XXIV. *Astronomical observations and experiments tending to investigate the local arrangement of the celestial bodies in space, and to determine the extent and condition of the Milky Way.* *By Sir* William Herschel, *Knt. Guelp. LL. D. F. R. S.*

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THE construction of the heavens, in which the real place of every celestial object in space is to be determined, can only be delineated with precision, when we have the situation of each heavenly body assigned in three dimensions, which in the case of the visible universe may be called length, breadth, and depth; or longitude, latitude, and Profundity.

The angular positions of the stars and other celestial objects, as they are given in astronomical catalogues, and represented upon globes, or laid down in maps, enable us, in a clear night, to find them by the eye or to view them in a telescope; for, in order to direct an instrument to them, a superficial place consisting of only two dimensions is sufficient; but although the line in which they are to be seen is thus pointed out to us, their distance from the eye in that line remains unknown; and unless a proper method for obtaining the profundity of objects can be found, their longitude and latitude will not enable us to assign their local arrangement in space.

With regard to objects comparatively very near to us, astronomers have completely succeeded by the method of parallaxes. The distance of the sun; the dimensions of the

orbits of the planets and of their satellites; the diameters of the sun, the moon, and the rest of the bodies belonging to the solar system, as well as the distances of comets, have all been successfully ascertained. The parallax of the fixed stars has also been an object of attention; and although we have hitherto had no satisfactory result from the investigation, the attempt has at least so far succeeded as to give us a most magnificent idea of the vast expansion of the sidereal heavens, by showing that probably the whole diameter of the earth's orbit, at the distance of a star of the first magnitude, does not subtend an angle of more than a single second of a degree, if indeed it should amount to so much; with regard to more remote objects, however, such as the stars of smaller size, highly compressed clusters of stars and nebulæ, the parallactic method can give us no assistance.

I. *Of the local situation of the stars of the heavens.*

The superficial situation of the stars having already been carefully assigned in the catalogues of astronomers, it will be proper to examine how far the arrangement of the stars into a certain order of magnitudes can assist us to determine their local situation.

When we look at the heavens in a clear night, and observe the different lustre of the stars, we are impressed with a certain idea of their different magnitudes; and when our estimation is confined to their appearance only, we shall be justified in saying, for instance, that Arcturus is larger than Aldebaran; the principle on which the stars are classed is, therefore, entirely founded on their apparent magnitude, or

brightness. Now, as it was thought convenient to arrange all the stars which in fine weather may be seen by the eye into seven classes, the brightest were called of the first, and the rest according to their gradually diminishing lustre, of the 2d, 3d, 4th, 5th, 6th, and 7th magnitudes. Then, since it is evident that we cannot mean to affirm that the stars of the 5th, 6th, and 7th magnitudes are really smaller than those of the 1st, 2d, or 3d, we must ascribe the cause of the difference in the apparent magnitudes of the stars to a difference in their relative distances from us; and on account of the great number of stars contained in each class, we must also allow that the stars of each succeeding magnitude, beginning from the first, are one with another farther from us than those of the magnitude immediately preceding. It may therefore be said, that since in our catalogues the magnitudes are added to the two dimensions which give the superficial place of the stars, we have also at least a presumptive value of the third dimension; but admitting that the naked eye can see stars as far from us as those of the seventh magnitude, this presumptive value, which can only point out their relative situation, will afford us no information about the real distance at which they are placed.

II. *Of a standard by which the relative arrangement of the stars may be examined.*

It is evident, that when we propose to examine how the stars of the heavens are arranged, we ought to have a certain standard of reference; and this I believe may be had by comparing their distribution to a certain properly modified equality of scattering. Now, the equality I shall here propose,

does not require that the stars should be at equal distances from each other; nor is it necessary that all those of the same nominal magnitude should be equally distant from us. It consists in allotting a certain equal portion of space to every star, in consequence of which we may calculate how many stars any given extent of space should contain. This definition of equal scattering agrees so far with observation, that it admits, for instance, Sirius, Arcturus, and Aldebaran to be put into the same class, notwithstanding their very different lustre will not allow us to suppose them to be at equal distances from us; but its chief advantage will be, that instead of the order of magnitudes into which our catalogues have arranged the stars, it will give us an order of distances, which may be used for ascertaining the local distribution of the heavenly bodies in space.

To explain this arrangement, let a circle be drawn with any given radius about the point S fig. 1, Plate XV. and with 3, 5, 7, 9, &c. times the same radius draw circles, or circular arcs, about the same centre. Then if a portion of space equal to the solid contents of a sphere, represented by the circle S, be allotted to each star, the circles, or circular arcs drawn about it will denote spheres containing the stars of their own order, and of all the orders belonging to the included spheres, and on the supposition of an equality of scattering, the number of stars of any given order may be had by inspection of the figure, which contains all the numbers that are required for the purpose; for those in front of the diagram express the diameters of spherical figures. The first row of numbers enclosed between the successive arcs, are the cubes of the diameters; the next column expresses the order

of the central distances; and the last gives the difference between the cube numbers of any order and the cube of the next enclosed order.

The use to be made of these columns of numbers is by inspection to determine how many stars of any particular order there ought to be if the stars were equally scattered. For instance, let it be required how many stars there should be of the 4th order. Then No. 4, in the column of the orders points out a sphere of nine times the diameter of the central one, and shows that it would contain 729 stars; but as this sphere includes all the stars of the 3d, 2d, and 1st order as well as the sun, their number will be the sum of all the stars contained in the next inferior sphere amounting to 343; which being taken from 729 leaves 386 for the space allotted to those of the 4th order of distances.

III. *Comparison of the order of magnitudes with the order of distances.*

With a view to throw some light upon the question, in what manner the stars are scattered in space, we may now compare their magnitudes, as we find them assigned in Mr. Bode's extensive catalogue of stars, with the order of their distances which has been explained.

The catalogue I have mentioned contains 17 stars of the 1st magnitude; but in my figure of the order of the distances we find their number to be 26.

The same catalogue has 57 stars of the 2d magnitude; but the order of distances admits 98.

Of the third magnitude the catalogue has 206, and the order of distances will admit 218.

The number of the stars of the 4th magnitude is by the catalogue 454, and by the order of distances 386.

Before I proceed, it may be proper to remark, that, by these four classifications of the stars into magnitudes, it appears already, that, on account of the great difference in the lustre of the brightest stars, many of them have been put back into the second class; and that the same visible excess of light has also occasioned many of the stars of the next degree of brightness to be put into the third class; but the principle of the visibility of the difference in brightness would have less influence with the gradually diminishing lustre of the stars, so that the number of those of the third magnitude would come nearly up to those of the third distance. And as the difference in the light of small stars is less visible than in the large ones, we find that the catalogue has admitted a greater number of stars of the 4th magnitude than the 4th order of distances points out; this may, however, be owing to taking in the stars that were thrown back from the preceding orders; and a remarkable coincidence of numbers seems to confirm this account of the arrangement of the stars into magnitudes. For the total number of the catalogued stars of the 1st, 2d, 3d, and 4th magnitudes, with the addition of the sun, is 735; and the number contained in the whole sphere of the 4th distance is 729.

Now the distinguishable difference of brightness becoming gradually less as the stars are smaller, the effect of the principle of classification will be, as indeed we find it in the 5th, 6th, and 7th classes, that fainter stars must be admitted into them than the order of distances points out.

The catalogue contains 1161 stars of the 5th magnitude, whereas the 5th order of distances has only room for 602.

Of the 6th magnitude the catalogue contains not less than 6103 stars, but the 6th order of distances will admit only 866.

And lastly, the same catalogue points out 6146 stars of the 7th magnitude, while the number of stars that can be taken into the 7th order of distances is only 1178.

The result of this comparison therefore is, that if the order of magnitudes could indicate the distance of the stars, it would denote at first a gradual, and afterwards a very abrupt condensation of them; but that, considering the principle on which the stars are classed, their arrangement into magnitudes can only apply to certain relative distances, and show that taking the stars of each class one with another, those of the succeeding magnitudes are farther from us than the stars of the preceding order.

IV. *Of a criterion for ascertaining the Profundity, or local situation of celestial objects in space.*

It has been shown that the presumptive distances of the stars pointed out by their magnitudes can give us no information of their real situation in space. The statement, however, that one with another the faintest stars are at the greatest distance from us, seems to me so forcible, that I believe it may serve for the foundation of an experimental investigation.

It will be admitted, that the light of a star is inversely as the square of its distance; if therefore we can find a method

by which the degree of light of any given star may be ascertained, its distance will become a subject of calculation. But in order to draw valid consequences from experiments made upon the brightness of different stars, we shall be obliged to admit, that one with another the stars are of a certain physical generic size and brightness, still allowing that all such deviations may exist, as generally take place among the individuals belonging to the same species.

There may be some difference in the intrinsic brightness of starlight: that of highly coloured stars may differ from the light of the bluish white ones; but in remarkable cases allowances may be made.

With regard to size, or diameter, we are perhaps more liable to error; but the extensive catalogue which has already been consulted, contains not less than 14,144 stars of the seven magnitudes that have been adverted to; it may therefore be presumed that any star promiscuously chosen for an experiment, out of such a number, is not likely to differ much from a certain mean size of them all.

At all events it will be certain that those stars the light of which we can experimentally prove to be $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$, $\frac{1}{25}$, $\frac{1}{36}$, and $\frac{1}{49}$ of the light of any certain star of the 1st magnitude, must be 2, 3, 4, 5, 6, and 7 times as far from us as the standard star, provided the condition of the stars should come up to the supposed mean state of diameter and lustre of the standard star, and of this, when many equalisations are made, there is at least a great probability in favour.

V. *Of the equalisation of starlight.*

In my sweeps of the heavens, the idea of ascertaining the

Profundity of space to which our telescopes might reach, gave rise to an investigation of their space penetrating power; and finding that this might be calculated with reference to the extent of the same power of which the unassisted eye is capable, there always remained a desideratum of some sure method by which this might be ascertained.

Of various experiments I have long ago tried, the equalisation of starlight, which about four years ago I began to put into execution, appeared to be the most practicable. A description of the apparatus and the method of making use of it is as follows.

Of ten highly finished mirrors I selected two of an equal diameter and focal length, and placed them in two similarly fitted up seven feet telescopes. When they were completely adjusted, I directed them both, with a magnifying power of 118, to the same star, for instance, Arcturus: and upon trial I found the light not only of this, but of every other star to which they were directed, perfectly equal in both telescopes.

The two instruments, when I viewed the stars, were placed one a little before the other, and so near together that it would require little more than one second of time to look from one into the other. This convenient situation of the instruments is of great importance. The impression of the light made by the view of one star should be succeeded as soon as possible by the view of the other; and these alternate inspections should also be many times repeated, in order to take away some little advantage which the last view of a bright object has over that immediately preceding.

In comparing the light of one star with that of another, I laid it down as a principle, that no estimation but that of per-

fect equality should be admitted; and as the equal action of the instruments was now ascertained, I calculated the diameters of several apertures to be given to one of the telescopes as a standard, so that the other, called the equalising telescope, might be employed, with all its aperture unconfined, to examine a variety of stars, till one of them was found whose light was equal to that of the star to which the standard telescope was directed.*

In order to be sufficiently accurate in the calculation of the diameter of the limiting apertures, I thought it necessary to take into consideration not only the obstruction of incident light occasioned by the interposition of the small mirror, but also of the arm to which it is fastened, and proceeded as follows:

If A be the diameter of the large mirror; b that of the small one; $\frac{A-b}{2}$ the length of the arm; t its thickness; π the circumference, diameter being unity; x an assumed quantity for finding the correction; A′ the aperture corrected for the interposition of the arm; L the light of the equalising telescope; p the proportion of the light required for the standard telescope; D the diameter of an aperture to give that light; D′ the diameter corrected for the interposition of the arm.

Then will the diameters of the limiting apertures be had by the following equations. $\frac{A-b}{2} \times t = \pi A x$; $\frac{A-b}{\pi A} \times t = 2x$; $A - 2x = A'$; $A'^2 - b^2 = L$; $pL = D^2 - b^2$; $\sqrt{pL + b^2} = D$; $\frac{D-b}{\pi D} \times t = 2y$; $D + 2y = D'$ the required diameter.

* I preferred the limitation of the light by circular apertures to the method of obtaining it by the approach or recess of two opposite rectangular plates, in order to avoid the inflections which take place in the angles.

In the calculation of a set of apertures for the intended purpose, I admitted none that gave less than $\frac{1}{4}$ of the light; for by a greater contraction of the aperture of the mirror, an increase of the spurious diameters would render a judgment of equality liable to deception;† when therefore a star of the third order of distances was to be found, I rejected the direct way of reducing a star of the first order to $\frac{1}{9}$ of its light, but selected a star previously ascertained to be of the second order; and by taking $\frac{4}{9}$ of its light, the equalising telescope, with all its light, was used to examine all such stars as appeared likely to give the required equality, till one of them was found; nor was it necessary to have a great number of limiting apertures, as it soon appeared that with eight or ten of them I could have many different gradations of light, which would ascertain even fractional degrees, and reach as far as the stars of any order of distances I could expect to be visible to the unassisted eye.

This method of equalising the light of the stars, easy as it may appear, is nevertheless subject to great difficulties; for as the brightness of a star is affected by its situation, with regard to the ambient light of the heavens, the stars to be equalised should, if possible, be in nearly the same region. When the sun is deep under the horizon, this is however not of so much consequence as the altitude of the star to be equa-

† This was fully proved by the following experiment. July 27, 1813, I viewed Arcturus in a 10 feet reflector; first with all its light; next with circular diaphragms, which confined its aperture to $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$, $\frac{1}{25}$, $\frac{1}{36}$, and $\frac{1}{49}$ of it; but I found that the different spurious diameters, arising from the smallness of the apertures, made estimations of what is generally called the magnitude of the stars impossible.

See also experiments on the spurious diameters of the celestial objects, Phil. Trans. for 1805, page 40.

lised, which ought to be as nearly as possible equal to that of the standard star. At great elevations some difference in the altitudes of the stars to be equalised may be admitted; but, if they are far from each other, the circumstance of the equal illumination of the heavens, and the equal clearness of the air, must still be attended to.

VI. *Of the extent of natural vision.*

The method of equalising star light may be rigorously applied to ascertain the extent of natural vision; for in this case it will not be required that the star on which the experiment is tried, should be of the same size or diameter with the standard star; nor is it necessary that the intrinsic brightness of the light of the two stars should be the same in both. It will be sufficient, that the star we choose for an equalisation is one of the smallest that are still visible to the natural eye. It is also to be understood that, till we can have a well ascertained value of the parallax of any one star of the first magnitude, the extent of natural vision can only be given in a measure of which the distance of the standard star is the unit.

The following equalisations were made in August and December 1803, and February 1814, and are given as a specimen of the method I have pursued.

Taking Arcturus for the standard of an experiment, I directed the telescope, with one quarter of its light, upon it; while the equalising telescope, with all its light, was successively set upon such stars as I supposed might be at double the distance of the standard star; which, as Arcturus is a star

of the first magnitude, I expected to find among those of the second.

The first I tried was β (Fl. 53) Pegasi, but I found it not quite bright enough.

The light of α Andromedæ, which next I tried, was nearly equalised to that of Arcturus; and the observation being repeated on a different night gave it equal.

Now as in these experiments the standard star is supposed to be one of the first order of distances, it follows that, if Arcturus were put at twice its distance from us, it would then appear like α Andromedæ, as a star of the 2d magnitude, and would also at the same time be really a star of the 2d order of distances.

In order to obtain some other stars whose light might be equalised by one quarter the light of Arcturus, I tried many different ones, and found among them α Polaris, γ Ursæ, and δ Cassiopeæ. These stars therefore may also be put into the class of those whose light is equal to the stars of the second order of the distance of Arcturus.

For the purpose of ascertaining the extent of natural vision, it will not be necessary here to give the equalisation of stars of the 3d, 5th, 6th, or 7th order of distances; but taking now the light of one of the stars of the 2d order of distances for a standard, I tried many that might be expected to have the required light, and found that when α Andromedæ, with its light reduced to one quarter, was in the standard telescope, the equalising one gave μ (Fl. 48.) Pegasi for a star of the 4th order of distances. That is to say, the equalisation proved that, if Arcturus were placed at four times its distance from

us, we should see it as a star of the 4th magnitude, and also as one of the 4th order of distances.

Proceeding in the same manner with μ Pegasi taken as a standard, I found that its light reduced to $\frac{1}{4}$ was equal to that of *q* (FL. 70.) Pegasi, when seen in the equalising telescope; and that consequently Arcturus, removed to 8 times its present distance from us, would put on the appearance of a star which in our catalogues is called of the 5th or 6th magnitude, but which would in fact be of the 8th order of distances.

As the foregoing experiments can only show that a star of the light of Arcturus might be removed to 8 times its distance, and still remain visible to the naked eye as a star of between the 5th and 6th magnitude; it will be proper to take also other stars of the first magnitude for the original standards.

For instance, if we begin from Capella as the standard star, we may with $\frac{1}{4}$ of its light equalise β Aurigæ and β Tauri, which stars will therefore be of the 2d order of distances. With $\frac{1}{4}$ of the light of β Tauri we equalise ζ Tauri and ι Aurigæ; they will then be of the 4th order. With $\frac{1}{4}$ of the light of ι Aurigæ we can equalise *e* Persei and H Geminorum which will be of the 8th order. And with $\frac{16}{25}$ of the light of H Geminorum we equalise *d* Geminorum, which makes it a star of the 10th order. That is to say, if Capella were successively removed to 2, 4, 8 and 10 times the distance at which it is from us, it would then have the appearance of the stars which have been named.

A similar deduction may be made from α Lyræ, as $\frac{1}{4}$ of its light equalises it with β Tauri; for it will be α Lyræ 1, β Tauri 2, ι Aurigæ 4, H Geminorum 8, and *d* Geminorum 10: the

numbers annexed to the stars expressing their orders of distances in terms of the distance of α Lyræ from us.

To find stars of the intermediate orders of distances, the following Table gives the proportional light that should be used with the star which is made the standard; for instance, a star of the 2d order of distances, with $\frac{4}{9}$ of its light, will equalise a star of the 3d order; $\frac{9}{25}$ of the light of a star of the 3d order of distances will give one of the 5th order, and so on.

A star of the order of distances.	With the proportion of its light.	Gives one of the order of distances.
1	$\frac{1}{4}$	2
2	$\frac{4}{9}$	3
	$\frac{1}{4}$	4
3	$\frac{9}{25}$	5
	$\frac{1}{4}$	6
4	$\frac{16}{49}$	7
	$\frac{1}{4}$	8
5	$\frac{25}{81}$	9
	$\frac{1}{4}$	10
6	$\frac{36}{121}$	11
	$\frac{1}{4}$	12

Some other proportions of light useful for fractional distances are $\frac{9}{16}$, $\frac{16}{25}$, $\frac{36}{49}$, $\frac{64}{81}$, and $\frac{100}{121}$.

The results of equalisations that are made with different standard stars, may be connected together by an equalisation of the standards; by which means many different sets may be brought to support each other. For instance, Capella with $\frac{36}{49}$ of its light is of an equal lustre with Procyon, which therefore is of the $1\frac{1}{6}$ order of Capella, and Sirius with

$\frac{16}{49}$ of its light is also of an equal lustre with Procyon, which consequently, with regard to Sirius, is of the $1\frac{3}{4}$ order; then, by compounding, it follows that Capella to Sirius is a star of the $1\frac{1}{2}$ order, and from this we obtain the following series. Sirius 1, Capella $1\frac{1}{2}$, Procyon $1\frac{3}{4}$, β Tauri 3, ι Aurigæ 6, H Geminorum 12, and *d* Geminorum 15. By this connection we shall be able to obtain an equalisation of the same ultimate star with all the standards; for if Sirius must be removed to the 15th order, to appear as faint as *d* Geminorum; and if Capella, and also α Lyræ must be removed to the 10th order of distances to appear as faint as the same star, then any star of the size and brightness of Sirius, Capella, and α Lyræ must generally appear as faint as *d* Geminorum, when it is removed to nearly 12 times its distance; and the more stars of the first order are admitted in these general equalisations reduced to the same faint star, the more will the probability of the result be extended. Now as *d* Geminorum is a star of the 6th magnitude, we may expect that a still fainter visible star will give a somewhat greater extent to the reach of the natural eye, if however I take its vision, including other stars of the 1st magnitude, to extend to the 12th order of distances, there will probably be no material error, at least none but what a diligent astronomer, who is provided with the necessary apparatus, may correct by observation.

But the extent of natural vision is not limited to the light of solitary stars only; the united lustre of a number of them will become visible when the stars themselves cannot be seen. For instance, the milky way; the bright spot in the sword handle of Perseus; the cluster north of η and H Geminorum; the cluster south of FL. 6 and 9 Aquilæ; the clus-

ter south of η Herculis, and the cluster north preceding ε Pegasi. But their distances cannot be ascertained by the method of equalising starlight: their probable situation in space may however be deduced from telescopic observations.

To these very faintly visible objects may be added two of a different nature, namely, the nebulosity in the sword of Orion, and that in the girdle of Andromeda.

VII. *Of the extent of telescopic vision.*

The powers of telescopes to penetrate into the Profundity of space is the result of the quantity of light they collect and send to the eye in a state fit for vision. The method of calculating the quantity of this power has been fully explained in a Paper read before the Royal Society, November 21, 1799; and the formulæ which have been given in that Paper have already been applied to show to what extent this power has been carried in the telescopes I used for astronomical observations. The calculated results, however, give this power only in reference to that of natural vision, and the uncertainty in which we were left with regard to its extent, was equally thrown over that of telescopic vision.

The equalisation of starlight, when carried to a proper degree of accuracy, will do away the cause of the error to which the telescopic extent of vision has been unavoidably subject, we may therefore safely apply this vision to measure the Profundity of sidereal objects that are far beyond the reach of the natural eye; but for this purpose the powers of penetrating into space of the telescopes that are to be used must be reduced to what may be called gaging powers; and as

the formula $\frac{\sqrt{x \cdot \overline{A^2 - b^2}}}{a}$* gives the whole quantity of the space penetrating power, a reduction to any inferior power p, may be made by the expression $\sqrt{\frac{p^2 a^2}{x} + b^2} = A$; when the aperture is then limited to the calculated value of A, the telescopes will have the required gaging power. Or we may prepare a regular set of apertures to serve for trials, and find the gaging powers they give to the telescope by the original formula.

In the formula by which the required apertures for the gaging powers were calculated, a has been put equal to two tenths of an inch, and to show that this assumption is founded upon observation, I give the following extract from my astronomical Journal.

Dec. 27, 1801. I looked at α Lyræ with one eye shut and the other guarded by a slip of brass with holes of various sizes in it. Through the hole which was 0 28 inch in diameter, I saw the star just as well as without the limiting diaphragm, which shows that the opening of the pupil of the eye does not exceed 0.28 inch.

I tried the same star through 0.24 and still saw it equally well. I tried next 0.21 and still saw it as well.

The slip of brass was held as close to the eye as possible. The next I tried was 0.17 in diameter, and through this I could perceive a small deficiency of light, so that the opening of the pupil exceeds 0.17 inch. The night is hardly dark enough yet for great accuracy.

Having been out long in the dark, and trying the same

* See Phil. Trans. for 1800, page 66.

experiment upon many different large and small stars, they all concur to show that 0.21 does not sensibly stop any light; but that less does certainly render the object rather less luminous; so that the opening may be put at two-tenths of an inch in my eye.

VIII. *Application of the extent of natural and telescopic vision to the probable arrangement of the celestial bodies in space.*

When the extent of natural and telescopic vision is to be applied to investigate the distance of celestial objects, the result can only have a high degree of probability; for it will then be necessary to admit a certain physical generic size and brightness of the stars. But when two hypotheses are proposed to explain a certain phenomenon, that which will most naturally account for it ought to be preferred as being the most probable. Now as the different magnitudes of the stars may be ascribed to a physical difference in their size and lustre, and may also be owing to the greater distance of the fainter ones, we cannot think it probable that all those of the 5th, 6th and 7th magnitude, should be gradually of a smaller physical construction than those of the 1st, 2d, and 3d; but shall, on the contrary, be fairly justified in concluding that, in conformity with all the phenomena of vision, the greater faintness of those stars is owing to their greater distance from us. The average size and brightness of several stars of the first magnitude being also taken as a standard, in the manner that has been shown, the conclusion drawn from different series of equalisations will support one another; so that we shall be able to say a distant celestial object is so far from us,

provided the stars of which it is composed are of a size and lustre equal to the size and lustre of such stars as Sirius, Arcturus, Capella, Lyra, Rigel, and Procyon, &c.

I proceed now to consider some conclusions that may be drawn from a known extent of natural vision, a very obvious one of which is, that all the visible stars are probably contained within a sphere of the 12th order of distances. Now as on the principle of equal scattering, we should see about 15625 of them, it may be remarked that the stars of the catalogue, including all those of the 7th magnitude, amount to 14144, which agrees sufficiently well with the calculated number; but the next inference is, that if they were equally scattered, there would be 2402 of the 10th, 2906 of the 11th, and 3458 of the 12th order of distances, which added together amount only to 8766, whereas the number of stars of the 6th and 7th magnitudes that must come into these three orders, is not less than 12249, which would indicate that the stars in the higher order of distances are more compressed than they are in the neighbourhood of the sun; but from astronomical observations, we also know that the stars of the 6th and 7th magnitude are very sparingly scattered over many of the constellations, and that consequently the stars which belong to the 10th, 11th, and 12th order of distances, are not only more compressed than those in the neighbourhood of the sun, but that moreover their compression in different parts of the heavens must be very unequal.

IX. *Of the construction and extent of the milky way.*

Of all the celestial objects consisting of stars not visible to the eye, the milky way is the most striking; its general

appearance, without applying a telescope to it, is that of a zone surrounding our situation in the solar system, in the shape of a succession of differently condensed patches of brightness, intermixed with others of a fainter tinge.

To enumerate a partial series of them, we have a very bright patch under the arrow of Sagittarius; another in the Scutum Sobiescii; between these two there are three unequally bright places; north preceding α β and γ Aquilæ is a bright patch; between Aquila and the Scutum are two very faint places; a long faint place follows the shoulder of Ophiucus; near β Cygni is a bright place; near γ is another, and a third near α. A smaller brightish place follows in the succession of the milky way, and a large one towards Cassiopea. A faint place is on one side; a second towards Cassiopea, and a third is within that constellation; a very bright place is in the sword handle of Perseus; and α and γ Cassiopeæ inclose a dark spot.

The breadth of the milky way appears to be very unequal. In a few places it does not exceed five degrees; but in several constellations it is extended from ten to sixteen. In its course it runs nearly 120 degrees in a divided clustering stream, of which the two branches between Serpentarius and Antinous are expanded over more than 22 degrees.

That the sun is within its plane may be seen by an observer in the latitude of about 60 degrees; for when at 100 degrees of right ascension the milky way is in the east, it will at the same time be in the west at 280; while in its meridional situation it will pass through Cassiopea in the Zenith, and through the constellation of the cross in the Nadir.

From this survey of the milky way by the eye I shall now

proceed to show what appears to be its construction by applying to it the extent of telescopic vision; but as I had prepared a gradually increasing series of reductions of the space-penetrating powers of my instruments for the purpose of measuring the Profundity of sidereal objects not visible to the eye, which I have called gaging powers, it will be necessary to give the following account of it.

From the formula which has been given, I calculated a set of apertures, which by limiting the light of the finder of my seven feet reflector would reduce its space-penetrating power to the low gaging powers 2, 3, and 4. I then limited in the same manner the space-penetrating power of my night glass, by using calculated apertures such as would give the gaging powers 5, 6, 7 and 8. From the space-penetrating power of the 7 feet reflector, I obtained by limitation the successive gaging powers 9, 10 and upwards to 17. And lastly, by limiting the space-penetrating power of my 10 feet reflector, I carried the gaging powers from 17 to 28.

For the purpose of trying these powers, I selected the bright spot in the sword handle of Perseus, as being probably a protuberant part of the milky way, in which it is situated. Its altitude at the time of observation was about 30 degrees, and no star in it was visible.

In the finder with the gaging power 2, I saw many stars; and admitting the eye to reach to stars at the distance of the 12th order, we may conclude that the small stars which were visible with this low power, are such as contribute to the brightness of the spot, and that their situation is probably from between the 12th to the 24th order of distances; at least we are certain, that if stars of the size and lustre of

Sirius, Arcturus, Capella, &c. were removed into the Profundity of space which I have mentioned, they would then appear like the stars I saw with the gaging power of the finder. I then changed this power from 2 to 3, and saw more stars than before; and changing it again from 3 to 4, a still greater number of them became visible. The situation of these additional stars was consequently between the 24th, 36th, and 48th order of distances.

With the gaging power 5 of the night glass I saw a great number of stars; with 6, more stars and whitishness became visible; with 7, more stars with resolvable whitishness were seen; and with 8, still more. The stars that gradually made their appearance, therefore, were probably scattered over the space between the 48th and 96th order of distances.

In the 7 feet reflector, with the gaging powers 9 and 10, I saw a great number of stars; with 11 and 12, a greater number of stars and resolvable whitishness were seen; with 13 and 14, the number of visible stars was increased, and was so again with 15; with 16 and 17 in addition to the visible stars, there were many too faint to be distinctly perceived. These gages therefore extend the space over which the additional stars were scattered from the 96th to the 204th order of distances.

With a 10 feet reflector, reduced to a gaging power of 18, I saw a great number of stars: they were of very different magnitudes, and many whitish appearances were so faint that their consisting of stars remained doubtful. The power 19, which next I used, verified the reality of several suspected stars, and increased the lustre of the former ones. With 20, 22, and 25, the same progressive verifications of suspected

stars took place, and those which had been verified by the preceding powers, received subsequent additional illumination. With the whole space-penetrating power of the instrument, which is 28.67, the extremely faint stars in the field of view acquired more light, and many still fainter suspected whitish points could not be verified for want of a still higher gaging power. The stars which filled the field of view were of every various order of telescopic magnitudes, and, as appears by these observations, were probably scattered over a space extending from the 204th to the 344th order of distances.

As the power of the 10 feet reflector could not reach farther into space, I shall have recourse to some of my numerous observations made with the 20 feet telescope. In addition to 863 gages already published,* above 400 more have been taken in various parts of the heavens, but with regard to these gages, which on a supposition of an equality of scattering were looked upon as gages of distances, I have now to remark that, although a greater number of stars in the field of view is generally an indication of their greater distance from us, these gages, in fact, relate more immediately to the scattering of the stars, of which they give us a valuable information, such as will prove the different richness of the various regions of the heavens.

July 30, 1785. Right ascension $19^h\ 4'$. Polar distance $87°\ 5'$. The milky way is extremely rich in stars that are too small for the gage.

Dec. 7, 1785. Right ascension $5^h\ 33'$. Polar distance $66°\ 6'$.

* See Phil. Trans. for 1785, p. 221.

There are about 66 stars in the field of view, and many more so extremely small as not to admit of being gaged.

Sept. 20, 1786. Right ascension $20^h\ 40'$. Polar distance $54°\ 36'$. There are about 80 stars in a quadrant, or 320 in the field of view, besides many more too small to be distinctly seen.

Oct. 14, 1787. Right ascension $21^h\ 57'$. Polar distance from $35°\ 18'$ to $38°\ 50'$. In this part of the heavens the large stars seem to be of the 9th and 10th magnitude. The small ones are gradually less till they escape the eye, so that appearances here favour the idea of a succeeding, more distant clustering part of the milky way.

Sept. 18, 1784. Right ascension $20^h\ 8'$. Polar distance from $70°\ 9'$ to $72°\ 49'$. The end of the stratum of the stars of the milky way cannot be seen.

By these observations it appears that the utmost stretch of the space-penetrating power of the 20 feet telescope could not fathom the Profundity of the milky way, and that the stars which were beyond its reach must have been farther from us than the 900dth order of distances.

I am far from limiting the milky way to the extent deduced from these observations; but as even the distance which has been stated may appear doubtful, I must repeat the argument which has been used with stars visible to the eye, but which now is greatly supported by telescopic vision. If the stars of the 5th, 6th, and 7th magnitudes cannot be supposed to be gradually of a smaller physical size and brightness than those of the 1st, 2d, and 3d, how much less can a supposition be admitted that would require that the stars, which by a long

series of gaging powers have been proved to make their gradual telescopic appearance from the 12th to the 900dth order of distances, should also be gradually of a different construction, with regard to physical size and brightness, from those which we see with the naked eye.

From the great diameter of the mirror of the 40 feet telescope we have reason to believe, that a review of the milky way with this instrument would carry the extent of this brilliant arrangement of stars as far into space as its penetrating power can reach, which would be to the 2300dth order of distances, and that it would then probably leave us again in the same uncertainty as the 20 feet telescope. When I made some sweeps of the heavens with the 40 feet telescope with a magnifying power of 370, I found it necessary to reduce the intended breadth of the sweep from one degree to 30 minutes, and the great length of time this would have taken up to examine only the ecliptic, to which I had directed the telescope, soon proved that by continuing to use this instrument for sweeping, I should have been obliged to neglect the necessary observations of the 20 feet telescope.

The following observations are extracted from my sweeps to support a few general remarks relating to the construction of the milky way.

Dec. 7, 1785. Right ascension 4^h 39′. Polar distance from 64° 0′ to 66° 12′. The straggling stars of the milky way seem now to come on gradually; most of them are small. Right ascension 4° 43′. They begin now to be intermixed with some large ones.

This observation proves that the telescopic breadth of the milky way, considerably exceeds the extent which in our

maps is assigned to it. In this situation it began to appear at 6 or 7 degrees from where it might have been expected to enter the telescope.

Aug. 21, 1791. Right ascension 18^h 59′. Polar distance from 84° 15′ to 86° 17′. The milky way comes on very suddenly, and is amazingly crowded with very small stars intermixed with many of several sizes.

By our maps this place is already within the limits of the milky way.

Jan. 1, 1786. Right ascension 5^h 17′. Polar distance from 89° 28′ to 91° 47′. Most of the stars are larger than usual, but the whole breadth of the sweep contains a great mixture of all sizes.

From the brightness of the stars we may conclude that the constellation of Orion to which the observation belongs, is one of those that are nearest to our own situation.

Dec. 27, 1786. Right ascension 6^h 49′. Polar distance from 87° 37′ to 89° 55′. From the appearance of the heavens in this neighbourhood, there is reason to suppose that there is a break or vacancy among the stars between our situation and the more remote parts of the milky way.

The place to which this observation refers is in the breast of Monoceros.

Oct. 14. 1787. Right ascension 22^h 14′. Polar distance from 35° 18′ to 38° 50′. It is very evident that in this part of the heavens there is some distance between us and the milky way, which is not equally scattered over with stars.

The situation of the place pointed out by the observation is near the crown of Cepheus.

Sept. 15, 1792. Right ascension 19^h 46′. Polar distance

52° 29′. There are 153 stars in a quadrant, or 612 in the field of view, and the whole breadth of the sweep, which is 2° 2′, is equally rich.

The gage was taken in the preceding branch of the milky way, in the neck of the Swan.

Aug. 22, 1792. Right ascension 19^h 35′. Polar distance 75° 5′. The field of view is extremely crowded, but the stars are too small and too numerous to be counted; there cannot be less than 100, or probably 150 in a quadrant. From some careful trials I suppose there were 150; this would give 600 stars in the field of view. The stars continue to be equally crowded throughout the whole breadth of the sweep, which was 2° 35′ till right ascension 19^h 54′, when there still were 440 in the field.

This gage was taken in the following branch of the milky way, in the wing of Aquila.

Sept. 13, 1784. Right ascension 20^h 43′. Polar distance from 54° 15′ to 57° 1′. This branch of the milky way is less rich than the preceding one.

The same sweep passed through both the branches, and the observation relates to a place in the following wing of the Swan.

Oct. 19, 1788. Right ascension 21^h 13′. Polar distance from 43° 35′ to 46° 13′. The milky way is very rich, but the stars are very unequally scattered.

This observation belongs to the tail of the Swan.

Nov. 26, 1788. Right ascension 23^h 40′. Polar distance 29° 13′. The milky way is very rich, but the stars are very unequally scattered. The stars are clustering. Right ascension 0^h 14′. Polar distance 29° 51′. Clustering small stars

considerably rich. Right ascension 0^h 27′. Polar distance 30° 5′. Clustering small stars.

These observations belong to a place preceding the back of Cassiopea's chair.

Dec. 27, 1786. Right ascension 6^h 36′. Polar distance 88° 5′. Clustering stars of the milky way, almost close enough, and so far separated from the rest of the stars as to be called a cluster, but still evidently joining to them.

This observation of the clustering of the stars of the milky way relates to a place that precedes the breast of Monoceros.

X. *Concluding Remarks.*

What has been said of the extent and condition of the milky way in several of my papers on the construction of the heavens, with the addition of the observations contained in this attempt to give a more correct idea of its profundity in space, will nearly contain all the general knowledge we can ever have of this magnificent collection of stars. To enter upon the subject of the contents of the heavens in the two comparatively vacant spaces on each side adjoining the milky way, the situation of globular clusters of planetary nebulæ, and of far extended nebulosities, would greatly exceed the compass of this Paper; I shall therefore only add one remarkable conclusion that may be drawn from the experiments which have been made with the gaging powers.

In fig. 2, Plate XV. let a circle, drawn with the radius of the 12th order of distances, represent a sphere containing every star that can be seen by the naked eye; then, if the breadth of the milky way were only 5 degrees, and if its profundity did not exceed the 900dth order of distances, the

two parallel lines in the figure, representing the breadth of the milky way, will, on each side of the centre of the inclosed circle, extend to more than the 39th order of distances.

From this it follows, that not only our sun, but all the stars we can see with the eye, are deeply immersed in the milky way, and form a component part of it.

WILLIAM HERSCHEL.

Slough, near Windsor,
May 10, 1817.

Fig. 1.

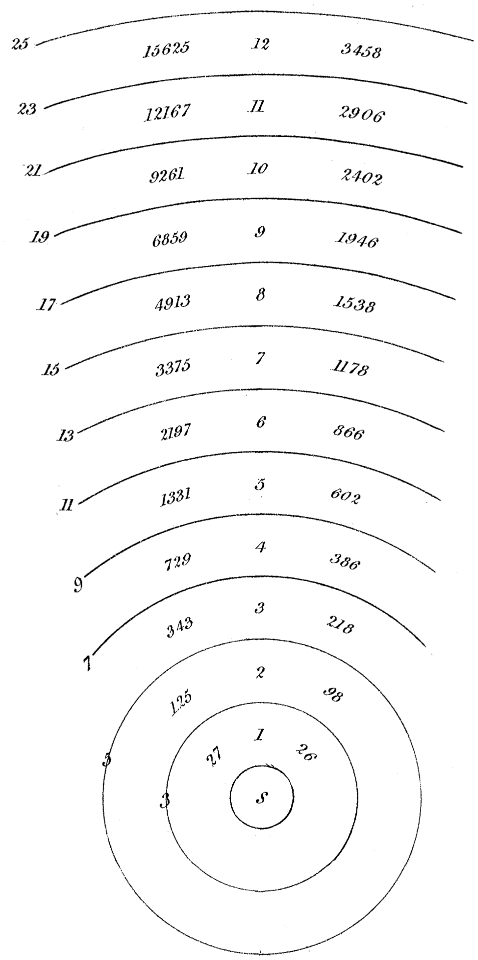
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Fig. 2.