The Discovery of Double Stars at Occultations

by

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When systematic photoelectric observations of occultations were started some dozen years ago it was realised that they yielded a significant crop of double star discoveries and observations. The limitations of the method were well recognised: only about ten percent of the area of the sky would ever be available and one could not choose which stars to be observed. Moreover the data obtained from a successful observation of a double star are less comprehensive than the normal visual observation. The result is the vector separation or the true separation projected along a line perpendicular to the actual lunar limb, that is the position angle of the point of occultation modified by the slope of the limb at that point.

The advantages of the method are the increased resolution going down in favorable cases to a few arc milliseconds and improved accuracy for vector separations of, say, half an arc second or less and the opportunity to make a photometric determination, in many cases in two colors, of the magnitude difference between the components. This range of resolution takes us into the region between the close visual binaries and the wider spectroscopic binaries and enables an observer with a relatively small telescope to surpass the resolution obtained by speckle observers with large telescopes. The occultation method plays a useful role in drawing attention to interesting systems whether for speckle observers or the Space Telescope astrometric team.

I recently made a card catalogue of all published photoelectric occultation observations known to me and have derived a catalogue of occultation double stars which forms an appendix to

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this contribution.

Questions of interest which arise include the following: If one embarks on a systematic program of occultation observations what is one likely to find in the way of double and multiple stars? After a dozen years of operation how near is the field to being worked out? Can one assess the reliability of the published data and can one draw any useful inferences about the observational selection effects involved and so make useful deductions about the real incidence of duplicity in stars of various kinds?

I have divided the stars into three groups:

(i) Bright stars with magnitudes of 6.7 or less
(ii) SAO catalogue stars fainter than this limit
(iii) Faint stars with no SAO numbers for many of which data on magnitudes or spectral types is wanting.

The raw results are exhibited in Table I.

TABLE I

Number of Stars

	O & B	A	Other	Total
Bright Stars:				
Stars observed	59	81	202	342
Doubles found	17	17	23	57
Percentage	29	21	11	17
SAO Stars				
Stars observed	131	435	1905	2471
Doubles found	9	36	110	155
Percentage	7	8	6	6
Faint Stars				
Stars Observed				261
Doubles found				12
Percentage				5
All Stars				
Stars observed				3074
Doubles found				224
Percentage				7

This then answers the first question and defines expected results. The catalogue is arranged by SAO numbers which do not immediately reveal the distribution on the sky. For the first two groups this is shown in Figures Nos 1 and 2 with the ecliptic and galactic equator marked in.

These data only refer to doubles revealed at occultation whether previously known or not and do not include doubles found from other types of observation. In several respects the data are obviously incomplete. Most of the observations have been made in the northern hemisphere so that two thirds of all stars observed are north of the equator. Secondly the program has only continued for a dozen years and not 18.6 years so that at large ranges of right ascension all the discoveries are on one side of the ecliptic.

We can also assess the completeness from the consideration that the Zodiacal Catalogue contains about 325 A-stars listed at 6.7 or brighter all of which are presumably occultable at some time or another, and even allowing for problems associated with counting to a certain magnitude limit the contrast between this number and the 81 actually observed is great enough to suggest that there is still useful work to be done.

In the catalogue a grade is assigned to each observation: this is zero if no duplicity was observed, unity if the observer rated duplicity as possible, two if rated probable and three if rated as certain. Most of the bright star doubles rate the highest designation, and in trying to assess the reliability of the data we assume that all the bright star doubles are genuine observations. If we have a trace showing distinct diffraction patterns and a well-defined intermediate level then there can be no doubt that we have observed a double. The diagnosis is less certain if all that we see is some deformation of a diffraction pattern. The situation is even less certain for a faint star for which the diffraction pattern is lost in the noise and where the only indication of a double is an apparent still stand on the steep part of the curve marked only by a few bins of noisy observations. We are at the mercy of the judgement of the observers and an over enthusiastic observer could conceivably mislead us by attributing every minor peculiarity in a trace - conceivably due to noise or to lunar limb effects - to the presence of a faint component. Is there any way of testing this? One possibility emerges from Table I. The A-stars have been segregated because as a group they are more homogeneous in absolute magnitude than other stars. Now the mean apparent magnitude of the double and non-double A-stars in the bright group in Table I is 5.8, that of the SAO A-type stars is 8.4 so that on the average the SAO group is at three times the distance of the bright ones and one should expect that if the real incidence of duplicity is the same the fainter group should show about one third of the incidence of doubles that are found in the brighter. Table I shows that this is so, which is encouraging.

We can also test by considering the contact angles at which doubles were discovered. These numbers are not published by all observers but they are provided from Texas and Illinois. Figure 3 shows plots of the results. All contact angles are adjusted by sign or difference from 180 degrees to give values between zero and 90 degrees. The impact range for contact angles between θ_1 and θ_2 is proportional to sin θ_2- sin θ_1 and we compare the observed numbers with this function in steps of ten degrees. Figure 3 which includes individual observations, including multiple observations of the same star, shows that the comparative numbers are well represented except that for the bright stars there are more successes for high contact angles than would be expected from the considerations given above. At high contact angles the relative motion of the lunar limb is much slower so that it becomes easier to detect duplicity because of the greater time interval between occultations of the components. If this argument is valid the inference would seem to be that if observations at smaller contact angles were as efficient as those at large contact angles then many more doubles - possibly even twice as many - would be discovered.

The same phenomenon is shown, though not perhaps in as striking fashion for the SAO stars where we can probably say that because of seeing effects it is still pretty hard to detect close doubles even when the lunar limb is moving exceptionally slowly.

We can also take a look at the measured vector separations which are illustrated in Figure 4. Notice that the histogram bins are not all of equal width. For the bright stars we have numbers of detections which increase steadily as the measured separations decrease. When reduced to the same total number the trend for the SAO stars is the same except that the number of results with separations below 10 arc milliseconds falls off. This is only to be expected because of the greater difficulty of detection of very close faint doubles.

None of these tests is of course conclusive but the show enough consistency to encourage one to believe that the entries in the catalogue should be taken seriously. They also suggest that selection effects arising from considerations of contact angle require observed percentages to be multiplied by a factor of the order of two and that for fainter stars an additional allowance needs to be made because of failure to detect close doubles. Figure 4 shows that for the bright stars 16 percent have separations less than 10 arc milliseconds and only 5 percent of the SAO stars. Again there is an encouraging ratio of about three to one. Of course if one could detect still smaller vector separations one might find that the proportion of small values went on climbing.

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Occultation traces of double stars give an opportunity for the determination of relative magnitudes which is in many cases superior to visual estimation. This is especially true for low noise observations or cases where the separation is large enough for the intermediate level to be held for a sufficient length of time to make a good determination. The catalogue shows many instances where this is true and where different observers have found very consistent values. It is however not surprising that from time to time when seeing is poor and the intermediate level ill-defined we find quite large discrepancies. I do not think we need be too alarmed about this. It is bound to happen and we can only hope that further observational opportunities will be vouchsafed to us.

A similar remark may be made concerning the negative observations (grade zero) in the catalogue. It is, of course, encouraging when several observers obtain consistent values on different occasions. However the nature of the work is such that one cannot choose one's conditions and one has no second chance. All kinds of reasons can lead to failure, ranging from intrusive clouds, to unfavorable position angles and the vagaries of equipment. One cannot ignore the message of numerous negative observations matched against one or two positive ones, but in this field the situation is not so compelling as in others and one should preserve an open mind.

Returning to Figure 1 one can see the distribution of doubles on the sky. The Pleiades show up well. So do the northern members of the Hyades. According to Wayman et al. (1965) there are 61 certain or possible Hyades members brighter than visual magnitude 6.7 of which 48 can be occulted. In fact 14 have actually been observed and of these six (SAO numbers 93870, 93925, 93955, 93957, 93961 and 93975) have been found to be occultation doubles. I do not wish to get involved in a discussion of the modulus of the Hyades but I would feel some alarm at trying to deduce the modulus of a cluster on photometric rather than kinematic grounds if this level of duplicity applies throughout.

There are some curious features about the distribution of occultation doubles on the sky. Note that there is not a single SAO A-type double between RA 20^h and RA 3^h (Figure 2). There seems to be no dearth of A-stars in the catalogue and our systematic approach to occultation observations ought to have ensured good coverage - as the number of later type doubles found attests. The figure also suggests a tendency for doubles to come in bunches, as indeed occultation observers often believe. There is a psychological danger here namely that once predisposed to attribute a peculiarity to duplicity one may be tempted to go on doing this over enthusiastically. However, a

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good many of these bunches are generated by different observers, or at totally different times and even are not apparent until one plots the SAO numbers which are arranged in zones on a sky map. I am not sure that this is real and I have no plausible explanation if it is. One can only await developments.

Finally I would like to remind observers that in exceptional cases one can use occultation observations to make very profitable analyses of multiple systems. The analysis of β Capricorni by Dr. Fekel and myself (1979) used an excellent series of occultation observations by generous colleagues and ourselves to derive most of the important astrophysical parameters of this triple system, including its parallax. The quintuple β Scorpii (Evans et al.1978) also yielded important secrets and one hopes - although occultations are now finished - that SAO 93957 (θ^2 Tauri) (Evans and Edwards 1980) can be marked for special attention by all types of observers as a possible guide to the modulus of the Hyades.

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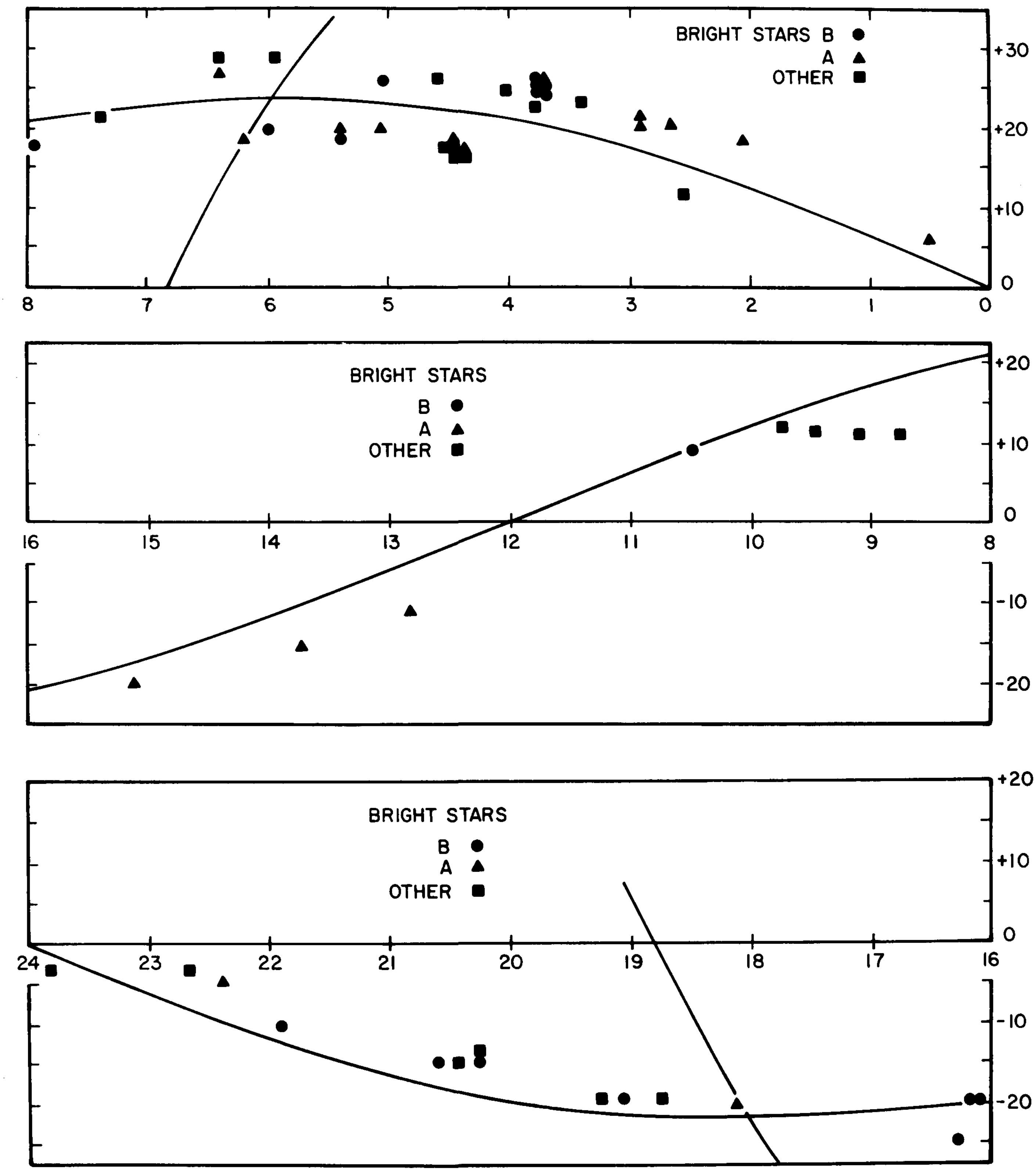
DISCUSSION

LACY: How many stars of spectral type A or earlier have had angular diameters determined by the lunar occultation technique?

EVANS: I think the answer, regretably, is none.

RADICK: One - Regulus.

EVANS: Thank you kindly, it is always nice to have any port in a storm. The unfortunate part is that the range in which we can make hay, occultation-wise, for angular diameters, runs out somewhere about the middle G's, and that is because God and the Nautical Almanac have not sent us any stars of that type with sufficiently bright apparent magnitude.



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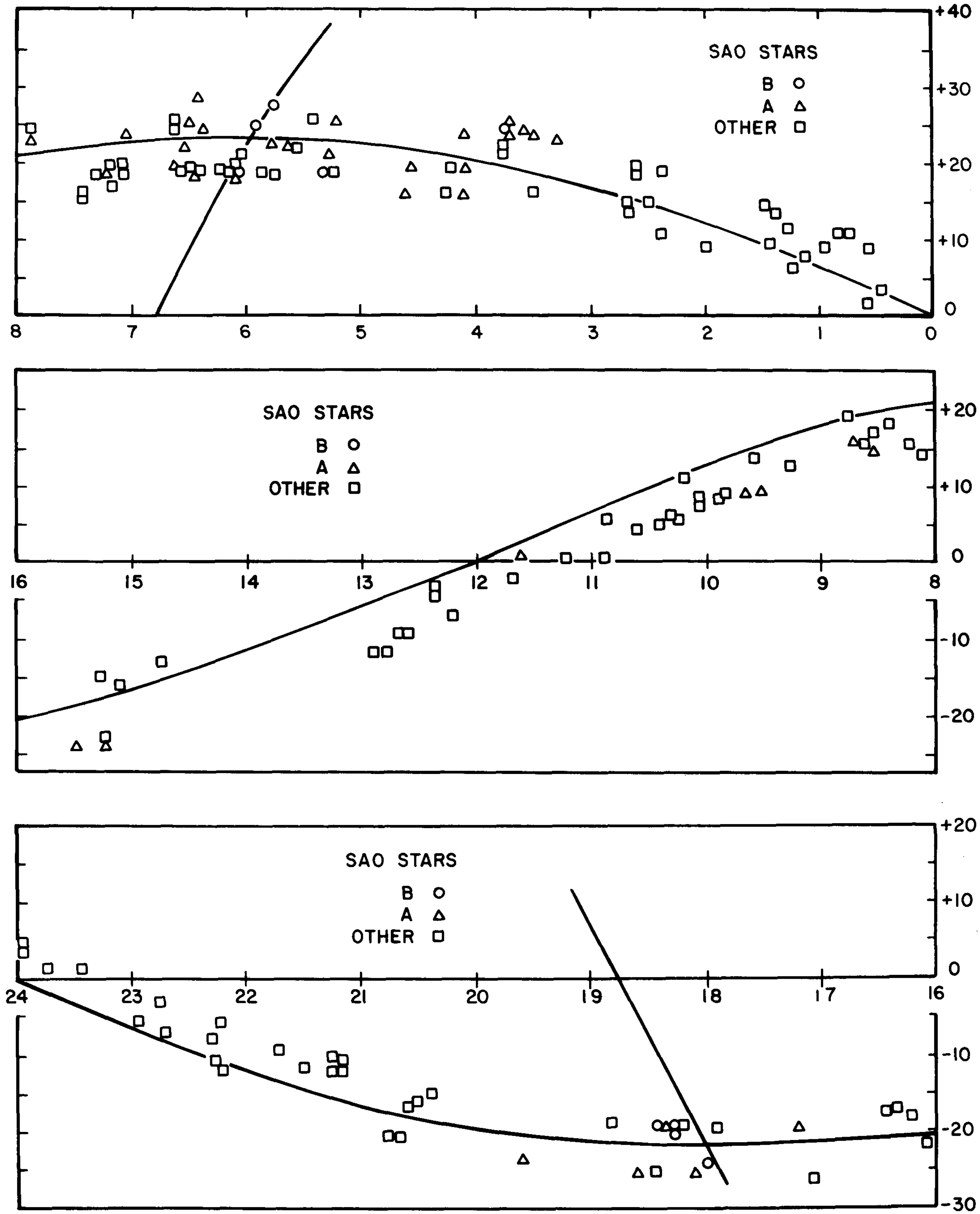

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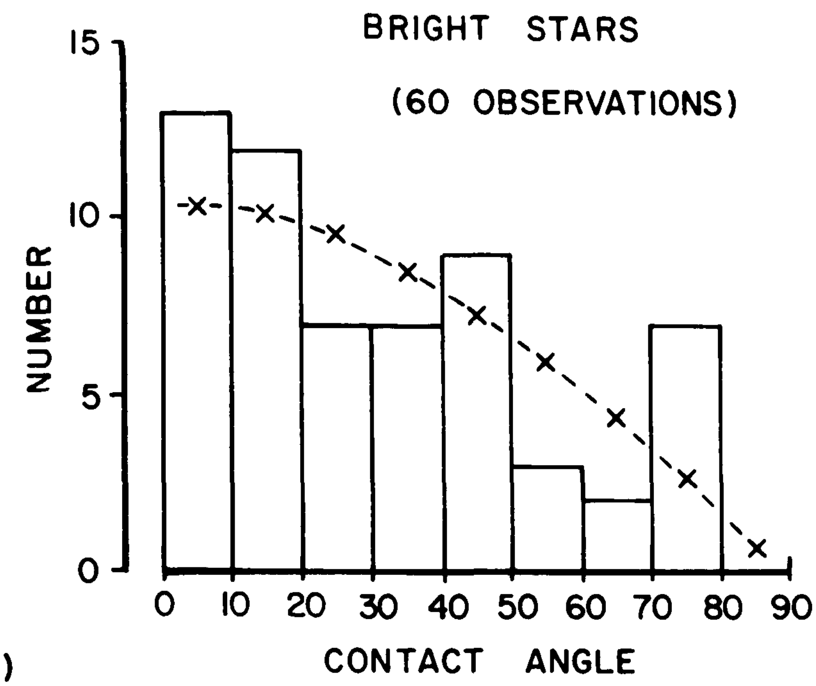

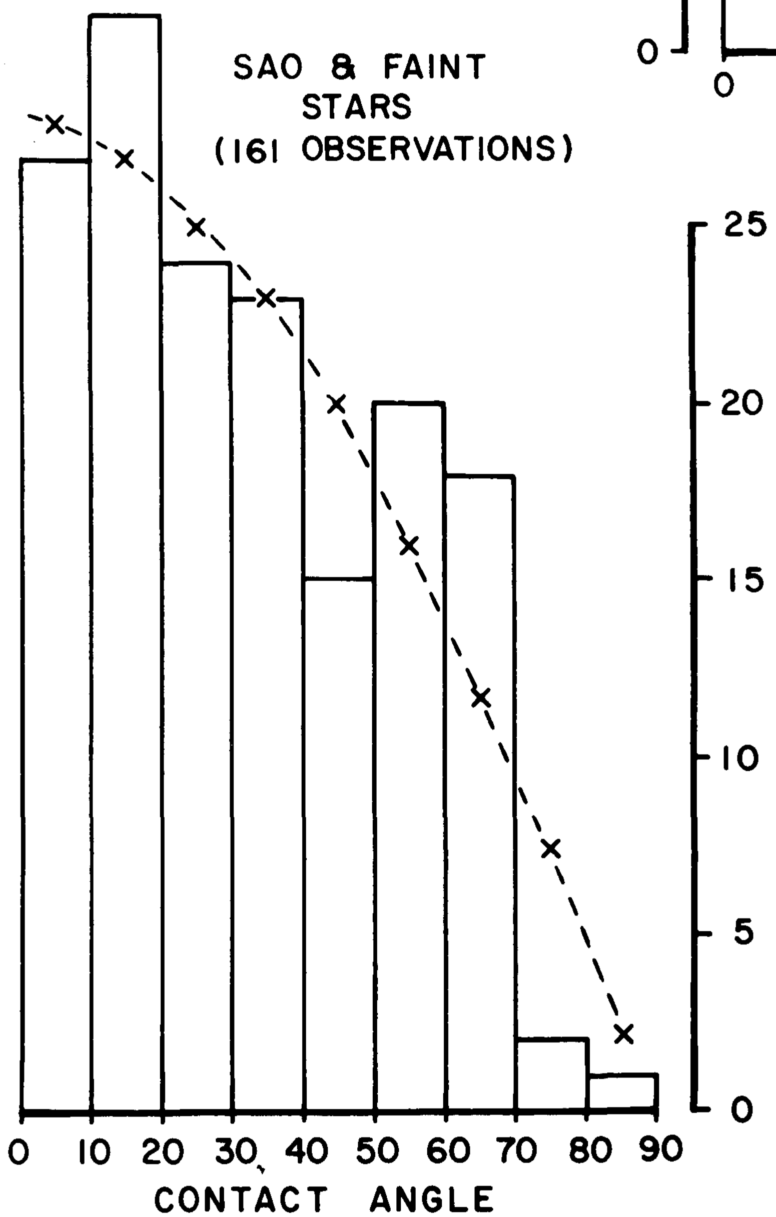

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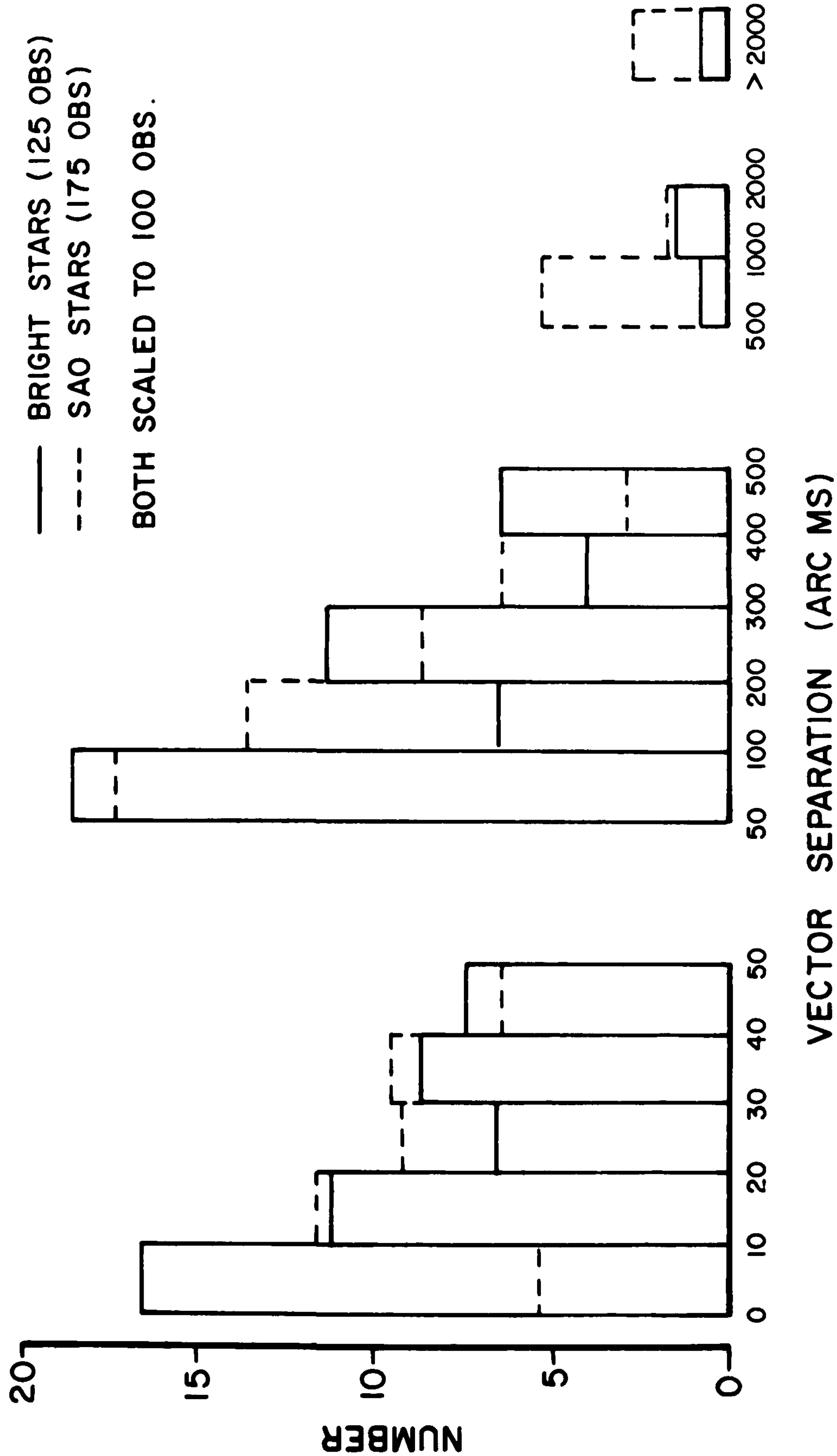

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