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JOURNAL OF

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1911.

THE 517TH ORDINARY MEETING OF MEMBERS

WAS HELD IN THE

ROOMS OF THE ROYAL SOCIETY OF ARTS
ON THE 24TH APRIL, 1911.

THE REV. CANON GIRDLESTONE IN THE CHAIR.

The Secretary read the Minutes of the previous Meeting, and announced the following elections by the Council :—

MEMBERS.—The Ven. Archdeacon W. M. Jefferis, D.D., Diocese of W. Virginia, U.S.A. ; Robert D. Richardson, Esq., Winnipeg.

ASSOCIATES :—Rev. Samuel B. McCormick, D.D., Chancellor of the University of Pittsburg, U.S.A. ; W. H. Seagram, Esq., London.

The CHAIRMAN, in introducing Sir David Gill, said :—The subject we have brought before us to-day is one of engrossing interest, and has been so from time immemorial. We are utterly lost in contemplation as we look up at night into the starry heavens, but perhaps we shall hear some things this afternoon which will make us feel a little more at home than we have been hitherto in that wonderful phenomenon, the sidereal universe.

The following paper, compiled by the Secretary from shorthand notes, was read :—

THE SIDEREAL UNIVERSE.

By Sir DAVID GILL, K.C.B., LL.D., D.Sc., F.R.S.

MR. CHAIRMAN, Ladies and Gentlemen : Your Chairman has just told you what an immense subject the sidereal universe is. In the hour at my disposal I shall try to tell you a little about it, but naturally you must expect me to pass over some points much more rapidly than one would have to do in discussing a more limited subject. Our sun is a star, and all the so-called fixed stars are suns, sources of light and heat, and probably accompanied by little bodies like our earth as planets surrounding them. The name "fixed stars" has descended to us, because until the year 1718 the stars were supposed to be absolutely fixed, relatively to each other, in the heavens. But Halley in that year, by comparing the old observations with the modern observations of his time, discovered that certain of them had certainly moved relatively to each other. We know nowadays that the stars not only all move, but that if they had been originally created at rest they would now be in motion in consequence of their mutual attractions. Tobias Mayer in 1760, was the first to recognise that if our sun moved amongst the stars, the mere effect of that motion must be to produce *apparent* motions amongst the stars. He used the illustration, and a very excellent one it is, that if a man walks through a wood not too closely planted with trees, he would observe that all the trees in front of him appear to open out as he proceeds, that those he leaves behind will close behind him, that those near him to the right and left will appear to move backwards as he moves forward. If the sun moves, then the stars right and left of the direction of the sun's motion must appear to move in an opposite direction to the sun; those stars in front must be opening outwards and those behind closing up. This will be easier to realise if I draw your attention to fig. 1 (p. 189). In this figure, if the line AB is taken to represent the movement of the sun and the crosses represent stars about the same distance from the sun in various directions, then the apparent movement of each star as the sun passes from A to B will be represented by the dotted lines. Those stars at right-angles to the direction of the sun's motion would apparently move the fastest (that is, through the greatest angles), while for those stars more in front and behind the resulting motion would be smaller. It is evident also that as the sun approaches a group of stars they open out, while those left behind close up. Fig. 1 gives you a good idea of what would take place if you could see certain stars now, and again at a sufficiently later point of time, But, in order to enable you to realise at all what these movements are, it has been necessary to draw this figure on an enormous scale of time. Suppose that the stars indicated by a cross are distant from the sun by the average distance of the first magnitude stars, then it would take half a million years to produce the changes in the apparent directions which are shown in the figure. If these stars were at the average distance of 9th magnitude stars, it would require five million years to produce a like change.

The first observations, sufficiently accurate for determining the proper motions of a number of stars, were made by Bradley 150 years ago, and have been made unceasingly ever since. Now, although it would be easy to find the direction of the sun's motion through space, if the stars were fixed as they are represented on fig. 1, you can easily realise what a much more complicated matter it must be to find the sun's motion through space if each of these stars has a proper motion of its own. In order to simplify our ideas about the question, let us imagine that all the stars are moving at random. Let me define what I mean by "at random." Imagine a swarm of bees and the queen bee at rest upon a bough of a tree, and that she is surrounded by her swarm of bees flying about her in all directions. If the queen bee looks outwards in any direction she will see as many bees flying away from her as towards her, as many to right as to left, as many up as down. If that were not the case the swarm would not retain its general globular form. If the stars moved like the bees we might call these proper motions "random-motions," that is to say, motions which on the whole have no sytematic tendency in any particular direction.

Now, to find out how the sun is moving, I will adopt Mr. Eddington's method of illustrating and discussing it, which will be probably the easiest for you to understand. We have ascertained the apparent direction of the motion of each of a large number of stars, of which sufficiently numerous old and recent observations exist.

A certain area in a map of the heavens or on a celestial globe is taken and a list prepared of all the stars in that area of which the motions have been determined. These motions are then sorted out in groups according to their directions. We then count the number of stars moving in a particular direction, and lay down as in fig. 2 (p. 190) a solid line from the centre towards 0°, representing in length and direction the number of the stars observed to be moving in that direction. Similarly other solid lines, from the centre towards 15°, 30°, etc., are drawn proportional in length to the number of stars moving in the direction of each of these lines respectively. Finally a curve is drawn through the ends of the lines radiating from the centre, which proves to be a rough ellipse. If all these lines were of equal length like the dotted lines we should assume that the stellar motions are not affected by any one common cause and do not show a tendency to any particular drift, but as a matter of fact that is not the case, and this figure means, therefore, that the star-drift as a whole is in the direction of 0°, and that the sun is moving with respect to the stars in the opposite direction. Now if we select a number of such regions symmetrically distributed over the sky, and form similar figures to the above from the motions of the stars in those regions, we find that the figures so formed would when placed in their corresponding positions upon a celestial globe have their longer axes directed nearly to one point, as shown in fig. 3, and that point will be the apex towards which our sun is moving amongst the stars. This apex is not far from the well-known star Vega or *α* Lyræ.

We have now considered the direction of motion of the sun, and must pass on to consider the velocity of that motion.

I think you are aware that the spectroscope can be applied to determining the velocity of the motion of stars in the line of sight. In the limited time at my disposal I cannot stop to explain the theory of the spectroscopic method of determining stellar velocities in the line of sight. I must ask you to take the statements from me on faith. A spectrum of the star *α* Centauri was here shown, taken at two epochs six months apart, that is to say when in one instance the earth in its orbit round the sun is moving towards *α* Centauri, and again six months afterwards when it is moving away from it. The difference in the position or displacement of the dark lines in the star's spectrum relative to the corresponding bright lines of the spectrum of iron was well shown on the screen. This displacement of the iron lines in the star's spectrum relative to the corresponding lines in the terrestrial spectrum of iron is accounted for by the fact that you are encountering more waves of light in a second of time when you are approaching the star than when you are receding from it. From the measured displacements the velocity of the earth in its motion round the sun, and therefore the distance of the earth from the sun can be accurately calculated. When the effect of the earth's motion round the sun is thus known, it can be eliminated, and thus the velocity of any star's motion, referred to our sun, can be determined by measuring the displacement of its spectral lines relative to corresponding lines of terrestrial spectra.

I have told you that the sun is moving towards the star Vega, and if Vega were at rest it would be easy to ascertain the sun's velocity in space. But Vega is itself moving, and we do not know the direction or velocity of its motion. How, then, are we to find out the velocity of the sun's motion? We can only do this by referring to a great number of stars, and imagine that in any particular region of the sky the stars are moving accidentally in all sorts of directions, but in no particular direction in the mean.

To make this more clear, let us return to our analogy of the swarm of bees. If the queen bee is at rest and all the bees are flying about her, the whole swarm keeping its general globular form, then we might reasonably assume their mean motion in space to be zero with reference to the queen-bee; otherwise, the swarm would not retain its globular form. Hence if we suppose the individual bees to constitute the stars of our sidereal universe, and if the motions of the stars resemble in some degree the motions of a swarm of bees about a central queen, we may assume that if we select a field of stars in any particular direction their motion will in the mean be zero.

If then the velocities of approach to the stars in any particular area are measured spectroscopically the average velocity of the sun's approach to these stars should be nearly the same as if the stars were at rest.

Fig. 4 (p. 191), *i.e.*, the diagram of spots, shows you in a simple graphic way the results of all published determinations of the velocity of stars in the line of sight. The spots represent the centres of areas of the sky in which there are two, three, or four stars of which the apparent velocities of their motions with respect to the sun have been determined. The positions of these areas are plotted in Right Ascension and Declination. A black spot indicates that the sun is moving towards the stars in that particular area and a ring the reverse. The size of each spot or ring is made proportional to the average velocity of the star-motion with respect to the sun in each area.

Nearly all the black spots are seen to be together, and nearly all the rings together, and this indicates the motion of the sun to be away from the rings and towards the black spots, and the exact apex of each group can be readily estimated and can be calculated mathematically with a very considerable precision. You will note how the calculated apices of motion fall in the middle of the largest spots, and you will also note that there are a few rings amongst the black spots and *vice versa*, but this merely shows that these exceptional stars have exceptional motions of their own.

The general result of this calculation is to show that the sun's motion through space is at the rate of about 13 miles a second.

Now thus far I have assumed that the motions are accidental, in other words, going back upon our old analogy, that the queen-bee is at rest. The great discovery was made by Professor Kapteyn and announced at the meeting of the British Association in South Africa, 1905, that we cannot assume that this motion is accidental. He proved that there were at least two great streams, or—to use our former analogy—that instead of there being one queen-bee accompanied by its surrounding bees there are two queen-bees, each with her own swarm. Imagine two queen-bees approaching each other, and that each bee knows its own queen-bee and follows her, and that the two swarms pass through each other. Then if you imagine all the bees to be stars you will have an idea of Kapteyn's discovery of the two great streams of stars. I will use Mr. Eddington's method of showing this, because his method is more easily understood than the original method employed by Kapteyn, the discoverer.

When Professor Lewis Boss published his catalogue of the proper motions of 6,000 stars, Mr. Eddington set to work to make figures exactly on the plan that I have shown you in fig. 2, and instead of finding nice ovals he found the kind of figures shown in fig. 5 (p. 192), which facetious astronomers call "Eddington's rabbit show." And you see that they are very irregular figures; some are more irregular than others. Mr. Eddington discussed all these by very beautiful mathematical processes.

I have not got a model of a globe here, but Mr. Eddington kindly got me a globe, and he painted on one hemisphere all the figures as he actually found them. And in fig. 6 (p. 193) you will see how beautifully the irregularities of these figures represent the fact that there are two apices of two star drifts. All the continuous lines converge to a point, and prove that there is one apex towards which one set of stars is moving, and the next (fig. 7) shows you by dotted lines the other apex. Mr. Eddington thus shows us practically this: that there are two streams of stars moving through each other, not quite, but nearly, in opposite directions. This seems to be a leading feature in the mechanics of our universe.

I have shown you now in what direction the sun is going through space, and with what velocity it is moving, and we have seen that there are two great streams of stars passing through each other, but I have told you nothing of the dimensions of space as we know it or of the distances of the stars. The nearest star we know of is *α* Centauri. I have measured its distance by various methods, and it would take a lecture of itself to tell you how that was done; but, in short, if its position is observed at two epochs six months apart, viz., when the earth is at the extremes of its orbit round the sun, we find that the position of the star is displaced by three-fourths of a second of arc from its mean position. The total displacement amounts to three-fourths of the diameter of a silver threepenny piece viewed a mile off.

A little time ago I delivered a presidential address to the Institute of Marine Engineers, and I was comparing the accuracy of old engineering measures with modern measures, and old with recent astronomical measures, and I told them that one-hundredth of a second of arc was the smallest stellar parallax that an astronomer could measure. The angle to be measured is equivalent to about the one-hundredth part of a threepenny bit viewed a mile off. At the dinner which followed, the gentleman who proposed my health said that there was no doubt about the nationality of their President, because no one but a Scotchman would trouble his head about the hundredth part of a threepenny bit a mile off!

From the distance of *a* Centauri, light, which travels about 186,000 miles a second, would occupy $4\frac{1}{3}$ years in reaching the sun or our earth. Astronomers speak of the distance that light travels in a year as a light-year; thus *a* Centauri would be distant $4\frac{1}{3}$ light-years. If one could travel to *a* Centauri at a penny a hundred miles it would cost one and a-half times our national debt for a single ticket! Sirius is about twice that distance from us, and so we go on till we get to the limit when ordinary observations stop. But we have been able to measure up to distances of 300 or 400 light years.

The following table gives you, according to Professor Kapteyn, the outcome of the combination of all known data bearing on the distances of the stars and their distribution in space. Within a sphere whose radius is 550 light-years (a distance corresponding with that of an average ninth magnitude star) there exist—

1 star	giving from	100,000·	to	10,000·	times the light of the sun.
46 stars	„	10,000·	„	1,000·	„ „ „
1,300 „	„	1,000·	„	100·	„ „ „
22,000 „	„	100·	„	10·	„ „ „
140,000 „	„	10·	„	1·	„ „ „
430,000 „	„	1·	„	·1	„ „ „
650,000 „	„	·1	„	·01	„ „ „

This shows that our sun is not a very important star; and, indeed, if it was viewed from the distance of the average first magnitude star it would only appear as a star of the fifth magnitude.

Our earth, therefore, is a very insignificant planet revolving round a very insignificant sun.

I now pass to the consideration of the constituents of the heavens.

You all know that irregularly shaped band of light forming a great circle in the sky called the Milky Way. I cannot, of course, show you pictures of the whole of it, but here are pictures of areas of it about 15° square, taken with a lens of short focus, in which the star images are necessarily very close together. These pictures, taken by Mr. Barnard, illustrate in a striking manner the grouping of the thousands of faint stars, clusters and nebulæ which together make up the light of the Milky Way when the latter is viewed without optical aid.

(Here the lecturer exhibited photographs of—

The great star cloud in Sagittarius.
The small star cloud in Sagittarius.
The region about θ Ophiuci.
Another region in Ophiucus, with nebula near ρ Ophiuci.)

Now these nebulæ—what are they?

Some are certainly gaseous, as proved by their spectra. The spectra of some nebulæ, as first proved by Sir William Huggins, instead of showing continuous spectra crossed by dark lines as in the spectra of the sun and stars, are made up simply of bright lines, which indicate a gaseous constitution. We find many stars—notably the stars of the Pleiades—enveloped in such nebulæ.

Apparently these stars have been formed out of this nebulous stuff that surrounds them, in accordance with the nebular hypothesis of Laplace.

Examples of gaseous nebulæ were shown on the screen, such as—

The Pleiades after different lengths of exposure.
The great nebula in Orion.
Nebula about η Argus
The Crab nebula.
The ring nebula in Lyra.
The planetary nebula 37 H IV Draconis.

This last was the nebula which first revealed to Sir William Huggins the gaseous constitution of some nebula. The beautiful Mount Wilson photograph shows this nebula to have a helix-like structure.

We have some spiral nebulæ such as M 64, Comae Bernicis (shown on the screen), which also seem to be purely gaseous; but there are others like—

The great nebula in Andromeda
M 33 Trianguli
M 81 Ursae Majoris
Spiral nebula in Can. Ven.
} shown on the screen,

which have continuous or stellar-like spectra.

I venture to suggest with reference to these spiral nebulæ a theory which, though not yet proven, seems to me to have many elements of probability. My belief is that these giant spirals are distant universes not unlike our own, and that if we could place ourselves on one of these—say the Great Andromeda nebula—we should, on looking towards our stellar system, see our Milky Way somewhat as we see (or rather as it has been photographed) the Andromeda nebula. That we should find there condensations of light having stellar spectra such as we see in the great spiral nebulæ, and that our own sun and the stars which surround it would be represented by one of these patches or condensations of light, the component stars being too distant to be separately visible.

In conclusion, the lecturer exhibited photographs of the 60-inch reflecting telescope with which the beautiful photographs of the nebulæ had been made.

The instrument is mounted on Mount Wilson, near Pasadena, in California. It was made by Mr. Ritchey there, by whom also the photographs were taken, and is a marvel of exact mechanical and optical workmanship.

The lecturer explained the details of its construction, the mode of its use, and made an appeal for funds to establish a similar telescope on the southern hemisphere.

DISCUSSION.

The CHAIRMAN said: Ladies and gentlemen, it is not very easy to speak after such a mental treat as we have had, and one hardly knows how best to put into words the thoughts that I am sure are in all our minds. The first is that we are deeply grateful to Sir David Gill for the labour and pains he has taken to make this magnificent subject as simple as it could possibly be for us. Many of our minds were like some of the nebulæ we have just been looking at, although I am afraid not quite as clear as these nebulæ now are.

I am sure we have learned two things; one is the greatness of the human mind. I take it that one of these magnificent instruments is a sort of embodiment of mind, and as you looked at it you saw the way in which the plan was carried out, and thought of the quiet work, and the way in which the observer would devote three nights to get an eleven hours' exposure, and you marvel at the ingenuity and perseverance of man. But whence does man get this ingenuity and this perseverance; whence is it that we get this marvellous gift of searching into the depths? I think we of the Victoria Institute have made up our minds on this point. It is not self-generated any more than the stars themselves. The other thing with which I think we must all be impressed, is the magnificence of the works of God. The heavens do declare to us something of the handiwork of God. We feel as if we have had a revelation made to us to-day by the telescope.

In the Bible there are three heavens spoken of: the heavens in which the birds fly, the heavens in which the stars are, and the heaven in which God dwells. The first, of course, is the air, the next is celestial and the last spiritual. Distance and time do not affect the spiritual as they affect the celestial. It is wonderful to see what provision the Bible has made for the subject before us in the following text:—"He telleth (that is counteth) the number of the stars and calleth them all by their names." What an idea that gives you of the individuality and care of the Most High. After all, how little we see. We dwell in a little corner of the universe; the inhabitants are but as dust; but though that is so there is something in a human being which is worth all the stars put together. There is something which brings us more into touch with the Creator and gives us a better idea of His mind because we are brought into union with Him through Christ. It is a glorious thing as you try to grasp the magnificence of these glorious bodies, to think that we are brought into relationship with the Being who has brought them into existence, and that we may call him Father. I am sure I shall voice all our feelings if I give to Sir David Gill our heartiest thanks for the very great treat he has given us to-night. I observed that he said something of a subsequent dinner on an occasion when he gave a lecture. The only dinner I hope we shall have is a dinner on the spectroscope on some future occasion if possible. Although stars might be very indigestible to serve up on the table yet I am sure we can digest another lecture from Sir David Gill.

Mr. MAUNDER: We are very greatly privileged this afternoon in having Sir David Gill to address us, and to unfold to us so high and important a subject. Sir David has taken us, as it were, to the very outposts of science, and from the very border of the territory that it has already conquered, bidden us to look out over the lands into which we may hope in the future to advance. I think that one of my own earliest astronomical recollections is that of meeting Sir David Gill before he set out with the Earl of Crawford, then Lord Lindsay, to observe the Transit of Venus of 1874. From that time to the present the science of astronomy has been advanced by the efforts of no one more effectually than by his; and in particular he has devoted himself to the solution of the great problems of the celestial distances; of the determination of the scale upon which the starry heavens are built. And the great fundamental unit of astronomical distance is necessarily the distance of the earth from the sun. To this Sir David devoted himself with unswerving determination, and infinite resource. He followed up the method of observation of the Transit of Venus, by that of heliometer measures of Mars at the opposition of 1877, and then by observations of various minor planets; Iris, Sappho and Victoria. At that time it seemed an almost preposterous supposition that the distance of the sun could be determined by the means of the spectroscope; through measures of the rate of motion of the earth in the line of sight, relative to various stars; the rate of motion either of recession or approach. Yet absurd as the idea then seemed, Sir David grasped the possibilities of the method and did not hesitate to predict its success, and his faith has been abundantly justified by the result; largely through work which he himself initiated and arranged at the great observatory over which he ruled for eight and twenty years. But this fundamental problem of the distance of the sun was only one of those to which he devoted himself. The distances of certain stars were measured by him, and he was one of the most strenuous and influential movers in setting on foot the photography of the heavens, some of the latest fruits of which we have seen in the beautiful slides that he has exhibited to us this afternoon. It is now nearly thirty years since the great comet of 1882 flared into our skies. Sir David had a number of fine photographs of that object taken at the Cape Observatory, and from the number and distinctness of the star-images shown on those plates, drew the inference that in photography we had the means for obtaining a fuller and more complete record of the heavens than direct eye-observation alone could ever give. He was therefore urgent in pressing the claims of the new method upon astronomers, and thus led on to the conception and accomplishment of the Great International Photographic Chart of the Heavens with all that it has implied. But he did not wait for the co-operation of others; he quickly put his ideas into actual practice by obtaining at the Cape Observatory a complete photographic survey of the southern hemisphere. Between that achievement and the great subject which he has expounded to us this afternoon—the existence in our neighbourhood of two great star streams—there is a strong historic connection. We have had, therefore, a subject of the highest interest laid before us by one who is essentially the master in that field.

There is just one point in Sir David Gill's address upon which I would like to ask for a suspension of judgment; I mean his reference to nebulæ as "external galaxies"; as stellar systems like our own, made nebulous to us by distance. I think that as yet we have no sufficient justification for departing from Herbert Spencer's view, expressed some forty years ago, that the stellar universe within reach of our vision, is essentially a unity, a single structure. The main fact upon which Herbert Spencer and R. A. Proctor after him, based this conclusion, was that the two great aggregations of nebulæ are found round the two poles of the Milky Way. It is true that the growth of our knowledge has somewhat altered the weight which we may attach to this fact. Yet I do not think that we can set it aside; I think it still points to the essential unity of the stellar universe within our ken, and that the idea that we are able to behold any "external galaxies" must be still regarded as very dubious.

I think that we are all unanimous in feeling that a very great favour, pleasure and instruction has been bestowed upon us this afternoon by Sir David Gill's lecture.

The ASTRONOMER ROYAL said: It has been a great pleasure to listen to Sir David Gill's address. We owe to him the most accurate measures we have of the distances of some of the stars. Many of the stars of which he told us are too far away for their individual distances to be determined and we have to be content with average values. But the accurate knowledge of the distances of the nearer stars is a secure basis which helps our knowledge of the still more distant bodies. Mr. Maunder told us that he did not altogether agree with some things in the address, and I think Sir David would admit that these parts are somewhat speculative. He began by showing us the different ways in which astronomical knowledge is being pursued, and it always seems to me that this makes a lecture much more valuable and interesting than a mere statement of results.

The difficulty in sidereal astronomy is to bring together the lines of thought so to obtain from them as correct an idea as possible of the stellar universe. Sir David's idea is that many of the stars are comparatively near the sun, but as we go further out we come to the Milky Way. All these, together, constitute what he calls our universe, and it is, he thinks, similar to one of the spiral nebulæ we see. These spiral nebulæ and the nebula of Andromeda are, in his view, much more distant, and may be said to constitute separate universes. One reason for this is that the spectroscopic observations of the Andromeda nebula made at Mount Wilson suggest that it is made up of a collection of bodies like our sun—but so far away that we cannot separate them in our largest telescopes. We cannot say that this is definitely proved, but must rather regard it as a speculation for the present.

Mr. MARTIN ROUSE said: When a photographic plate is exposed beyond a certain number of hours, does it not cease to give any more stars, and does not the number of stars gradually imprinted on the plate gradually diminish with the time of the exposure? Does the lecturer think this indicates that we are approaching the limit of the universe?

Sir DAVID GILL said: That has been investigated, and we find that there is a very rapid decrease in the number of stars and that they are much more sparsely scattered in space, the farther we go.

The Rev. JOHN TUCKWELL asked if Sir David would just say a word as to the nature of the light emanating from the nebulæ?

Professor ORCHARD asked what was the explanation of those extraordinary black spaces shown in some of the slides; do they indicate that the universe is limited and beyond this there is outer darkness?

Sir DAVID GILL in reply said: I entirely agree with Mr. Maunder and the Astronomer Royal that what I have said to you in the latter part of my address is speculative. We have no absolute proof as yet that the stars immediately surrounding the sun if viewed say from the great nebula in Andromeda would constitute a nebulous-looking cluster, and that the Milky Way if viewed at a like distance would present the appearance of a spiral nebula. But there is one point that I omitted to bring before you. It was this. If there is dust scattered through space there is no doubt that it would absorb the blue rays of light more than the red or other less refrangible rays. Those of you who remember the great volcanic explosion at Krakatoa may remember that the dust of that explosion was carried right round the world, and gave rise to glorious red sunsets, due to the absorption of the blue light by the dust. Now suppose two stars having similar spectra (that is to say, originally of the same colour)—if dust pervades space, and if the two stars are at very different distances, then the blue light of the more distant of the two stars would be more absorbed than that of the nearer star.

Now ordinary photographic plates are more sensitive to blue than to red light—therefore the difference between the photographic and the visual magnitude of a star becomes a means of estimating its distance. The process is difficult to explain in a few words, and the results are not very accurate. But on the assumption that cosmical dust is uniformly distributed in space, Professor Kapteyn has estimated that the Andromeda nebula is distant 10,000 light-years. But if, as I think most probable, when you get to that part of space where there are fewer stars, then I think it probable there will also be less cosmical dust, and if that is so Kapteyn's estimate of the distance of the Andromeda nebula will require to be largely increased—and that is one of the reasons why I think that some spiral nebulæ are so distant as to be beyond our so-called universe, and may be considered universes in themselves.

There are other reasons for this view which it would take me too long to explain now, but I quite agree with the Astronomer Royal and Mr. Maunder that the latter part of my lecture is, and was intended to be, speculative—and that the view I expressed with regard to the spiral nebulæ, though it seems to me probable, is not to be as yet accepted as a proved scientific fact.

As to Mr. Tuckwell's question—about the light of nebulæ—I suppose the question refers to those nebulæ which do not give a continuous spectrum—whose spectra are not continuous like stellar spectra.

These purely gaseous nebulæ (such as 37 H. iv Draconis) give a spectrum of bright lines—coincident with those emitted by incandescent hydrogen, helium and nitrogen—and another line, which, so far, has not been identified with any terrestrial spectrum and which, for want of a better name, we call "nebulum." As to the blank spaces seen in the photograph of portions of the Milky Way. My belief is that they are quite possibly due to absorbing clouds of matter. We have nebulous clouds which shine; I can conceive that there are others which do not shine but which absorb light. But here also we are not yet certain—the matter is not yet *proved.*

I thank you once more for the kind rèception you have given to my remarks.

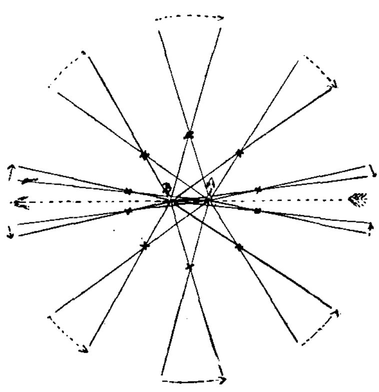
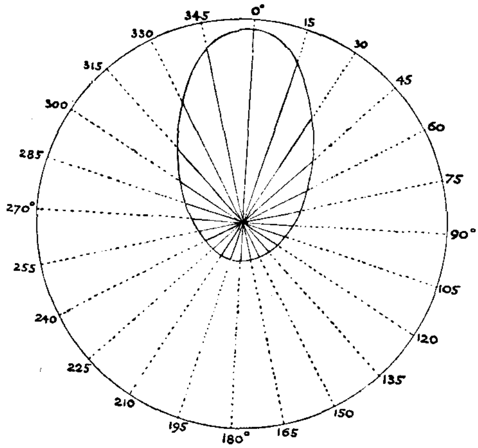


FIG. 1.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345

FIG. 2.

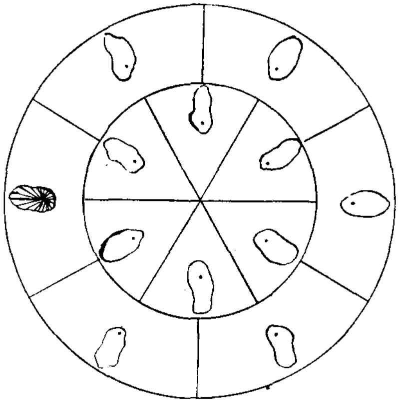
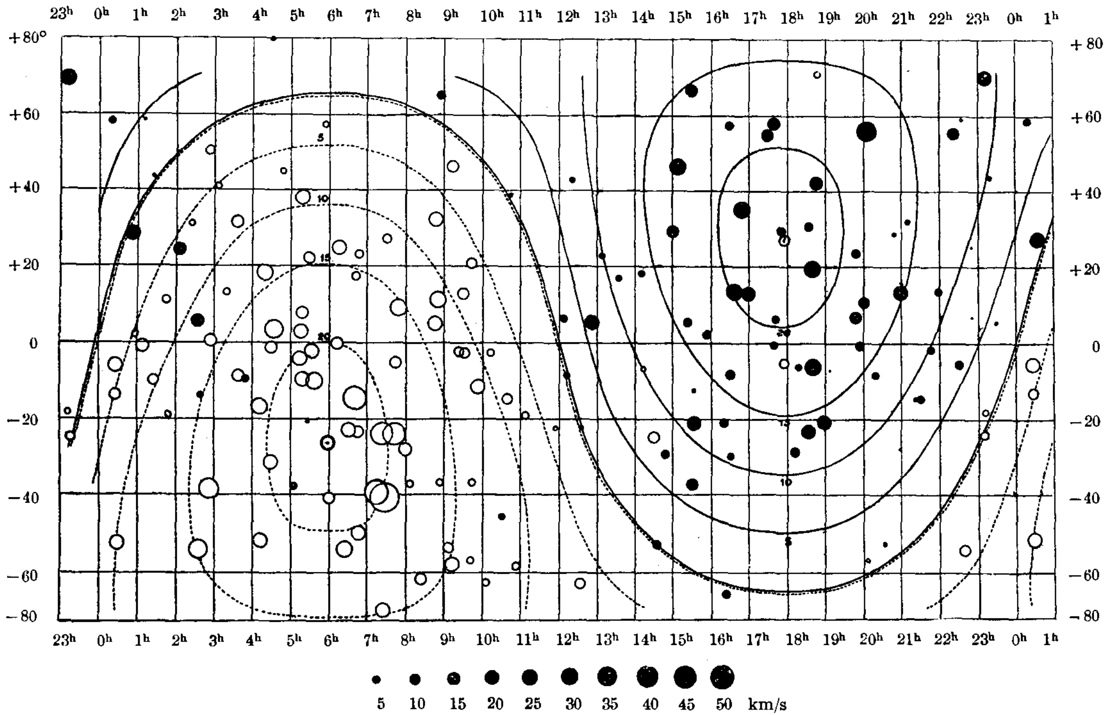


FIG. 3.



Scale of Magnitudes of Velocities.

RINGS indicate motion from ⊙ : BLACK SPOTS motion towards ⊙.

FIG. 4.—CHART SHOWING MOTIONS OF STARS (RADIAL VELOCITIES) RELATIVELY TO SUN.

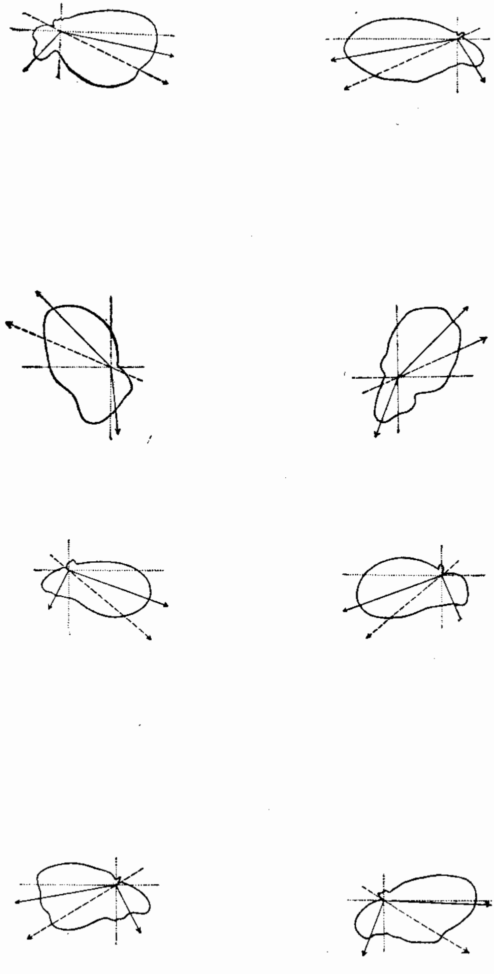


FIG. 5.

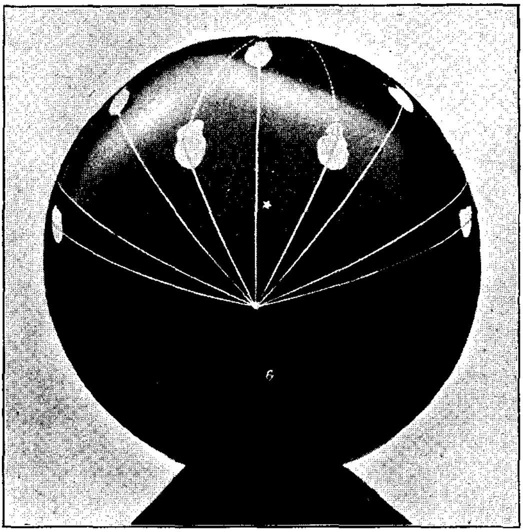


FIG. 6.

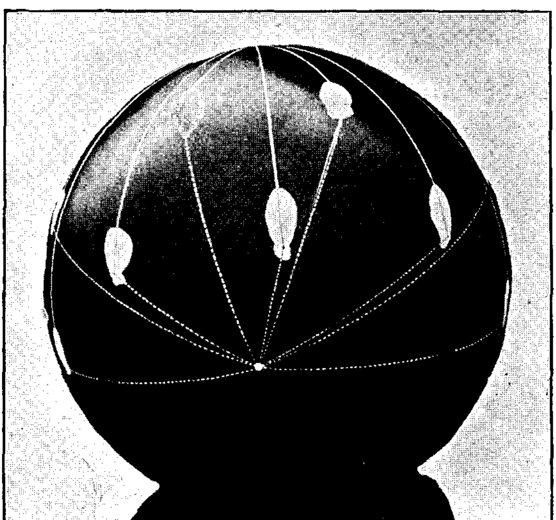


FIG. 7.