WHAT IS THE REAL SHAPE OF THE SPIRAL NEBULÆ?

ONE of the greatest works of the two Herschels, father and son, was the exploration of the region of the nebulæ. When they began their labors, less than one hundred such objects were known. Sir John Herschel's catalogue contains more than five thousand nebulæ, and of these more than four thousand were discovered by the Herschels alone. Such amazing activity in mere discovery did not leave much leisure for a minute study of the details of nebulous structure. Although the nebulæ in general had been divided into classes by Sir William Herschel, and although a few of the more important ones had been carefully studied by Sir John, it was not until after the mounting of Lord Rosse's great reflector that the systematic study of the minute structure of special nebulæ was fairly begun. And one of the first-fruits of the establishment of this great telescope was the discovery of quite a new class of these objects—the spiral nebulæ.

It was found by Lord Rosse that many nebulæ had all their parts disposed in true spirals, and it was also found that many other nebulæ of the brighter and more interesting kind—the great nebula of Orion among them—also had many of their principal features disposed in spirals. The best drawings of such objects that we possess are due to Mr. Lassell, who constructed with his own hands several splendid reflecting telescopes, and who used them with a skill and insight which many a professional astronomer may envy. Figures 1 and 2 give representations of spiral nebulæ of pronounced type, taken from the collection of drawings made by Mr. Lassell at Malta. From simple shapes like these we can pass by insensible degrees to the highly complex forms of some of the larger nebulæ. These two figures will, however, serve excellently to exhibit the type of spiral nebulæ.

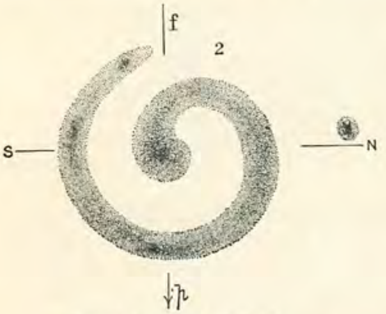

FIGURE 1. SPIRAL NEBULA.

FIGURE 2. SPIRAL NEBULA.

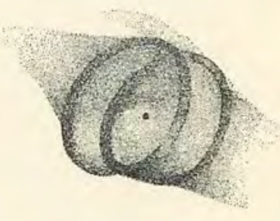

FIGURE 3. HELIX NEBULA.

When the great telescope of the Lick Observatory was installed in the summer of 1888 some of the first objects examined were of this class. Although many new details were added to those previously known, no real new light was thrown on the constitution and character of the class of spiral nebulæ. Also many of the so-called planetary nebulæ — objects usually circular or elliptic with a disk somewhat resembling that of a planet — were carefully studied. One of these, as is shown in figure 3, yielded very novel results.

To the Herschels, and to all previous observers, this nebula had presented the aspect of a pale blue elliptical disk, evenly illuminated over all its surface, with a faint dot of a central star or nucleus. The great power of the Lick telescope quite changed all that and gave us new details which have made this one of the most interesting objects in the heavens. The central star — which has a reddish tinge — was there; but the pale uniform elliptic disk was resolved into two interlacing hoops or rings of nebulosity. Although these were projected on the flat ground of the heavens, and although there seemed to be no possible way of absolutely demonstrating our conclusions, we did not hesitate to announce this as the first known nebula of an entirely new class and species — as a nebula whose parts were undoubtedly arranged in space in the form of a helix. No one can study this nebula through the great telescope without feeling certain that he is actually seeing something like the true shape of the object, and that it is in fact what we have called it, a helix nebula, and the first of its class. There was no doubt that the spiral nebulæ were also the projections of helixes, but there was not the slightest evidence to demonstrate their real shape in space. All that was known was that they were seen as spirals, and that *some* helical shape projected on the background of the sky must produce their spiral form.

The discovery of the helix nebula (figure 3) naturally led to the search for a method which might enable one, in some cases at least, to determine the actual situation of the different branches of a nebula in space of three dimensions, from the meager data afforded by the projection of these branches upon the background of the sky. In general, this problem is hopelessly insoluble by our present means. I have, however, obtained some most interesting results for one class of nebulæ at least, and perhaps the method employed is capable of still wider applications.

To understand the method let us first get a clear conception of the manner in which we see any distant heavenly body, as a nebula, for example. Every point of the nebula is constantly giving off its feeble light in straight lines — rays of light — in every possible direction. Most of these rays pass to other parts of space than ours, but a certain number of them are directed towards the solar system (A in figure 4). These rays alone come to the eye and are alone effective in making the picture

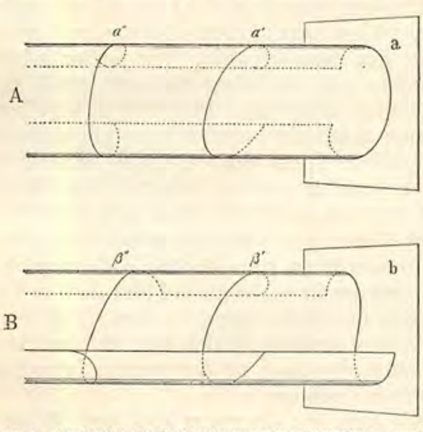

FIGURE 4. SHOWING TWO DRAWINGS OF DIFFERENT NEBULÆ, *a* AND *b* THEIR PROJECTING CYLINDER.

on our retina which corresponds to a particular nebula. The source of light is so distant that all the rays from each point of the nebula are absolutely parallel. The moon is the nearest celestial body, and yet rays which pass from each point of the lunar disk over the 240,000 miles between the moon and the earth are, for all practical purposes, exactly parallel. Still more must we regard the rays from every point of even the nearest nebula as parallel. The picture on the retina of our eye is thus formed by bundles of parallel rays coming from all those points of the nebulæ which are turned towards us. The angle between the axes of the outside bundles of these rays corresponds to the angular diameter of the nebula, and this angle is usually very small.

Suppose, for example, that the nebulæ as it really exists in space is a circle; and that the edge — the rim — of the nebula is turned towards the earth. We shall see such a shape as a straight line. Just as in this case so in others. In figure 4 the eye at A will receive a cylinder formed by parallel rays from the nebula at α' or α'' and will project the directions of those rays backward upon the ground of the sky into a curve like *a*. The only thing that we know, in general, about a nebula is that its projection on the background of the sky is a curve, like *a*, for example. And the shape *a* is what we see in our telescopes, or it is what a photograph of the region will show us. We have to conceive, then, a real nebula of unknown form situated somewhere in space between the eye and the background of the sky; of bundles of parallel rays of light from this real nebula reaching the earth at A; and, finally, of these rays projected backward to the real concave of the heavens and meeting this background in a projected curve *a*, which is the nebula as it appears to us and as it is depicted in drawings. Looking at it geometrically, the curve *a*, whatever it is, circle, ellipse, spiral, must be considered as the base of a sort of cylinder; and the rays reaching from *a* to A must be considered as the elements of the cylinder, which taken all together form its surface. If the base *a* is a circle, we have the ordinary cylinder; if it is an ellipse or other closed curve, still we have a cylinder; if the base *a* is not a closed curve but an open one, like a spiral, still we have a cylindrical surface or sheet. This surface may be highly complicated; parts of it may intersect and cross in an involved fashion, depending on the curve of its base; but, finally, we have always the cylindric sheet or surface, with the projection *a* of the nebula at one end of it, and the eye A at the other, and with straight lines between *a* and A. For example, the cylinder B*b* of the same figure shows a more complex cylindrical sheet than the one first drawn, corresponding to a more complex projected curve *b*. Every nebula drawing then must be conceived as the base of some projecting cylinder. The case is very different for one of the nearer heavenly bodies — as Jupiter, for example. Here we actually see all the details of the surface, and know that it is a sphere and not a flat disk by determining the time of rotation of these spots and markings.

Let us consider the two projecting cylinders of figure 4 a little more closely. It is clear that it is only the *surface* of the cylinder which corresponds to the drawing *a* or *b*. The interior volume has nothing to do with the matter. Moreover it is clear that the surface of the cylindric sheet corresponds *exactly* to the drawing. And in this way: *any* curve drawn on the surface of the cylinder A must be projected back on the sky in one and the same curve *a*. Draw any curve whatever on the surface of the cylinder and in general it will be projected back on the sky in the one curve *a*.

or ribbons of nebulous matter twisted about a central nucleus and seen by us in the form of a spiral curve. There are many other classes of nebulæ, as those with circular or oval disks —the planetary nebulæ; those consisting of one or two straight parallel rays; those disposed in oval rings, etc. We are now concerned only with the spiral nebulæ, and figures 1 and 2 are the most striking of these which we may select as types.

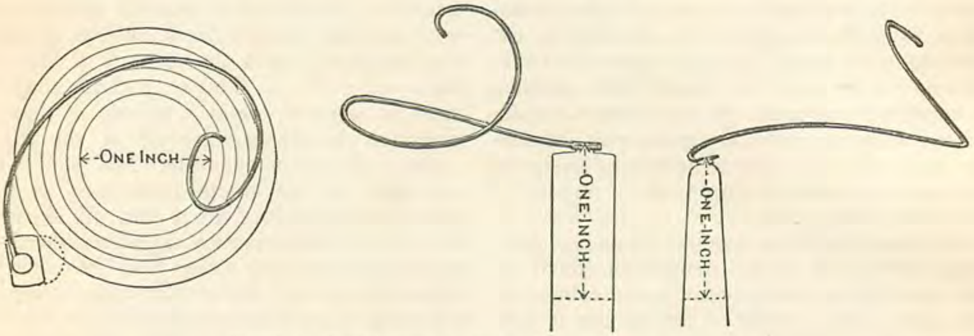

FIGURE 5. THREE VIEWS OF THE MODEL OF THE TYPE-HELIX.

This means that no matter what shape the real nebula α' or α'' may have in space, provided only that it lies on the surface of this cylinder, we can see it projected on the background of the sky in only one curve; namely, in *a*. Exactly in the same way, *any* curve on the surface of the cylinder B can be projected on the sky into only one drawing as *b*. β' and β'' are two such curves, but it is clear that there may be an infinite number of them. Any one out of this infinite number, provided only that it is drawn on the surface of the cylinder, must be projected back into the single curve *b*, and it can be projected into no other.

This is all that we know, in general, about a nebula: we have made a drawing of it, or it has been photographed, and we have the picture *a* or *b*. About the real shape of the nebula itself we know next to nothing. It may have almost any fantastic shape. Almost any; but finally there is a limitation. The nebula must lie on the surface of its projecting cylinder. If it fulfills this one condition, it may be, for all that we know, *any* one of the myriad curves which can be so drawn.

The problem to be solved is to determine, if possible, which one of these myriad curves we must choose to represent the real nebula in space. This problem has never been solved, and, in general, it is probably quite insoluble.

In a very particular case it has received a solution, and perhaps the method of solution may be capable of wider application. The particular case in question is that of the spiral nebulæ. These are usually elongated strings

We must recollect that the representations of nebulæ in this article are taken from drawings, and that, like all drawings, they are subject to errors due to imperfect telescopic, visual, and artistic powers.

Photographs of nebulæ are subject to a different and less hurtful class of errors, and they are quite free from anything like personal bias or opinion; and therefore they are much better data than drawings. But only a very few of the spiral nebulæ have yet been photographed, and hence I am obliged to be content with these drawings, which are the best we have, and to wait until the great telescope of the Lick Observatory and other photographic instruments have provided us with more accurate delineations. With the best data available we may proceed to make the best solution possible of our problem, which is to find out the real situation in space of the various branches of the spiral nebulæ.

We have the drawings *a*, *b*, etc. What are the true curves in space? Recollect that any curve on the surface of the cylinder A will produce the curve *a*, and that any curve on the cylinder B will produce *b*, and so on. Notice also that, in general, the surfaces of such projecting cylinders as A, B, etc. must be very different, because the pictures of the nebulæ *a*, *b*, etc. are so utterly dissimilar.

Suppose that we could find a pair of curves, *a*, *b*, whose cylinders, A, B, were of such a shape that the same curve *can* be drawn on their surfaces, then there is at least a probability that this particular curve is in fact the true shape of this pair of nebulæ. If, again, we can find another nebula, *c*, whose cylinder, C, is so similar in shape to that of *a* that like curves can be drawn on the three surfaces, A, B, C, then there is a still greater probability that the identical curve on these three surfaces is in fact the true shape of these three nebulæ in space. If we find yet another nebula, *d*, whose cylinder, D, is of such a shape that we can also draw the same curve on its surface, then once more there is a much higher probability that we have found the real shape of all four nebulæ, *a*, *b*, *c*, *d*. As we get more and more examples all fulfilling the same condition, the probability that we have really obtained the veritable shape of the nebulous form in space is very rapidly increased; and by finding enough examples we may increase the probability to essential certainty.

We can attack the problem practically by seeking to form a wire model of such a shape that when it is held at different angles and in varying positions it can be made to cover accurately the outlines of each drawing of each nebula. The model must be changed and corrected in many trials, but finally I have found that it is possible to construct a helix or corkscrew-like curve, such that it can be projected into nearly every one of the multifarious forms assumed by the different spiral nebulæ. At first sight it would seem strange that one such helix was enough, but in fact it is. All the spiral nebulæ seem to be of the same type. Each of them is nothing more than a different view, a different projection, of one and the same parent curve. This curve is a true helix of not very complex form. It is shown in figure 5. Looking directly down upon it we have the left-hand position in the figure, and two views from the east and north sides respectively are shown beside the first. After constructing such a model as this, by many trials, it was applied to all the drawings of spiral nebulæ which we possess, and it has been found to fit them accurately within the limits of precision of the drawings themselves.

With more accurate drawings the model or type-helix will have to be slightly modified, but I think we may now for the first time say that the situation of the different parts of a nebula in space is known. We have previously not known this for any nebula.

This result may have the most interesting and far-reaching consequences. We shall be able to fix the directions of the axes of each of the spiral nebulæ and to say how they lie in space. Are they all parallel? do they all point to some central point? or, as is most likely, are they entirely arbitrary in direction? What is the law of force by which the surrounding particles are attracted to, or repelled from, the central nucleus of the nebula? Is there a resisting medium surrounding these bodies? Are they in motion? Some of the parts of each nebula must be approaching us, some receding from us. Is it possible to make our spectroscopic observations sufficiently delicate to decide between these two directions with the clues afforded by our knowledge of their real shape? These and many similar questions at once suggest themselves with regard to each individual nebula. And some of these can certainly be answered, as respects some particular nebulæ. The answers so obtained will have the most important bearing on the larger question of the mode of formation of the solar system. In the spiral nebulæ we have an example of the working of the nebular hypothesis on a comprehensible scale, and we may hope to make some further steps onward by the light of the knowledge which seems now to be opening to us by the application of an unexpectedly simple method.

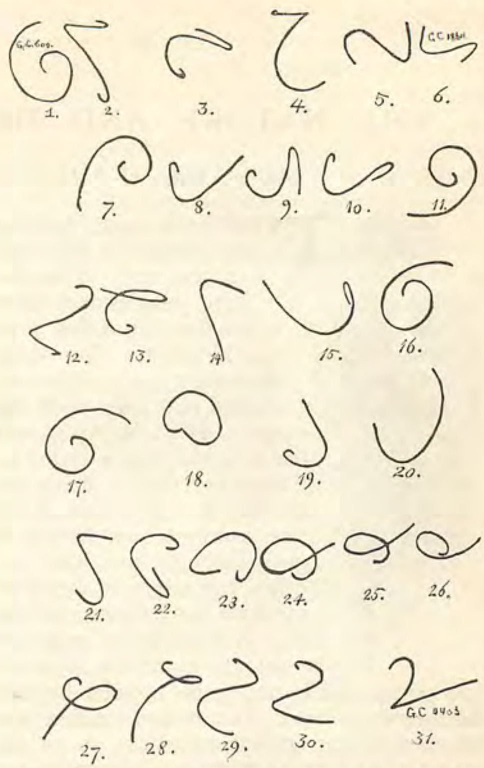

FIGURE 6. PROJECTIONS OF THE TYPE-HELIX ON A PLANE.

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LICK OBSERVATORY.