

SCIENCE

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THE STRUCTURE OF THE UNIVERSE¹

I HAVE been asked to address you on the structure of the universe. The title is ambitious, and I fear that what I have to say on the subject will be sadly in disproportion with what some of you will be led to expect by this title.

It will, however, I hope, give you a glimpse of what astronomers now-a-days are attempting to do, in order to penetrate somewhat into the mystery of the starry sky.

The problem, as I take it, is a double one. We have, first, the structure of the universe as it is at the present moment; and this problem is, in the main, no other than finding the star distances, because the star directions we can readily ascertain.

We have, second, the problem of the history and evolution of the system.

The time at my disposal being so short, I must confine myself to one of the two. At the present moment, undoubtedly, the first is the more promising one, owing to the recent discovery of star-streaming. Furthermore the history of the system during the past ages, ages to be counted by millions, probably hundreds of millions of years, is and perhaps forever will remain enshrouded in much mystery. Still I have thought that the second problem, that of the evolution of the system, may, perhaps, be the more suitable subject for the present lecture.

You will all, of course, understand, without my saying anything to the purpose, that what we have to expect can not well be anything else than a few more or less

¹ Address delivered before the National Academy of Sciences, April, 1913.

probable inferences about the course of events that have made our system what it is.

Some additional considerations might easily have been added, but as I have had to give up the idea of giving a general review of what has been done, I thought it might be as well to confine myself to just a few illustrations of the kind of speculations that we are being at present led to; and as these speculations, mainly or wholly, depend on the theory of star-streaming, it may be well to begin by saying a few words about that theory.

In order to get a clear idea of what is understood by the phenomenon of star-streaming: Imagine two clouds or swarms of stars, at first wide apart in space; imagine that the stars within each cloud move in all directions, indiscriminately, pretty much as do the molecules of a gas, and let us call this motion in the cloud the "internal motion." In fact, imagine two immense gas bubbles, the molecules of which will be our stars.

Now, imagine these two clouds or bubbles to be moving in space, and let that motion bring the two gas bubbles together, so that they will penetrate each other. Then imagine that we, the spectators, are in that part of the universe where the two bubbles have intermixed, and finally imagine that we, the spectators, have a motion of our own.

What we shall see of the motion of the individual gas molecules will very nearly correspond to what we see of the motion of the stars actually going on in the sky.

Now, what is the appearance of such a motion? Had the molecules in each gas bubble no internal motion, that is, had they no other motion than the common cloud-motion of all the molecules together, as a whole, then of course what we would see would be this: We would see two im-

mense streams of stars, all moving in perfectly parallel lines, with what, linearly, must be perfectly equal velocity.¹ If, however, the internal motion is not zero, then, of course, what we shall see will be more or less different. The internal motion gives to each molecule, besides the motion which is common to the whole of the bubble, an additional individual motion, which will make the total motion of the several molecules diverge more or less from perfect parallelism and perfect equality. Instead of seeing two streams with perfectly parallel motions, we must now see the stars *in the main* parallel to two directions, but there will be deviations—small deviations will be frequent, greater deviations will be rare, and very great deviations will be decidedly exceptional. The motion of the two individual bubbles will still be clearly discernible.

Now this is indeed what we observe in the sky. We recognize in the star motions two clearly defined *preferential* motions. These directions make an angle of about one hundred degrees. The stars are not moving all in these directions. Small deviations are frequent; greater deviations are somewhat rare; very great deviations are decidedly exceptional.

We may say that all investigations made since the first announcement of star-streaming in 1904—investigations based on very different materials—all agree in the establishment of these two preferential directions of motion among the stars. We find them in the brighter stars; we find them in the fainter stars; they show in the swift-moving stars; they show in the slow-moving stars. They betray their existence in the radial motions as well as in the motion at right angles to the visual ray.

In the *interpretation* of the facts, how-

¹ Throughout the address the motions are to be understood as relative to the sun.

ever, there is a difference. *Our* representation by the two independent star clouds is one of them. Whether this interpretation is the correct one, is a question of evolution of the system and will have to be considered presently.

Our conclusion will then be in favor of the two-cloud theory; and so, for the sake of greater clearness, I will provisionally continue to use this representation. In reality what will be advanced will not be changed, or but slightly, if we simply start from the observed facts.

In the study of the history of the system, we start from what we know, or think we know, about the evolution of the separate stars.

The stars have been classified by Secchi into four spectral classes. We have at present far more elaborate classifications, but for the present purpose Secchi's classification will do. The stars of the fourth type are so few in number that we may, for the present, neglect them. Part of the first type has later on been separated from the rest; they show the helium lines in their spectrum and are now generally brought to a separate class, the class of the helium stars.

We will thus consider the four classes: the helium stars, those of the first, second and third types—helium, first, second and third—in which the bulk of all the stars with known spectrum are contained.

Now, there is much evidence to show that this classification is a natural one. I mean that this order is really an order of evolution; the helium stars being the stars of recent birth; while we get to older and older stars as we pass from the helium stars to the first, from the first to the second, and from the second to the third type. I will adopt this order of evolution in what follows, although well aware of the fact that all astronomers do not agree with me. I feel justified in this course, not only because

I think it is the opinion of the great majority of our eminent spectroscopists, but also because the very facts which I wish to put before you about star streaming strongly confirm it.

When we wish to penetrate into the history of the system, it seems natural to investigate the problem of star streaming separately for those four classes of stars in the order of their evolution. There are some difficulties, mainly the consequence of scantiness of material. Still, however, even now it has been possible to carry the investigation through in such a way as to establish a couple of facts, and to give clear indications of others. Of these I will consider only the two following, about the reality of which I think there can hardly be left any doubt.

First, the older the stars, the greater the internal velocity, and

Second, the older the stars, the richer the second stream, at least in comparison with the first stream.

I wish to consider some of the inferences to which these facts lead us. And in the first place, these facts at once lead us back to the question just now mentioned, about the order of evolution of the individual stars. For this regularity in the increase both of the internal velocity and of the richness of the second stream exist only *if we adopt* for the order of evolution either the order, helium, first, second and third, or the exact verse order, third, second, first, helium, and in no other arrangement.

Therefore, with the same right that we expect that all the properties of the stars will change with age, gradually, and not per saltum, with that same right, I think, we conclude that the order of evolution must be helium, first, second, third, or the exact reverse. That it is not just the reverse is proved by other facts we can not now consider.

We thus have strong confirmation here of what, on totally different grounds, is pretty generally considered as the order of the different ages in a star's life.

But to proceed: As the younger the stars, the smaller their internal motion, it follows at once that from whatever matter our youngest stars—the helium stars—may have been evolved, that matter must, in all probability, have still smaller internal motion. Let us call this matter *primordial matter*. As the internal velocity of the helium stars is already so very small we come to the conclusion that primordial matter must practically have hardly any other motion than the motion of the cloud to which it belongs.

There is more. According to the second of the observed facts, the second stream, which is rich for the older stars, is much poorer for the younger ones; it almost dies out in the helium type stars. We must expect, therefore, that for primordial matter there will practically be no second stream or second star cloud.

Therefore, finally, we must expect that the particles of primordial matter will all move in practically parallel lines, and that in the direction in which all but a very few of the helium stars move, and with the same velocity.

Now it is a very general notion that it is from the nebulae that the stars are formed. Therefore that what we called primordial matter would be nothing else than the matter of the nebulae. What precedes gives us the means of testing the notion by observation. What then does observation show?

The number of available data is as yet extremely small. The determination of what we call astronomical proper motion of these very ill-defined objects is extremely difficult, and has been up to the present time invariably unsuccessful. For the de-

termination of the radial velocity by the spectroscope, the faintness of the nebulae is a serious obstacle. The consequence is that, as yet, we know the radial velocity of only fourteen of these objects in all. Still, even this limited number is decisive in showing that there can be no question that the real motions of these objects are approximately parallel to the motion of the helium stars, or even parallel to any fixed direction whatever. Their velocity, moreover, is exceedingly unequal. Must we conclude that the nebulae are not the birthplace of the stars? It may seem so.

Meanwhile let us not go too fast. There are nebulae and nebulae. It so happens—and there is ample practical reason for it—that with one exception observation of radial velocity has, up to the present time, been confined to what we call the planetary nebulae—elliptical or round nebulae—which show an appearance remotely like that of a planetary disc. Herschel saw in them a likeness to what, according to Laplace's cosmogony, must have been the primitive stage of our own planetary system and so imagined that these planetary nebulae must be the birthplace of the stars.

According to what precedes, this view seems now untenable. The planetary nebulae can not be the birthplace of the stars. If they were, they would show the parallel and equal motion of practically all the helium stars. Their motions, on the contrary, are extremely unparallel and unequal, and we must rather assign these objects a place at the end of the order of evolution than at the beginning.

We may, perhaps, see an independent confirmation of this view in the stars called temporary stars, but time will not permit me to pursue the argument further.

As I said just now, there is one nebula for which the radial velocity has been determined which is *not* a planetary. This

exception is the well-known Orion nebula, which is classified under the irregular nebulae. May not then these irregular nebulae give birth to the stars?

It turns out that this one object has exactly the radial velocity of the first stream helium stars; that is, we find exactly the motion we must expect in this nebula, if it were the birthplace of stars. We shall not, of course, on this single fact base far-reaching conclusions; but we have a right, in my opinion, to say that here is a fact that singularly strengthens what had already been concluded from other facts.

We see, moreover, that the observation of the radial velocity of other irregular nebulae must, ere long, furnish us with a crucial test of the theory.

There is another problem involved in our observations which might seem to be of no less importance than the one just mentioned. How have we to explain the fact that the internal velocity of the stars gradually increases with age? The astronomer who, in the study of the motion of the heavenly bodies, has found hardly a trace of any other force than gravitation will naturally turn to gravitation for such an explanation. It really seems a necessity that, under the influence of their mutual gravitation, bodies, which at the outset have little or no relative motion, must get such a motion; they must come to fall toward each other, and this velocity, up to a certain limit at least, must increase with time.

Thus far, there is no great difficulty. But now let us look farther back in time, back to the time in which the stars had not yet been formed, in which matter was still in its primordial state. If it be true that mutual attraction of the stars has generated such an enormous amount of internal motion in the time needed by the stars to develop from the helium type to the second

and third type, how have we to explain the fact that we find that same matter nearly at rest at the first stage of evolution at which we meet it? How have we to explain that in pre-helium ages gravitation has produced no effect?

He who believes in the creation of matter at a finitely remote epoch may find no difficulty in the question; but to him who does not, it is simply astonishing to see matter behaving as if there were no gravitation at all. What may be the explanation? Is there no gravitation in primordial matter, or is there another force exactly counterbalancing its effects?

I shall offer no solution. I simply wish to point out that here is a problem which must be interesting to the physicist no less than to the astronomer.

Passing now to other inferences, I wish to draw your attention to a question already alluded to: does the observed fact of the preference of the star motions for two definite directions lead us with necessity to the assumption that our system has been formed by the meeting of two independent star clouds? Or is it still possible, and in that case more plausible, to explain it without sacrificing the unity of the system? In other words, is our universe a dual system, or is it one unit?

Suppose² a very elongated system of stars which are originally at rest; now let these be left to their mutual attraction. It is evident that the stars, in opposite parts of the cloud, will begin to fall towards each other. Two streams will be set up, opposite in direction, approximately parallel to the axis of the cloud, though in no wise absolutely and exclusively so. In other words, we get two preferential directions of motion. There is no real difficulty in the fact

² The following supposition was first considered in a lecture held at Harlem in 1906 ("Programme de la Soc. Holl. des Sc. pour 1906," p. liv).

that they are exactly opposite, whereas the streams observed in the sky make an angle of about a hundred degrees. For opposite streams, viewed from a self-moving body, as in our earth, will appear to make an angle and we can readily determine the earth's motion in such a way as to bring us in perfect harmony with observation. Thus far no objection. But there are further consequences.

In an elongated universe, as here supposed, *both* the mean longitudinal motion (what in this lecture was called the stream motion) and the deviations therefrom (the internal motion) must gradually increase, beginning with velocity *zero*.

Now as to the internal velocities, this is exactly what we find by observation. Do we find the same for the stream motion? By no means.

Recent Mt. Wilson observations have enabled us to derive at least a pretty reliable value of the relative stream velocity for the first type stars. For the helium stars we can as yet only assign a limit which the relative velocity of the two streams must exceed. For the older stars we have had reliable information for some time.

All these determinations show, contrary to what takes place with the internal motion, that the relative velocity of the two streams or clouds does not change, or does not change very much, with age. It certainly is not nearly vanishing for the helium stars. It seems to me that this consideration is fatal to the present explanation.

Professor Schwarzschild has developed a different theory, which also leaves the universe a unit; but this theory too, elegant though it be, can not, I think, be maintained. Among other things, we have, as a main objection, the fact—which was not known at the time Professor Schwarzschild

proposed his theory—that the richness of the two streams is not the same for stars of different age. The tacit assumption is made, and must be made, in Schwarzschild's theory, that the two streams have the same number of stars. Now, this may be more or less approximately true of the stars of the second and third types, for the first type the number of stars in the second stream can not be much different from *one third* of that in the first stream. For the helium stars it must not be a *tenth*. The second stream is so poor here that it has been altogether overlooked till quite recently.

The conclusion to be drawn from all this seems obvious. It would seem that we are driven to the theory assumed here, from the first, the theory of the two-star clouds, which, owing to their initial velocity, have come to meet and intermingle in space. It must be confessed, however, that in this theory also there remain some hard nuts to crack. Until we succeed in this it seems unsafe to claim any great certainty for the theory, and it seems preferable to put it forward as the hypothesis which, for the time being, best fits the observed facts.

There remains to be considered the question how to explain that the second stream or cloud hardly contains any helium stars.

There is something in the small local star-groups which may help us. Everybody knows the group of the Pleiades. There can be no doubt that the bright and many of the faint stars that we see in this part of the sky are really near together in space and not merely near the same visual line, the one far behind the other. They undoubtedly form a physical system, and must have had a common origin. At present we know several of such local groups, among them the Hyades, the Ursa Major group, and we may perhaps add the great Scorpius-Centaur group.

Now, in these local groups, we find,

amongst others, two very remarkable facts. The first is that, ignoring a few, though significant exceptions, if the stars of such groups are arranged in the order of their brightness, we find that they are at the same time approximately arranged in the order of the spectral classes. As an instance, take the Scorpius-Centaur group. We find that the very brightest stars are of the earliest helium type; the somewhat fainter ones are of the older helium type; the next fainter ones are of the next stage in the stellar life, or the first type. If we can not follow the series further on to the second and perhaps the third type, this is probably due to our lack of knowledge of the fainter stars belonging to the group. In the Pleiades, where we have a somewhat more extensive knowledge of the fainter stars, we can follow the series at least until in the middle of the second type stars. It follows from this that in all these groups, what there is of helium stars can not be overlooked, for they all are of the very brightest stars, and our knowledge of the brightest stars is pretty complete.

Notwithstanding this—and this is the second remarkable fact, the fact that bears directly on the question in hand—we find not a single helium star, neither in the Hyades nor in the Ursa Major group. The stars in these groups show the same gradual change of spectrum with the brightness, but instead of beginning with the earliest helium stars, the series begins abruptly with the second stages of a star's life. In the Pleiades the series begins somewhat earlier; still here too there is not a single star of the earliest helium type. It is only in the Scorpius-Centaur group that we find the complete series.

Our second stream, therefore, behaves much as do the local groups of the Hyades and Ursa Major. The explanation must, in all likelihood, be the same in both cases.

How, therefore, does it come to pass that in such groups as those of the Hyades and the Ursa Major, the helium stars are absolutely wanting?

For those who, as I did in this lecture, adopt the view of the order of evolution as helium, first, second, third type, there can be no question but that the stars which we now see are first type stars, must in past ages have been helium stars.

Therefore, such a group as the Hyades, which now-a-days does not contain any helium stars, but which contains first type stars, must in past ages have contained the helium stars in great numbers. Going back in time still further, these helium stars must have been evolved from some primordial matter, probably some nebulous matter. Therefore, in a remote past the groups of the Hyades and Ursa Major must have been full of nebula. As far as I know there is no trace of nebulosity now.

There thus must have been an epoch in the past that nebulous matter was exhausted, had probably all gone into the formation of stars. Since that time evidently there could be formed no more helium stars; and as the helium stars that had been formed developed gradually into first type stars we see the necessity of a time in which the groups must not contain any more helium stars.

Therefore, finally, our answer to the question: how does it come to pass that in the second stream or cloud we find hardly any helium stars, would be: because since some time nebulous matter must have been exhausted in this cloud.

As to the first stream or star cloud, we similarly conclude that the nebulous matter must not yet have been exhausted, or if so, only at a very recent period.

It has been my aim to show, *not* that much has been done, but that there is a beginning; *not* that we have entered far into

the promised land, the land lying open to the human view, so temptingly since the first man looked up to the sky, but that a few pathways are being mapped out, along which we may direct a hopeful attack. Our problems take a more definite form, and even though we were never to solve them completely, let us remember the words of the poet:

If God held in His right hand all truth, and in His left nothing but the ever ardent desire for truth, even with the condition that I should err forever, and bade me choose, I would bow down to his left, saying, "Oh, Father, give; pure truth can be but for Thee alone."

J. C. KAPTEYN

BLOOD PARASITES¹

YOU will remember that Mephistopheles, when he insists upon the bond with Faust being signed with blood, says, "Blut ist ein ganz besondrer Saft" (Blood is a quite special kind of juice). Goethe would probably not have used the word "Saft" had he been writing "Faust" to-day instead of in 1808, for at that time the cellular elements of the blood—although they had been seen and described by Leeuwenhoek in 1686—were believed to be optical illusions, even by so distinguished a person as the professor of medicine of that time at the Sorbonne. The incredulity of scientific men as to what they see is proverbial and astounding, fortunately; but it is probably because science is really quite sure of nothing that it is always advancing.

I have the privilege this evening of trying to show you the barest outlines of our present knowledge of the parasitology of the blood. It is a subject of great practical and economic importance, as many grave diseases of man and beast are caused by these parasites, which, on account of their minuteness, enormous numbers and

very complex life-histories, are very difficult to eradicate or to deal with practically. On this account there is a good deal of the enthusiasm of the market-place mixed up with this subject, which, although a new one, has advanced with great rapidity, and has revolutionized pathology and medicine as far as possible. From our point of view it began in 1880 with the discovery by Laveran, in the military hospital of Constantine, of the parasite which causes malaria. This caused the protozoa, to which order most of these parasites belong, to oust bacteria from the proud position they then occupied of being the cause of all the ills we have to bear, and to reign in their stead; not an altogether desirable change; for when you have seen what I shall show you, you will agree with me that sufficient unto life is the evil thereof. It has had all the disadvantages of a new subject, and since that time floods of work have been poured into journals, annals, proceedings, etc., some of it of the best, with much of it that is indifferent, temporary and bad; so that at times it seems as if this branch of science were in danger of being smothered in the dust of its own workshop, or drowned in the waters of its own activity. We do not, nowadays, keep our ideas and scraps of work to ourselves until they are either established, or, as is more likely, dissipated, so we have a huge mass of what is called "literature," filled with many trivial, fragmentary and doubtful generalizations, many of which we have with pain and trouble to sweep into the dustbin: nature's blessed mortmain law taking too long to act. You remember Carlyle complained—to use a mild term—of Poggendorff's "Annalen," and I feel sure that, if he had had to study blood parasites now, he would have said that it was a much over-be-Poggendorffed subject. Blood parasites are afflicted, too, with ter-

¹ Abstract of a lecture before the Royal Institution of Great Britain, May 2, 1913.