No. of Stars	% of Stars
2	152	304	53	513	1026	58	527	1054	72
3	63	189	33	150	450	25	95	285	19
4	19	76	13	74	296	17	26	104	7
5,6							6	32	2

TABLE 3

MULTIPLICITY AMONG THREE STELLAR SAMPLES

	Brightest Stars			Nearby Stars			M-dwarf Stars		
No. of Components	No. of Systems	No. of Stars	% of Stars	No. of Systems	No. of Stars	% of Stars	No. of Systems	No. of Stars	% of Stars
1	28	28	31	107	107	42	436	436	61
2	12	24	27	55	110	43	104	208	29
3	5	15	17	9	27	11	17	51	7
4	4	16	18	1	4	2	3	12	2
5	1	6	7	1	5	2	1	5	1

cent result is one reported by Bakos (1974), who obtained spectroscopic observations for 61 binaries, of which a large proportion (55) represented evolved systems. Rather surprisingly, he estimated that about 50% of the primaries were probably double, and that three out of seven of the secondaries were also double. These high percentages disagree with an earlier estimate by Jaschek and Gomez (1970), who found a considerably lower incidence for evolved systems, but Bakos believes their criteria for testing variability of radial velocity were too restrictive.

Some other statistical results which have a bearing on the mode of formation and evolution of small stellar systems are the distance ratios, the degree of co-revolution, and the question of coplanarity of orbits.

For 233 of the brighter triple systems in his sample, Wallenquist found a distribution peaking at a ratio of less than 50/1 in separation between the inner and outer orbits. Jaschek (1970) was able to explain this observed distribution with a combination of two hypotheses; namely, that the distribution function of the distances follows Kuiper's (1935) distribution, and that triple stars are formed randomly by combinations of binaries and single stars.

Some years ago the writer reexamined the question of the relative sense of revolution for subsystems in triple and multiple stars. For 54 systems it appeared that about 70% showed co-revolution. However, it is possible to see a co-revolving system as counter-revolving if the earth happens to be located in the acute angle between the orbit planes. Nevertheless, it appears that while co-revolution is the rule for multiple systems, there are some genuinely counter-revolving systems. A popular current theory of multiple star formation is in accord with this, for it assumes a general sense of co-revolution imparted by the original rotating cloud, but creates some counter-revolving systems during the dynamical decay of unstable higher-multiplicity systems.

Finally, an unsolved problem is whether multiple systems tend to have coplanar orbits or not. Unfortunately, the observational evidence is limited to about a dozen systems (Worley 1967), and is of poor quality, since the outer orbits in nearly all cases are determined weakly. Moreover, the lack of spectroscopic determination of the ascending nodes leaves the angle between the orbit planes ambiguous in most of the systems (van Albada 1968). The solution to this interesting problem is apt to be long in coming, since the observational material is not likely to increase very rapidly.

Over a period of time, it has gradually become apparent that binary and multiple stars form such an important part of the stellar population in the solar neighborhood that they, in fact, represent the normal configuration in which stars are found. It is then inescapable that theories of star formation must use this fact as an implicit assumption.

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DISCUSSION

Harrington: Given that masses of single stars can only be inferred from spectroscopic information, can anything be said about whether masses of single stars are taken from a sample different than that represented by the components of multiple stars; e.g., are single stars statistically less massive (later type) than components of multiples?

Worley: We know the mass of only one single star. Otherwise, I don't know the answer to the question.

Walker: Binary stars have been observed for over 100 years, and we know of no system with seven or more components. Would you comment on the maximum number of components in multiple systems and if you consider trapezia as multiple systems?

Poveda: The work of Sharpless and my work would draw the line at 100 stars for a trapezium system. More than 100 stars is a cluster.

Scarfe: Could you define what you mean by co-revolution and counter-revolution in the case of non-coplanar orbits?

Worley: I am only talking about the apparent sense of revolution. One must remember that, in an individual case, it might be that one looked into the acute angle between the orbit planes; in such an event one could see co-revolution as counter-revolution (and vice-versa).

Fekel: Dr. Slettebak has obtained a spectrum of β^2 Tuc which contains two components. Thus the total β Tuc system contains seven and perhaps eight components.