THE STAR DEPTHS.

A LECTURE

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Delivered in the Hulme Town Hall, Manchester, December 11th, 1872.

It would be easy for me to occupy far more than the hour or so allotted to this lecture, with the mere account of those facts concerning the stars which are to be found recorded in treatises on astronomy. But there would be a double objection to such a course. In the first place, I should be relating matters which could not but be known to many of my audience; and, in the second place, those among you who heard those matters for the first time could obtain such information far more conveniently and satisfactorily from the pages of one or other of our astronomical text-books. The course that I propose to adopt, then, in order to employ the short time at my disposal in the manner most likely, as I think, to interest you, is—not indeed to take it for granted that all those matters are known to you—but to speak of them without discussing at any length either their history or explanation, and so to make time to introduce to your consideration those parts of my subject which are more likely to be new to you, and to which my own researches relate.

If we contemplate the heavens on a calm, clear night, when all the stars shine, and

> The immeasurable heavens
> Break open to their highest,

the mind is impressed with the thought that perfect peace prevails amid those solemn depths. Thus the poet has, in all ages, found in the star-depths the aptest emblem of repose and stillness. Not has astronomy, so far as it relates to the aspect of the heavens, taught any other lesson. It is true, indeed, that the astronomer recognises movement where to ordinary survey there is rest. He sees the star-sphere carried round day by day from east to west; he knows that as the year progresses the same motion can be perceived; while he recognises yet a third motion of the heavens, a motion carrying the whole celestial sphere gyratingly round an axis through the constellation of the Dragon in a period of nearly 26,000 years. But it is this rotating, revolving, and gyrating sphere which the astronomer has called the sphere of the fixed stars. For all these motions are but apparent. It is our earth, not the star sphere, which rotates once in each day; our earth which revolves once on its orbit in a year; our earth which gyrates like a gigantic top in the long period of 26,000 years, just mentioned. Her movements within the star sphere cause that sphere to change in aspect as though it moved around us, while in reality it is at rest.

To the general survey, then, of the astronomer, as well as to the contemplation of the poet, the star-depths present a scene of stillness and repose.

But so soon as we pass from these first considerations to study the teachings of modern astronomy more closely, we find that the heaven of the stars is in reality instinct with a vitality and energy, compared with which all the forms of life and motion known to us on earth sink into utter insignificance. The least of the stars visible to the unaided eye—some star so faint that on the darkest and clearest night it shows itself only by momentary twinklings—is in reality an orb full of life and energy; an orb giving forth during each moment of its existence greater supplies of force than all that are at work upon our earth during decades of years; an orb, in fine, resembling our sun in all those attributes which render him fit to be the beneficent ruler of a scheme of circling worlds. The least discernible change of brilliancy in any one of these orbs means an access or a loss of energy far exceeding the whole supply of light and heat which we receive from our sun in many thousands of years. And there is one circumstance we are apt to overlook, the consideration of which suggests strange conceptions respecting those seemingly silent depths amid which the stars are set. Our sun appears to supply us *silently* with light and heat, and with the other forms of force necessary to our well-being; but in reality the great central engine of our system works out its purpose amid noise, compared with which the loudest sounds known to us are as silence. The roar of the hurricane, the crash of the thunderbolt, the bellowing of the volcano, and the hideous groaning which forms so terrible a feature of the earth-throe, all are transcended a millionfold by the uproar which must accompany the processes at work on every square mile of the solar surface. Now picture to yourselves that the tumult and uproar amid which our own sun beats out life to the worlds around him are repeated in every one of the thousands of suns we call the stars, in the millions on millions of stars revealed by the telescope, and in a million times as many suns which no telescope yet made by man can render visible. This is no idle dream or imagination, but has become, by the labours of our astronomers and physicists, a scientific certainty. It is the very charter of a star's existence that it shall be as a central heart, pulsating light, and life, and heat, and energy to the worlds over which it bears sway; that it shall be as a central engine whose roaring fires maintain the whole machinery of its system until the fuel which feeds them shall be exhausted.

At the beginning of the long series of researches by which these results have been ascertained lies the determination of the distances of the stars. So soon as the Copernican theory had been established, and it was known that year by year the earth circles around the sun on an orbit many millions of miles in extent, astronomers began to hope that the distances of the stars might be determined.

Before passing to the consideration of the conclusions which are to be drawn from the vastness of the stellar distances, I propose to indicate to you in a picture the basis on which astronomers have founded the determination of the sun's distance—on which these other determinations depend. Here, as in all cases where the distance of an inaccessible object is to be determined, change of direction, when the same object is viewed from different stations, is the point on which the determination rests. The stations in this case are on opposite sides of our earth, some 8,000 miles in diameter. There will now be shown on the screen a picture of our little earth, as supposed to be seen from the sun on the occasion of the transit of Venus, in December, 1874. You see Venus as a white disc in the centre of a triple circle, and below you see our earth at different stations, as if moving descendingly and towards the right past Venus, which planet, for convenience, is supposed to be at rest. It is from places at opposite sides of that tiny rotatory orb, which lies farther away than Venus (for, in fact, the two globes are of about the same size, whereas, as you see, Venus appears the larger), that astronomers

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are to observe Venus as she crosses the sun's face. And now a picture will show you how much (or rather how little) Venus will be displaced. You have now on the screen a picture of the sun, and the path of Venus's centre across it (as supposed to be seen from the earth's centre) is shown by the central line of a set of lines crossing the sun's disc from left to right and ascendingly. The heavy shaded lines on either side of the central line indicate the zone along which Venus would seem to travel, if she could be viewed from the centre of the earth; the uppermost line shows the extreme limit of the zone she would traverse if she could be viewed throughout from the most southerly place on the earth; while the lowest line shows the extreme limit of the zone she would traverse if she were viewed throughout from the most northerly place on the earth. You perceive that the displacement is by no means great: nevertheless it has been measured on former occasions of the kind, and we know certainly from these and other observations that the sun's distance is about 91½ millions of miles, and the span of the earth's orbit twice as great.

It seemed certain, then, that the nearest among the stars would be seen in a different direction when the earth was at any given point of her orbit than when she was at the opposite point, 183 millions of miles away. Nevertheless, even this enormous base line has proved barely sufficient, in conjunction with the use of the most delicate and powerful astronomical instruments, to exhibit the minutest measurable displacement of two or three of the nearest stars. To show how extremely delicate is the problem thus attacked by astronomers, I will indicate the actual displacement of direction of the nearest of all the stars (so far as known), the star Alpha, of the constellation of the Centaur. You all know how slightly the minute-hand of a clock or watch moves in a single second of time—it is barely possible to recognise its change of direction. Now, in a second the minute-hand of a clock or watch changes in direction four hundred times as much as a line pointed to the star Alpha Centauri changes in direction while the earth circles on its orbit, though that orbit has a span of 180 millions of miles. If you conceive that star as the centre of a gigantic clock-face, and a line from it to the sun as the minute-hand of a mighty clock, then the length of that hand would be so enormous that its end would move over 180 millions of miles, not in an hour, nor in a minute, nor in a second, but in the four-hundredth part of a second. Two stars are known (in one case the knowledge has come quite recently) to lie at about twice the distance of Alpha Centauri. But it affords at once an indication of the tremendous difficulty of the problem, and of the uncertainty which even now surrounds its solution, that one of these stars (a celebrated, though small star, known as 61 of the Swan) was set until lately at about three times the distance of Alpha Centauri, instead of rather less than twice that distance—a trifling error truly when the actual mistake in the estimated displacement of the star is concerned, but nevertheless an error in distance amounting to some two hundred thousand times the distance of our sun. It may be safely said that Alpha Centauri is the only star whose distance can be regarded as even approximately determined; and even in the case of that star the probable error amounts, not to a few millions of miles, but to some thousands or tens of thousands of millions. But it must be remembered that this circumstance introduces no doubt whatever as to the fact that *all* the stars lie beyond distances such as we have been considering. It may be regarded as practically certain that there is not a single star in the heavens lying at a distance less than two hundred thousand times that of the sun, while the great majority, all in fact save perhaps some ten or twelve, lie at distances enormously greater.

Now, since the nearest of the fixed stars is more than 200,000 times as far away as the sun, it follows that if the sun were removed to the place occupied by such a star, his light would be reduced, not 200,000 times, but 200,000 times 200,000 times, or 40,000 million times. But the light of Alpha Centauri has been measured, and has been found to be equivalent to about 17,000 millionth part of the sun's! So that even if we set this star at only 200,000 times the sun's distance, its light exceeds the sun's more than twofold. But, according to the best estimates of the star's distance, it must emit about three times as much light as the sun. Accordingly, if it is a globe, whose surface gives out as much light, mile for mile, as the sun's, then its surface must be three times as great as the sun's: whence it is easily shown that its diameter must be more than half as large again as his, and its volume about five times his. As a matter of fact, the star is double, and the companion gives out one-seventh, or thereabouts, of the total light supplied by the pair. But this leaves the larger star still far greater than our sun in bulk—certainly fully four times as great, on the supposition I have made as to the star's light.

Setting all assumptions of this kind on one side, it is certain that our sun, placed where Alpha Centauri is, would shine only as a leading second-magnitude star; placed twice as far away, or where 61 of the Swan lies, our sun would be reduced to the brightness of a medium third magnitude star. Now these, be it remembered, are the distances of the very nearest of the stars. We have only to set our sun at the greater distance at which astronomers set Sirius, the brightest star of all in the heavens, to find him reduced to a low fourth-magnitude star; while, at the distance where lie, most probably, the greater number of the leading orbs—Vega and Arcturus, Altair and Betelgeux, Rigel, Aldebaran, and Antares—our sun would resemble those faint stars which can only be seen on the clearest and darkest nights.

But it may be urged that, after all, though the stars are thus seen to be lights as brilliant as our sun, and many of them far more brilliant, doubt may yet remain whether they are in other respects like him. The idea has indeed been entertained by eminent students of science that the stars may be *mere* lights, not vast and massive orbs like our sun, capable of swaying the motions of schemes of dependent worlds. And a quarter of a century ago it seemed impossible to show that this theory, strange though it might appear, was unsound. But that wonderful method of research—spectroscopic analysis—has definitely removed these doubts, proving beyond all possibility of question that the stars are suns; not, indeed, constituted in all respects like our sun, but resembling him in all essential characteristics.

It is fortunately (considering the progress of time) unnecessary for me to enter here into a description of the methods and results of spectroscopic analysis, for you have heard those methods and results explained in this room by the very ablest expositors of the subject,—Professor Roscoe and Dr. Huggins. But I must touch, in passing, on those points which relate specially to the star-depths, since otherwise the evidence I am adducing would want an important link.

You know that prismatic analysis resolves the light of our sun into a rainbow-tinted streak, crossed by multitudinous dark lines; and that the lesson taught us by this fact is that the sun is a mass of glowing solid, liquid, or very densely compressed vaporous matter, shining through vapours less intensely heated, though still very hot. It is these vapours which produce the dark lines. Hence, if it be shown that the spectrum of a star resembles the sun's in these general features, we learn that the star is constituted in like manner.

Now there will be thrown upon the screen the various forms of spectra which Father Secchi, the Italian astronomer, has recognised among six hundred stars which he has examined. I do not say that you are to attach any great weight to this classification;

but it serves well enough to indicate the general nature and varieties of the stellar spectra. You see, in the first place, that *all* the spectra afford the kind of evidence I just now mentioned — all these spectra are crossed by dark lines; and therefore all the stars examined by Secchi are masses whose light shines through extensive vaporous envelopes. All, therefore, are *suns*, not mere lights.

Proceeding to details, you see that the uppermost spectrum is the largest, and it should be the brightest, but is not so shown in the picture. It is the spectrum given by Sirius, Altair, Rigel, Vega, and other stars, mostly distinguished by their great brightness, and all characterised by a somewhat bluish tint. The spectrum is crossed by four very strongly-marked dark lines, which are those corresponding to the gas hydrogen. Of the six hundred stars examined by Secchi, about three hundred gave a spectrum of this order. There are reasons for believing that the stars giving this spectrum are much larger than our sun, and have vaporous envelopes much deeper than his. Sirius, certainly, the only star of the kind whose distance has been even roughly determined, is from 1,000 to 8,000 times as large as the sun—supposing his size is to be estimated by the quantity of light which he emits. We may infer, as at least highly probable, that these stars are not simply larger than our sun, but belong to a higher order of suns altogether.

The second spectrum is that of a star resembling our sun in constitution. It may be regarded, in fact, as the spectrum of our sun in miniature. Secchi found that about 150 of the 600 stars he examined gave a spectrum of this order. Among the stars belonging to this class are Capella, Pollux, Alpha in the Great Bear, Procyon, &c.

The third and fourth spectra indicate the extreme range of the various forms under which star spectra of the third order are seen. Those spectra of this class which differ least from the second spectrum correspond very closely (according to Secchi) to the spectrum of a sun-spot; and he therefore infers that the stars of this order are suns covered with many spots. Amongst these stars Secchi includes Antares (the Scorpion's Heart), Betelgeux, the famous irregular variable on the shoulder of the Giant Orion; the star Mira, or Wonderful (the even more celebrated variable in the Whale); and other stars.

The fourth spectrum is that presented by certain red stars about thirty in number), chiefly inconspicuous.

In passing to the work of Dr. Huggins and the late Professor

Miller, I must not omit to notice that although Secchi examined a greater number of stars, the work of our two English physicists is of far greater real weight and importance. They were not content with the mere general survey of star-spectra, but instituted a careful analysis of the individual lines of different spectra, comparing the places of these lines with those of the bright lines obtained from various elements. Thus they were able to announce with confidence that certain elements, familiar to ourselves, exist in the vaporous envelopes surrounding stars which they examined.

The next picture brought upon the screen illustrates the work of these eminent men.

You see on the screen three coloured spectra. The upper most shows the solar spectrum, with its principal lines. The next is the spectrum of the star Betelgeux, the bright star on Orion's shoulder. The lowest is the spectrum of the ruddy Aldebaran. To begin with this star: you perceive the great number of dark lines shown on this spectrum; these, however, are only the lines whose position the observer actually measured; many more were seen. Now below the spectrum are many bright lines. These are the lines obtained from different elements, whose spectra the observers compared with that of the star. Whenever a set of these bright lines agreed in position exactly with a set of dark lines in the spectrum of the star, the observers knew that the corresponding element exists in the strata of absorbing vapour in the atmosphere of the star. They tried in this way sixteen elements, and satisfied themselves that nine of these exist in Aldebaran's atmosphere. These elements are — the metals iron, bismuth, antimony, mercury, sodium, magnesium, calcium, and telluriun, and the gas hydrogen. In the case of the star Betelgeux, they determined the presence of five elements, viz., sodium, magnesium, bismuth, calcium, and iron. The hydrogen lines could not be recognised in the spectrum of this star. You will understand that the elements here mentioned are those which may be regarded as certainly present in these stars; but that those elements whose lines have not been recognised are not therefore to be regarded as necessarily absent. Especially it is to be noted that hydrogen is not probably wanting in the star Betelgeux, though its characteristic lines are not seen. It is probable that either the hydrogen envelope is simply too shallow to produce atmospheric lines which the spectroscopist can recognise, or else the hydrogen in Betelgeux exists at so high a temperature that its light is as effective as that of the glowing matter beneath, so that it fills up the space where its dark lines would otherwise show with light of the same brightness as the rest of the spectrum, and therefore shows no lines. It is indeed noteworthy that Betelgeux is a variable star, and that possibly the spectrum may be found to vary as respects the brightness or darkness of the hydrogen lines. In fact, spectroscopic analysis, which tells us what elements exist in the stars, is capable also of supplying information as to the condition in which those elements exist.

In passing, I may remark that Dr. Huggins has found that some stars give a spectrum in which the lines of hydrogen are not dark as in the spectrum of Aldebaran, or wanting as in that of Betelgeux, but are bright. Notably was this so, as you will probably remember, in the case of the spectrum of that wonderful star T of the Northern Crown (of which Mr. Baxendell was one of the discoverers), which suddenly blazed out in May, 1866.

As another illustration of the kind of information which spectroscopic analysis can give respecting the condition of stars, I will cite the case of those beautiful objects, the coloured double stars. A picture will be brought on the screen showing one of these objects—the star Albireo in the Swan. You perceive that the brighter star is of a strong orange colour, while the smaller is beautifully blue. Now we might be in doubt whether these stars shone with inherent orange or blue light, or whether their light appears orange and blue on account of the nature of vapours through which it shines. Spectroscopic analysis at once answers this question. You see now on the screen the spectra of these two stars. Both spectra show the complete range of the spectral colours, and we hence learn that the inherent light of both stars is white. But the spectrum of the orange star—the lowest in the picture—shows several strong dark lines in the blue. Hence a considerable proportion of the blue light of the star is cut off, and an excess of light from the red, orange, and yellow parts of the spectrum remains, so that the star appears orange. The spectrum of the blue star, on the contrary, shows a number of dark lines in the orange, so that there is an excess of light from the blue end of the spectrum, and the star appears blue.

Yet another illustration of the teachings of spectroscopic analysis respecting the star-depths:—Besides the stars, there are in the heavens many cloud-like objects, some of which have been found to be composed of multitudes of stars, while others had remained of a doubtful nature. Now, the spectroscope tells us that many of these cloudlets, or nebulæ as they are called, really consist of suns like our own, since they give a spectrum resembling the star spectra you have seen. But others are of a totally different nature. One of these is now shown upon the screen. It is the famous ring-nebula in Lyra. The spectrum of this object will now be shown. You perceive that it is not a rainbow-tinted streak like those which were before shown, but consists of three bright lines. Dr. Huggins has already told you what he has ascertained about these lines. My subject only requires me to mention that the spectrum shows this object to be formed of glowing gas. You will presently see that this discovery has an important bearing on the ideas we are to form respecting the constitution of the stellar system.

I will now pass on to discuss another circumstance in the condition of individual stars. We have seen that the stars are suns like our own in all essential matters. And thus we can apply to them what we have learned respecting our sun, and infer that processes are at work in the stars resembling those wonderful processes which we know to be at work in our own sun. But, as we are thus enabled to apply our knowledge respecting the sun in order to make inferences respecting the condition of the stars, so from our study of the stars we can form inferences respecting one important circumstance, at least, in the constitution of our sun. It is a matter of great interest to us to determine whether our sun has, in former ages, had the same brilliancy as at present, and whether he is likely, during the coming centuries, to emit, without diminution or increase, the light and heat necessary for the wellbeing of the worlds which circle around him, Now it is certain that many stars vary in lustre either periodically, or, so far as is known, irregularly. If it should appear that most of the stars are subject to irregular variations of brightness, the inference would certainly be that our sun is likely to change likewise, for he is one among the stars. Precisely as we should feel anxious in travelling on a railway where accidents were common, so the astronomer might feel doubtful about the sun's steadfastness, as a source of light and heat, if change were common among the suns. Now, in order to answer the question thus suggested, a very careful comparison of the brightness of the stars has to be undertaken. But, even when this has been done, we must not expect that in the course of a few years, or even of a few centuries, we shall be able to form an opinion. Several good observers in our own day have made systematic observations of the stars, and have, in fact, discovered many variable stars, though few compared with the total number of stars. Amongst these observers not one has achieved greater success than your distinguished townsman, Mr.

Baxendell. Now these observations will enable the astronomers of a future epoch to determine whether variation is the common fate of stars, or whether constancy is the more general law. But before this can be done many years must elapse—probably many generations of astronomers must pass away. We are led, then, to inquire whether any method exists for obtaining a readier, if a somewhat less satisfactory, solution of the problem. I think that such a method exists in the study of those seemingly absurd figures, the constellations. If it be admitted that the first observers of the heavens really recognised the figures of men and animals in those star-groups to which they gave corresponding names, it would be interesting to inquire whether such star-groups retain a sufficient resemblance to those figures to account for the names they bear. Now there can be little question, I think, that the ancients did recognise certain resemblances, for some constellation names are common to many different nations and races. Amongst such constellations may be mentioned the Bear, the Lion, and the Ship. Now, there will be thrown on the screen a map of the northern constellation-figures. Probably it is on too small a scale to be seen from many parts of this hall. But those who cannot perceive the figure of the Bear, know, nevertheless, that in our modern maps the Bear appears as a long-tailed animal, whereas, as every one knows, the Bear is short-tailed, one may almost say tailless. Now those who first called this star-group the Great Bear, must have known perfectly well all the chief peculiarities of the bear's shape. It is indeed a rather singular circumstance that we find among the Egyptians (who would not be familiar with the bear) that the same star-group was named after the hippopotamus, an animal resembling the bear in being short-tailed, cumbrous, small-headed, heavy-muzzled, and short-eared. None of these characteristics can be recognised in the modern constellation of the Great Bear.

Again as to the Lion. A map will now be shown in which you will see the modern division of the stars including the constellation of the Lion. You perceive a sickle-shaped group in the middle of the mass. Well, the Lion's head in our modern maps corresponds to the stars forming the point of the sickle, a group utterly unlike a lion's head. The distinguishing characteristics of the lion are his fine head and mane, his mighty limbs, and his long tufted tail. None of these features can be recognised in the modern constellation of the Lion. Now a map will be thrown on the screen showing the actual star-grouping where the ancients recognised the Lion and the Bear. Near the top you see the well-known seven stars of the Bear. Now I think that if instead of regarding those three stars which form the Bear as forming part of the outline of the animal's hind-quarters, you may begin to recognise the configuration of an animal larger than the modern constellation figure of the bear, and not unlike a bear. The claws are well indicated by three bright triangular sets of stars. The small short-eared head would occupy the upper left hand part of the map, and though the star-group here (being formed of small stars) does not show well in a star map, it does in reality somewhat strikingly resemble the peculiar shape of a bear's head. Below is the Lion; and I think that, by the exercise of a little imagination, you can recognise the shape of a lion's head on the right, the outline of the mane (formed by stars corresponding to the Bear's claws), the figure of the body, and here, in this group of stars which modern astronomers call the Hair of Berenice, you have the tuft at the end of the lion's tail. It agrees with this view of the matter that the Arabians did actually call Coma Berenices the Lion's tuft. Now, in the next picture you see the figures of the Bear and the Lion as I conceive that the ancients recognised those figures on the heavens: I think you can see that all the more remarkable parts of the star-grouping are accounted for in the two figures.

The inference from this would be that at least the greater number of the stars in this part of the heavens have remained with little change of brightness; and that the real change has been in our method of figuring the constellation, not in the stars. However, in the very region of the heavens which has led us to this encouraging result, there is a star which has changed so remarkably as to show that we cannot certainly trust in the continuance of the sun's light and heat. It is the star, Delta of the Great Bear, the middle star of the well-known seven. This star was as bright as the others two centuries ago, and has now sunk to the fourth magnitude. There can be no doubt that if a corresponding change took place in the brightness of the sun, nearly all the creatures living on our earth would perish.

I pass on to another illustration of this method. In the map next shown you see the figure of the Ship Argo on the right, and close by is the figure of the Greater Dog. Next a map is shown in which you see how the stars are at present divided between Argo and the Dog. But I think you can perceive that the stars in this map form a figure resembling the stern of an ancient ship, if only the constellation is not limited by the modern boundaries. This is better shown in the next map, where the boundaries are removed; and in yet another map you see the figure of such a ship as it was undoubtedly recognised by the ancients—the stern-half, namely, of a large ship, with the stern towards the west. Here, then, again, I think that we have reason to believe that at least the greater number of the stars in question have changed little in brightness; and that it is because our method of dividing the stars into constellations, differs from the ancient method, that there is often a want of resemblance between the constellations and the figures with which they are associated. But in this instance again, as in the former, there is a star whose history should teach us not to be absolutely certain that our sun's lustre and heat will remain without change. I refer to the celebrated star, Eta in the Ship, which only a quarter of a century ago was shining more brightly than any star in the heavens, except Sirius alone, while it is now so faint as to be barely discernible on the darkest and clearest night. There can be no doubt that if our sun thus changed in brightness, until he shone but with one-hundredth part of his present lustre, every form of life would perish from off the face of our earth.

Let us now turn to the consideration of the various theories which have been formed respecting the constitution of the stellar system.

First there will be shown on the screen the star sphere as it was conceived by Kepler. You see in the middle the solar system; then around that there is a ring, which represents a section of the sphere of the fixed stars. By ingenious, but quite untenable reasoning, into the nature of which I need not here enter, Kepler was led to the conclusion that the star-sphere is about seventy miles in thickness.

The next picture presents the theory of Wright, of Durham, commonly ascribed to Sir W. Herschel. You see in the middle his conception of our star system (shown only in section)—a disc of stars somewhat uniformly scattered. Wright explained the Milky Way as the region towards which this disc of stars has the greatest expansion, so that when we look in its direction the line of sight passes through a long array of stars, producing a cloudy light by their united lustre. The disc is shown cloven, to correspond to the fact that the Milky Way is divided along one part of its length into two streams. Around it are other systems of stars differently shaped—some disc-like, some ring-shaped, some spiral, and so on.

Next a picture is shown of the stellar system according to the ideas of Lambert. Again we find the figure (in section) of a cloven disc, but instead of the stars being uniformly scattered throughout this disc, they are arranged, according to the theory of Lambert, into separate clusters, generally globular in shape.

I pass over the labours of the Herschels, as forming a subject altogether too wide to be discussed in the brief time now at my disposal. I note only that according to the theory ascribed to the elder Herschel by our books of astronomy, the stars are arranged as in the theory of Wright, that is, somewhat uniformly within a space shaped like a cloven disc.

William Struve, the eminent German astronomer, recognised the fact that if this theory be true the stars of the leading orders of magnitude ought to show no tendency to aggregation along the zone of the Milky Way. Taking the catalogue of Weiss, containing about 32,000 stars of the first seven orders, he found that they show a marked tendency of the kind. And he announced accordingly his belief that the stars are not spread uniformly throughout the galactic disc, but are gathered towards the central region or mean plane of that disc. His theory is illustrated in the picture next thrown on the screen, where, as you will perceive, there is no longer a uniform scattering of the stars, but a gathering towards the central line of the galactic cloven disc (again shown in section).

I now pass to the results to which I have been led by my own researches. The purposes I have had in view during my inquiries have been mainly these: First, to proceed, in perfect independence of all preconceived theories, to inquire how stars and star cloudlets are spread throughout space, how they differ in magnitude, motion, constitution, &c., and what laws govern their changes and movements, instead of adopting assumptions on these points as bases for reasoning; and, secondly, to endeavour in every case to render clear to the eye those relations which hitherto (where they have been discovered at all) have been presented only in catalogues or tables of stellar statistics.

First, I have applied to stars of different orders of brightness processes of equal-surface charting, which serve to show how the stars are distributed. In the map now shown are all the stars of the northern hemisphere to those of the fourth magnitude. You perceive that even among the stars of these, the brighter orders, there is no uniformity of distribution, but that they are richly spread in parts, while elsewhere there are regions where they seem wholly wanting. The next picture shows four parts of the heavens, equal to each other in extent; and the stars down to the fifth magnitude only are shown. You perceive that there is a great difference in the number of stars presented in these four equal spaces.* You can also notice in all four maps that there are well marked streams and aggregations of stars. The fourth of the charts includes the constellation of the River, which (as its name implies) includes a stream of stars recognised by the ancients. Next another map, showing the self-same region, but including stars down to the sixth magnitude, will be brought on the screen. Now there you can perceive that there is a gathering of the stars towards the lower part of the map. It would be interesting then to see what would be the effect of showing in a single map—or, perhaps, first in two maps, one northern one southern—all the stars down to the sixth magnitude. Now the next two maps have been constructed for this purpose. In the first we have all the northern stars visible to the unaided eye on a dark, clear night. You can see at once that there is not the general uniformity of scattering commonly believed in, but that there is a certain large region where the stars are aggregated with much greater richness than elsewhere. In the next, or southern map, you have a similar phenomenon, but much more markedly shown. The rich region here is a part of the heavens where stars are spread so densely that, according to the account of Captain Jacob (a late well-known astronomer), the sky is filled with light as from a young moon when this part of the heavens is above the horizon. I think it will be admitted that the density of aggregation here is not the effect of mere chance distribution, but indicates a real aggregation of the stars into certain portions of space, and their segregation or withdrawal from others. This is perhaps even more clearly shown in the next picture, in which are included all the visible stars in the heavens—that is, all which were shown in both the last maps. You can there see the rich northern region as well as the rich southern region, while between them lies a well-marked zone of darkness, where scarcely any stars can be seen.

It is worthy of notice that the richness of star-gathering is not only shown in those two regions, but even more markedly in the Milky Way, even though the Milky Way crosses the zone which is so poor in stars. I have found, indeed, that the stars in the Milky Way are so richly spread, that, if the whole heavens were covered with equal richness, there would be about nine thousand more stars visible to the eye than can actually be seen. On the other hand, to show that it is the galaxy itself, and not the galactic region, which is thus rich in stars, the dark gaps and spaces within

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* A great number of charts were shown on the screen, the teachings of which cannot, of course. be satisfactorily indicated by mere verbal description.

the Milky Way are actually so poorly strewn with stars, that, if the whole heavens were similarly bestrewn, there would be four thousand fewer stars than are now visible.

It seemed to me that it would be desirable to extend this process of star-guaging farther. Having Argelander's splendid series of forty large charts of the northern heavens, containing in all 324,198 stars, I determined to map these in a single equal surface chart. These maps include all the stars down to the tenth magnitude inclusive, and, according to the theory of the elder Herschel, no signs of a special gathering of these stars on the galaxy ought to be recognised. I shall leave you to judge whether this is the case or not. We will first of all have the map brought on the screen in seven successive parts, so that we may have a large scale. [This was done, and the maps were described as they were placed in succession on the screen. The point chiefly dwelt upon was the gathering of the stars towards the Milky way.] You have now seen that wherever the Milky Way crosses any part of one of these maps, the stars are strewn with greatly increased richness. We will, now, however, have the whole map on the screen at once. It is now before you, and you can see that the place of the Milky Way is shown with perfect distinctness, merely through the exceptional richness of stellar aggregation along that zone.

I will now pass from the stars to the star cloudlets, and show the evidence I have obtained as to the distribution of these objects. I have applied to them the same process of equal-surface charting which I applied to the stars. There will now be placed upon the screen a map showing the distribution of all the star cloudlets known to astronomers. You can see that the arrangement is somewhat remarkable. Over the Milky Way, where, as we have seen, stars are more richly spread than elsewhere, nebulæ are almost wholly wanting, while they are clustered elsewhere. It seems as though along the galaxy all the star material had been, as it were, used up in making stars; while elsewhere material had been left whence star-clusters could be formed. You may wish to see these great clustering aggregations separately. I therefore will now have two other maps brought upon the screen showing them. You will observe that from the great central mass of aggregating nebulæ streams of nebulæ extend, both in the northern and southern hemispheres, but more markedly in the southern. It is very noteworthy that where those two more remarkable southern nebular-streams appear, there are two of the most remarkable star-streams, viz., that seen in the constellation of the River before mentioned, and the stars which form the streams from the water urn of Aquarius. Yet more remarkable is the fact that each of these intermixed streams of stars and of nebulæ passes on until it loses itself in a great cluster of intermixed nebulæ and stars—the Greater and Lesser Magellanic Clouds.

It seems to me that all this evidence proves, beyond all reasonable question, that the nebulæ are associated with the stellar system, though what may be the exact nature of the association is not as yet clear to us. It seems to me that this is further indicated by the way in which many of the nebulæ seem to cling around groups of stars. Several illustrations of this peculiarity will now be brought upon the screen. You will see that in many instances the association is too remarkable to be attributed to accident. This is especially the case in the nebulæ around the stars c_1 and c_2 of Orion (shown on the screen); for here we have two double stars, each occupying the exact centre of two well-marked nodules of the nebulæ.

Further to test this matter, I determined to map on a large scale all the nebulæ in two regions of the heavens, where these objects are spread with exceptional richness, and to include in the same map all the stars down to the tenth magnitude. One is the great nebular region in the constellation Virgo. It is now shown on the screen, and those among you who are nearest can recognise a peculiar law of association between the nebulæ and the stars; for the stars are gathered into streams, and very few are seen in certain parts of the map. Now, it is not where few stars are seen that many nebulæ are seen; but, on the borders of the star-groupings, and in the places where the star-groups seem incomplete for want of a star or two, nebulæ are found so placed as to suggest the idea that they represent the missing stars. Another map showing the rich nebular region in the constellation Coma Berenices, is now before you. It teaches precisely the same lesson as the former.

Before passing from the subject of the nebulæ, I may mention that, as there are variable stars, so also there are variable nebulæ. In the picture next brought on the screen you see two views of the variable nebula surrounding the remarkable variable star Eta Argûs; and, as you will see, the two pictures appear to indicate a somewhat considerable variation.

I pass now to the motions of the stars. Astronomers, carefully comparing the present positions of the stars with their positions as observed by the astronomer Bradley in the last century, have recognised slight changes of place. These slight changes indicate real motions of enormous velocity. It appeared to me that it would be well to show in some graphic way how the stars were moving. I have accordingly drawn charts of all the stars which have been compared in the way I have mentioned, and I drew a small arrow from each star to show the direction in which the star is moving. The two charts now shown indicate the general result of this process. They include about 1,500 stars. You perceive that the motion-arrows of many of the stars are very large, while other stars are moving at a comparatively slow rate. I may mention that these arrows show the amount of motion of the stars in 36,000 years: that is, each star at the end of about that time will be in the place occupied by its arrow's point instead of its present position. This will give you an idea of the extreme slowness of the apparent motion: nevertheless, the real motion is in many cases known to be very rapid—several miles per second, for instance.

One of the objects which I had in view in applying this process of charting was to determine whether the stars which seemed from my other maps to show a tendency to grouping together, might not show also a tendency to drift together, as groups of stars might be expected to do. I recognised several instances where, as it seemed to me, this tendency to star-drift is very strongly shown. I select two cases of different kinds. The first case, illustrated by the map now before you, relates to the motions of the stars in Gemini and Cancer. You can see that nearly all the stars included in the map are travelling in the same general direction. In the next map you have the proper motions of the stars in the Great Bear. You will notice that of the seven principal stars (the familiar stars of the Plough), five are travelling in the same direction and at the same rate. It is a noteworthy circumstance that the direction of their drift is exactly opposite that which would be due to the sun's motion in space. It seemed to me so clear that we have here an instance of true star-drift (and if we can accept this case as proved we shall be ready to admit the other cases where the evidence is less perfect), that I ventured on a prediction respecting these stars. I knew that my eminent friend, Dr. Huggins, was about to apply to these, among others of the brighter stars, a method of spectroscopic research, by which he is enabled to determine at what rate a star is receding from or approaching the earth; and I announced, three years ago, my belief that whenever he applied this method to the five bright stars in the Great Bear, which are here shown as drifting together, he would find that they were either all approaching or all receding, and at a common rate. This prediction has been exactly confirmed by the result. Of the other two stars of the seven, one is approaching, the other is receding at a moderate rate. *All the five bright stars enclosed within that curve on the map** are receding at the common and enormous rate of seventeen miles per second. They also all show the same spectrum, indicating that they belong to the same order—the order, namely, to which Sirius, Rigel, Vega, and Altair belong.

The general conclusions to which I have been led by the methods of research which I have described are briefly these: First, the sidereal system is altogether more complicated and more varied in structure than has hitherto been supposed. The picture now on the screen is intended to indicate (necessarily in a very rough and coarse manner) my ideas as to the constitution of the heavens. It seems to me that within certain regions of space stars of many orders of real magnitude are gathered together. All the star cloudlets hitherto discovered, gaseous or stellar, irregular, planetary, ring-formed, or elliptic, exist within the limits of the sidereal system. They all form part and parcel of that wonderful system whose nearer and brighter parts constitute the splendour of our nocturnal heavens.

It has been supposed that my views tend to reduce our ideas as to the scale on which the universe is constructed. The exact reverse is, however, the case. It is true that I cannot recognise external galaxies in the star cloudlets—that I recognise parts of our system where it has hitherto been believed that outlying universes are in question. But I reason thus because I have been led to the conclusion that our sidereal system is much more extensive than has been hitherto supposed. It is not that I draw the nebulæ inwards to the star depths, but that I extend the star depths outwards, so as to include the nebulæ.

In concluding, I would address to you a few words on the wonderful scene presented by the star-depths. Let our thoughts pass from our earth, which seems so magnificent, to the giant orbs of Saturn and Jupiter, which dwarf her dimensions to insignificance; thence to the sun, compared with which the largest of the planets seem so small. Then let us consider the dimensions of the solar system, compared with which even the dimensions of the sun are as nothing. Next let us pass on in thought to the vast region of space within which our whole solar family is travelling.

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* It should be mentioned that the map to which these remarks are applied was not drawn after the prediction had been fulfilled, but had appeared in the lecturer's treatise, "Other Worlds than Ours," published two years earlier.

Then let us picture the scheme of suns of which our sun is a member;—not the sidereal system, scarcely even an appreciable fraction of that system, but the particular family of suns to which the sun belongs—and let us consider how the domain of the sun, the region of space over which he bears sway, is in its turn reduced to mere nothingness by comparison with the scheme of suns of which our sun is a member. Then, lastly, let us picture to ourselves that the scheme of stars to which our sun belongs is but one of the atoms of which the frame of the sidereal systems is built.

We can speak of these things, but we cannot conceive them. The astronomer can spread out the figures which represent these wonders, but he can neither enable others to conceive them, nor can he conceive them himself. I know not then how I can more fitly draw my subject to a conclusion than by quoting the wonderful dream in which the German poet, Jean Paul (nobly translated by our own prose poet, De Quincey), pictures the feebleness of human conceptions in the presence of the infinite wonders of the universe:—

"God called up from dreams," &c.