II. *Experiments for ascertaining how far Telescopes will enable us to determine very small Angles, and to distinguish the real from the spurious Diameters of celestial and terrestrial Objects: with an Application of the Result of these Experiments to a Series of Observations on the Nature and Magnitude of Mr.* Harding's *lately discovered Star. By* William Herschel, *LL.D. F.R.S.*

Read December 6, 1804.

The discovery of Mr. Harding having added a moving celestial body to the list of those that were known before, I was desirous of ascertaining its magnitude; and as in the observations which it was necessary to make I intended chiefly to use a ten-feet reflector, it appeared to me a desideratum highly worthy of investigation to determine how small a diameter of an object might be seen by this instrument. We know that a very thin line may be perceived, and that objects may be seen when they subtend a very small angle; but the case I wanted to determine relates to a visible disk, a round, well defined appearance, which we may without hesitation affirm to be circular, if not spherical.

In April of the year 1774, I determined a similar question relating to the natural eye: and found that a square area could not be distinguished from an equal circular one till the diameter of the latter came to subtend an angle of 2′ 17″. I did not think it right to apply the same conclusions to a telescopic view of an object, and therefore had recourse to the following experiments.

1st *Experiment, with the Heads of Pins.*

I selected a set of pins with round heads, and deprived them of their polish by tarnishing them in the flame of a candle. The diameters of the heads were measured by a microscopic projection, with a magnifying power of 80. These measures are so exact, that when repeated they will seldom differ more than a few ten thousandths parts of an inch from each other. Their sizes were as follows: ,1375 ,0863 ,0821 ,0602 ,0425. I placed the pins in a regular order upon a small post erected in my garden, at 2407,85 inches from the centre of the object mirror of my ten-feet reflecting telescope. The focal length of the mirror on Arcturus is 119,64 inches, but on these objects 125,9. The distance was measured with deal rods.

When I looked at these objects in the telescope, I found immediately that only the smallest of them, at this distance could be of any use; for with an eye-glass of 4 inches, which gives the telescope a magnifying power of no more than 31,5, this pin's head appeared to be a round body, and the view left no doubt upon the subject. It subtended an angle of 3″,64 at the centre of the mirror, and the magnified angle under which I saw it was 1′ 54″,6. This low power however required great attention.

With a lens 3,3, power 38,15, I saw it instantly round and globular. The magnified angle was 2′ 18″,9.

With a magnifying power of 231,8,* I saw it so plainly that

* The powers have been strictly ascertained as they are at the distance where these objects were viewed.

the little notch in the pin's head between the coils of the wire making the head, appeared like a narrow black belt surrounding the pin in the manner of the belts of Jupiter. This notch by the microscopic projection measured ,00475 inch; and subtended an angle, at the centre of the mirror, of 0″,407.

With 303,5 I saw the belt still better, and could follow it easily in its contour.

With 432,0 I could see down into the notch, and saw it well defined within.

With 522,3 the pin's head was a very striking globular object, whose diameter might easily be divided by estimation into ten parts, each of which would be equal to 0″,364.

With 925,6 I saw all the same phenomena still plainer.

The result of this experiment is, that an object having a diameter ,0425 may be easily seen in my telescope to be a round body, when the magnified angle under which it appears is 2′ 18″,9, and that with a high power a part of it, subtending an angle of 0″,364 may be conveniently perceived.

When I considered the purpose of this experiment, I found the result not sufficient to answer my intention; for as the size of the object I viewed obliged me to use a low power, a doubt arose whether the instrument would be equally distinct when a higher should be required. To resolve this question, it was necessary either to remove my objects to a greater distance, or to make them smaller.

2d Experiment, with small Globules of Sealing-wax.

I melted some sealing-wax thinly spread on a broad knife, and dipt the point of a fine needle, a little heated, into it, which took up a small globule. With some practice I soon acquired the art of making them perfectly round and extremely small. To prevent my seeing them at a distance in a different aspect from that in which they were measured under the microscope, I fixed the needles with sealing-wax on small slips of cards before the measures were taken.

Eight of these globules of the following dimensions ,0466 ,0325 ,0290 ,02194 ,0210 ,0169 ,0144 ,00763 were placed upon the post in my garden, and I viewed them in the telescope.

With a power of 231,8 I saw all the first seven numbers well defined, and round, and could see their gradual decrease very precisely from No. 1 to No. 7.

With 303,5 I saw them better, and had a glimpse of No. 8, but could not be sure that I saw it distinctly round; though the magnified angle was 3′ 18″,2.

With 432,0 they are all very palpable objects, and, as a solid body, No. 8 may be seen without difficulty; at the centre of the mirror it subtends an angle of 0″,653. With attention we may also be sure of its roundness; but here the magnified angle is not less than 4′ 42″,1.

With 522,3 I see them all in great perfection as spherical bodies, and the magnitude of No. 7 may be estimated in quarters of its diameters. The angle is 1″,253, and one quarter of it is 0″,313. No. 8 may be divided into two halves with ease; each of which is 0″,327.

With 925,4 I saw No. 8 still better; but sealing-wax is not bright enough for so high a power.

By this experiment it appears, that with a globule so small as ,00763 of a substance not reflecting much light, the magnified angle must be between 4 and 5 minutes before we can see it round. But it also appears that a telescope with a sufficient power, will show the disk of a faint object when the angle it subtends at the naked eye is no more than 0″,653.

3d Experiment, with Globules of Silver.

As the objects made of sealing-wax, on account of their colour, did not appear to be fairly selected for these investigations, I made a set of silver ones. They were formed by running the end of silver wires, the 305th and 340th part of an inch in diameter, into the flame of a candle. It requires some practice to get them globular, as they are very apt to assume the shape of a pear; but they are so easily made that we have only to reject those which do not succeed.

Thirteen of them, in a pretty regular succession of magnitude, were selected and placed upon the post. Their dimensions were ,03956 ,0371 ,0329 ,0317 ,0272 ,0260 ,0187 ,0178 ,0164 ,0125 ,01137 ,00800 ,00556.

For the sake of more conveniency I had removed my telescope from its station in the library to a work-room. The distance of the objects from the mirror of the telescope, measured with deal rods, was here only 2370,5 inches; and the focal length of the mirror, the magnifying powers of the telescope, and the angles subtended by the objects have been calculated accordingly.

With 522,7 I see all the globules, from No. 1 to No. 13, perfectly well, and can estimate the latter in quarters of its diameter. The angle it subtends at the centre of the mirror is 0″,484; and one quarter of it is 0″,121.

With the same power I see the wires which hold the balls, so well that even the smallest of them may be divided into half its thickness. It measures ,00237; the angle is 0″,206; and half of it 0″,103.

With 433,0 I see all the globules of a round form, and can by estimation divide No. 13 into two halves. The magnified angle is here 3′ 29″,0, but as its diameter could by estimation be divided into two parts, the round form of a globule somewhat less might probably have been perceived, so that the magnified angle would perhaps not have much exceeded the quantity 2′ 18″,9 that has been assigned before.

After some time the weather became much overcast, and as the globules were placed over a cut hedge, the leaves and interstices of which did not reflect much light, they received the greatest part of their illumination from above. This made them gradually assume the shape of half moons placed horizontally. The dark part of these little lunes, however, did not appear sensibly less than the enlightened part, so that there could not be any thing spurious about them.

By this experiment we find that the telescope acts very well with a high power, and will show an object subtending only 0″,484 so large that we may divide it into quarters of its diameter.

4th Experiment, with Globules of Pitch, Bee's-wax, and Brimstone.

I had before objected to sealing-wax globules on account of their dingy-red colour; in the last experiment a doubt was raised with regard to the silver ones, because they were perhaps too glossy. In order to compare the effect of different substances together in the same atmosphere, I put up three globules, No. 1 of silver, diameter ,01137; No. 2 of sealing-wax ,01125; No. 3 of pitch ,00653.

With 522,7 I saw No. 1 round, and could estimate $\frac{1}{4}$ of its diameter. The angle is 0″,989; $\frac{1}{4}$ of it is 0″,247.

I saw No. 2 round, but of a dusky-red colour. It is not nearly so bright as No. 1; nor does it appear quite so large as the proportional measure of the globules would require. I can estimate $\frac{1}{3}$ of its diameter. The angle is 0″,979; and $\frac{1}{3}$ of it is 0″,326.

No 3 reflects so little light that I can barely perceive the globule, but not its form; and yet it subtends an angle of 0″,568.

To discover whether this ought to be ascribed intirely to the want of reflection of the pitch, I took up some white melted bee's-wax, by dipping the fine point of a needle perpendicularly into it. This happened to be only half a globule, and its diameter was ,0105.

When I examined the object with 523 I saw it with great ease, and could estimate $\frac{1}{4}$ of its diameter. The angle is 0″,914; and $\frac{1}{4}$ of it is 0″,228. I saw also that it was but half a globule.

I took up another, that I might have a round one; but found that again I had only half a globule. It was so perfectly bisected, that art and care united could not have done it better. Its diameter was ,0108. In the telescope I saw its semiglobular form, and could estimate $\frac{1}{4}$ of its diameter.

By some further trials it appeared, that a perfect globule of this substance could not be taken up, the reason of which it is not difficult to perceive; for as it melts with very little heat, it will cool the moment the needle is lifted up; and the surface, which cools first, will be flat.

The roundness of the objects being a material circumstance, I melted a small quantity of the powder of brimstone, and dipping the point of a needle into it, I found that globules, perfectly spherical and extremely small, might be taken up. I had one of them that did not exceed the 640th part of an inch in diameter.

When four of the following sizes, ,00962 ,009125 ,00475 ,002375 were placed on the post in the garden and viewed from the work-room station with 522,7 I saw No. 1, 2, and 3, round, but No. 4 was invisible.

These globules reflect but little light, so that they are not easily to be distinguished from the surrounding illumination of the atmosphere; but when I placed some dark blue paper a few inches behind them, I then could also perceive No. 4 as a round body. The angle it subtends is 0″,207.

5th Experiment with Objects at a greater Distance.

Having carried the minuteness of the globules as far as appeared to be proper, I considered that a valuable advantage would be gained by increasing the distance of the objects. The experiments might here be made upon a larger scale, and the body of air through which it would be necessary to view the globules would bring the action of the telescope more upon a par with an application of it to celestial objects.

On a tree, at 9620,4 inches from the object mirror of the telescope, I fixed the sealing-wax globules of the 2d experiment. The distance was measured by a chain compared with deal rods, and by calculation the altitude of the objects has been properly taken into the account.

With 502,6 No. 1 is a very large object; so that were I to see a celestial body under the same angle, I could never mistake it for a small star. The angle it subtends is 0″,999.

I see the diameters of No. 2 and 3 very clearly, and can divide them by estimation into two parts, half of No. 3 is 0″,311.

I see No. 4 and 5 as round bodies, but cannot divide them by estimation. The diameter of No. 5 is 0″,45. No. 6 may also be seen, but 7 and 8 are invisible.

These objects reflecting too little light, the silver globules of the 3d experiment were placed on the tree. It will be right to mention that they were all so far tarnished by having been out in the open air for more than a fortnight, that no improper reflection was to be apprehended.

The air being uncommonly clear, I saw with 502,6 the globules No. 1, 2, 3, 4, 5, and 6, as well defined black balls. I could easily distinguish $\frac{1}{4}$ of the diameter of No. 6; which is 0″,139.

With 415,7 I saw them all round as far as No. 10 included.

With 502,6 I saw No. 9 and 10 very sharp and black, and could divide No. 10 into two parts, each of which would be 0″,134.

With a new lens, power 759,7, I saw No. 10 better than with 502,6, and could with ease distinguish it into halves, or even third parts of its diameter. $\frac{1}{3}$ of it is 0″,089.

With 223,1 I saw them all as far as No. 10 included as visible objects, but the smallest of them were mere points. No. 6 might be divided with this power into two parts; each being 0″,279.

With 292,1 I saw No. 10 sharp and round. The magnified angle is only 1′ 18″,3. One half of No. 6 may be perceived with great ease.

The weather being as favourable as possible, I saw with 415,7 the globule No. 10 round at first sight; the magnified angle is 1′ 51″,2. I can see No. 12 steadily round; the angle is 0″,172. It is however a mere point, and divisions of it cannot be made.

With a new 10-feet reflector, power 540, the globule No. 10 is beautifully well defined, and $\frac{1}{2}$ of it may be estimated; the angle is 0″,268; $\frac{1}{2}$ of it is 0″,134.

With the old reflector, and 502,6, I see No. 12 steadily round. No. 7, 11, and 13, have met with an accident, and could not be observed.

6th Experiment with illuminated Globules.

The night being very dark, 8 silver globules, from ,0291 to ,00596 in diameter were placed on the post, and illuminated by a lantern held up against them.

With 522,7 I saw them all perfectly well, but the small quantity of light thrown on them was not sufficient to make angular experiments upon them. As objects I saw them as easily as in the day time. Probably the phases of the illuminated disks I saw might be such as the moon would show when about 9 or 10 days old. The angle of No. 8, had it been full, would have been 0″,519. A better way of illumination might be contrived.

SPURIOUS DIAMETERS OF CELESTIAL OBJECTS.

Observations and Experiments, with Remarks.

July 17, 1779. With a 7-feet reflector, power 280, I saw the body of Arcturus, very round and well defined. I saw also ζ Ursæ majoris and other stars equally round, and as well defined.

REMARKS.

(1.) As these diameters are undoubtedly spurious, it follows that, with the stars, the spurious diameters are larger than the real ones, which are too small to be seen.

Sept. 9, 1779. The two stars of ε Bootis are of unequal diameters; one of them being about three times as large as the other.

(2.) From this and many estimations of the spurious diameters of the stars* it follows, not only that they are of different sizes, but also that under the same circumstances, their dimensions are of a permanent nature.

August 25, 1780. The large star of γ Andromedæ is of a very fine reddish colour, and the small one blue.

(3.) By this and many other observations it appears, that the spurious diameters of the stars are differently coloured, and that these colours are permanent when circumstances are the same.

Nov. 23, 1779. I viewed α Geminorum with a power of 449, and saw the two stars in the utmost perfection. The vacancy between them was about $1\frac{1}{2}$ diameter of the largest. I found when I looked with a lower power, that the proportion between the distance and magnitude of the stars underwent an alteration. With 222, the vacancy was $1\frac{1}{4}$ diameter, and with 112, it was no more than 1 diameter of the smallest of the two stars, or less.

(4.) By many observations, a number of instances of which

* See Catalogues of double Stars. Phil. Trans. for 1782, p. 115; and for 1785, page 40.

may be seen in my catalogues of double stars, their spurious diameters are lessened by increasing the magnifying power, and increase when the power is lowered.

(5.) It is also proved by the same observations, that the increase and decrease of the spurious diameters, is not inversely as the increase and decrease of the magnifying power, but in a much less ratio.

Nov. 13, 1782. The two stars of the double star 40 Lyncis, with a power of 460 are very unequal; and with 227 they are extremely unequal.

(6.) From this we find, that the magnifying power acts unequally on spurious diameters of different magnitudes; less on the large diameters, and more on the small ones.

Aug. 20, 1781. I saw ε Bootis with 460, and the vacancy between the two stars was 1¼ diameter of the large one. I then reduced the aperture of the telescope by a circle of paste-board from 6,3 inches to 3,5, and the vacancy between the two stars became only ½ diameter of the small star.

The proportion of the diameters of the two stars to each other was also changed considerably; for the small one was now at least ⅔ if not ¾ of the large one.

(7.) This shows that when the aperture of the telescope is lessened, it will occasion an increase of the spurious diameters, and when increased will reduce them.

(8.) It also shows that the increase and decrease of the unequal spurious diameters, by an alteration of the aperture of the telescope, is not proportional to the diameters of the stars:

(9.) But that this alteration acts more upon small spurious diameters, and less upon large ones.

Aug. 7, 1783. I tried some excessively small stars near γ

Aquilæ. When γ was perfectly distinct and round, the extremely small stars were dusky and ill defined; the *excessively* small ones were still less defined. As there are stars of all sizes in this neighbourhood, I saw some so very minute, that they only had the appearance of a small dusky spot, approaching to mere nebulosity. By very long attention I perceived many small dusky nebulous spots, which had it not been for this attention might have been in the field of view without the least suspicion.

(10.) From this we find that stars, when they are extremely small, lose their spurious diameters, and become nebulous.

July 7, 1780. I saw the spurious diameter of Arcturus gradually diminished by a haziness of the atmosphere till it vanished intirely.

A more circumstantial account of this observation has already been given; and some other causes that affect the spurious diameter of the stars, have been pointed out in the same paper, such as tremulous air, wind, and hoar-frost.*

January 31, 1783. The star in the back of Columba makes a spectrum, about 5 or 6″ long, and about 2″ broad, finely coloured by the prismatic power of the atmosphere at this altitude.

July 28, 1783. Fomalhaut gives a beautiful prismatic spectrum, on account of its low situation.

July 17, 1781. With a new lens, power between 5 and 6 hundred, I saw ζ Aquarii, and found the vacancy between the two stars exactly 2 diameters. With my old one, power only 460, it was full 2 diameters. As it should have been larger with the high power than with the low one, it shows that the best eye-lens will give the least spurious diameter.

* See Phil. Trans. for 1803, page 224.

Oct. 12, 1782. I tried a new plain speculum, made by a very good workman, and found that when I viewed α Geminorum with 460, the vacancy between the two stars was barely $1\frac{1}{2}$ diameter, but the same telescope and power with my own small speculum, made the distance 2 diameters, so that the figure of this mirror affects the spurious diameters of the stars.

(11.) Hence we may conclude that many causes will have an influence on the apparent diameter of the spurious disks of the stars; but they are so far within the reach of our knowledge, that with a proper regard to them, the conclusion we have drawn in Rem. (2.) "that under the same circumstances "their dimensions are permanent," will still remain good.

SPURIOUS DIAMETERS OF TERRESTRIAL OBJECTS, WITH SIMILAR REMARKS.

7th Experiment with Silver Globules.

A number of silver globules were put on the post, before they had been tarnished; and the sun shone upon them. When I viewed them in the telescope, there was on each of them a lucid appearance resembling the spurious disk of a star. I could distinguish this bright spot from the real diameters of the globules perfectly well, and found it much less than they were.

REM. (1.) Hence we conclude that the terrestrial, spurious disks of globules are less than the real disks; whereas we have seen, in Remark (1.) of the celestial spurious disks, that these are larger than the real ones.

8*th Experiment.*

The luminous spots, or spurious disks of the globules were of unequal diameters. The globule No. 1 had the largest disk, and the smaller ones the least; and the gradation of the sizes followed the order of the numbers.

(2.) This agrees with the spurious disks of celestial objects: the stars of the first, second, and third magnitude having a larger spurious disk than those that are of inferior magnitudes.

9*th Experiment.*

I found that there was a considerable difference in the colour of the spurious disks; one of them was of a beautiful purple colour, another was inclined to orange, a large one was straw coloured, a small one pale-ash coloured, and most of them were bluish-white.

(3.) With respect to colours, therefore, the terrestrial also agree with the celestial spurious disks.

10*th Experiment.*

I made two globules of different diameters, and placed them very near each other, so that their spurious disks might resemble those of a double star; this succeeded perfectly well. I viewed them with different powers.

With 177, the vacancy between them is $\frac{3}{4}$ diameter of the large star.

With 232, it is $1\frac{1}{4}$ diameter.

With 303,8, it is $1\frac{5}{8}$ diameter.

With 432,3, it is $1\frac{3}{4}$.

(4.) This experiment proves that the spurious diameters of the globules are also in this respect like the spurious disks of the stars; for they are proportionally lessened by increasing the magnifying power, and increased when the power is lowered.

(5.) When the estimations are compared with the powers, it will also be seen that the increase and decrease of the spurious disks of the globules is not inversely as the powers, but in a much less ratio.

11th Experiment.

Two other globules of different sizes were examined; and

With 706,3 they were pretty unequal.

With 522,7 they were considerably unequal.

With 303,8 they were very unequal.

(6.) This proves that the effect of magnifying power is unequally exerted on spurious diameters; and that, as with celestial objects, so with terrestrial, this power acts more on the small spurious disks than on the large ones.

12th Experiment.

I viewed a different artificial double star with 522,7, and keeping always the same power, changed the aperture of the telescope.

With the inside rays I found them considerably unequal, and $2\frac{1}{2}$ diameters of the largest asunder. The spurious disks are perfectly well defined, round, and of a planetary aspect.

With all the mirror open, they are also round and well defined.

With the outside rays, they are near 4 diameters of the largest asunder, and are also round and distinct, but surrounded with flashing rays and bright nodules in continual motion.

(7.) This shows that the spurious terrestrial disks, in this respect again resemble those of the stars; increasing when the aperture is lessened, and decreasing when it is enlarged.

13th *Experiment.*

With the same magnifying power 432,3, but a change of aperture, I viewed two equal globules, and two unequal ones.

With the inside rays the equal globules were 1 diameter asunder.

With all the mirror open, they were 1½ diameter asunder.

And with the outside rays they were 2 diameters asunder.

The unequal globules, with the inside rays, were a little unequal, and 1 diameter of the large one asunder.

With the outside rays they were considerably unequal, and 2 diameters of the large one asunder.

(8.) By these experiments it is proved, that the increase and decrease of the diameters occasioned by different apertures is not proportional to the diameters of the spurious disks.

(9.) But that the change of the apertures acts more on the small, and less on the large ones.

14th *Experiment.*

No. 1 of a set of globules, has the largest spurious diameter. No. 3 is larger than No. 2; whereas No. 2 has the largest real diameter. It is inclined to a greenish colour. No. 3 is now reddish, and is larger than No. 1, which is at present less than No. 2. No. 1 grows bigger, and is now the largest.

The sun which had been shining, was obscured by some clouds, but the spurious diameters of the globules I was viewing remained visible, and were almost as bright as when the sun shone upon them.

I saw one of the globules lose its spurious diameter while the sun continued to shine. After some time the spurious diameter came on again, and very gradually grew brighter, but not larger. The colour of one of the globules being of a beautiful purple, changed soon after to a brilliant white.

The sun being obscured by some clouds, a globule lost its spurious diameter, and acquired the shape of an half moon, of the size of the real disk or diameter of the globule. I saw the sun break out again, and the half moon was gradually transformed into a much smaller spurious disk.

(10.) The spurious disks of globules are lost for want of proper illumination, but do not change their magnitude on that account. The brightness of the atmosphere in a fine day is sufficient to produce them; though the illumination of the sun is generally the principal cause of them.

(11.) The diameters of spurious disks are liable to change from various causes; an alteration in the direction of the illumination will make the reflection come from a different part of the globule, which can hardly be expected to be equally polished in its surface, or of equal convexity every where, being very seldom perfectly spherical; but as upon the whole the figure of them is pretty regular, the apparent diameter of the spurious disks will generally return to its former size.

15th Experiment, with Drops of Quicksilver.

At a time of the year when bright sun-shine is not very frequent, I found that my silver globules would seldom give me an opportunity for experiments on spurious disks; to obviate this inconvenience, I used small drops of quicksilver. They are more lucid, and will give a bright spot with very little sunshine. Many of these drops of all sizes were exposed upon a plate of glass, and some on slips of steel. The management of them is a little different from that of the globules. For in order to represent a double star these must be placed one almost behind the other, as otherwise they cannot be brought near enough without running together. The following general observation will include all the necessary particulars.

The bright spots on drops of quicksilver are very small compared to the size of the drops.

They are not proportional to the magnitude of the drops, though less on the small ones and greater on large ones.

In some of the large ones the bright spot is about $\frac{1}{30}$ or $\frac{1}{40}$ of the diameter of the drop.

The magnitude of the luminous spots is liable to changes, but is rather more permanent than with the silver globules.

There is a little difference in the colour of the luminous spots; they are generally of a brilliant white, but sometimes they incline to yellow, and the small ones to ash-colour.

With high magnifying powers they are very well defined, and, on account of their brightness, will bear these powers better than the silver globules.

If M and m, stand for the diameters of the large and small mirror of my telescope, then will an aperture $= \sqrt{\frac{M^2 - m^2}{2} + m^2}$ give half the light of the telescope. With this I examined two of the drops, and found the luminous spots upon them with

925,4 nearly equal, and $2\frac{1}{2}$ diameters of the largest asunder.

706,3 nearly equal, and above 2 diameters of the largest asunder.

432,3 pretty unequal, and 2 diameters of the largest asunder.

177,0 considerably unequal, and $1\frac{1}{4}$ diameter of the largest asunder.

I examined also two other drops, with different apertures, without changing the power, which was 706,3.

With the inside rays they were very little unequal, and $\frac{3}{4}$ diameter of the largest asunder.

With the outside rays they were considerably unequal, and $1\frac{1}{4}$ diameter of the largest asunder.

From what has been said, it appears that all the remarks which have been made with regard to the spurious disks of the silver globules are confirmed by the luminous spots on the drops of quicksilver. There is a difference in the proportion which the spurious disks on quicksilver bear to the drops, and that on the silver globules to the size of the globules; the latter also give a greater variety of colours and magnitudes than those on quicksilver; these are circumstances of which it would be easy to assign the cause, but they can be of no consequence to the result we have drawn from the experiment.

16th Experiment, with black and white Circles.

I tried to measure some of the spurious disks by projecting them on a scale with a moveable index, but found their diameters were too small for accuracy by this method; for this reason I had recourse to artificial measuring-disks, and prepared a set of eleven white circles on a black ground, and eight black ones on a white ground. In order to guard against deceptions, I fixed them up against a tablet 154 inches from the eye, where it was intended to project the spurious disks of the globules, and examined them at that distance with the naked eye. Comparing then the size of the black to the white, I judged No. 1 of the black to be a little larger than No. 6 of the white circles. By a measure taken afterwards, it appeared that the black one was ,40 and the white ,39. Without supposing that every estimation may be made at this distance with equal accuracy, to the hundredth part of an inch, it is sufficiently evident that no material deception can take place in estimating by either of the sets of circles on account of their colour.

17*th Experiment, with different Illumination.*

A similar experiment was made in the microscope, by which the globules were measured. Two of them were placed on the measuring stand, and with an illumination from below, they appeared black, and were projected on white paper. The diameter of each globule and the distance between them were then measured. After this, I caused the illumination to come from above, and the globules being now of a silvery white, were projected on a slate. In this situation, when I repeated the former measures, no difference could be perceived.

18*th Experiment. Measures of spurious Disks.*

The spurious disk of a globule was then projected on the tablet where the white circles were placed. While I was comparing it with No. 4, which is ,31 in diameter and estimated it to be a little less than the circle, the spurious disk grew brighter; but it remained still of the same size; so that a variation in the quantity of the illumination will make no difference.

Every thing being now arranged for the measurement, I viewed the spurious diameter, with a magnifying power of 522,7, and compared it to the circles which succeeded each other by small differences of magnitude.

With all the mirror, from the centre to 8,8 inches open, the diameter of the spurious disk was ,31 inches.

With 6,3 inches open, it was less than ,40 and larger than ,355.

With 5 inches open, it was ,40.

With 4 inches open, it was ,42.

With 3 inches open, it was ,465 nearly.

From these measures it might be supposed that by lessening the quantity of light, we bring on a certain indistinctness which gives more diameter to the spurious object; to prove that this is not the cause of the increase, I used the following apertures.

With an annular opening from 6,5 to 8,8 inches, the spurious disk was rather less than ,18.

With another from 5 to 8,8 it was exactly ,18.

With an opening from 4 to 6,5 it was ,22.

With another from 1,6 to 4 it was ,42.

(12.) Now since the outside rim from 6,5 to 8,8, which reflected less than half the light of the mirror, produced a spurious disk less than ,18 in diameter, and the whole light as we have seen gave a disk of ,31, it is evidently not the quantity of the light, but the part of the mirror from which it is reflected, that we are to look upon as the cause of the magnitude of the spurious disks of objects.

(13.) These measures therefore point out an improvement in my former method of putting any terrestrial disk we suspect to be spurious to the test. For the inside rays of a mirror, as before, will increase the diameter of these disks, but the outside rays alone will have a greater effect in reducing it, than when the inside rays are left to join with them.

19th *Experiment. Trial of Estimations.*

I placed two silver globules at a small distance from each other upon the post, but without measuring either the globules or their distance. When I viewed them with 522,7 they appeared in the shape of two half moons in an horizontal situation. The unenlightened parts of them were also pretty distinctly visible. I estimated the vacancy between the cusps of the lunes to be $\frac{1}{4}$ diameter of the largest.

On measuring the diameters and distance under the microscope, it appeared that the largest was ,0312; a quarter of which is ,0078. The distance of the globules from each other measured ,0111. The difference in the estimation ,0033 is less than $\frac{1}{300}$ part of an inch.

The experiment was repeated with a change of the distance of the globules from each other. They were then estimated to be less than the diameter of the large one asunder, but full that of the small one. When they were measured it was found that their distance was ,02608, and the diameter of the small one was ,0247, which estimation is still more accurate than the former.

20th *Experiment. Use of the Criterion.*

It remained now to be ascertained whether these half moons were spurious or real; for although I could also imperfectly perceive the dark part of the disks of the globules, yet a doubt would arise whether the two halves were really of equal magnitude; to resolve this question, I viewed them first with the inside rays of the mirror, then with the outside, and found that in both cases the distance of the lunes remained without the least alteration. I viewed them also with the whole mirror open, but it occasioned no change.

21*st Experiment. Measures of the comparative Amount of the spurious Diameters, produced by the Inside and Outside Rays.*

I divided the aperture of the mirror into two parts, one from 0 to 4,4 and the other from 4,4 to 8,8 inches. When I measured the spurious diameter of a globule, the inside rays made it ,40; with all the mirror open it was ,31; and with the outside rays it was ,22.

(14.) From this we may conclude that the diameters given by the inside rays, by all the mirror open, and by the outside rays, are in an arithmetical progression; and that the inside rays will nearly double, the diameter given by the outside. It remains however to be ascertained whether this will hold good with spurious disks of various magnitudes.

It will not be necessary to carry the divisions of the aperture farther; for as the application of these experiments is chiefly intended for astronomical purposes, we can hardly do with less than half the mirror open; and on the other hand with a very narrow rim of reflection from the outside of the mirror, distinctness would be apt to fail.

22*d Experiment. Trial of the Criterion on celestial Objects.*

I viewed *α* Lyræ with the outside rays, and found its spurious disk to be small; with all the mirror open it was larger, and with the inside rays it was largest.

As far as the imagination will enable us to compare objects we see in succession, the magnitudes appeared to be in an arithmetical progression.

23d Experiment.

I examined α Geminorum with 410,5, and with the outside rays the stars were considerably unequal, and $1\frac{1}{4}$ diameter of the largest asunder. With all the mirror open they were more unequal, and $1\frac{1}{2}$ diameter of the largest. With the inside rays they were very unequal, and $1\frac{7}{8}$ of the largest asunder.

These experiments show that, if it had not been known that the apparent disks of the stars were spurious, the application of the improved criterion of the apertures would have discovered them to be so; and that consequently the same improvement is perfectly applicable to celestial objects.

OBSERVATIONS ON THE NATURE AND MAGNITUDE OF MR. HARDING'S LATELY DISCOVERED STAR.

It will be remembered that in a former Paper, where I investigated the nature of the two asteroids discovered by Signior PIAZZI and Dr. OLBERS, I suggested the probability that more of them would soon be found out; it may therefore be easily supposed that I was not much surprised when I was informed of Mr. HARDING's valuable discovery.

On the day I received an account of it, which was the 24th of September, I directed my telescope to the calculated place of the new object, and noted all the small stars within a limited compass about it. They were then examined with a distinct high magnifying power; and since no difference in their appearance was perceivable, it became necessary to attend to the changes that might happen in the situation of any one of them. They were delineated as in Fig. 1, (Plate I.) which is a mere eye-draught, to serve as an elucidation to a description given with it in the journal; and the star marked *k*, as will be seen hereafter, was the new object.

Sept. 25. The moon was too bright to see minute objects well, and my description the night before, for the same reason, had not been sufficiently particular; nor did I expect, from the account received, that the star had retrograded so far in its orbit.

Sept. 26. The weather being very hazy, no regular observations could be made; but as I noticed very particularly a star not seen before, it was marked *l* in Fig. 2, and proved afterwards to have been the lately discovered one, though still unknown this evening, for want of fixed instruments.

Sept. 27. I was favoured with Dr. MASKELYNE'S account of the place of the star, taken at the Royal Observatory, by which communication I soon found out the object I was looking for.

Sept. 29. Being the first clear night, I began a regular series of observations; and as the power of determining small angles, and distinctness in showing minute disks, whether spurious or real, of the instrument I used on this occasion, has been sufficiently investigated by the foregoing experiments, there could be no difficulty in the observation, with resources that were then so well understood, and have now been so fully ascertained.

" Mr. HARDING'S new celestial body precedes the very
" small star in Fig. 3, between 29 and 33 Piscium, and is a
" little larger than that star; it is marked A. *f g h* are taken
" from Fig. 1. I suppose *g* to be of about the 9th magnitude,

" so that the new star may be called a small one of the " 8th."

With the 10-feet reflector, power 496,3, I viewed it attentively, and comparing it with *g* and *h*, Fig. 3, could find no difference in the appearance but what might be owing to its being a larger star.

By way of putting this to a trial, I changed the power to 879,4, but could not find that it magnified the new one more than it did the stars *g* and *h*.

" I cannot perceive any disk; its apparent magnitude with " this power is greater than that of the star *g*, and also a very " little greater than that of *h*; but in the finder, and the night-" glass *g* is considerably smaller than the new star, and *h* is " also a very little smaller."

I compared it now with a star which in the finder appeared to be a very little larger; and in the telescope with 879,4 the apparent magnitude of this star was also larger than that of the new one.

" As far as I can judge without seeing the asteroids of Mr. " Piazzi and Dr. Olbers at the same time with Mr. Harding's, " the last must be at least as small as the smallest of the " former, which is that of Dr. Olbers."

" The star *k*, Fig. 1, observed Sept. 24, is wanting, and was " therefore the object I was in search of, which by computation " must have been that day in the place where I saw it."

" The new star being now in the meridian with all those to " which I am comparing it, and the air at this altitude being " very clear, I still find appearances as before described: the " new object cannot be distinguished from the stars by mag-" nifying power, so that this celestial body is a true asteroid."

Mr. BODE's stars 19, 25 and 27 Ceti are marked 7m, and by comparing the asteroid, which I find is to be called Juno, with these stars, it has the appearance of a small one of the 8th magnitude.

With regard to the diameter of Juno, which name it will at present be convenient to use, leaving it still to astronomers to adopt any other they may fix upon, it is evident that, had it been half a second, I must have instantly perceived a visible disk. Such a diameter, when I saw it magnified 879,4 times, would have appeared to me under an angle of 7′ 19″,7, one half of which, it will be allowed, from the experiments that have been detailed, could not have escaped my notice.

Oct. 1. Between flying clouds, I saw the asteroid, which in its true starry form has left the place where I saw it Sept. 29. It has taken the path in which by calculation I expected it would move. This ascertains that no mistake in the star was made when I observed it last.

Oct. 2, 7^h. Mr. HARDING's asteroid is again removed, but is too low for high powers.

8^h 30′. I viewed it now with 220,3 288,4 410,5 496,3 and 879,4. No other disk was visible than that spurious one which such small stars have, and which is not proportionally magnified by power.

With 288,4, the asteroid had a larger spurious disk than a star which was a little less bright, and a smaller spurious disk than another star that was a little more bright.

Oct. 5, with 410,5. The situation of the asteroid is now as in Fig. 4. I compared its disk, which is probably the spurious appearance of stars of that magnitude, with a larger, an equal, and a smaller star. It is less than the spurious disk of the larger, equal to that of the equal, and larger than that of the smaller star. The gradual difference between the three stars is exceedingly small.

" With 496,3, and the air uncommonly pure and calm, I see " so well that I am certain the disk, if it be not a spurious one, " is less than one of the smallest globules I saw this morning " in the tree."

The diameter of this globule was ,02. It subtended an angle of 0″,429, and was of sealing-wax; had it been a silver one, it would have been still more visible.

With 879,4. All comparative magnitudes of the asteroid and stars, remain as with 496,3.

I see the minute double star *q* Ophiuchi * in high perfection, which proves that the air is clear, and the telescope in good order.

The asteroid being now in the meridian, and the air very pure, I think the comparative diameter is a little larger than that of an equal star, and its light also differs from star-light. Its apparent magnitude, however, can hardly be equal to that of the smallest globule I saw this morning. This globule measured ,01358, and at the distance of 9620,4 inches subtended an angle of 0″,214.

When I viewed the asteroid with 879,4 I found more haziness than an equal star would have given: but this I ascribe to want of light. What I call an equal star, is one that in an achromatic finder appears of equal light.

Oct. 7. Mr. HARDING's asteroid has continued its retrograde motion. The weather is not clear enough to allow the use of high powers.

* See Cat. of double Stars, I. 87.

Oct. 8. If the appearance resembling the spurious disks of small stars, which I see with 410,5 in Mr. HARDING'S asteroid, should be a real diameter, its quantity then by estimation may amount to about 0",3. This judgment is founded on the facility with which I can see two globules often viewed for this purpose.

The angle of the first is 0",429, and of the other 0",214; and the asteroid might be larger than the latter, but certainly was not equal to the former.

With 496,3, there is an ill defined hazy appearance, but nothing that may be called a disk visible. When there is a glimpse of more condensed light to be seen in the centre, it is so small that it must be less than two-tenths of a second.

To decide whether this apparent condensed light was a real or spurious disk, I applied different limitations to the aperture of the telescope, but found that the light of the new star was too feeble to permit the use of them. From this I concluded that an increase of light might now be of great use, and viewed the asteroid with a fine 10-feet mirror of 24 inches diameter, but found that nothing was gained by the change. The temperature indeed of these large mirrors is very seldom the same as that of the air in which they are to act, and till a perfect uniformity takes place, no high powers can be used.

The asteroid in the meridian, and the night beautiful. After many repeated comparisons of equal stars with the asteroid, I think it shows more of a disk than they do, but it is so small that it cannot amount to so much as 3-tenths of a second, or at least to no more.

It is accompanied with rather more nebulosity than stars of the same size.

The night is so clear, that I cannot suppose vision at this altitude to be less perfect on the stars, than it is on day objects at the distance of 800 feet in a direction almost horizontal.

Oct. 11. By comparing the asteroid alternately and often with equal stars, its disk, if it be a real one, cannot exceed 2, or at most 3-tenths of a second. This estimation is founded on the comparative readiness with which every fine day I have seen globules subtending such angles in the same telescope, and with the same magnifying power.

" The asteroid is in the meridian, and in high perfection. I " perceive a well defined disk that may amount to 2 or 3-tenths " of a second; but an equal star shows exactly the same ap- " pearance, and has a disk as well defined and as large as that " of the asteroid."

RESULT AND APPLICATION OF THE EXPERIMENTS AND OBSERVATIONS.

We may now proceed to draw a few very useful conclusions from the experiments that have been given, and apply them to the observations of the star discovered by Mr. HARDING; and also to the similar stars of Mr. PIAZZI and Dr. OLBERS. These kind of corollaries may be expressed as follows.

(1.) A 10-feet reflector will show the spurious or real disks, of celestial and terrestrial objects, when their diameter is $\frac{1}{4}$ of a second of a degree; and when every circumstance is favourable, such a diameter may be perceived so distinctly, that it can be divided by estimation into two or three parts.

(2.) A disk of $\frac{1}{4}$ of a second in diameter, whether spurious or real, in order to be seen as a round, well defined body, requires a distinct magnifying power of 5 or 6 hundred, and must be sufficiently bright to bear that power.

(3.) A real disk of half a second in diameter will become so much larger by the application of a magnifying power of 5 or 6 hundred, that it will be easily distinguished from an equal spurious one, the latter not being affected by power in the same proportion as the former.

(4.) The different effects of the inside and outside rays of a mirror, with regard to the appearance of a disk, are a criterion that will show whether it is real or spurious, provided its diameter is more than $\frac{1}{4}$ of a second.

(5.) When disks, either spurious or real, are less than $\frac{1}{4}$ of a second in diameter, they cannot be distinguished from each other; because the magnifying power will not be sufficient to make them appear round and well defined.

(6.) The same kind of experiments are applicable to telescopes of different sorts and sizes, but will give a different result for the quantity which has been stated at $\frac{1}{4}$ of a second of a degree. This will be more when the instrument is less perfect, and less when it is more so. It will also differ even with the same instrument, according to the clearness of the air, the condition, and adjustment of the mirrors, and the practical habits of the observer.

With regard to Mr. HARDING's new starry celestial body, we have shown, by observation, that it resembles, in every respect, the two other lately discovered ones of Mr. PIAZZI and Dr. OLBERS; so that Ceres, Pallas, and Juno, are certainly three individuals of the same species.

That they are beyond comparison smaller than any of the seven planets cannot be questioned, when a telescope that will show a diameter of $\frac{1}{4}$ of a second of a degree, leaves it undecided whether the disk we perceive is a real or a spurious one.

A distinct magnifying power, of more than 5 or 6 hundred, has been applied to Ceres, Pallas, and Juno, but has either left us in the dark, or at least has not fully removed every doubt upon this subject.

The criterion of the apertures of the mirror, on account of the smallness of these objects, has been as little successful; and every method we have tried has ended in proving their resemblance to small stars.

It will appear, that when I used the name asteroid to denote the condition of Ceres and Pallas, the definition I then gave of this term* will equally express the nature of Juno, which, by its similar situation between Mars and Jupiter, as well as by the smallness of its disk, added to the considerable inclination and excentricity of its orbit, departs from the general condition of planets. The propriety therefore of using the same appellation for the lately discovered celestial body cannot be doubted.

Had Juno presented us with a link of a chain, uniting it to those great bodies, whose rank in the solar system I have also defined,† by some approximation of a motion in the zodiac, or by a magnitude not very different from a planetary one, it might have been an inducement for us to suspend our judg-

* See Phil. Trans. for 1802, p. 229, line 10.

† Ibid. page 224, line 3 of the same Paper.

ment with respect to a classification; but the specific difference between planets and asteroids appears now by the addition of a third individual of the latter species to be more fully established, and that circumstance, in my opinion, has added more to the ornament of our system than the discovery of another planet could have done.

Slough, near Windsor,
Dec. 1, 1804.

Fig. 1.

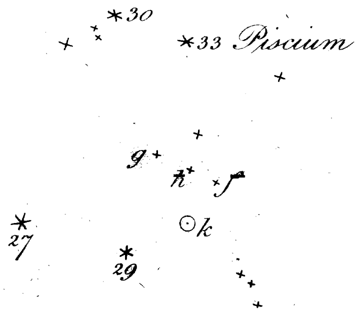


Fig. 2.

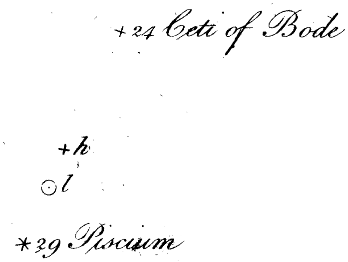


Fig. 3.

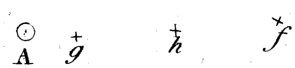
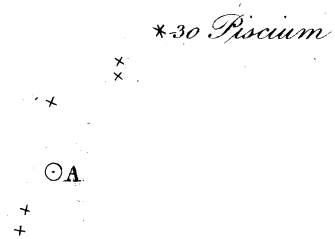


Fig. 4.



Basire sc.