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MODERN THEORIES OF THE SPIRAL NEBULAE [1]

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In one sense, that theory of the spiral nebulae to which many lines of recently obtained evidence are pointing, can not be said to be a modern theory. There are few modern concepts which have not been explicitly or implicitly put forward as hypotheses or suggestions long before they were actually substantiated by evidence.

The history of scientific discovery affords many instances where men with some strange gift of intuition have looked ahead from meagre data, and have glimpsed or guessed truths which have been fully verified only after the lapse of decades or centuries. Herschel was such a fortunate genius. From the proper motions of a very few stars he determined the direction of the sun's movement nearly as accurately, due to a very happy selection of stars for the purpose, as far more elaborate modern investigations. He noticed that the star clusters which appeared nebulous in texture in smaller telescopes and with lower powers, were resolved into stars with larger instruments and higher powers. From this he argued that all the nebulae could be resolved into stars by the application of sufficient magnifying power, and that the nebulae were, in effect, separate universes, a theory which had been earlier suggested on purely hypothetical or philosophical grounds, by

[1] Abstract of a lecture given on March 15, 1919, at a joint meeting of the Washington Academy of Sciences and the Philosophical Society of Washington. The lecture was illustrated with numerous lantern slides.

Wright, Lambert, and Kant. From their appearance in the telescope he, again with almost uncanny prescience, excepted a few as definitely gaseous and irresolvable.

This view held sway for many years; then came the results of spectroscopic analysis showing that many nebulae (those which we now classify as diffuse or planetary) are of gaseous constitution and cannot be resolved into stars. The spiral nebulae, although showing a different type of spectrum, were in most theories tacitly included with the known gaseous nebulae.

We have now, as far as the spiral nebulae are concerned, come back to the standpoint of Herschel's fortunate, though not fully warranted, deduction; and the theory to which much recent evidence is pointing is that these beautiful objects are separate galaxies, or "island universes", to employ the expressive and appropriate phase coined by Humboldt.

By means of direct observations on the nearer and brighter stars, and by the application of statistical methods to large groups of the fainter or more remote stars, the galaxy of stars which forms our own stellar universe is believed to comprise perhaps a billion suns. Our sun, a relatively inconspicuous unit, is situated near the centre of figure of this galaxy. This galaxy is not even approximately spherical in contour, but shaped like a lens or thin watch. The actual dimensions are highly uncertain; Newcomb's estimate that this galactic disk is about 3,000 light-years in thickness, and 30,000 light-years in diameter, is perhaps as reliable as any other.

Of the three classes of nebulae observed, two, the diffuse nebulosities and the planetary nebulae, are typically a galactic phenomenon as regards their apparent distribution in space, and are rarely found at any distance from the plane of our Milky Way. With the exception of certain diffuse nebulosities whose light is apparently a reflection phenomenon from bright stars involved within the nebulae, both these types are of gaseous constitution, showing a characteristic bright-line spectrum.

Differing radically from the galactic gaseous nebulae in form and distribution, we find a very large number of nebulae predominantly spiral in structure. The following salient points must be taken into account in any adequate theory of the spiral nebulae.

1. In apparent size the spirals range from minute flecks, just distinguishable on the photographic plate, to enormous spirals like *Messier* 33 and the Great Nebula in Andromeda, the latter of which covers an area four times greater than that subtended by the full moon.

2. Prior to the application of photographic methods, fewer than ten thousand nebulae of all classes had been observed visually. One of the first results deduced by Director Keeler from the programme of nebular photography which he inaugurated with the Crossley Reflector at Lick Observatory, was the fact that great numbers of small spirals are within reach of modern powerful reflecting telescopes. He estimated their total number as 120,000 early in the course of this programme, and before plates of many regions were available. I have recently made a count of the small nebulae on all available regions taken at the Lick Observatory during the past twenty years[1] and from these counts estimate that there are at least 700,000 spiral nebulae accessible with large reflectors.

3. The most anomalous and inexplicable feature of the spiral nebulae is found in their peculiar distribution. They show an apparent abhorrence for our galaxy of stars, being found in greatest numbers around the poles of our galaxy. In my counts I found an approximate density of distribution as follows:

Galactic Latitude +45° to +90°	34 per square degree.
Galactic Latitude −45° to −90°	28 per square degree.
Galactic Latitude +30° to +45° and −30° to −45°	24 per square degree.
Galactic Latitude −30° to +30°	7 per square degree.

No spiral has as yet been found actually within the structuer of the Milky Way. We have doubled and trebled our exposures in regions near the galactic plane in the hope of finding fainter spirals in such areas, but thus far without results. The outstanding feature of the space distribution of the spirals is, then, that they are found in greatest profusion where the stars are fewest, and do not occur where the stars are most numerous. This distribution may be illustrated graphically as follows:

[1] Curtis, H. D. *On the number of spiral nebulae*, Proc. Amer. Phil. Soc. 57: 513. 1918.

THE FACTOR OF SPACE DISTRIBUTION

400,000±Spiral Nebulae

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Our own stellar universe
is shaped like a thin lens, and is perhaps
3,000 by 30,000 light-years in extent. In this
space occur nearly all the stars, nearly all the new stars, nearly
all the variable stars, most of the diffuse and
planetary nebulae, etc., but *no spiral
nebulae.*

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300,000±Spiral Nebulae.

4. The spectrum of the spirals is practically the same as that given by a star cluster, showing a continuous spectrum broken by absorption lines. A few spirals show bright-line spectra in addition.

5. The space-velocities of the various classes of celestial objects are summarized in the following short table:

THE FACTOR OF SPACE-VELOCITY

1. *The Diffuse Nebulae.*
   Velocities low.
2. *The Stars.*
   Velocities vary with spectral type.

Class B Stars: average speeds 8 miles per second.
Class A Stars: average speeds 14 miles per second.
Class F Stars: average speeds 18 miles per second.
Class G Stars: average speeds 19 miles per second.
Class K Stars: average speeds 21 miles per second.
Class M Stars: average speeds 21 miles per second.

3. *The Star Clusters.*
   Velocities perhaps 150 miles per second.
4. *The Planetary Nebulae.*
   Average speeds 48 miles per second.
5. *The Spiral Nebulae.*
   Average speeds 480 miles per second.

The peculiar variation of the space-velocity of the stars with spectral type may ultimately prove to be a function of relative mass. The radial velocities of but few spirals have been determined to date; future work may change the value given, but it seems certain that it will remain very high.

It will be seen at once that, with regard to this important criterion of space-velocity, the spiral nebulae are very distinctly in a class apart. It seems impossible to place them at any point in a coherent scheme of stellar evolution. We can not bridge the gap involved in postulating bodies of such enormous space velocities either as a point of stellar origin, or as a final evolution product.

On the older theory that the spirals are a part of our own galaxy, it is impossible to harmonize certain features of the data thus far presented. If this theory is true, their grouping near the galactic poles, inasmuch as all evidence points to a flattened or disk form for our galaxy, would indicate that they are relatively close to us. In that event, we should inevitably have detected in this class of objects proper motions of the same order of magnitude as those found for the stars at corresponding distances. Such proper motions are the more to be expected in view of the fact that the average space velocity of the spirals is about thirty times that of the stars. I have repeated all the earlier plates of the Keeler nebular programme, and was able to find no certain evidence of either translation or rotation in these objects in an average time interval of thirteen years.[1] Their form, and the evidence of the spectroscope, indicate, however, that they are in rotation. Knowing that their space-velocities are high, the failure to detect any certain evidence of cross motion is an indication that these objects must be very remote.

Even if the spiral is not a stage in stellar evolution, but a class

[1] Curtis, H. D. *The proper motion of the nebulae.* Publ. Astron. Soc. Pacific 27: 214. 1915.

apart, is it still possible to assume that they are, notwithstanding, an integral part of our own stellar universe, sporadic manifestations of an unknown line of evolutionary development, driven off in some mysterious manner from the regions of greatest star density?

A relationship between two classes of objects may be one of avoidance just as logically as one of contiguity. It has been argued that the absolute avoidance which the spirals manifest for the galaxy of the stars shows incontrovertibly that they must, by reason of this very relationship of avoidance, be an integral feature of our galaxy. This argument has proved irresistible to many, among others to so keen a thinker as Herbert Spencer, who wrote:

"In that zone of celestial space where stars are excessively abundant nebulae are rare; while in the two opposite celestial spaces that are furthest removed from this zone nebulae are abundant. . . . Can this be mere coincidence? When to the fact that the general mass of the nebulae are antithetical in position to the general mass of the stars, we add the fact that local regions of nebulae are regions where stars are scarce . . . does not the proof of a physical connection become overwhelming?"

It must be admitted that a distribution, which has placed three-quarters of a million objects around the poles of our galaxy, would be against all probability for a class of objects which would be expected to be arranged at random, unless it can be shown that this peculiar grouping is only apparent, and due to some phenomenon in our own galaxy. This point will be reverted to later.

It has been shown that the factors of space-velocity and space-distribution separate the spirals very clearly from the stars of our galaxy; from these facts alone, and from the evidence of the spectroscope, the island universe theory is given a certain measure of credibility.

Another line of evidence has been developed within the past two years, which adds further support to the island-universe theory of the spiral nebulae.

New Stars

Within historical times some twenty-seven new stars have suddenly flashed out in the heavens. Some have been of interest only to the astronomer; others, like that of last June, have rivalled *Sirius* in brilliancy. All have shown the same general history, suddenly increasing in light ten thousand-fold or more, and then gradually, but still relatively rapidly, sinking into obscurity again. They are a very interesting class, nor has astronomy as yet been able to give any universally accepted explanation of these anomalous objects. Two of these novae had appeared in spiral nebulae, but this fact had not been weighed at its true value. Within the past two years over a dozen novae have been found in spiral nebulae, all of them very faint, ranging from about the fourteenth to the nineteenth magnitudes at maximum. Their life history, so far as we can tell from such faint objects, appears to be identical with that of the brighter novae. Now the brighter novae of the past, that is, those which have not appeared in spirals, have almost invariably been a galactic phenomenon, located in or close to our Milky Way, and they have very evidently been a part of our own stellar system. The cogency of the argument will, I think, be apparent to all, although the strong analogy is by no means a rigid proof. If twenty-seven novae have appeared in our own galaxy within the past three hundred years, and if about half that number are found within a few years in spiral nebulae far removed from the galactic plane, the presumption that these spirals are themselves galaxies composed of hundreds of millions of stars is a very probable one.

If, moreover, we make the reasonable assumption that the new stars in the spirals and the new stars in our own galaxy average about the same in size, and absolute brightness, we can form a very good estimate of the probable distance of the spiral nebulae, regarded as island universes. Our galactic novae have averaged about the fifth magnitude. The new stars which have appeared in the spiral nebulae have averaged about the fifteenth magnitude, but it would appear probable that we must inevitably miss the fainter novae in such distant galaxies, and it is perhaps reasonable to assume that the average magnitude of the novae in spirals may be about the eighteenth, or thirteen magnitudes fainter than those in our own galaxy. They would thus be about 160,000 times fainter than our galactic novae, and on the assumption that both types of novae average the same in mass, absolute luminosity, etc., the novae in spirals should be four hundred times further away. We do not know the average distance of the new stars which have appeared in our own galaxy, but 10,000 light years is perhaps a reasonable estimate. This would indicate a distance of the order of 4,000,000 light-years for the spiral nebulae.[1] This is an enormous distance, but, if these objects are galaxies like our own stellar system, such a distance accords well with their apparent dimensions. Our own galaxy, at a distance of 10,000,000 light years, would be about 10 minutes of arc in diameter, or the size of the larger spiral nebulae.

On such a theory, a spiral structure for our own galaxy would be probable. Its proportions accord well with the degree of flattening observed in the majority of the spirals. We have very little actual evidence as to a spiral structure for our galaxy; the position of our sun relatively close to the centre of figure of the galaxy, and our ignorance of the distances of the remoter stars, renders such evidence very difficult to obtain. A careful study of the configurations and star densities in the Milky Way has led Professor Easton, of Amsterdam, to postulate a spiral structure for our galaxy.

Disrtibution of Spirals

There is still left one outstanding and unexplained problem in the island universe theory or any other theory of the spiral nebulae. Neither theory, as outlined, offers any satisfactory explanation of the remarkable distribution of the spirals. On the older theory, if a feature of our galaxy, what has driven them out to the points most remote from the regions of greatest star density? If, on the other hand, the spirals are island universes, it is against all probability that our own universe should have chanced to be situated about half way between two great groups

[1] Recent parallaxes of 4 novae indicate smaller distance for galactic novae, so that the Andromeda nebula is probably 5C0,000 to 1,000,000 l.y. distant.

of island universes, and that not a single object of the class happens to be located in the plane of our Milky Way.

There is one very common characteristic of the spirals which may be tentatively advanced as an explanation of the peculiar grouping of the spirals.

A very considerable proportion of the spirals show indubitable evidence of occulting matter, lying in the plane of the greatest extension of the spiral, generally outside the whorls, but occasionally between the whorls as well. This outer ring of occulting matter is most easily seen when the spiral is so oriented in space as to turn its edge toward us. But the phenomenon is also seen in spirals whose planes make a small, but appreciable angle with our line of sight, manifesting itself in such appearances as "lanes" more prominent on one side of the major axis of the elongated elliptical projection, in a greater brightness of the nebular matter on one side of this major axis, in a fan-shaped nuclear portion, or in various combinations of these effects. The phenomenon is a very common one. Illustrations of seventy-eight spirals showing evidences of occulting matter in their peripheral equatorial regions, with a more detailed discussion of the forms observed, are now being published.[1] and additional examples of the phenomenon are constantly being found.

While we have as yet no definite proof of the existence of such a ring of occulting matter lying in our galactic plane and outside of the great mass of the stars of our galaxy, there is a great deal of evidence for such occulting matter in smaller areas in our galaxy. Many such dark areas are observed around certain of the diffuse nebulosities, or seen in projection on the background furnished by such nebulosities or the denser portions of the Milky Way; these appearances seem to be actual "dark nebulae".[2] The curious "rifts" in the Milky Way may well be ascribed, at least in part, to such occulting matter.

[1] Curtis, H. D. *A study of Occulting effects in the spiral nebulae.* Lick. Observ. Publ. Vol. XIII, Part II.

[2] BARNARD, E. E. *On the dark markings of the sky,* with a catalogue of 182 such objects. Astrophys. Journ. 49: 1. 1919; Curtis, H. D. *Dark nebulae.* Publ. Astron. Soc. Pacific 30: 65. 1918.

Though we thereby run the risk of arguing in a circle, the fact that no spirals can be detected in our galactic plane, a natural result of such a ring of occulting matter, would in itself appear to lend some probability to the hypothesis. The peculiar distribution of the spiral nebulae would then be explained as due, not to an actual asymmetrical and improbable distribution in space, but to a cause within our own galaxy, assumed to be a spiral with a peripheral ring of occulting matter similar to that observed in a large proportion of the spirals. The argument that the spirals must be an integral feature of our own galaxy, based on a relationship of avoidance, would then lose its force. The explanation appears to be a possibility, even a strong probability, on the island universe theory, and I know of no other explanation, on any theory, for the observed phenomenon of nebular distribution about our galactic poles.

Summary

The Spiral Nebulae as Island Universes.

1. On this theory, it is unnecessary to attempt to co-ordinate the tremendous space-velocities of the spirals with the thirty-fold smaller values found for the stars. Very high velocities have been found for the Magellanic Clouds, which may possibly be very irregular spirals, relatively close to our galaxy.

2. There is some evidence for a spiral structure in our own galaxy.

3. The spectrum of the majority of the spirals is practically identical with that given by a star cluster; a spectrum of this general type is such as would be expected from a vast congeries of stars.

4. If the spirals are separate universes, similar to our galaxy in extent and in number of component stars, we should observe many new stars in the spirals, closely resembling in their life history the twenty-seven novae which have appeared in our own galaxy. Over a dozen such novae in spirals have been found, and it is probable that a systematic programme of repetition of nebular photographs will add greatly to this number. A comparison of

the average magnitudes of the novae in spirals with those of our own galaxy indicates a distance of the order of 10,000,000 light-years for the spirals. Our own galaxy at this distance would appear 10′ in diameter, the size of the larger spirals.

5. A considerable proportion of the spirals show a peripheral equatorial ring of occulting matter. So many instances of this have been found that it appears to be a general though not universal characteristic of the spirals; the existence of such an outer ring of occulting matter in our own galaxy, regarded as a spiral, would furnish an adequate explanation of the peculiar distribution of the spirals. There is considerable evidence of such occulting matter in our galaxy.

An English physicist has cleverly said that any really good theory brings with it more problems than it removes. It is thus with the island-universe theory. It is impossible to do more than to mention a few of these problems, with no attempt to divine those which may ultimately be presented to us.

While the data are too meagre as yet, several attempts have been made to deduce the velocity of our own galaxy within the super-galaxy. It would not be surprising if the space-velocity of our galaxy, like those of the spirals of the Magellanic Clouds, should prove to be very great, hundreds of miles per second.

Further, what are the laws which govern the forms assumed, and under which these spiral whorls are shaped? Are they stable structures; are the component stars moving inward or outward? A beginning has been made by Jeans and other mathematicians on the dynamical problems involved in the structure of the spirals. The field for research is, like our subject matter, practically infinite.