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Catalogue of Micrometrical Measurements of Double Stars. By the Rev. W. R. Dawes.

The *Introduction* to the Catalogue is as follows :—

The series of Micrometrical Measurements of Double Stars, which I have now the honour of presenting to the Royal Astronomical Society, contains all the measures obtained between the close of my second series (published in the *Memoirs R.A.S.* vol. xix) and the present time. The former and principal part of the series contains the observations made to the end of the year 1854; to which is added an Appendix, containing such as have been subsequently effected. The Catalogue itself is preceded by a description of the different micrometers employed.

In the computation of all the Mean Results, the weights attached to the individual measures when made have been introduced,—the sum of the weights of each set representing its aggregate value on the plan adopted in my two previous series of assigning 10 to a measure judged to be as perfect as possible. The sum of the weights attached to a single night's measures of any object is always below 100 ; and in computing the mean of several nights' measures, the labour of the necessary multiplications and divisions has been greatly alleviated by the use of "*Crelle's Rechentafeln;*"—a work which is in fact an extension of the multiplication table to 999 × 999.

To the first and principal portion of the Catalogue, and also to the Appendix, are attached *Notes* on each star which I have measured; in which are collected for comparison the results obtained by other observers. In most cases these comprise all with which I was acquainted ; while in others, principally those of least interest, a liberal selection has been deemed sufficient. In this part of the work I have profited greatly by the kindness of the late Professor Struve and of Professor Mädler of Dorpat in forwarding to me many of the volumes of the Dorpat Observations ; and also of Professor Secchi in sending me the volumes of Memoirs of the Observatory of the *Collegio Romano*, containing his observations of double stars. Mr. Otto Struve also, to whom I had communicated my measures of several of the stars discovered by him at Pulkowa, sent me in return the results of his own observations of them for comparison with mine. These are introduced in the comparative series, and are in fact in several instances the only observations with which mine could be compared. Some very valuable results which have been communicated to the *Astron. Nachr.* by Professor *Kaiser* of *Leiden*, and by the Baron *Dembowski*, have also been introduced

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The Repeating or Parallel-Wire Micrometer, employed at Mr. Bishop's Observatory, South Villa, Regent's Park, London.

The arrangement of the wires in this micrometer, constructed by Mr. Dollond, was assimilated to that of the micrometer which I had used at Ormskirk;—two parallel metallic wires being inserted at right angles to the moveable webs, and their interior edges being about 12″ apart. Between these the double stars were placed for the measurement of the angle of position, the micrometer being turned in position till the direction of the wires was judged to be parallel to an imaginary line joining the centres of the stars. The advantage of using the thicker wires instead of the fine spider lines for the measurement of position is very considerable in reference to the firmness of the judgment formed by the eye; and from the very feeble illumination requisite for their visibility, stars can be observed in position fully one magnitude below the limit which would be imposed by the use of sufficient illumination of the field to render the spider's webs distinctly visible.

Besides these fixed wires, two others were inserted parallel to the fine webs, and moving with them. These, however, though useful for cometary observations, were never employed for measurements of the distance of double stars.

The position circle of this micrometer is read off by its two opposite verniers to a single minute. The value of one revolution of the screw was found to be 15″·955. The thickness of each of the fixed and moveable wires was 3″·54 in arc; and of the spider's lines 0″·73.

A concave achromatic lens made by Dollond (as suggested by Professor Barlow, and therefore most appropriately called, "The Barlow-lens,") was occasionally inserted between the object-glass and its focus in the manner mentioned in the *Introduction* to the first series of my observations of double stars made at Ormskirk (*Memoirs R.A.S.* vol. viii); and more particularly explained in the Introduction to the second series. (*Memoirs R.A.S.* vol. xix.) It nearly doubled the magnifying power of the object-glass; and the value of one revolution of the micrometer screw was thereby reduced to 8″·243.

In measuring distances, one of the webs was always fixed by a bolt which effectually prevents any accidental change in its place; and the measures were made by means of the moveable web on each side of the fixed one, the zero correction being thus eliminated. This plan I have always employed in observing with the parallel-wire micrometer.

A very important aid to the convenient and accurate use of this micrometer is the piece of mechanism termed a *slipping-*

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piece. This, being applied to the tail-piece of the telescope, receives the micrometer into a stout plate of brass which is moveable in right ascension and declination by fine screws. A double star can thus be brought precisely into the middle between the position wires; and either of the webs can be placed upon either of its component stars with ease and certainty.

The magnifying powers produced by the double eye-pieces belonging to this micrometer were about 63, 105, 185, 320, 420, and 600. Two more, magnifying 190 and 300, were added to the original series for the sake of avoiding the inconvenience of changing the adapter during observation. With the addition of the BARLOW-lens, the powers were about 122, 203, 360, 368, 580, 620, 810, and 1160. Of these, 360 and 620 were alone employed.

A double convex crossed lens, giving a power of 520, was used on a few occasions.

Description of the Prismatic Crystal Micrometer employed at the South Villa Observatory.

As there seems to be some personal peculiarity attaching to most observers with the repeating or parallel-wire micrometer, it appeared to be very desirable to compare the results, in distance especially, obtained by means of that instrument with those which might be procured of the same objects with a double-image micrometer. Having in the year 1842 conferred with Mr. Bishop on this subject, I was requested by him to order from Mr. Dollond such an instrument as I considered most suitable to the purpose. I had no hesitation in giving the preference to some application of the double-refracting crystal, as it is of prime importance that in the measurement of the position of double stars the images should be as good as possible. The scale of the *spherical* crystal micrometer being far from uniform, and also of very small extent, though as made by Mr. Dollond it gives beautiful images, it was resolved to adopt a modification of Rochon's plan of producing a double image by causing a double prism of rock crystal to slide along the inside of the tube. Mr. Dollond had previously constructed such with the substitution of a sphere of the same substance for the usual magnifier or eye-lens; which, by its rotation on an axis at right angles to the plane of double refraction, was used to complete an approximate measure made by means of the sliding prisms. The want of uniformity of the scale of the sphere introducing some uncertainty in the result, I preferred the use of single crossed convex lenses as magnifiers; and had three such applied, whose powers on the South Villa refractor were, 185, 350, and 520. By adjusting the length of the adapting tube of each

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lens to its focal length, the lens is brought as near as can be allowed to a fixed plate, which carries two fine spider-lines at right angles to each other, and crossing in the centre of the field. These lines being as close as possible to the surface of the eye-lens when pushed home are quite invisible, and do not sensibly disturb the image. One of them is placed precisely in the direction of the separation of the images, so as to bisect both the images of a single star when widely separated; the eye-lens being drawn out till the line is in focus. Then, by turning the position-circle till a star runs along this line, the zero of position is given by the reading of the index, which will be 90° when there is no index error. The angle of position (which is read off by the two opposite verniers to one minute) was obtained by bringing the four components of the two images into a straight line alternately on both sides of the point of single vision; and the mean of the readings was adopted. With the first set of prisms the secondary image did not pass the fixed image quite centrally; but the difference of the observed angle on each side was not such as to render necessary a correction of the double distance measured by placing the four stars at equal distances. By the mean result of a great number of careful observations on artificial stars, the nearest approach of the centres (a) was found to be $0''\cdot1559$. Where, however, in consequence of the distance being too great to allow of the measures being made on both sides of the point of single vision, or from any other cause, the observations were confined to one side, a correction to the angle was calculated by the formula, *tan. of angular correction*$=0''\cdot1559\times 2d$; —$2d$ being the double distance measured by the micrometer. In all such cases the fact is mentioned in the notes that a zero of distance has been employed, and a calculated correction applied to the measured angle. The zero-point has in these instances been deduced from measures on both sides of zero, taken with the same eye-lens either on the same night, or very near the time of observation. From the construction of the instrument, the zero reading is very different with each of the eye-lenses; but the fluctuations of that reading were very small, far less in fact than the probable errors of observation.

From some subsequent observations on artificial stars, it appeared as if the nearest approach of the centres were not precisely the same with the different eye-pieces; but as the variations were very small, and the amount not very certain, the value of a above given was adhered to, being extremely near the mean of all the results with power 350, which was the one most frequently employed. The value of one division of the scale with these prisms was $0''\cdot5742$, determined by the interval of time between the transits of the two images of a juxta-polar single star over the web placed perpendicular to the direction of motion.

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A new set of prisms inserted by Mr. Dollond was used after 1843, Aug. 16, with which the passing of the images was so nearly central that no correction to the angle was required. The value of one division of the scale with the new prisms was determined to be 0″·28986.

It is essential to accuracy that the object should be pretty near the middle of the field of view. When the driving clock goes well, there is no difficulty in keeping it there; but as the field was usually dark when this micrometer was employed, a little illumination was occasionally admitted to render the margin of the field visible; or the eye-lens was withdrawn till the cross webs became visible on the enlarged image of the object, which generally had sufficient light to render illumination of the field unnecessary for this purpose.

On the whole, I formed the opinion that the angles of position measured with this micrometer (by placing the four stars in a line) are not quite worthy of the same confidence as those procured by placing the image between the thick parallel wires of the repeating micrometer; notwithstanding that the double image is as perfect, or very nearly so, as the single image with an ordinary eye-piece. The distances, on the contrary, I believe to be as accurately measured as the observer's eye was capable of under the atmospheric circumstances. And very tolerable measures of distance may be obtained by the estimation of equal intervals between the components, even when the stars are so violently and rapidly agitated that the webs could not be kept on their disks for an instant, and the observer's eye would soon be distressed and wearied by continued and ineffectual attempts. Moreover, a less perfect action of the driving clock is needed with a double-image micrometer than with the parallel-wire micrometer.

This micrometer is referred to by the abbreviation, *Pr. Cr. M.*

Description of Merz's Parallel-wire Micrometer.

The parallel-wire micrometer which accompanied the equatoreal made for me by Merz and Son, of Munich, in the year 1846, differed considerably from those usually constructed in this country. Only one of the micrometer screws has a graduated head, the other carries the thread on either side of which the measures of distance are made; but it is not furnished with the means of bolting or otherwise fixing the thread at any given point. The only threads in the field are the two parallel spider's lines, with which the measures both of position and distance are taken. The number of whole revolutions of the screw are conveniently read off on the outside of the micrometer frame;—an arrangement which does not, like the interior comb, require illumination of the field and the application of a low power to render the scale visible, and which might therefore be advantageously copied by in-

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strument-makers in this country. This micrometer was furnished with the means of illuminating the threads in a dark field; but I soon found that though useful for *approximate* measurements of objects too faint to bear illumination of the field, they could not be depended on for *accurate* determinations of distance; and no observations thus made are included among the measures in the following catalogue.

The value of one revolution of the screw was found to be 25″·606. This micrometer was furnished with seven double eye-pieces, whose magnifying powers on the 8½-foot object-glass, of 6⅓-in. clear aperture, were 120, 155, 260, 322, 435, 572, and 690. These powers, as well as all others quoted in this catalogue, were determined by careful measurement of the emergent pencils. The real powers are therefore not smaller than the quotations. This is to be taken into consideration in comparing the powers used in my observations with those employed by Professor Struve at Dorpat, in whose great work (*Mensuræ Micrometricæ*) the powers are quoted as stated by the maker, though the actual powers were found by Struve himself to be much less, as appears from the following table given in the Introduction to that work:

Eye-pieces of the Parallel-wire Micrometer of the Dorpat Refractor.

No.	Nominal power.	Actual power.
1	94	86
2	140	133
3	214	198
4	320	254
5	480	420
6	600	532
7	800	682
8	1000	848
9	1500	1150
10	2000	1500

The spider's lines inserted by Merz were beautifully round and uniform in thickness; but they were inconveniently thick for measurement in distance of very close stars, and totally occulted very small ones. Wishing to try the effect of the Barlow concave achromatic lens in diminishing the arc subtended by the threads, I requested of Sir John Herschel the loan of one which had been made by Mr. Dollond for him before his departure for the Cape of Good Hope; and finding that it perfectly answered my purpose, he kindly presented it to me in December 1846. From that time this lens has been frequently used; and the magnifying powers of the four lowest eye-pieces of the micrometer were increased to about 300, 387, 648, and 803; and the value of one revolution of the micro-

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meter screw was 10″·268. The defining power of the object-glass was not sensibly impaired by the intervention of this lens.

This micrometer continued in use till 1848, Feb. 25, when I exchanged it with Mr. Lassell for a parallel-wire micrometer made for him in 1839 by Mr. Dollond under my direction, in which the system of thick wires and webs was similar to that which had been inserted into Mr. Bishop's micrometer, as stated above.

The eight eye-pieces of Dollond's micrometer produced the following powers on the $8\frac{1}{2}$-foot refractor, 87, 136, 200, 268, 353, 467, 591, and 780. With the Barlow-lens interposed, the powers of the six lowest became 163, 252, 375, 500, 658, and 870; the tube of the Barlow-lens having been somewhat shortened, and its effect therefore rather diminished. One revolution of the screw was equal to 19″·9935 on the Munich refractor, which on the application of the lens was reduced to 10″·680.

It may be well to mention here that I have found it very convenient to have the tube of the Barlow-lens divided into several pieces, any of which can be used, and thus any degree of relative fineness of the webs secured. The value of the micrometer screw will of course require to be ascertained for each length of the tube.

Description of the Spherical Crystal Micrometer.

Two of these instruments have been occasionally employed since the erection of my Munich equatoreal at Cranbrook in the autumn of 1846. Both of them were made by Dollond, who first contrived this form of double-image micrometer. One had belonged to Mr. F. Baily; and after his death it was purchased at the sale of his library and instruments by Mr. R. Hodgson, who obliged me with the use of it to the close of this series of double-star measures. It has a small position circle, but is not furnished with any means of determining the zero of position. To obviate this defect, I fixed temporarily a fine wire upon a diaphragm in the focus of the sphere. The zero of position was then determined by letting a star travel along this wire; and the angles were measured by placing the wire alternately on each side of the *single image* of a double star, and thus judging of the parallelism of the wire to the imaginary line joining the centres of the two stars. I believe this method to be considerably more accurate than placing the stars of the two images in a line; and even than attempting to bisect both the stars of one image by a fine web; yet as the result is inferior in precision to that obtained by placing the double star between two parallel wires, I have allowed to such observations only half the weight which would have been assigned to them if taken by the latter method.

The measurement of distance with this micrometer is effected

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by the rotation of the sphere upon an axis perpendicular to the plane of double refraction. The same axis carries an index which shows on a circular arc the number of degrees through which the sphere has rotated on either side of the zero point of the scale in the middle of the arc. The greatest separation of the images occurs at 45° from the zero point.

Though the greatest distance measurable with such a micrometer is only about 13″ or 14″ when the magnifying power is 100; and, varying inversely as the power, becomes very small when the micrometer is attached to a telescope of long focus; yet from the excellent images it gives when worked as perfectly as those I have employed, (all made by Dollond,) it must long ago have been considered a very useful instrument for the measurement of very small angles if the degrees of the arc, over which the index passes as the sphere is rotated, were of equal value; or, in other words, if the value of the scale were uniform throughout the arc. But this is very far from being the case, as immediately appears from experiments; and this reason is given by Dr. Pearson in his "*Practical Astronomy*" for laying it aside as useless.

Being unacquainted with any experiments from which the law of variation could be deduced, I determined to institute such a series as would give with great accuracy the values at several points of the scale. For this purpose I applied a parallel-wire micrometer to a telescope on which the value of one revolution of its screw had been well ascertained; and employed the telescope so furnished by way of collimator to another telescope to which was applied the spherical crystal micrometer; the focal length of each object-glass having been very accurately determined. The moveable webs of the parallel-wire micrometer being thus rendered perfectly distinct to an observer with the spherical micrometer, they were set to a succession of equal intervals, which were most carefully measured by daylight with the spherical micrometer on each side of its zero point. These measures expressed in parts of the index arc (a circular scale) being laid down as abscissæ, and seconds and fractions of a second as ordinates, on a sheet of small squares, a curve was drawn through the points indicated, and the readings tabulated to each degree of the scale. Any considerable and irregular variations in the differences of consecutive values, arising from the combined effect of errors of observation, of drawing the curve, of reading it off, and of imperfections in the form of the squares themselves, were subsequently smoothed down. This plan having been carried into effect with both the spherical micrometers, it became obvious that the law of variation was the same in both; and after a little consideration I found that the value of the angles indicated by the index varied very nearly, if not precisely, *as the sine of twice the angle through which the sphere rotated*, commencing from the zero point. On a focal length of 102·5 inches, the largest arc

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measurable with one of these micrometers (designated as No. 1) is $2''\cdot85$,—the index then pointing to $45°$ on the circular scale: and with the other micrometer (No. 2) the largest arc on the same focal length is $7''\cdot70$. From these values tables were calculated of the value corresponding to each division of the scale. In only 9 out of the 45 values in No. 1 did the difference between the value deduced from the observations and the value given by calculation amount to $0''\cdot01$; and of these 9, four are + and five are —. The results of the calculation therefore appear to represent the true values quite as correctly as they could be deduced from any series of observations.

Putting r = the value of the separation of the images on any given focal length when the sphere is turned through $45°$ from the zero point,

the value ϱ of any other angle θ indicated by the index will be given by the formula,

$$\varrho = r \,.\, \sin 2\theta$$

The value of r will of course vary inversely as the focal length of the telescope to which the micrometer is applied.

This micrometer is referred to by the abbreviation, *Sph. Cr. M.*

Description of Amici's Double-image Micrometer.

This micrometer was constructed by the late Professor *Amici* of *Modena* for Sir John Herschel; but it was furnished with only one eye-piece which was of an inconveniently high power,—magnifying nearly 1000 times on the 20-foot reflector, for which I presume the Professor designed it, as the position-circle is graduated suitably for a front-view reflector. It was, I believe, but little if at all used by Sir John in his observations at the Cape. As I was desirous of trying such a micrometer on my refractor, Sir John lent it me for that purpose, and I found it very efficient on many objects. In reply to a favourable report of its performance, Sir John most kindly made me a present of it as a new year's gift on the first of January, 1855. I soon after had some important additions made to it by Dollond, by which its usefulness was greatly increased. The principal of these was a sliding tube, which could be accurately fixed at four different lengths, at each of which the divisions on the scale have a different value;—thus extending the use of the micrometer for wider stars, and giving a finer scale for very close stars, than was possible with the original tube of a fixed and unalterable length. Three new double eye-pieces were also applied, which on 100 inches of focal length produce powers of about 212, 360, and 508;—the original eye-piece giving a power of 380. On a diaphragm I

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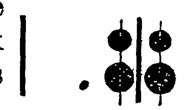
had two very stout and beautifully round spider's lines fixed parallel to each other, and at about 10″ apart, for the measurement of angles of position.

When the whole aperture of the object-glass is used, the divided glass of the micrometer makes a spectrum of each star; and in this form it is of course almost impossible that good measures of position should be obtained. When however the stars are not extremely close, (the central distance not less than $1\frac{1}{4}''$ when an 8-inch object-glass is in use,) the disks may be made beautifully round by employing a double circular or figure-of-eight aperture, or an elliptic aperture:—as I have shown in my paper on the use of this micrometer inserted in the *Monthly Notices*, vol. xviii, No. 3.

Another plan which I contrived soon after this instrument came into my possession, and which I would take this opportunity of specially recommending to the attention of astrometers, is this. Instead of the tube containing the eye-pieces, I had my parallel-wire micrometer adapted to the Amici micrometer. The thick parallel wires in the former are easily brought to coincide with the direction of separation of the images in the latter; and thus the single image when nicely central and well defined may be measured in position by those thick wires; or, when the double-circular or elliptic aperture is employed, and the stars in each of the images are therefore round and neat, *one* of those images may be measured in position by placing it between the thick parallel wires. But there is this peculiar advantage in this kind of double-image micrometer for the measurement of double stars, that by moving the object but a small distance from the middle of the field all the rays may be made to pass through one of the halves of the divided glass; and thus the advantage of the whole aperture will be secured both in its *illuminating* power on very *faint* objects, and in its *separating* power on very *close* ones.

Another mode of measuring the angle of position which I have occasionally practised when the double-circular or the elliptic aperture has been in use, is, I think, worthy of adoption in some cases, especially where it may be desirable to test and compare the results of different methods on the same object at the same time. In this method, the thick wires are placed *at right angles* to the direction of separation; and the two images being separated by a few seconds only, one of the images is placed on each side of one of the thick wires. The images may be separated to various distances, and the effects compared together.



For the measurement of distances also, there is considerable advantage to be derived from this combination of the double-image and parallel-wire micrometers. The thick position-wires being placed *parallel* to the direction of separation, the fine webs should be placed as exactly as possible on the centres of the components of one of the images; and then, by delicately

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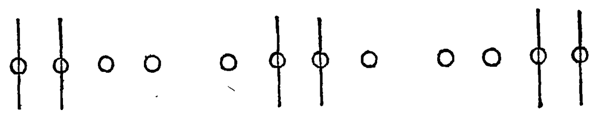
moving the objects in the field, the three intervals, formed by placing the four stars in the two images at equal distances, are brought to the webs in succession: and thus their equality is tested to the greatest exactness of which the eye is capable. This may be illustrated by a diagram. Such a mode of



using the webs, it will be understood, is intended merely to assist the judgment of the eye in making the interval between the two images exactly equal to the distance between the components. And this method may be employed when the whole aperture of the object-glass is in use; for the prismatic images of the stars being elongated in the direction of the webs, the *distance* may be correctly measured, though the *position* cannot.

Another and by no means an inconsiderable advantage of thus combining the two micrometers is this;—that the measures of distance are performed with both micrometers at the same time, and therefore under precisely the same condition of the atmosphere, of the instruments, and of the observer himself:—the last being sometimes by no means the least in importance.

It is obvious that the Barlow-lens may be used with this micrometer, or combination of micrometers; so as to bring the value of the scale to what may be deemed most convenient.

Description of the Four-glass Double-image Micrometer.

In the early part of 1860 I received from Mr. Simms a 4-glass double-image micrometer, with all the latest improvements contrived or approved of by the Astronomer Royal. It was furnished with four first-lenses of different focal lengths, by the change of which the magnifying power is varied. The powers as first arranged were such as on a focal length of 100 inches would be about 150, 258, 430, and 540. Finding that the highest was more than would be needed for such a micrometer, except on very rare occasions, I had it changed for a power of about 80 on 100 inches of focal length, which for wide stars is often convenient.

In the focus of the positive eye-piece formed by the two glasses nearest the eye, I had two parallel thick webs inserted for the measurement of position-angles; and they can be easily placed either parallel or perpendicular to the direction of separation of the images. A prism is adapted to the eye-piece to enable the observer to place the double star in any apparent position he may desire.

In a paper which I had the honour of presenting to the Society in Jan. 1858, "On the Measurement of Position-angles with a Divided-glass Double-image Micrometer," I noticed

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the possibility of producing round images by introducing a diaphragm before the divided glass of the micrometer ;—such diaphragm having "two circular apertures touching each other in a point coinciding with the line of collimation of the telescope, and the diameter of each aperture exactly equal to the semi-diameter of the cone of rays at the distance of the diaphragm from the focal point of the object-glass." And with reference to its practical application I remarked that, though it would have the advantage of turning with the position circle, and thus obviating the necessity of altering the position of the double-circular aperture (when such a one was placed before the object-glass) for each double star observed ; yet that there would be great difficulty in exactly proportioning the size of the apertures in the diaphragms to the powers employed ; and also in illuminating the field sufficiently to enable the position-wires to be pleasantly seen. In making the micrometer for me, Mr. Simms acted upon this suggestion, and introduced one such diaphragm for each power of the micrometer. But though the utmost care has evidently been taken to proportion the excessively minute apertures correctly, I found that the apertures for the highest power (593 on my 8¼-inch object-glass) were not only too large for that power, but even for the next lower, (472) : proving that the difficulties I anticipated were practically almost insurmountable.

It may be well however to mention here, as it was inadvertently omitted in the description of the Amician micrometer, that in that form I have frequently used a diaphragm placed nearly in contact with the divided glass, and pierced with two minute holes as above described. But though this form of micrometer is more favourable to the application of such a diaphragm than is the 4-glass micrometer, inasmuch as one pair of holes is sufficient for all the different powers, yet I must confess to my decided preference for the double-circular or elliptic aperture placed before the object-glass ; especially when the parallel wires are used for measuring the position, and illumination of the field is therefore necessary.

To render more easy and certain the turning of such an aperture to the proper position, I had the brass dew-cap of my telescope divided to every 5° by bold strokes on the outside of the distant end ; the zero, or 0°, being coincident with the middle of the declination axis, and consequently 90° from the zero point of the position circle of the micrometer when properly adjusted. The observer then has nothing to do but to take an approximate measure of the position of the double star he is about to observe, (if the approximate angle is not previously known,) and to set the line which passes through the centres of the two circular apertures, or the major axis of the elliptic aperture, to the same angle engraved upon the dew-cap.

By a small addition to the instrument as usually made, the 4-glass double-image micrometer may be converted into an

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Amician. This I contrived by having a tube made to apply in the place of the usual eye-tube, and furnished with an adapting screw, into which all the eye-pieces of the wire micrometer might be fitted. It must, however, be acknowledged that the 4-glass micrometer converted into an Amician does not make so good an instrument as the originally constructed Amician,—the divided glass being too deep a concave.

One great advantage of the Amician form is, that any desired change of magnifying power can be made during the time of obscuration by merely changing the eye-piece, and consequently without any risk of disturbing the zero adjustment of the position-wires; which can scarcely be done where, as in the 4-glass micrometer, the optical portion has to be removed to change the first glass. Moreover, in the Amician the change of power does not alter the value of the scale, as it does in the other.

Another very useful purpose to which the 4-glass micrometer may be applied is, as a *double-image dynamometer*. But on this subject I hope to submit to the Society a few remarks in another communication.

I may here advert to one or two points which the experience of more than five and thirty years has convinced me are of some importance in the measurement of double stars both in position and distance. And first in *position*.

1. The thick position-wires having been turned, as nearly as can be estimated, into the same direction as the imaginary line joining the *unequal* components of a double star placed midway between them, the stars should be brought nearly to touch one of the wires alternately on each side of it; by which a tendency to place one of the double wires nearly in the direction of a tangent to the disks of moderately unequal stars, may not unfrequently be detected. When such stars are *between* the wires, the eye may unconsciously be directed to the edge of one wire rather than of the other; but the placing of the star alternately on either side of the same wire will immediately remove this tendency.

2. The wires having been brought up approximately to the right direction, attempts will usually be made to improve the measure by repeated small movements of the wires in the same direction,—the eye being kept intently fixed upon the stars. Very soon after I commenced my double-star observations, I became conscious of a tendency in the eye to accommodate its judgment to the position of the wires before they had been quite brought up to the right point. And thus, if the wires were alternately brought up from opposite sides of the true direction, the resulting measures would be alternately too large and too small. I was much interested some time ago in some remarks on this subject by that excellent and indefatigable double-star observer, the Baron *Dembowski*, who had detected

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the same tendency in himself. To remove the error arising from it he adopted the plan of bringing up the wires alternately from each side of the true direction, and taking the same number of measures each way. This is exactly the same plan as I adopted for some years ; and I still continue always to derange the measures, as soon as read off, alternately in opposite directions. But I have now for many years practised a mode of observing which yields a far more uniform series of results. When the eye is not quite satisfied with the position of the wires, and a succession of small alterations is required in the same direction, I always remove my eye from the telescope for a few moments after each alteration ; and thus endeavour to get rid of the previous impression, and to bring up my eye fresh to its work. I find that a more independent and correct judgment is thus formed ; and the individual measures are usually much more accordant, and always free from any systematic differences.

3. In the measurement of the *distance*, of rather close double-stars especially, I have found it very useful to previously place on each of the stars, as centrally as possible, a single web of the parallel-wire micrometer ; and carefully to note the change which is thus made in the form of its disk. The effect on a star of moderate size is to *swell out the disk on each side of the web ;* so that if the part of it covered by the web were supplied, the figure instead of being round would be nearly elliptical. The consequence of this is, that in a double star just neatly separated with the aperture and power in use, the swelling out of the disks obliterates the interval between them, and renders it very difficult to judge of the bisection of the disks. If however the form of each disk when bisected by the web has been accurately noted, a trustworthy measure of the distance may be obtained by placing the webs so as to produce on each the same effect as was previously observed. But if this effect is not known or is disregarded, the measure will almost inevitably be considerably *too large ;* the webs being placed too near the outer edge of each disk.

I cannot but think that some such cause as this must have produced the enormous excess of the measured distance in many objects in the early observations of some excellent observers, as may be seen in the series of results brought together for comparison in the *Notes* appended to the following Catalogue. For my own part, I am conscious that until I detected this source of error, it was one of the causes which produced the same effect on my earlier measures of distance. But the principal cause of their excess was, that I then imagined the only measures I was acquainted with, contained in the *Phil. Trans.* for 1824 and 1826, were standard results to which my own ought to approximate ; and consequently I tried to accustom my eye to the largest measures it could endure. This delusion was in part dissipated by finding that, in the case of such a star as

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ζ Aquarii, (whose position-angle was not far from 0°,) when its distance was deduced from excellent observations of the difference of declination, obtained by letting the stars pass through the field threaded on the micrometer-webs placed on each side of zero, that distance was actually less by more than 1″ than those contained in the comparative series under date 1822 and 1828. I refer to this fact especially to guard against the conclusion that, because more recent observations show in many cases a large diminution of distance, a real approximation of the components must therefore have actually occurred.

Remarks on the Use of various Telescopic Apertures.

1. Sir John Herschel has recommended the use of a round disk placed centrally before the object-glass, having a diameter from a sixth to a fifth of that of the object-glass. In the *Introduction* to my first series of double-star measurements, (see *Mem. R.A.S.*, vol. viii., p. 63,) I have referred to the effect of this application as increasing the *separating* power of the telescope, but at the same time increasing both the number and the brightness of the rings round the brighter stars. They are also thrown further from the disks; the small companions of rather bright stars are often hidden by them; and the disks of nearly equal stars are apt to be elongated by the rings passing through them. I have therefore seldom used this expedient, though in some instances it is undoubtedly advantageous.

2. I have frequently found great advantage from the use of a *perforated whole aperture*. The perforated card-board used for making the Berlin wool-work is very suitable for bright stars, such as *Castor*, *γ Leonis*, *γ Virginis*, or even *ζ Bootis*. At some distance from the star are arranged highly coloured prismatic spectra of great beauty. The effect of this aperture on *Venus* is exquisitely fine, producing a central image of the planet perfectly colourless, and very sharply defined. The area of the exposed surface of the $8\frac{1}{4}$-inch object-glass scarcely exceeds that of a 2-inch object-glass. But when the object is not sufficiently bright to bear so great a loss of light, a smaller degree of the same effect may be produced by a disk of card-board, of which a circular portion of the size of the object-glass is pierced with holes of equal size arranged in concentric circles. The one I have principally employed with an $8\frac{1}{4}$-inch object-glass, has 15 circles containing with a central one 770 holes. They are all 0·2 inch in diameter; so that the exposed surface of the object-glass is about equal to that of an object-glass of $5\frac{1}{2}$ inches. The effect of this is very agreeable. The disks are considerably smaller than with the whole aperture, in consequence of having less than half the brilliancy; the ratio of the area being nearly as 0·45 to 1; while the effect of the whole aperture in reducing the diameter

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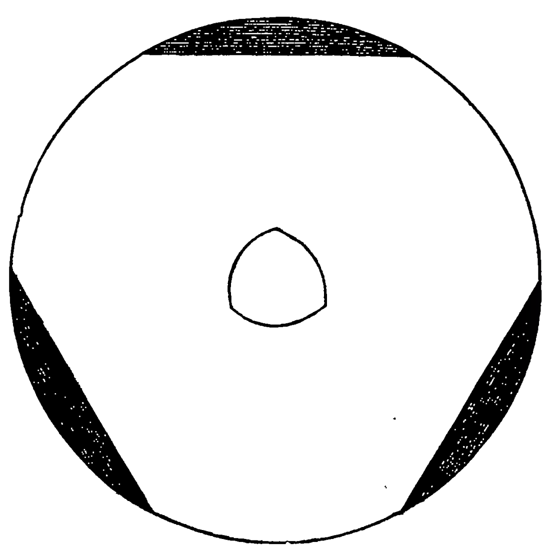
of the disk is also preserved. The brightness of the rings is also proportionably diminished, and except on very bright stars is scarcely perceivable. Around these there are concentric prismatic rings, but at such a distance as not usually to interfere with companion stars.

3. A different and in some respects a still more useful effect is produced by the employment of *angular* apertures. Sir John Herschel has mentioned the inscribed triangle as destroying the rings round bright stars. The principal inconvenience of such an aperture consists in the six bright rays which proceed from the disk at equal distances. Great care is necessary to prevent a small companion from being obliterated or distorted by these rays. The disk of the star is *not round* with this aperture, as it has been supposed to be, but *hexangular;* and a ray proceeds from each side of the hexagon. If the focus is a trifle too short, the image becomes triangular in one direction; and if too long, in the opposite direction,—the sides in the latter case occupying the situations of the angles in the former. It is therefore possible to obtain an exquisitely fine focal adjustment by reducing all the rays to an exact equality in brightness. The illuminating power of the object-glass is reduced in the ratio of about 0·4 to 1. A kind of aperture usually more advantageous, especially on stars of only moderate brightness, is an inscribed *hexagon.* With this the rays (which are six in number, as in the triangle) are much more feeble compared with the greater illuminating power of the exposed area, the ratio of which to the whole aperture is more than 0·8 to 1; or double the area of the inscribed triangle.

4. It is sometimes very desirable to provide an antidote to the curious but annoying tendency which is occasionally seen in the telescopic disks of stars to become triangular, especially when the wind is in the east or south-east. Such an antidote is effectually produced by cutting off three equi-distant segments from the whole aperture of the object-glass, the base of each of which is the chord of 60°. Then, the chords being placed so as to coincide in position with the angles of the telescopic inverted image, those angles will be reduced by the larger circular aperture between the segments, and a fairly round image will be substituted for the triangular one, the form of which usually approaches that of an obtuse-angled spherical triangle; thus,



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The production of this triangular telescopic image is a very curious phenomenon, and its association with the east wind seems unaccountable. When I had the honour of receiving the late Professor Struve at my residence in Kent, I mentioned the subject to him; and he said he had often seen it, but could not at all account for it. In reply to an inquiry as to its probable cause, which I made on one occasion of Professor Wheatstone, he informed me that the subject had been investigated by some eminent German astronomer; but he could not recollect the particulars, and I have never received from him any further information. I have noticed it most distinctly in telescopes remarkable for exquisitely fine definition. Yet that it does not arise from anything in the object-glass itself may be proved by unscrewing it one sixth of a turn; when, if the object-glass is in fault, the angles of the triangular image will take the places previously occupied by the sides. I have also had an opportunity of proving this when the phenomenon has been strongly marked, by exchanging the object-glass for another at the time. On the occasion of Mr. Alvan Clark's visit to me in the summer of 1859, he brought with him two excellent object-glasses, one of 8 inches, the other of 8¼ inches in diameter. On an exceedingly fine evening, the stars being almost perfectly quiet, I was trying one of these object-glasses, and was surprised to find a very strong triangular tendency in the disk of *Arcturus*,—one of the sides of the triangle being nearly parallel to the horizon, but raised a little on the eastern or following side. Mr. Clark saw it exactly as I did. On changing the object-glass for the other, after the telescope had rested on the star for a few minutes the image was as strongly triangular as before, and precisely in the same direction. The wind was in the south-east, but it was nearly calm. I have supposed that the cause must exist in the temperature of the air in different parts of the tube; but if so, it is difficult to imagine why it should be affected by an east wind. That it is so I have frequently noticed, and on one occasion it was proved with remarkable certainty. On an exceedingly fine night, I had been observing with the 8¼-inch object-glass with great delight till near 3 in the morning, the stars having been for several hours beautifully defined and round. At that time I noticed an occasional tendency to triangularity, lasting for a few seconds at a time. These triangular fits increased in frequency and continuance; and I was greatly surprised at it, inasmuch as the gentle wind had been all night nearly in the south-west; and I noted down the occurrence before I left the observatory as being an extraordinary deviation from the usual circumstances. On coming out of the observatory, however, I found that the wind had changed to the south-east!

5. It may be worthy of remark, that a smaller aperture may sometimes show a very delicate and close companion to a bright star, when a larger aperture fails to show it. A singular

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instance in illustration of this occurred to me when I was observing at Mr. Bishop's observatory at South Villa in the Regent's Park. After a totally cloudy day, a sudden and complete clearance showed the stars with remarkable brilliancy; and to ascertain whether the night was as fine as it looked, I turned the 5-foot refractor by Dollond (aperture 3·8 inches), which I had at Ormskirk, on to ζ *Herculis*. With power 400 the image was beautifully sharp and steady; and the small companion was usually in loose contact, and at best moments just separated from the large star. The one bright ring passed outside of the smaller star, and in contact with it, but did not distort it. The central distance was at that time about $1\frac{1}{4}''$. Now, with a 5-inch aperture, the bright ring being of considerably smaller diameter, and also brighter, would pass through the small star, and elongate it to such a degree as to make it appear like a somewhat brighter portion of the ring. Thus it might happen, and I have no doubt has happened, that the companion of such objects as ζ *Herculis* and δ *Cygni* might be seen with a smaller aperture, though invisible with a somewhat larger. It is difficult otherwise to account for the fact that the companions of both these stars could not be perceived by Sir James South with his exquisitely perfect 5-inch refractor under the finest circumstances, and with various powers up to 787.

6. On such stars as the two just referred to, a considerable increase of visibility may sometimes be obtained by a very slight variation in the adjustment of the object-glass with respect to the axis of the tube. To enable this to be made by the observer whenever required, the adjusting screws should be accessible without removing the object-glass; and not placed as they often are within the tube, which of course renders it necessary to take out the object-glass in order to get at them :—an operation by no means free from danger with the feeble light usually employed in an observatory, and the observer probably without assistance. By such variation of the adjustment, the ring round a bright star may be attenuated to almost any extent on one side without perceptible injury to the form of the disk; and thus a very minute companion may be rendered plainly visible, which with a perfect adjustment of the object-glass would not be seen at all.

7. It is a point of considerable interest to determine the *separating* power of any given telescopic aperture. Having ascertained about five and thirty years ago, by comparisons of the performance of several telescopes of very different apertures, that the diameters of star-disks varied inversely as the diameter of the aperture, I examined with a great variety of apertures a vast number of double stars, whose distances seemed to be well determined, and not liable to rapid change, in order to ascertain the separating power of those apertures, as expressed in inches of aperture and seconds of distance. I

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thus determined as a constant, that a 1-inch aperture would just separate a double star composed of two stars of the sixth magnitude, if their central distance was $4''\cdot 56$;—the atmospheric circumstances being moderately favourable. Hence, the separating power of any given aperture, *a*, will be expressed by the fraction $\frac{4''\cdot 56}{a}$. The following table is thus calculated, and may be convenient for reference, containing ordinary apertures and the least central distances of stars separable by them:—

Aperture in inches.	Least separable distance.	Aperture in inches.	Least separable distance.	Aperture in inches.	Least separable distance.
	s		″		″
1·0 ..	4·56	4·0 ..	1·14	8·5 ..	0·536
1·6 ..	2·85	4·5 ..	1·01	9·0 ..	0·507
2·0 ..	2·28	5·0 ..	0·91	9·5 ..	0·480
2·25 ..	2·03	5·5 ..	0·83	10·0 ..	0·456
2·5 ..	1·82	6·0 ..	0·76	12·0 ..	0·380
2·75 ..	1·66	6·5 ..	0·70	15·0 ..	0·304
3·0 ..	1·52	7·0 ..	0·65	20·0 ..	0·228
3·5 ..	1·30	7·5 ..	0·61	25·0 ..	0·182
3·8 ..	1·20	8·0 ..	0·57	30·0 ..	0·152

It might be not unreasonably imagined that the brightness of the stars would make a great difference in the central distance to which any given aperture could reach. But though it may make *some* difference, it is in fact far less than would at first sight appear probable. This arises from the much higher powers which the brighter stars will bear; and as the diameter of the disks does not increase in proportion to the power, the separability of all magnitudes is nearly the same, provided the state of the air is such as to bear well the increase of power.

8. Nor is so great a difference as seems to be generally supposed produced by a moderate degree of uncorrected spherical aberration. I was struck with this fact nearly 40 years ago, when I happened at the same time to be in possession of one of the very best, and also of one of the worst, telescopes I ever had. The good one was made for me by Dollond, and was of the ordinary size called the 2-foot; the focal length being 19½ inches, and the aperture 1·6 inch. It had, as was usual at that time, a triple object-glass, and was in a portable mounting with sliding tubes, and furnished with one of Dr. Kitchiner's Pancratic eye-pieces, magnifying from 45 to 180 times; other eye-pieces of the Huyghenian construction being afterwards added. With powers of 60 and upwards the disks of *α Lyræ*, *Capella*, *Rigel*, &c., were shown with scarcely the slightest trace of a ring; and the small companions of *Polaris* and *Rigel* were readily seen, and not by myself only. The former however was often seen by me with the aperture con-

Pritchard says 10 May that if separation is not in ~~function of~~ the aperture there is an end of the undulatory theory.

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tracted to 1·4 inch; and on one occasion, under an unusually pure sky, with 1·3 inch: and this is the smallest aperture with which I have ever been able to see it with certainty. As a contrast to this exquisite instrument, I had a 45-inch refractor with aperture 2·75 inches; but so bad was the figure that any aperture exceeding 1¾ inch showed considerable spherical aberration; and with the whole the error was enormous. With the aperture contracted to 1·6 inch, the appearance of *Castor* was almost precisely the same as with the perfect 2-foot: and this first proved to me that the ratio of focal length to aperture does not affect the size of star-disks. But notwithstanding the wretched figure of the larger telescope, any increase of aperture beyond 1·6 inch was found to diminish the disks so decidedly that the perfect little glass had no chance in the comparison. The two double sets, which together constitute ε *Lyræ*, were shown with the 2-foot, ε_1(4)*Lyræ*, just neatly separated; and ε_2(5)*Lyræ* in close contact, power 120. But with the 45-inch, both sets were widely separated with the same power. Pursuing these observations, I came to the conclusion that with the 2¾-inch aperture the disks were of the proper size for that aperture; but that round the brighter stars the false and scattered light was enormously too great; and it is principally in this particular that the effect of a bad figure is seen. Hence it follows that the tests of separating power furnished by close double stars are by no means to be relied on as determining the character of a telescope; and further experience has fully confirmed me in this opinion. The severest test of figure is the similarity of the image of a bright star when the focus is a little too long, and to an equal extent too short. If the *rings* in these out-of-focus images are similarly disposed in both cases, the figure is perfect; but a moderate deviation from this perfect equality does not stamp a telescope as bad, or even unfit for delicate work. And it is a fact, which I have proved by experiment, that the difference between an object-glass which bore this most severe test perfectly well, and one which fell obviously short of it, was not to be discovered by any decided superiority of the one over the other, either in separating power upon close double stars, or even in the perception of faint objects close to bright ones; though this latter is more likely than the former. The question is much more important *how* a telescope shows a difficult object, than whether it can show it at all. It is therefore my confirmed opinion that a list of test objects is of comparatively small importance in the trial of a telescope, especially as so much must depend on the eye and the habit of the observer, and the circumstances under which the scrutiny is performed.

9. In measuring the diameter of a planet with the webs in a parallel-wire micrometer, it has no doubt been frequently noticed by other observers as well as by myself, that when the web is brought to touch the edge of the planet's disk, light is

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immediately seen on the outer side of the webs through the effect of diffraction. This gives the impression that the measure is too small. But if the web is withdrawn till this effect disappears, the measure will undoubtedly be too large. To obviate the source of this error, I had two sets of stout webs inserted parallel to the single webs, and at a convenient distance from them: the proximate edges of the webs in each set being about 4″ apart. Like the single webs, these can pass each other so as to allow of measures being taken on both sides of the zero point. In measuring the diameter of a planet, the edges of the disk are placed in the middle of the interval between the webs of each set, where they are seen sharply defined and entirely free from distortion. I believe that results thus obtained are much more worthy of reliance than those derived from the use of single webs, and at least equal to those produced by the double-image micrometer.

10. A curious fact with which I have been familiar for more than thirty years, may perhaps be worthy of notice in this place; namely, that stars at small altitudes require a shorter focus than those at large altitudes, to be seen with perfect distinctness. Of course the difference is slight, yet it is decided and constant. It is independent of the brightness of the object, but yet is, I think, most obvious when the actual difference of magnitude is just so far in favour of the lower star as to render its apparent brilliancy equal to that of the higher. I was first struck with it when observing at Ormskirk, with Dollond's 5-foot refractor, the stars η *Coronæ*, ξ *Scorpii*, and μ_2 *Bootis*, within a short space of time; and I have noticed the same with every telescope of whatever dimensions with which I have since observed.

11. It may be a matter of sufficient interest to deserve notice here, that much fatigue of the eye in long-continued observation will be saved by the exercise of great care never to commence observations of any object with too short a focal adjustment. I have met with instances in which young persons, in reality not at all short-sighted, (as was proved by very distant objects and even the features of the Moon being accurately described,) who, nevertheless, in adjusting the focus of a telescope for themselves, would always set it far too short for my own eye, which requires a deep No. 9 concave of Dollond's scale. This obviously arises from an involuntary shortening of the focus of the eye attending the intense effort to see perfectly well while setting the focus. It is well known that such an effort has this tendency; and I cannot doubt that in many instances the projection of stars on the Moon, when the disappearance occurs at the bright limb, arises from this cause. Be this as it may, it is certain that a very adjustable eye soon becomes fatigued by continued observation with a focus much shorter than is suitable to its natural and usual condition; and the adjustment of the telescope will require to be gradually

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lengthened. But when care is taken to avoid any constraint upon the adjusting apparatus of the eye, by the instrumental adjustment being at first rather too long than too short, the eye will quietly accommodate itself, and may work on delicate and difficult objects for many hours together without conscious fatigue; and may continue its efforts from time to time, as from experience I can testify, for half a century with scarcely any perceptible deterioration.

Motion of the Solar System in Space. By E. J. Stone, Esq.

In vol. xxviii of the *Memoirs* of the Society will be found a paper by the Astronomer Royal on the motion of the Solar System in space. The method proposed for the treatment of the subject was new, inasmuch as no *à priori* assumption was made of an approximate position of the apex of the Sun's motion. The method was in this Memoir applied to the discussion of the proper motions of 113 stars. The investigation was afterwards calculated to the discussion of the proper motions of 1167 stars. The calculations for this investigation were made in duplicate at the Royal Observatory. The numbers to which I shall in the present paper refer are extracted from the books of calculation. The direct results of this investigation were presented to the Society in a paper drawn up by Mr. Dunkin, *Memoirs*, vol. xxxii. The resulting position of the apex of solar motion was in agreement with the results of previous investigations; the velocity of solar motion was in fair agreement with the result obtained by Professor Otto Struve. The sum of the squares of the proper motions in parallax and N.P.D. were, however, scarcely diminished by the application of the corrections arising from the supposed solar motion. The comparison, therefore, of the squares of the corrected proper motions and the uncorrected proper motions gave but little evidence in favour of the hypothesis of the motion of the Solar System in space. It has appeared to me that some information for or against the hypothesis of a solar motion in space might be very simply obtained by considering the agreement or disagreement in sign between the proper motions in parallax and N.P.D. and the computed parallactic effects of the assumed solar motion. In this way of looking at the question we are free from any error in the magnitude of the assumed solar motion. The number of stars whose proper motions are discussed in the Greenwich investigation is 1167. If there should be no truth whatever in the assumed proper motion in the Solar System in space, we might expect $\frac{1167}{4}$, or 291 cases, in which the observed proper motions and the computed effects of parallactic displacement would have the same signs in both elements. On an inspection of the books of calculation I find

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