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photographic plate, as the case may be. With a photographic plate ground to a *concave* surface of the proper curvature, there is reason to believe that symmetrical star images may be obtained in a field of the usual angular extent. But this is subject to the objection that the plate will always stop out the central and best part of the pencil.

4. In the SPHERICAL MIRROR the visible image will not coincide with the focus for rays incident at the centre of the mirror unless the angle subtended by the arc of the mirror is supposed to be small relatively to the angle of incidence of the oblique pencil. For the actual conditions of astronomical images the visible field will be the locus of the point F, or locus of the epicycloidal cusps, which are the points of greatest condensation for the respective pencils. For any given pencil the cusp of the caustic lies in the line where the ray is a radius of the spherical surface. Hence the geometric field is a spherical surface concentric with the mirror and having half the radius; and the visible field lies very near it.

5. Evidently a spherical mirror will not give symmetrical images, except near the centre, because it is only at the centre of the field that the visible images are formed by the central part of the mirror. Neither will the sphere give a flat field, though it will give a nearer approach to one than the parabola. Against this advantage we must set off the objection that, except at the centre of the field, its images are not formed by the central part of the mirror.

6. As to the CYCLOIDAL MIRROR, if the preceding analysis be correct, the locus of the cusps of the cycloidal caustic is a plane surface, but the images become unsymmetrical as they recede from the centre of the field. It is not meant to be asserted that the visible field will be a true plane, because the visible field is the locus of the circle of least aberration, which is not identical with the locus of the caustic cusps. But the field will be very nearly a plane surface.

It is right to add that the possibility of obtaining a flat field by reflexion has been doubted by mathematicians of high authority, and it must be left to the reader to form his own opinion of the validity of the reasoning by which the conclusion last announced has been reached.

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## *On some Nebulæ hitherto suspected of Variability or Proper Motion.*

By J. L. E. Dreyer, Ph.D.

The discrepancies met with in comparing observations of nebulæ by different observers are frequently so great that more or less positive assertions have naturally from time to time been made as to variability or changes in the objects. While many of these assertions can at once be dismissed as showing that too

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little regard has been paid to the great difficulties attending observations of nebulæ or to the vast influence of the state of our atmosphere from night to night, others are either founded on undoubted facts or appear at least to others than practised observers of nebulæ to be so. It seems that the only well authenticated cases of change in nebulæ are changes of brightness only, while we *so far* do not possess any clear evidence of change of form or change of place.

The most generally known case of a nebula having disappeared—that of Hind's nebula in *Taurus*—is also the most certain and undisputed one. Chacornac's nebula (G.C. 1191), though only seen by that observer, doubtless also existed in a place where no nebulosity has since been seen; but these two cases are the only ones which are quite certain. It is true that some of William Herschel's nebulæ cannot now be found, but these may either have been comets, or, more probably, some error of observation has vitiated the position he gives for the object in question. The latter case must, *e.g.*, have occurred on April 2, 1801, when he compared a number of nebulæ (among which are three of the first class) with one comparison star, which he identifies as "208 (N) *Camelop.* of Bode's Cat." As not one of these objects can now be found, it is evident that he made a mistake either in identifying the star or in making or recording the observation of it. Another case is G.C. 2179 = I 26, which possibly may be an erroneous observation of the neighbouring M 95. The remarkable nebula at Merope, and a less notable one, G.C. 710, were by d'Arrest and others supposed to be variable, because the difficulty of seeing them with a large aperture made it appear strange that they had been described as conspicuous in small instruments. This difficulty is, however, now universally understood to arise from the use of too high a power with consequent smallness of field; and nobody now suspects these two nebulæ of variability.

I shall not enter into an examination of the numerous instances where observers disagree as to the brightness of an object. Probably atmospheric or instrumental circumstances could in most cases account for this disagreement; but, all the same, the possibility of nebulæ changing in lustre cannot be denied, since we have witnessed the total disappearance of two of them. But I propose to go through all the objects which have been suspected of having changed in form or position, and I trust I shall be able to prove that not one of the cases can be considered as well established.

Most of the nebulæ examined in the following are double nebulæ, which have been suspected of being in motion. They have been collected (from d'Arrest's work) by M. Flammarion in an appendix to his "Catalogue des Étoiles doubles et multiples en mouvement relatif certain." In all cases the suspicion is founded on differences in their relative positions, as recorded by Sir William and Sir John Herschel and by later



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observers, and it does not seem to have been generally noticed that Sir W. Herschel never employed a micrometer, but merely *estimated* the position-angles and distances of neighbouring nebulæ, and that Sir John Herschel did the same from the commencement of his observations, and up to July 5, 1828.* After this date the eye-piece of his 18-inch Reflector was furnished with a wire micrometer, with which, however, only position-angles could be measured, while, as formerly, distances (both of nebulæ and double stars) were only estimated. Even then he frequently estimated angles, in which case they were given only to whole degrees; whenever a decimal is given it shows that the position-angle was measured. Although such estimations should evidently not be used (or at least only with great caution) in drawing conclusions as to orbital or proper motion, I have thought it desirable to re-observe many of the objects with the new 10-inch Refractor at the Armagh Observatory, which I am devoting to micrometric observations of nebulæ. The pair h 444–445 were measured with a filar micrometer; the others with a small micrometer with steel bars instead of spider lines, and requiring no illumination. Although distances measured with the latter kind of micrometer are doubtless subject to systematic errors (which I intend to investigate), their accuracy is quite sufficient for the present purpose.

*Great Nebula in Andromeda.*—The question as to variability of this object, first raised by Le Gentil, has been thoroughly discussed by G. P. Bond in his well-known Memoir, and he comes to the conclusion that the views of Le Gentil are "far from being supported by an amount of evidence adequate to such a conclusion." The nucleus has been drawn or described in a remarkably different manner; by some (*e.g.* Schultz, Schönfeld, Vogel) as starlike, by others at the very same time (*e.g.* Schmidt: see Vogel's note in *Astr. Nachr.* No. 2681) as a very soft and gradual condensation. These strange discrepancies are, however, explained by the valuable experiments made by Dr. Copeland† with different eyepieces, which show what an immense influence the magnifying power has on the appearance of the nucleus, the lower powers making it more starlike, the higher ones more soft-looking and extensive. Whether the new star of 1885 really belonged to the nebula or not does not concern us here; but Dr. Copeland's experiments with artificial stars and different illumination of the field prove that, even if a real change had taken place in the nebula at the time of the outburst, it could not have been detected as long as the star was shining brightly. Since the fading of the star the nebula has quite resumed its former appearance.

III. 228–229 = *h* 251–252.—M. Flammarion remarks that W. Herschel estimates the distance at about 1′, while d'Arrest gives

* See *Mem. R.A.S.*, vol. iv. p. 331.
† *Monthly Notices*, vol. xlvii. p. 60.

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$\Delta\alpha = 8^s$, and estimated (on one occasion) the distance $= 112'' \pm$. There is, however, perfect accordance between J. Herschel and d'Arrest, for the former gives $\Delta\alpha = 7^s{\cdot}5$, while the distance resulting from his positions is $134''$. Both nebulæ are very faint, especially the following one, which d'Arrest describes as "indubitatum nebulæ vestigium, adeo tenue tamen, ut visum ægre sustineat." His estimated distance is too small, as one can see by a glance at his $\Delta\alpha$.

III. 574–575 = *h* 294–295.—While Sir W. Herschel does not say anything about the relative positions of these two very faint objects, Sir John gives the following positions for 1830 (one observation):—

| | h | m | s | ° | ″ | |
|---|---|---|---|---|---|---|
| *h* 294 | 3 | 10 | 25·8 | 49 | 1822 | The *np* of 2. Pos. from the following, which is the largest, 352°·4, dist. 100″. |
| 295 | 3 | 10 | 26·9 | 49 | 1644. | The *nf* of two. |

while according to d'Arrest $\Delta\alpha = 4^s$, the following one being $124''$ *south* of the preceding one. A glance at Sir J. Herschel's positions and remarks shows that no conclusion can be drawn from them. If the first one was "the *np* of 2," the second cannot have been "the *nf* of 2," and if the position-angle of the first one from the second one was 352°·4, the N.P.D. of the first one must have been smaller than that of the second, and not greater. D'Arrest's $\Delta\alpha$ and $\Delta\delta$ give the position-angle of the first one = 339°·9 and the distance = $132''$; but he remarks: "Situs relativi observatio plurimis laborat difficultatibus," so that the difference of 12° between Herschel and d'Arrest is not surprising. Probably Sir John Herschel determined the R.A. and Decl. of the following one, measured the position-angle, estimated the distance, and afterwards from these data made out the $\Delta\alpha$ and $\Delta\delta$, in doing which he accidentally gave the latter the wrong sign, placing the preceding nebula south of the following one, instead of north of it.

II. 8–9 = *h* 316–317.—M. Flammarion says that in 1830 (should be 1827) the position-angle was 30° to 40°; while d'Arrest in 1862 (should be 1863–65) found it = 80°±. This is however not correct, for Herschel says: "Pos. by a drawing made at the time 30° . . . 40° *nf*," which means that he estimated it equal to 60° . . . 50°. At Birr Castle the angle was in 1850 on two nights measured = 77° and 75°·5, and in 1876 = 78°·8. In 1783 Sir W. Herschel determined the places of these two nebulæ, according to which the second one should then have been 1′ *south* of the first one; but as his earliest observations are very inaccurate, no conclusion can be drawn from them. At any rate, the objects were stationary from 1850 to 1876.

*Great Nebula in Orion.*—This object has more frequently than any other nebula been suspected of having varied in form, but on the other hand it has been more thoroughly examined and discussed than any other. From his own observations and his

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examination of the principal monographs, d'Arrest drew the conclusion that "the observed changes in this vast mass of gas seem exclusively to turn out to be temporary fluctuations of brightness,"* and the elaborate discussion of all previous observations in connection with his own led Professor Holden to state "that the figure of the nebula in *Orion* has remained the same from 1758 till now (if we except a change in its apex about 1770, which appears quite possible), but that in the brightness of its parts undoubted variations have taken place, and that such changes are even now going on."†

IV. 25 = *h* 428.—A double star, *h* 749, involved in (or projected on) a fan-shaped nebula. In 1827 the position-angle was estimated = 125°, and the distance 12″; in 1863 d'Arrest estimated them 120° and 4″. There has been no change, as two observations made at Birr Castle in 1874–76 give 119° 11″. But even if there had been a change in the distance of the double star, this could not really be called a change in a nebula. Sir W. Herschel did not notice the duplicity of the star.

II. 316–317 = *h* 444–445.—In the *Astr. Nachr.* No. 1366, d'Arrest called attention to the following remarkable discrepancy between the then existing observation of this fine double nebula:—

| | | | | | |
|---|---|---|---|---|---|
| H | 1785 | Pos. | — ° | Dist. | 60″ |
| *h* | 1827 | „ | 45 | „ | 45 |
| d'A | 1862 | „ | 56·5 | „ | 28·5 |

At first sight this certainly looks like orbital motion. But, unfortunately, Sir John Herschel only estimated the angle and distance, and his two estimates of the latter differ very much *inter se*, being 30″ and 60″. It is, however, only fair to add that d'Arrest merely showed the disagreement without making it out to be a sure case of motion. The following later measures show that the pair have been at rest during the last twenty-five years:—

| | | | | | |
|---|---|---|---|---|---|
| Schultz | 1864-65 | Pos. | 59°·1 | Dist. | 31″·6 (4 nights). |
| Dreyer | 1876 | „ | 53·9 | „ | 27·7 (Birr Castle, 1 night). |
| Dreyer | 1887 | „ | 57·3 | „ | 32·3 (2 nights). |

The two nebulæ are connected (see *Phil. Trans.* 1850, pl. xxxviii., and *Birr Obs.* 1848–78, pl. ii.). The following one is fainter, smaller, and far less condensed in the middle than the preceding one.

*h* 705.—This is a very interesting object: a double star (*h* 2529) with nebulosity attached. In "The Observatory," vol. viii., p. 127, Mr. H. Sadler suggested that here might be a possible case of proper motion in a nebula, since Mr. Burnham

* *Undersögelser over de nebulose Stjerner* (1872), p. 42.
† Holden's *Monograph*. p. 225.

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in 1879–82 saw the nebula "19″ from the principal star," while Sir J. Herschel in 1830–31 said the nebula was about the principal star. It will be well to put together all the observations made by Herschel, both as they are recorded in his fifth list of double stars * and in the *Phil. Trans.* 1833.

| Sweep. | Double Star Obs. | | | | Obs. of Neb. |
|---|---|---|---|---|---|
| 243 | Pos. 95°·3 | Dist. 1″½ | A most curious, delicate, and interesting object. The nucleus of a very faint nebula examined with 320, proves to be distinctly a first-class double star. | | A very close D * of the first class involved in a nebulous wisp. "A most curious, delicate, and interesting object." |
| | ,, 10 8 | ,, 7 | | | |
| 242 | ,, 95·4 | ,, 1 | A nebula strongly suspected about the close double star and a fourth star also suspected. | | A triple star in a nebula, a fourth * suspected. |
| | ,, 8·0 | ,, 7 | | | |
| | ,, 330° ± † | ,, 6 | | | |
| 338 | ,, 7·0 | ,, 18 | A double star in a very faint nebula (a hurried observation). | | A double * in a *v* F nebula. |

In the "Remarks" on the double-star observations (*l.c.* p. 78) Herschel alludes to this object, saying that "a minute and very close double star forms the nucleus of a small round nebula; one or two other small stars in the immediate vicinity seem unconnected with it, but the exactly central position of the double star strongly points to a physical relation between them." It is, however, not to these remarks, written several years afterwards, but to the observations themselves that we must look for evidence of motion. D'Arrest observed the object three times in 1864–65; he saw a star of 10·11 magnitude with a star 13 mag. about 12″ *nnf.*, the latter being the centre of a nebula which reached to the former star. In 1872 the following observation was made at Birr Castle: "Neb. to * 9m Pos. 193°·0, Dist. 19″·7, * 9 to * 12m 243°·3, 8″·8," and in 1876: "Double star, 10·11 and 15·16 mag. 5°·0, 21″, *v* F *neby* round it, E north and south." Mr. Burnham ‡ in 1879 and 1882 saw only the wide pair in Pos. 7°·9, Dist. 19″·0 (and once the faint companion *sp* the brighter star), and remarks, "The nebula is now 19″ from the principal star."

All this does not seem to prove that the nebula has moved away from the close double star, for it is only in the *remarks* that Herschel calls the latter the nucleus of the nebula, while the observation in sweep 243 merely says that it was involved, which is not contradicted by the later observers. Mr. Burnham of

* *Mem. R.A.S.*, vi. p. 32.
† Should be 230°. See d'Arrest and Burnham.
‡ *Mem. R.A.S.* xlvii. p. 270.

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course did not mean that the *edge* of the nebula was 19″ from the close double, but that the nucleus was at that distance, which it is still. Having during the two years elapsed since Mr. Sadler's note appeared quite forgotten all the details about this object, I looked it up on March 15 last on finding it on my working list, and noted :—

"Nebulosity nearly reaches the south * if it does not actually touch it. It is oval in shape, E in the same pos. angle as the two stars. I saw only the two stars, but definition was not particularly good. The north star looks more like a nucleus than a *."

This agrees perfectly with d'Arrest's observations, so that there can have been no "proper motion" between 1865 and 1887, and it may safely be inferred that there has been none since 1830, unless we are to believe in this and similar cases that nebulæ in the good old days moved about as they liked, but have been on their good behaviour since 1861 and kept quiet.

*Great Nebula around η Argûs.*—It is sufficient to refer to the various papers on the alleged discovery of vast changes in this nebula in the *Monthly Notices*, vol. xxxi. There has ever since been perfect unanimity among astronomers that the changes were "altogether imaginary" (*Ibid.* xxxii. p. 178).

I. 248, II. 832 = *h* 983–984.—W. Herschel in 1790 made $\Delta\alpha = 12^s$, giving both nebulæ same N.P.D. In 1832 J. Herschel found $\Delta\alpha = 12^s$, the second nebula being (estimated) 45″ north of the first. In 1866 d'Arrest found $13^s{\cdot}5$ and 57″. "Mouvement certain," says M. Flammarion. On the 27th April last I found Pos. angle = 61°·1, Dist. = 120″·0, or $\Delta\alpha = 14^s{\cdot}0$, $\Delta\delta = 58''$. Both are pretty large and *vgb* M to a very soft-looking nucleus. No change.

III. 394–395 = *h* 1065–1067.—M. Flammarion considers that the position-angle has changed 20° since Sir J. Herschel in 1830 twice estimated it = 70°; while d'Arrest in 1864 on three occasions states that they are on the same parallel. But in 1865 he says that the second one is "pauxillum quid ad boream," and so it is, for at Birr Castle in 1872 it was measured in Pos. 82°·7, Dist. 69″·5, and on April 11 last I found Pos. 79°·5, Dist. 68″·5.

II. 751–752 = *h* 1905.—Two connected nebulæ, the preceding one very little elongated, the following one much so; figured in *Phil. Trans.* 1833, fig. 77 (one observation) and 1861, fig. 31. The late Lord Rosse remarked (*l.c.* p. 704) that in Herschel's drawing the axes of the two nebulæ are in a line; in 1850 Mr. G. Johnstone Stoney found them not to be in a line; in 1855 Mr. Mitchell (at Birr Castle) remarked that the axes were not in a line but were parallel; while in 1861 (when the drawing in P.T. 1861 was made) they were neither in a line nor parallel, but inclined at an angle of 16°. Since then the following observations have been made :—

Birr Castle, 1871. No E of *p* neb noticed, the axis of the *f* neb makes an angle of about 12° by a diagram.

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Birr Castle, 1872. The *f* one E 130°·4 (2 meas.), Pos. of line joining centres 117°·6 (2). The E neb [*f* one] slightly cometic.

Armagh, 1887, April 27. *p* one vvl E, apparently towards *f* one, the latter very diffused and hazy, Pos. of E 128°·4 (2 meas.), therefore difficult to measure; line joining them 120°·2 (2 meas.).

The very hazy look of the two nebulæ, the small amount of elongation of the first one, and the want of sharp condensation in both of them are more than sufficient to account for the disagreement between the various observers.

M 20=V 10, 11, 12=*h* 1991, 3718, the "trifid nebula." This forms the subject of an elaborate monograph by Professor Holden,* in which it is attempted to prove that from 1784 to 1833 the triple star was centrally situated between the three nebulosities, but that from 1839 to 1877 it was involved in the south following mass of nebulosity. The latter proposition rests on a firm basis, as the nebula has been repeatedly examined and drawn with every care since 1839; but this cannot be said about the first proposition. At the Cape of Good Hope, Sir J. Herschel made a drawing in a single night (August 1835), which exhibits the triple star on the very edge of the *sf* nebulosity. A careful drawing made at Slough was lost, and that engraved in P.T. 1883, fig. 80 (which shows the triple star in the midst of a vacuity) was constructed from sketches "the rudest imaginable aided by memory." The other evidence as to the position of the star between 1784 to 1833 consists in various notes by Sir William and Sir John Herschel. But the former never says that the double star was *in the middle of the vacuity*, but in 1784 he describes the object as "three nebulæ faintly joined form a triangle; in the middle is a double star," and in 1786: "a double star with extensive nebulosity of different intensity; about the double star is a black opening." It is quite true that Sir John Herschel on three occasions† states that the star is in the middle of the vacuity. But is it so strange that at an altitude of only 15°, and during the strong twilight of our summer months (sweep 30 was made on July 1, 1826), the nebulosity could not be traced close to a bright double star of the 8·5 and 9th magnitude? It is at any rate curious that the critical time when the alleged motion of the nebula towards the star should have taken place is precisely the moment when we exchange strong twilight, very low altitude, rude sketches for little or no twilight, much higher altitude, and careful drawings.

The drawings made by Mason, Lassell, and Trouvelot differ in many details just as the various drawings of *Orion* do; and very possibly changes of brightness have taken place, both near

* *Am. Journ.* xiv. Dec. 1877.

† *Mem. R.A.S.* ii. p. 490, in a footnote to a paper on the *Orion* nebula, *ibid.* iii. p. 63, in his observations of double stars, and in sweep 30, *Phil. Tr.* 1833, p. 460.

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the double star and in the other part of the nebula; but that the nebula should about 1835 in the course of a few years have *moved* so as to envelop the star, after which no sensible change occurred again so far as published observations go, does not seem sufficiently well proved.

M 17=*h* 2008, *Omega* nebula.—In the *American Journal*, vol. xi., May 1876, Professor Holden published a paper "On Supposed Changes in the Nebula *M* 17," in which he endeavours to show by a comparison of his own observations (made with the Washington 26-inch refractor) with those of J. Herschel, Lamont, Lassell and Trouvelot that the western branch of the Ω has moved relatively to the little group of stars 10, 3, 11 (Lassell) at the *np* end, and particularly with regard to the star No 1 at the *sp* side of the Ω.* The nebulosity is very diffused at the group of stars, yet there is very little difference between the various drawings, but the star 1, on which reliance is chiefly placed, was by J. Herschel in 1837, and Lassell in 1862, found to be on the inner (concave, north following) edge of the curve of the nebula; while Holden and Trouvelot in 1875 placed it well within the nebulosity, in fact preceding nine-tenths of it. A drawing by Le Sueur made in 1869 (*Proc. R. S.* vol. xviii., overlooked by Professor Holden) agrees with the one made at Washington, so that the change should have taken place between 1862 and 1869. But a drawing made by M. Tempel in 1876 with the 11-inch refractor at Arcetri† agrees with the *earlier* drawings in this particular, while two sketches made at Birr Castle in 1854‡ agree with the *later* drawings. There has therefore certainly not been any bodily shifting of the nebula, but the possibility of changes of brightness are not excluded.

II. 426–427=*h* 2087–2089.—M. Flammarion remarks that there is a great disagreement between J. Herschel's and d'Arrest's difference of declination, the former observer making $\Delta\delta = 82''$, the latter $61''$. It should have been stated that it was only on one night that d'Arrest found $\Delta\delta = 59''$ to $63''$, for the mean results of his three nights give $81''$. In 1876 I found at Birr Castle $78''{\cdot}4$ (one measure of pos. and distance).

III. 210–211=*h* 2202–2203.—M. Flammarion repeats a remark of d'Arrest's that J. Herschel in 1828 found $\Delta\alpha = 10^{s}{\cdot}0$ (should be $9^{s}{\cdot}0$) and $\Delta\delta = 37''$, while d'Arrest found $10^{s}{\cdot}5$ and $53''$. But the mean of d'Arrest's results gives $8^{s}{\cdot}2$ and $62''$. This faint pair, between which d'Arrest found a *v* F, *v* S nebula (G.C. 6112), and of which the elongation of the preceding one makes the measurement of $\Delta\delta$ difficult, has been frequently observed of late years, showing no appreciable change.

* See Mr. Lassell's drawing (fig. 32) and skeleton chart (fig. 32 A) in *Mem. R.A.S.* vol. xxxvi.

† See Winnecke's review in *Vierteljahrsschrift d. a. G.* xii. p. 245.

‡ *Observations of Nebulæ*, 1848–78, pl. vi.

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| | | $\Delta\alpha$ (s) | $\Delta\delta$ (″) | |
|---|---|---|---|---|
| D'Arrest | 1861-64 | 8·2 | 62 | 3 nights. |
| Schönfeld | 1861 | 9·72 | 59·5 | 5 „ |
| Schultz | 1863-65 | 9 05 | 61·0 | 3 „ |
| Schönfeld | 1864 | 9·38 | 71·3 | 1 night. |
| Vogel | 1869 | 9·38 | 69·0 | 2 nights. |
| Dreyer | 1877 | 8·92 | 60·7* | 1 night. |
| Dreyer | 1885 | 8·86 | 66·0 | 1 „ |

III. 855-856 = *h* 2294-2295.—These also occur in M. Flammarion's list, because W. Herschel in 1790 *estimated* the position-angle = 60° and the distance 60″, while d'Arrest found 50° and 43″. The objects are both excessively faint, and it would be easy to count up hundreds of similar discrepancies. In 1872 the angle and distance were measured at Birr Castle, and found = 51°·0 and 61″·5.

I have spared no trouble in going through these cases one by one, although in some the evidence was of such a character as hardly to deserve a refutation. I would suggest to anybody who in future should feel inclined to lay a case of proper motion or variability of a nebula before the public, first to peruse the remarks of d'Arrest in the *Astr. Nachr.* vol. lvii. col. 342. In making micrometric observations of these interesting objects we must be content to work for unborn generations, or at least not to expect immediate and startling results, which would look well in popular books.

*Armagh Observatory:*
1887, *May.*

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## *Note on the Effect of Refraction in Stellar Photography.*

By J. L. E. Dreyer, Ph.D.

In his paper read at the April meeting of the Society, Mr. Grubb has assumed that a displacement of 0″·5 is the smallest which would sensibly affect the symmetry of the image of a star on a photographic plate. It is of interest to see how soon refraction will move the image to this extent, assuming the action of the clock to be absolutely perfect and the instrument accurately adjusted.†

The well known expressions for refraction in Right Ascension and Declination, first given by Bessel in the *Monatliche Correspondenz*, xvii. p. 214, are

$$57''\frac{\tan t \sin\psi}{\cos\delta \sin(\psi+\delta)} \text{ and } 57'' \cot(\psi+\delta)$$

* In the single measure of distance at Birr Castle on Oct. 29, 1877, there is an obvious error of one revolution of the screw = 65″·1.

† This question is not considered in Prof. Pickering's valuable paper, "Investigation in Stellar Photography."

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