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The Rotation of the Galaxy

By Dr. J. S. Plaskett, F.R.S.

The Chairman:—Gentlemen, all of us have looked at the stars with awe and wonder and perhaps with some disturbing reflections about our ordinary everyday sense of values. There may have been occasions when we have been moved to poetry in a mystical vein. There have certainly been occasions when we have been mystified and wanted to have a student of astrophsics at hand to answer what might be, to him, foolish quentions. Experts in the field of astronomy are extremely rare, and if we cannot meet Dr. Plaskett under the most favorable conditions in his observatory, we are nevertheless very fortunate to have him here today. He will speak about the rotation of the galaxy which I believe has nothing to do with dancing nor the procession of speakers through the Canadian Clubs, but with something which I will leave him to describe. I have much pleasure in introducing Dr. Plaskett.

Dr. Plaskett:—Mr. Chairman and members of the Canadian Club, I have chosen the rotation of the galaxy for the topic of my address today, partly because it is a subject which is largely occupying the attention of astronomers at the present time and partly because we have been responsible at Victoria Observatory, of which I have the honor to be director, for furnishing most convincing proof of a rotation of the galaxy. But before going into the details of such a rotation let us inquire more particularly, especially in view of the chairman's remarks, exactly what is meant by the term galaxy. When the word galaxy is used it refers to the system of stars outlined by the Milky Way and is practically synonymous with the term stellar system. Until recently we believed there was not more than one stellar system. The galaxy is a system of stars, of which our sun is one relatively insignificant star among thousands of millions of others and it contains all the objects readily visible in our telescopes with the exception of certain of the nebulae of spiral form which we now believe are separate galaxies or separate stellar systems. It is readily seen when you look at the Milky Way through the naked eye that it must extend a very great distance and it must have a relatively flat shape. This idea of the form of the stellar system was first introduced by Wright two hundred years ago and was later elaborated by the elder Herschel who assumed that the shape of the galactic system approximated a grindstone.

Our ideas of the size or the dimensions of this galactic system have grown with increasing knowledge of the distance of the stars. Early guesses of the nineteenth century were based on meagre information with little pretence to accuracy and it was not until 1905 that Newcomb and Seeliger gave as an estimate of the diameter of the system the distance of seven thousand light years. This modest estimate is very small compared with the modern idea of two hundred thousand or three hundred thousand light years, but yet seven thousand light years is a tremendous distance, and before we proceed it would be better perhaps to see if we could get some conception of what seven thousand light years actually means. The light year is the distance that light will travel in a year moving at the rate of one hundred and eighty-six thousand miles per second. It is six million million miles and the distance of the nearest fixed star to our sun, the star in the southern hemisphere, is a little over four light years or twenty-five million million miles. It is relatively easy to say twenty-five million million miles and yet I don't think many of us have a conception how great a distance that is. One or two examples: take a train travelling 60 miles an hour, day in and year in and year out, it would take over fifty seven million years to reach that star. While if we attempted to span that distance with the spider's web—it has been estimated it would take two pounds to go around the equator—it would take one million tons of spider web to reach the nearest star and over seventeen hundred million tons to stretch across that modest distance of seven thousand light years. This diameter was increased in 1914 to ten thousand light years and shortly after to fifteen thousand light years.

But by far the most thorough and extended investigation of the structure and dimensions of our stellar system is due to the famous Dutch astronomer Kapteyn who in 1920, after extended investigations, stated that in the galaxy the stars thinned out a great deal as they went away from the sun and that if you went to the distance where the stars are only one-tenth as thickly spaced as near the center the diameter of that system would be about eighteen thousand light years, and the thickness three thousand five hundred, whereas if you went further out where the stars are only 1-100 as thick as in the center the diameter would be about fifty-five thousand light years and the thickness about eleven thousand. But all these estimates of the diameter and the constitutional structure of the stellar system refer to a simplified sort of a watch shaped system around the sun and gradually thinning out towards the edges with the sun as the center. It only requires a glance at the Milky Way on a clear night to see how far from reality such a conception is. Instead of uniformity they seem to be divided into star clouds; they are very far from regularity. I had a couple of slides to indicate that. These slides show how the stars are clustered into great clouds with the darker regions between them. So this conception of a watch shaped form was a little better than a mathematical conception rendered necessary by the complexity of the problem. You all know how necessary it is to make some assumptions so that we can attack these complexities.

An entirely new conception of the magnitude and the complexity of the stellar system was given by the researches of Professor Shapley at the Mount Wilson Observatory. About twelve years ago he evolved a new method of determining distances of the stars, a method depending on the intrinsic brightness of certain stars, and by those means determined the distances of the globular clusters. The Hercules cluster is a compact aggregation of stars, containing fifty or sixty thousand, the stars being much more closely spaced than in the neighborhood of the sun, being probably only a light year or two away from each other.

But the density decreases as you go out and it is probably a compact unit, a small stellar system. Shapley estimates the clusters are distant between twenty thousand and two hundred thousand light years and he calculated their distribution with respect to the central plane of the Milky Way. He found they were distributed symmetrically with respect to this central plane, with as many on one side as on the other and there was no escape from the conclusion that these were members of the Milky Way or galactic system. The central position of the sun with respect to the greater system was irretrievably lost when it was found by distribution of the clusters that it was about sixty thousand light years from the center of the system, nearly half way between the center and edge of the great galactic system which Shapley estimated to have a diameter of three hundred thousand light years and a thickness of about twelve thousand: a tremendous organization indeed. Shapley's conceptions of the structure and dimensions have been confirmed by investigations with the proviso that the distance of the clusters, and hence the scale of the system, may have to be slightly reduced, possibly by thirty thousand, but even this leaves us with a system over two hundred thousand light years in diameter. A modern conception of the galactic system, then, is not a single watch-shaped cluster of stars, only much thinner than a watch, but an aggregation composed of the stars immediately surrounding the sun, which has been up until lately considered the whole universe, and numerous others represented by the Milky Way clouds, the whole forming a disc-like system of about two hundred thousand light years.

It has been estimated that there are thirty thousand million stars in the galactic system in which our sun is a relatively insignificant member.

Having thus attempted to give you some, perhaps inadequate, realization of the immensity and complexity of our galactic system, let us go on to consider more particularly the rotation of such system. You must imagine the galactic system rotating in its own plane like a great disc or wheel. It was almost inevitable, as soon as it was found that the satellites revolved around the planets and the planets around the sun, that speculation should arise as to the revolution

of the stars of this system around some central star or sun, and almost equally inevitable that the sun should be selected as the center of the universe. This, however, was varied by the middle of the nineteenth century by Madler who claimed to have found that the star Alcyone, the brightest star of the Pleiades, was the sun around which the Universe rotated, was the center of the system. However none of these speculations had any real evidence to support them. Little had been heard for several decades about the rotation of the galaxy.

The matter, however, was placed on an entirely different footing scarcely three years ago by the astronomer Lindblad who, in an excellent paper to the Swedish academy, said the galactic system, this great aggregation of thirty thousand million stars, was in rotation in its own plane or rather was composed of a number of subsystems approximately concentric with one another and going around a common axis perpendicular to the galactic plane. The sub-system with the highest plane of rotation would obviously be the most flattened and on his idea the system containing our sun, the great aggregation of the Milky Way clouds, extended to two hundred thousand light years in diameter and included the vast majority of the stars. Sub-systems with a lower speed of rotation would have less concentration towards the galactic plane and the stars in these sub-systems would on account of the high speed appear to be moving much faster than the stars in our own system. The system with the least speed is believed to be that of the globular clusters which on account of the high rotational speed of the center, believed to be one hundred and eighty thousand or one hundred and ninety thousand miles per second, appeared to be moving very fast. Lindblad's hypothesis was immediately successful in explaining certain hitherto mysterious and unexplainable systematic motions of the stars. But he did not bring forward any new evidence in support of his theory.

This was left to a young Dutch astronomer, Oort, who in 1927 published a masterly paper on the rotation of the galaxy. He attempted to show that the system rotated from observations of the motions of the stars out of the system and obviously that the sun and stars are rotating together.

Let us try to see exactly what the rotation of the galactic system implies. Such a rotation must necessarily require some central attracting force, some force to keep the stars together and keep them moving in paths, otherwise they would go off into space. Obviously such an attractive force is provided by the stars of the system themselves, which are more than sufficient to keep the orbits of the paths of the stars closed, so they will move around the system instead of the whole system scattering. It is necessary to consider what kind of attractive force our galactic system will provide, and this depends upon the distribution of the stars within the system itself, whether they are uniformly distributed or whether there is a condensation of the stars towards the center of this system.

In the first place with a uniform distribution the laws of dynamics tell us immediately that the force will increase with the distance from the center—twice the distance there will be twice the attracting force, three times the distance, three times the force, and in such case of uniform distribution the stars will revolve around the centre of the system in exactly the same time. There would be no relative motion of any of the stars. There would be no means of detecting a revolutionary rotation any more than a fly on the hub of a rapidly rotating wheel could tell from a fly on the rim whether they were in motion or not.

If, however, on the other hand, the matter instead of being uniformly distributed throughout this galactic system is concentrated towards the center then the law of course would be quite different. Instead of the force increasing as you went away from the center it would decrease and with the square of the distance. That is to say that twice the distance from the center the force of attraction would be only one-fourth instead of twice; at three times the distance the attractive force would be one-ninth instead of three times. And this law of course also tells us that instead of moving around the center, all at the same time, the stars near the center will move much faster than those further away and quite similar to the case of our own solar system in which 99¾ per cent of the matter is concentrated in the sun itself and in which the inner planets move much more rapidly than the outer. If you could observe the speed of the planets in the system you could then tell from the speeds of these different planets, the circumstances and the rotation of the solar system. So by measuring the velocities of the stars with respect to the sun in the greater galactic system we could at once determine the circumstances of the rotation of such system.

I will proceed to consider the rotation of the galaxy more particularly. If we consider instead of uniform distribution of the stars that they are more concentrated towards the center of the galaxy, then the law of force and the way in which the bodies rotate around the sun will be quite different. Instead of revolving uniformly as a solid body the motion will be quite different. The stars near the sun will move much more quickly than those further out, similar to the motions in our solar system. And if we could measure the speed of the different planets we could immediately tell all the circumstances of the rotation of the solar system. Similarly then in the galactic system in which the stars are in motion around the sun, we could by the relative motion of the stars in this system determine the circumstance of the rotation of the galactic system. Oort's great advance was, by means of a method of analysis of Lindblad's theory, to determine the rotation of the galaxy from the motions of the stars within the system itself. By measuring the velocities of the distant stars he was able to show that the whole system was in rotation. Differences in velocity correspond to a speed of about five-eighths of a mile per second for stars at a distance of two hundred light years. So a velocity of five kilometres per second is perhaps the smallest that could be observed where we have to deal with stars a thousand light years from the sun. We already know the velocities of some six or seven thousand stars, the majority of these invisible to the naked eye, but unfortunately the vast majority of these stars are closer than one thousand light years and hence not very suitable for determining the rotation of the galaxy. However, Oort was able to show from the velocities of about one hundred stars one thousand or more light years from the sun that the directions and the speeds of these stars conform very closely to the speed that would be produced by the rotation of the galaxy. But it was obvious with the distances that many more stars were required to make this certain. And this was proved by investigation being carried on by the Dominion Astrophysical observatory in measuring the velocities of five hundred stars. These were very distant, ranging from one thousand to five thousand or more light years away, and secondly on the ratio that we have just spoken of: one kilometres to two hundred light years, the rotational effect would be from five to twenty-five kilometres per second.

Altogether we had the velocities of eight hundred and seventy-five stars. The gaseous medium filling the stellar space showed lines from which we could measure the velocity. This gaseous medium is composed of elements similar to those which we have on the earth and it is extensively diffused, there being in the whole body only about one third of an ounce of this matter—millions of times as diffused as in the incandescent light. So that to test the rotation of the galaxy we have the velocities of eight hundred and seventy-five stars and the rotational velocities of this stellar cloud in two hundred and sixty-one different positions along the sky.

We find the rotational effect for one group is about 27½ kilometres per second. This corresponds to two hundred multiplied by 27½ or five thousand five hundred light years. This means stars five thousand five hundred light years away from the center of the system will be moving 27½ kilometres faster and those five thousand five hundred further from the center of the system will be moving 27½ kilometres slower. And as we believe that the rotational velocity of the sun is about three hundred kilometres per second, the rotational velocity of the stars five thousand five hundred light years nearer the center will be 327½, that of those opposite, 272½ kilometres.

I have just time to summarize. We have seen that the great galactic system is about two hundred thousand light years in diameter and about ten or twelve thousand in thickness and that it is in rotation in a peculiar way, the stars nearer the sun moving more quickly than those further out. And we have seen that the speed of rotation is about three hundred kilometres a second. This enormous speed is over two thousand times as fast as the recent remarkable speed attained in the Schneider Cup races, and yet, though the sun is moving with the speed of three thousand kilometres per second the rotation of the galaxy is an extremely leisurely operation. It will take three hundred million years to make one revolution and consequently only about three revolutions have taken place in the whole span of geological time. This remarkably high speed when translated into angular measure is extremely small. So the sun if viewed from a distance would appear to be moving over the sky. Thus in a thousand years it would only move over the diameter of a twenty-five cent piece, viewed from the distance of a mile. Our modern methods can attain almost inconceivable accuracy.

Although we cannot observe the rotation of the galaxy directly I think we can be quite sure from our analysis of the motions of some of the distant stars that this great system is in rotation; and I think when the imagination tries to realize the magnitude and the complexity and the grandeur of our solar system, we must become staggered. But when we see this complex system can be arranged and ordered into the most orderly and useful fashion and the extraordinarily complex and almost hopeless confusion of the motions of the stars can be reduced into the measured and stately rotation of the galactic system, I think no one can help believing in the majesty and beneficent power of the ruler of the Universe.

The Chairman:—Professor, I apologize to you for the disturbing state of things here today but on behalf of the club I tender you our thanks for coming here and giving us this interesting talk. Gentlemen, the slides are now ready and if any of you can stay the professor will be delighted to show them.

Dr. Plaskett received the thanks of the chairman and then displayed a number of slides.