A Vibert Douglas "Island Galaxies" Publication 87.

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To G. V. D.
great lover of M. 31.
from AVD.

Island Galaxies.

By A. Vibert Douglas, Ph.D.
McGill University, Montreal.

THE knowledge that the heavens contain bodies that are neither planets nor stars is age-old, for the keen eyes of the star-gazers of civilizations long since gone did not fail to detect such objects as the nebulosity in the constellation of Orion and the small, hazy patch in Andromeda. But the significance of these objects remained a mystery for many centuries.

With the invention of the refracting telescope by Galileo about 1600, many of the apparently nebulous regions in the Milky Way were found to be resolvable into separate stars. These are so closely strewn in the sky that to the unaided eye their light is completely merged and blended. Towards the end of the seventeenth century, the second great type of telescope was devised by Sir Isaac Newton, namely, the reflecting telescope in which the starlight is brought to a focus not by a lens but by a mirror. About one hundred and fifty years later, when the small pioneer telescopes of Galileo and Newton had given place to large and powerful instruments, Lord Rosse discovered that a certain nebulous region in the constellation Canes Venatici when viewed through his great telescope was a cluster of many stars, and not merely a random, haphazard cluster, but distinctly grouped in the configuration of a spiral (Fig. 5). Thereafter the search for and discovery of other spiral nebulae became one of the most fruitful tasks of the astronomer. From that time to the present, as a result of ever-increasingly powerful instruments together with the introduction of photographic methods, many hundreds of spiral nebulae have been found.

[*Photo, Mt. Wilson Obsy.*

FIG. 1.
ISLAND GALAXY (M. 64).
An early type spiral nebula in the constellation Coma Berenices.

Speculation was at once begun. Could it be that all the nebulae were in reality close assemblages of stars requiring only yet more powerful telescopes to show each star separately?

Sir Wm. Huggins gave the decisive negative answer to this question—some of the nebulae are great clusters of stars, but there are others truly named nebulae, for they are masses of glowing gas having the type of spectrum typical of gas so hot that the atoms are radiating their characteristic quanta of energy.

Such is the nature of the Great Nebula in Orion, and of many other nebulae where vast regions of space are sparsely filled with gaseous matter. Where these gases are sufficiently hot, they radiate the distinctive wave-lengths of light associated with the atoms and molecules of which they are composed. Thus the spectroscopist identifies in these nebular spectra the unmistakable radiations of hydrogen and helium, often also nitrogen and carbon, and in addition to these he finds intense radiations which, until recently, were attributed to an unknown substance called nebulium. The mystery is now solved by Dr. Bowen, California, who attributes these radiations to oxygen and nitrogen atoms, radiating in an unusual manner as a result of their ionized condition and the low density of the nebulae.

The gaseous nebulae are not all sufficiently hot to radiate; some of them glow on, because of the proximity of very bright hot stars; others are so cool that they absorb all the starlight that falls on them, thus forming great black patches in the sky. A famous dark nebula in the region of the Southern Cross is known as the "coalsack." A great American observer, the late Professor Barnard, has made a systematic study of these opaque clouds, of which he listed over one hundred and eighty, varying from very small patches with sharp outlines to the long irregular "dark lanes" so striking a feature of the constellation of Ophiuchus.

We know, then, that of the celestial objects called nebulae, some are vast clouds of gas occupying regions of space compared with which our solar system is absolutely insignificant, while other nebulae, in particular the spiral nebulae, are clusters of stars.

For a long time no one had any conception of the immensity of spiral nebulae. They were thought of as comparatively small aggregations of stars within the great assemblage of stars surrounding our sun in all directions. The authors of the Planetesimal Theory drew an analogy between the arms of a spiral nebula and the arms of gaseous matter which they assumed to have been drawn out from the surface layers of our sun by the tidal forces produced by a passing star, these disrupted arms giving rise to the several condensations of matter which eventually became the planets of the solar system. Gradually, however, it became apparent that a spiral nebula was not to be compared with the solar system, but rather with the whole galaxy of stars—our sun and the thousand million other suns which stud the heavens all around us.

[Photo, Mt. Wilson Obsy.

FIG. 2.
ISLAND GALAXY (H.V. 24).
Edge-on view of a spiral nebula in the constellation Coma Berenices. Five hours exposure. Foreground stars are in our Galaxy and the brighter ones are distorted by over-exposure.

There are known to be many thousand spiral nebulae, and if each be comparable in size to our whole stellar galaxy, it is obvious that they are not within it. They are, in fact, *island galaxies.* The term is here used to denote exactly the same thing as the term Island Universes which has become so common an expression in American astronomical writing. Since "Universe" is defined as "all that exists, the creation and the Creator," its use in the plural seems unfortunate, especially as the word Galaxy is quite adequate. Dignifying our stellar system by the name *the* Galaxy—not merely because it is the system to which our sun belongs, but for the more logical reason that as yet no other aggregation of stars is known to be quite as large —it then becomes natural to divide all nebulae into two main classes, termed respectively the *galactic* and the *extra-galactic* nebulae.

Our galaxy is a gigantic aggregation of stars and gaseous nebulae. It comprises all the stars visible to the naked eye and the many thousands more revealed by the telescope when used visually. These numbers are multiplied many-fold by the use of photography when stars so faint or remote as to be invisible leave the impress of their images upon the sensitive plate after many hours of exposure. The study of these photographs, counting the numbers of the stars of different magnitude or brightness, and comparing the numbers in different parts of the sky, has shown that it is possible to make an estimate of their number and a representation of their distribution in space.

Even with the unaided eye it is evident that the distribution of stars is not spherically symmetrical. All along a great circle in the heavens the stars are more numerous than elsewhere, and this encircling band is called the Milky Way. The photographic plates reveal the same concentration, and so the Milky Way is called the galactic plane, while the directions at right angles to this plane, where the stars are less numerous and on the average less distant, are termed the galactic poles. Our sun happens to be situated not far from the centre of this great lens-shaped cluster of stars. The dimensions of the galaxy are so vast as to be best appreciated when expressed in light-years, the unit so frequently employed by astronomers, equivalent to nearly six billion miles. Our galaxy is approximately 100,000 light-years across the galactic plane, and about one-fifth as much measured towards the galactic poles.

In this vast region, at great distances one from another, there are thirty thousand million stars,

[*Photo, Mt. Wilson Obsy.*

FIG. 3.

THE GREAT NEBULA IN ANDROMEDA (M. 31).

One of the least distant of the Island Galaxies, just visible to the naked eye; it is made up of some thousand million stars and much gaseous matter, and is the best known of these bodies.

according to the most recent calculations reported by Dr. C. G. Abbot of the Smithsonian Institution, Washington. As these are by no means equi-spaced, there are concentrations of stars here and there which, seen from another part of the galaxy, produce such beautiful effects as the "star-clouds" in Sagittarius or the "globular clusters" in Hercules and other parts of the sky. Within the galaxy, too, filling great regions of space around and between some of the stars, are the gaseous nebulae both dark and bright.

Returning now to the extra-galactic nebulae—the great gaseous objects and star clusters like islands in a three-dimensional ocean of space beyond the Milky Way—we are indebted to Dr. E. P. Hubble of Mt. Wilson Observatory for much new knowledge concerning them. In a recently published paper* he has given the results of a careful study of four hundred such nebulae. Some of the extra-galactic nebulae show no regularity of shape or structure. These form a sub-class by themselves, and to this class belong the Magellanic Clouds, great irregular star-clouds visible from the southern hemisphere like detached portions of the Milky Way, though actually as far away again. Far more numerous than the irregular nebulae are those having a definite shape or structure, the ellipsoidal and the spiral nebulae. The spectra of the former are so similar to the solar spectrum that there is no room for doubt that they are clusters of stars, even though the individual stars cannot be photographed. Possibly the stars are being gradually condensed out of the gases of which the nebulae were composed, and the residual gases act as envelopes rendering the star images indistinct.

Some of the nebulae are apparently at a transition stage between ellipsoidal and spiral, while yet others display well-developed spiral arms. The evidence seems strongly to point towards an evolutionary process as a glance at the illustrations will make clear—the gradual unwinding, the appearance of stars and star streams, the whole vast process of the development of island galaxies.

With this idea of progressive development in mind, the spiral nebulae are said to be of *early*, *intermediate* or *late* type, according as they present the appearance

[*Photo, Mt. Wilson Obsy.*

FIG. 4.

SPIRAL NEBULA (M. 101).

A very beautiful Island Galaxy in the constellation Ursa Major. Four hours exposure.

* "Extra-Galactic Nebulae." E. P. Hubble. *Astrophysical Journal*, December, 1926.

of the uncondensed nebula in Fig. 1, or intermediate forms between that and the well-developed, far-flung, stellar arms so clearly shown in Figs. 4 and 5.

The distances of some of the spirals have been determined in a very interesting way. These spirals contain stars, known as Cepheid Variables, whose light is not steady but fluctuates with perfect regularity, falling slowly from maximum to minimum and then rising rapidly to maximum. The light cycles usually have periods of a few hours or a few days. When studying similar stars whose true brightness was known, Miss Leavitt of Harvard Observatory discovered the fact that the longer the period of light variation the greater the intrinsic luminosity of the star. This relation was well established for the less distant stars, and it seemed so logical to expect stars with identical characteristics to obey the same law whether near or far, that it has been applied to stars in these remote galaxies. From a series of photographs, the period of light variation is found, then the established relation gives the true luminosity, and this, together with the apparent brightness on the photographs, gives the necessary data for calculating the distance.

[*Photo, Mt. Wilson Obsy.*

FIG. 5.

THE WHIRLPOOL NEBULA (N.G.C. 5194-5).

This spectacular spiral in the constellation Canes Venatici was first carefully observed by Lord Rosse and seen to be not merely a mass of glowing gas, but an aggregation of many stars.

It was by this method that Hubble determined the distance of the Great Nebula in Andromeda (Fig. 3) to be more than nine hundred thousand light-years. Another very large, bright spiral in the constellation of Triangulum was found by similar means to be at about the same distance. It is believed, however, that the thousands of fainter spirals are very much more distant. In Figs. 1 and 2 are shown two of the spirals in the region of the heavens designated by the constellation name Coma Berenices. Here, and in the adjacent region of Virgo, spiral nebulae are richly strewn on photographic plates of long exposure, and both Hubble and Shapley have estimated for some of these no less a distance than a hundred million light-years.

In spite of these tremendous distances much can be learned about the island galaxies, though, of course, the further away a galaxy is, the less up to date will be the news which the light brings. Thus, in the case of the Andromeda Nebula, approximately one million light-years distant, the rays of light which produced the image on the negative of Fig. 3 had been travelling through space for a million years, and consequently the picture we see is not Andromeda Nebula as it is to-day, but as it was one million years ago.

Just what it is like now we can only conjecture—probably not so very different from the picture, for one million years is less in the life of a star than one second of time in the average life of a man.

The radial velocities of the brighter nebulae can be determined by means of the spectroscope, and show that they are moving through space with great velocities. The Andromeda Nebula is approaching our galaxy with a velocity of 300 kilometres per second. Most of the spirals, however, are receding at speeds averaging 600 kilometres per second.

There are two ways of endeavouring to find out the total mass of a galaxy, and when two quite independent methods lead to results which are in good agreement the astronomer feels considerable confidence in the reliability of his calculations. The first method is based upon a speculation regarding the ratio of luminous to non-luminous matter in a galaxy and the theory that the luminosity is determined by the mass. When the absolute luminosity of a galaxy is known, its total mass can therefore be calculated. This method has been used by Opik, and gives for the Andromeda Nebula a mass nearly two thousand million times the mass of an average star like our sun. The second method depends upon the spectroscopic determination of the line of sight velocity of opposite edges of the nebula. If one side be found to be approaching and the other side receding, the only logical conclusion is that the whole nebula is rotating. Now a rotating mass will fly asunder by centrifugal force unless some equal and opposite force hold its members together. If gravitation, acting towards the centre of the nebula, provide this balancing force, it is possible to calculate the total mass necessary to give rise to the restraining force required. The period of rotation of the Andromeda galaxy was found to be 17,000,000 years. From this its mass was calculated, giving just over three thousand million suns. The agreement with Opik's result is satisfactory.

Our picture of this best known island galaxy can be briefly summed up in a few words: A thousand million stars—like those in our own galaxy, some larger and some smaller than our sun—and much uncondensed gas, all forming the giant spiral nebula travelling through space at least 300 kilometres per second, and as it travels slowly expanding and unwinding its spiral arms, while as a whole it is turning round with solemn, majestic deliberation.

The Einstein Universe.

Men of science throughout all the ages have been obsessed with the idea that there is order in the Universe.* When the great wave of agnosticism passed over Europe, threatening to sweep the thoughts of men from all moorings, this fundamental tenet of scientific faith was the sheet anchor which saved mankind. So deeply implanted is this belief in natural law and order, that when some facts of astronomy and physics appeared to be incompatible with the current conception of the Universe, based as it is on the stately geometry of Euclid and the Newtonian mechanics, men of science were willing to consider throwing over the old conception and adopting a new conception suggested by Einstein. This willingness is the more remarkable when it is remembered that, to the non-mathematical mind, the four-dimensional spacetime universe of Einstein seems mysterious, fantastic, and unreal. Yet there is already considerable evidence in its favour, and so, generalizing from his detailed study of 400 galaxies, Hubble proceeds to evaluate the radius, volume, and mass of the Einstein Universe.

He calculates first the average density of space. If the matter forming all the stars and gaseous nebulae in our galaxy and in the 400 other galaxies studied by him were to be spread evenly throughout the space occupied by these galaxies, there would be a density of matter equivalent to one atom of hydrogen in every 300 cubic feet. He then evaluates the radius of curvature of spacetime, which, according to Einstein, depends only upon this average density and two constants, the velocity of light and the gravitational constant. This radius comes out to be five thousand billion astronomical units (5×10^{15} times the sun-earth distance). This value is a thousand times greater than that calculated by Silberstein from other relations and other data available three years ago.† Here in reality, as always metaphorically, the horizon recedes as knowledge increases.

What then is the total amount of matter distributed as stars and nebulae, in clusters and in galaxies, throughout this vast yet finite Universe? To express these figures in words is far too cumbersome, and so we set them forth in the elegant shorthand used always by the physicist and the astronomer. If M be the total mass of matter in the Einstein Universe, then

$$M = 1.8 \times 10^{57} \text{ gms.}$$
$$= 9.0 \times 10^{22} \text{ suns}$$
$$= 3.5 \times 10^{15} \text{ normal galaxies.}$$

In other words, there are about a thousand octillion (10^{51}) tons of matter, and were this to consist only of hydrogen there would be 10^{81} atoms.

How much real value these stupendous figures have, it is impossible to say. Firstly, they involve the Einstein conception of the Universe, not yet indisputably established. Secondly, they are conclusions regarding a Universe not one ten-millionth of whose volume can be explored by even the giant telescope at Mt. Wilson Observatory. If the distance of a galaxy exceed only one six-hundredth of the radius of curvature above mentioned, no telescope yet constructed can detect it. But a man will judge the world of humanity, their habits and characteristics, their comings and goings, by his knowledge of a few score individuals and his passing glimpses of a few thousand, and his conclusions will not be entirely valueless. So, too, the astronomer, with reliable knowledge of hundreds of stars and many nebulae, and glimpses of thousands yet more distant, will not refrain from speculation regarding the vast regions as yet beyond his ken—the ocean of space-time studded with a thousand billion glorious Island Galaxies.

* An interesting treatment of this subject may be found in "Science and the Modern World," by Dr. A. N. Whitehead.

† See "Measuring the Universe," *Discovery*, September, 1924.

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A. VIBERT DOUGLAS, M. B. E., Ph. D.

FROM THE SMITHSONIAN REPORT FOR 1928, PAGES 193–199
(WITH 5 PLATES)

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With the invention of the refracting telescope by Galileo about 1600, many of the apparently nebulous regions in the Milky Way were found to be resolvable into separate stars. These are so closely strewn in the sky that to the unaided eye their light is completely merged and blended. Toward the end of the seventeenth century the second great type of telescope was devised by Sir Isaac Newton, namely, the reflecting telescope, in which the starlight is brought to a focus not by a lens but by a mirror. About 150 years later, when the small pioneer telescopes of Galileo and Newton had given place to large and powerful instruments, Lord Rosse discovered that a certain nebulous region in the constellation Cannes Venatici when viewed through his great telescope was not merely a random, haphazard agglomeration, but a cluster of many stars distinctly grouped in the configuration of a spiral. (Pl. 5.) Thereafter the search for and discovery of other spiral nebulæ became one of the most fruitful tasks of the astronomer. From that time to the present, as a result of ever-increasingly powerful instruments, together with the introduction of photographic methods, many hundreds of spiral nebulæ have been found, and it is estimated that a thorough search of the entire heavens would disclose hundreds of thousands of them.

Speculation was at once begun. Could it be that all the nebulæ were in reality close assemblages of stars requiring only yet more powerful telescopes to show each star separately?

[1] Reprinted by permission, with alterations, from Discovery, Vol. IX, No. 99, March, 1928.

Sir William Huggins gave the decisive negative answer to this question—some of the nebulæ may be great clusters of stars, but there are others truly named nebulæ, for they are masses of glowing gas having the type of spectrum typical of gas whose atoms are radiating their characteristic quanta of energy.

Such is the nature of the great nebula in Orion and of many other nebulæ where vast regions of space are sparsely filled with gaseous matter. Where these gases are sufficiently excited they radiate the distinctive wave lengths of light associated with the atoms and molecules of which they are composed. Thus the spectroscopist identifies in these nebular spectra the unmistakable radiations of hydrogen and helium, often also nitrogen and carbon, and in addition to these he finds intense radiations which until recently were attributed to an unknown substance called nebulium. The mystery is now solved by Doctor Bowen, California, who attributes these radiations to oxygen and nitrogen atoms, radiating in an unusual manner as a result of their ionized condition and the low density of the nebulæ.

The gaseous nebulæ are not all sufficiently hot to radiate; some of them glow only because of the proximity of very bright hot stars; others are so cool that they absorb all the starlight that falls on them, thus forming great black patches in the sky. A famous dark nebula in the region of the Southern Cross is known as the "coal sack." A great American observer, the late Professor Barnard, made a systematic study of these opaque clouds, of which he listed over 180, varying from very small patches with sharp outlines to the long, irregular "dark lanes" so striking a feature of the constellation of Ophiuchus.

We know, then, that of the celestial objects originally called nebulæ some are vast clouds of gas occupying regions of space compared with which our solar system is absolutely insignificant; others are clusters of stars; while yet others, in particular the spiral nebulæ, are composed of both stars and gaseous nebulosity.

For a long time no one had any conception of the immensity of spiral nebulæ. They were thought of as comparatively small aggregations of stars within the great assemblage of stars surrounding our sun in all directions. The authors of the planetesimal theory drew an analogy between the arms of a spiral nebula and the arms of gaseous matter which they assumed to have been drawn out from the surface layers of our sun by the tidal forces produced by a passing star, these disrupted arms giving rise to the several condensations of matter which eventually became the planets of the solar system. Gradually, however, it became apparent that a spiral nebula was not to be compared with the solar system, but rather with the whole galaxy of stars—our sun and the thousand million other suns which stud the heavens all around us.

There are known to be many thousand spiral nebulæ, and if each be comparable in size to our whole stellar galaxy it is obvious that they are not within it. They are in fact *island galaxies*. The term is here used to denote exactly the same thing as the term "island universes," which has become so common an expression in American astronomical writing. Since "universe" is defined as "all that exists, the creation and the Creator," its use in the plural seems unfortunate, especially as the word "galaxy" is quite adequate. Dignifying our stellar system by the name "*the* galaxy"—not merely because it is the system to which our sun belongs but for the more logical reason that as yet no other aggregation of stars is known to be quite as large—it then becomes natural to divide all nebulæ into two main classes, termed, respectively, the "galactic" and the "extragalactic" nebulæ.

Our galaxy is a gigantic aggregation of stars and gaseous nebulæ. It comprises all the stars visible to the naked eye and the many thousands more revealed by the telescope when used visually. These numbers are multiplied manyfold by the use of photography when stars so faint or remote as to be invisible leave the impress of their images upon the sensitive plate after many hours of exposure. The study of these photographs, counting the numbers of the stars of different magnitude or brightness and comparing the numbers in different parts of the sky, has shown that it is possible to make an estimate of their number and a representation of their distribution in space.

Even with the unaided eye it is evident that the distribution of stars is not spherically symmetrical. All along a great circle in the heavens the stars are more numerous than elsewhere, and this encircling band is called the Milky Way. The photographic plates reveal the same concentration, and so the Milky Way is called the galactic plane, while the directions at right angles to this plane, where the stars are less numerous and on the average less distant, are termed the galactic poles. Our sun happens to be situated not far from the center of this great lens-shaped cluster of stars. The dimensions of the galaxy are so vast as to be best appreciated when expressed in light-years, the unit so frequently employed by astronomers, equivalent to nearly 6,000,000,000,000 miles. Our galaxy is approximately 100,000 light-years across the galactic plane and about one-fifth as much measured toward the galactic poles.

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With this idea of progressive development in mind, the spiral nebulæ are said to be of early, intermediate or late type, according as they present the appearance of the uncondensed nebula in Plate 1, or intermediate forms between that and the well-developed, far-flung, stellar arms so clearly shown in Plates 4 and 5.

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[2] Extragalactic Nebulæ. E. P. Hubble. Astrophysical Journal, December, 1926.

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In spite of these tremendous distances much can be learned about the island galaxies, though, of course, the farther away a galaxy is the less up to date will be the news which the light brings. Thus in the case of the Andromeda nebula, approximately 1,000,000 light-years distant, the rays of light which produced the image on the negative of Plate 3 had been traveling through space for 1,000,000 years, and consequently the picture we see is not the Andromeda nebula as it is to-day but as it was 1,000,000 years ago.

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THE EINSTEIN UNIVERSE

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He then evaluates the radius of curvature of space time, which, according to Einstein, depends only upon this average density and two constants, the velocity of light and the gravitational constant. This radius comes out to be 5,000 million million astronomical units (5×10^{15} times the sun-earth distance). This value is a thousand times greater than that calculated by Silberstein from other relations and other data available three years ago. Here, perhaps, in reality, as always metaphorically, the horizon recedes as knowledge increases.

What then is the total amount of matter distributed as stars and nebulæ, in clusters and in galaxies, throughout this vast yet finite universe? To express these figures in words is far too cumbersome, and so we set them forth in the elegant shorthand used always by the physicist and the astronomer: If M be the total mass of matter in the Einstein universe, then

$$\begin{aligned} M &= 1.8\times10^{57} \text{ gms.} \\ &= 9.0\times10^{22} \text{ suns} \\ &= 3.5\times10^{15} \text{ normal galaxies} \end{aligned}$$

In other words, there are about 10^{51} tons of matter, and were this to consist only of hydrogen there would be 10^{81} atoms.

How much real value these stupendous figures have it is impossible to say. Firstly, they involve the Einstein conception of the universe, not yet indisputably established.[3] Secondly, assuming that the Einstein universe has a real significance, these figures are conclusions regarding a universe not one ten-millionth of whose volume can be explored by even the giant telescope at Mount Wilson Observatory. If the distance of a galaxy exceed only one six-hundredth of the radius of curvature above mentioned, no telescope yet constructed can detect it. But a man will judge the world of humanity, their habits and characteristics, their comings and goings, by his knowledge of a few score individuals and his passing glimpses of a few thousand, and his conclusions will not be entirely valueless. So, too, the astronomer, with reliable knowledge of hundreds of stars and many nebulæ, and glimpses of thousands yet more distant, will not refrain from speculation regarding the vast regions as yet beyond his ken—the ocean of spacetime studded with 1,000 million million glorious island galaxies.

[3] Indeed there are many who reject the Einstein cosmology in favor of the modifications proposed by de Sitter, modifications which obviate some of the difficulties inherent in Einstein's cosmology. Doctor Silberstein, for example, denies any reality to the above figures, retaining confidence in his own value of the radius of curvature based upon his deductions from the de Sitter equations.

ISLAND GALAXY (M. 64)

An early type spiral nebula in the constellation Como Berenices

ISLAND GALAXY (H. V. 24)

Edge-on view of a spiral nebula in the constellation Coma Berenices. Five hours' exposure. Foreground stars are in our Galaxy and the brighter ones are distorted by overexposure

THE GREAT NEBULA IN ANDROMEDA (M. 31)

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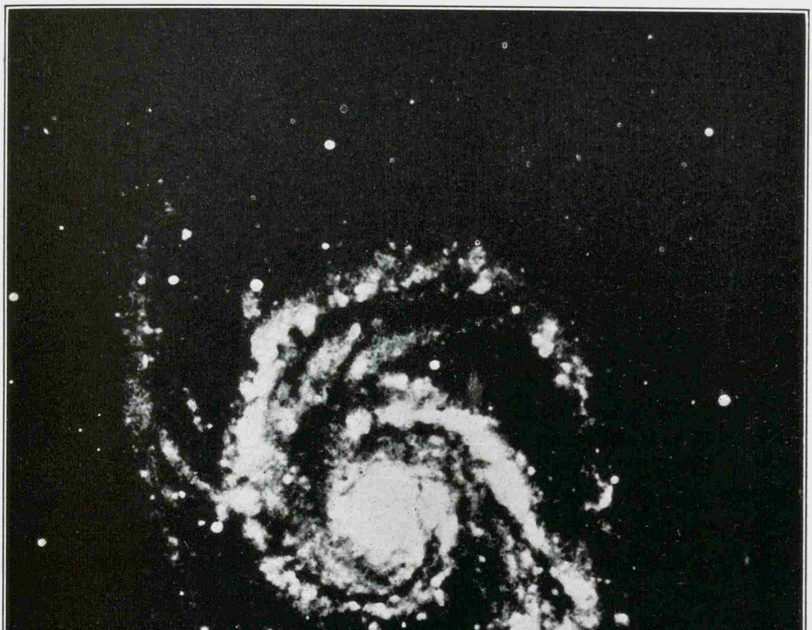
SPIRAL NEBULA (M. 101)

A very beautiful Island Galaxy in the constellation Ursa Major. Four hours' exposure



THE WHIRLPOOL NEBULA (N. G. C. 5194-5)

This spectacular spiral in the constellation Canes Venatici was first carefully observed by Lord Rosse and seen to be not merely a mass of glowing gas but an aggregation of many stars

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To O.M.C.D.
with happy memories of Punta
where this article came into
being — AVD.

Island Galaxies.

By A. Vibert Douglas, Ph.D.
McGill University, Montreal.

THE knowledge that the heavens contain bodies that are neither planets nor stars is age-old, for the keen eyes of the star-gazers of civilizations long since gone did not fail to detect such objects as the nebulosity in the constellation of Orion and the small, hazy patch in Andromeda. But the significance of these objects remained a mystery for many centuries.

With the invention of the refracting telescope by Galileo about 1600, many of the apparently nebulous regions in the Milky Way were found to be resolvable into separate stars. These are so closely strewn in the sky that to the unaided eye their light is completely merged and blended. Towards the end of the seventeenth century, the second great type of telescope was devised by Sir Isaac Newton, namely, the reflecting telescope in which the starlight is brought to a focus not by a lens but by a mirror. About one hundred and fifty years later, when the small pioneer telescopes of Galileo and Newton had given place to large and powerful instruments, Lord Rosse discovered that a certain nebulous region in the constellation Canes Venatici when viewed through his great telescope was a cluster of many stars, and not merely a random, haphazard cluster, but distinctly grouped in the configuration of a spiral (Fig. 5). Thereafter the search for and discovery of other spiral nebulae became one of the most fruitful tasks of the astronomer. From that time to the present, as a result of ever-increasingly powerful instruments together with the introduction of photographic methods, many hundreds of spiral nebulae have been found.

[*Photo, Mt. Wilson Obsy.*

FIG. 1.
ISLAND GALAXY (M. 64).
An early type spiral nebula in the constellation Coma Berenices.

Speculation was at once begun. Could it be that all the nebulae were in reality close assemblages of stars requiring only yet more powerful telescopes to show each star separately ?

Sir Wm. Huggins gave the decisive negative answer to this question—some of the nebulae are great clusters of stars, but there are others truly named nebulae, for they are masses of glowing gas having the type of spectrum typical of gas so hot that the atoms are radiating their characteristic quanta of energy.

Such is the nature of the Great Nebula in Orion, and of many other nebulae where vast regions of space are sparsely filled with gaseous matter. Where these gases are sufficiently hot, they radiate the distinctive wave-lengths of light associated with the atoms and molecules of which they are composed. Thus the spectroscopist identifies in these nebular spectra the unmistakable radiations of hydrogen and helium, often also nitrogen and carbon, and in addition to these he finds intense radiations which, until recently, were attributed to an unknown substance called nebulium. The mystery is now solved by Dr. Bowen, California, who attributes these radiations to oxygen and nitrogen atoms, radiating in an unusual manner as a result of their ionized condition and the low density of the nebulae.

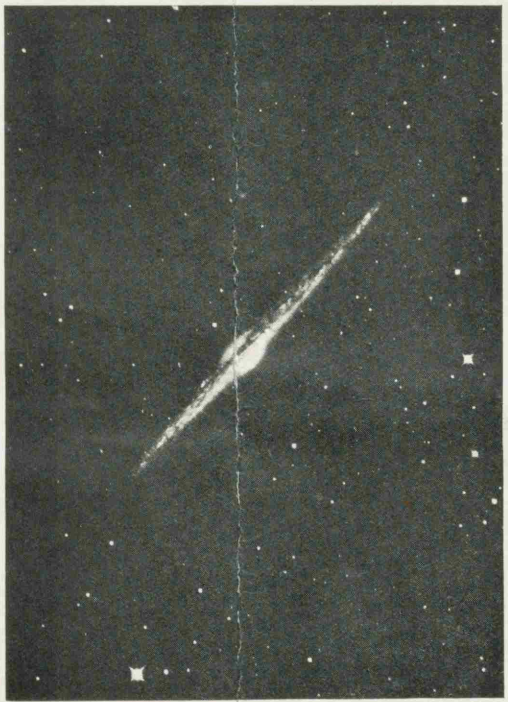
The gaseous nebulae are not all sufficiently hot to radiate ; some of them glow on, because of the proximity of very bright hot stars ; others are so cool that they absorb all the starlight that falls on them, thus forming great black patches in the sky. A famous dark nebula in the region of the Southern Cross is known as the "coalsack." A great American observer, the late Professor Barnard, has made a systematic study of these opaque clouds, of which he listed over one hundred and eighty, varying from very small patches with sharp outlines to the long irregular "dark lanes" so striking a feature of the constellation of Ophiuchus.

We know, then, that of the celestial objects called nebulae, some are vast clouds of gas occupying regions of space compared with which our solar system is absolutely insignificant, while other nebulae, in particular the spiral nebulae, are clusters of stars.

For a long time no one had any conception of the immensity of spiral nebulae. They were thought of as comparatively small aggregations of stars within the great assemblage of stars surrounding our sun in all directions. The authors of the Planetesimal Theory drew an analogy between the arms of a spiral nebula and the arms of gaseous matter which they assumed to have been drawn out from the surface layers of our sun by the tidal forces produced by a passing star, these disrupted arms giving rise to the several condensations of matter which eventually became the planets of the solar system. Gradually, however, it became apparent that a spiral nebula was not to be compared with the solar system, but rather with the whole galaxy of stars—our sun and the thousand million other suns which stud the heavens all around us.

There are known to be many thousand spiral nebulae, and if each be comparable in size to our whole stellar galaxy, it is obvious that they are not within it. They are, in fact, *island galaxies*. The term is here used to denote exactly the same thing as the term Island Universes which has become so common an expression in American astronomical writing. Since "Universe" is defined as "all that exists, the creation and the Creator," its use in the plural seems unfortunate, especially as the word Galaxy is quite adequate. Dignifying our stellar system by the name *the* Galaxy—not merely because it is the system to which our sun belongs, but for the more logical reason that as yet no other aggregation of stars is known to be quite as large—it then becomes natural to divide all nebulae into two main classes, termed respectively the *galactic* and the *extra-galactic* nebulae.

Our galaxy is a gigantic aggregation of stars and gaseous nebulae. It comprises all the stars visible to the naked eye and the many thousands more revealed by the telescope when used visually. These numbers are multiplied many-fold by the use of photography when stars so faint or remote as to be invisible leave the impress of their images upon the sensitive plate after many hours of exposure. The study of these photographs, counting the numbers of the stars of different magnitude or brightness, and comparing the numbers in different parts of the sky, has shown that it is possible to make an estimate of their number and a representation of their distribution in space.

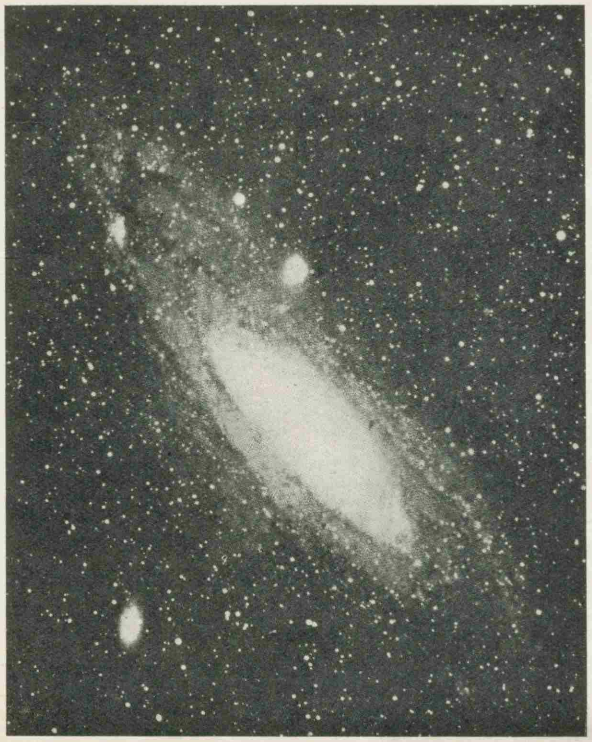


[*Photo, Mt. Wilson Obsy.*

FIG. 2.
ISLAND GALAXY (H.V. 24).
Edge-on view of a spiral nebula in the constellation Coma Berenices. Five hours exposure. Foreground stars are in our Galaxy and the brighter ones are distorted by over-exposure.

Even with the unaided eye it is evident that the distribution of stars is not spherically symmetrical. All along a great circle in the heavens the stars are more numerous than elsewhere, and this encircling band is called the Milky Way. The photographic plates reveal the same concentration, and so the Milky Way is called the galactic plane, while the directions at right angles to this plane, where the stars are less numerous and on the average less distant, are termed the galactic poles. Our sun happens to be situated not far from the centre of this great lens-shaped cluster of stars. The dimensions of the galaxy are so vast as to be best appreciated when expressed in light-years, the unit so frequently employed by astronomers, equivalent to nearly six billion miles. Our galaxy is approximately 100,000 light-years across the galactic plane, and about one-fifth as much measured towards the galactic poles.

In this vast region, at great distances one from another, there are thirty thousand million stars,



[*Photo, Mt. Wilson Obsy.*

FIG. 3.
THE GREAT NEBULA IN ANDROMEDA (M. 31).
One of the least distant of the Island Galaxies, just visible to the naked eye; it is made up of some thousand million stars and much gaseous matter, and is the best known of these bodies.

according to the most recent calculations reported by Dr. C. G. Abbot of the Smithsonian Institution, Washington. As these are by no means equi-spaced, there are concentrations of stars here and there which, seen from another part of the galaxy, produce such beautiful effects as the "star-clouds" in Sagittarius or the "globular clusters" in Hercules and other parts of the sky. Within the galaxy, too, filling great regions of space around and between some of the stars, are the gaseous nebulae both dark and bright.

Returning now to the extra-galactic nebulae—the great gaseous objects and star clusters like islands in a three-dimensional ocean of space beyond the Milky Way—we are indebted to Dr. E. P. Hubble of Mt. Wilson Observatory for much new knowledge concerning them. In a recently published paper* he has given the results of a careful study of four hundred such nebulae. Some of the extra-galactic nebulae show no regularity of shape or structure. These form a sub-class by themselves, and to this class belong the Magellanic Clouds, great irregular star-clouds visible from the southern hemisphere like detached portions of the Milky Way, though actually as far away again. Far more numerous than the irregular nebulae are those having a definite shape or structure, the ellipsoidal and the spiral nebulae. The spectra of the former are so similar to the solar spectrum that there is no room for doubt that they are clusters of stars, even though the individual stars cannot be photographed. Possibly the stars are being gradually condensed out of the gases of which the nebulae were composed, and the residual gases act as envelopes rendering the star images indistinct.

Some of the nebulae are apparently at a transition stage between ellipsoidal and spiral, while yet others display well-developed spiral arms. The evidence seems strongly to point towards an evolutionary process as a glance at the illustrations will make clear—the gradual unwinding, the appearance of stars and star streams, the whole vast process of the development of island galaxies.

With this idea of progressive development in mind, the spiral nebulae are said to be of *early*, *intermediate* or *late* type, according as they present the appearance

[*Photo, Mt. Wilson Obsy.*

FIG. 4.
SPIRAL NEBULA (M. 101).
A very beautiful Island Galaxy in the constellation Ursa Major. Four hours exposure.

* "Extra-Galactic Nebulae." E. P. Hubble. *Astrophysical Journal*, December, 1926.

of the uncondensed nebula in Fig. 1, or intermediate forms between that and the well-developed, far-flung, stellar arms so clearly shown in Figs. 4 and 5.

The distances of some of the spirals have been determined in a very interesting way. These spirals contain stars, known as Cepheid Variables, whose light is not steady but fluctuates with perfect regularity, falling slowly from maximum to minimum and then rising rapidly to maximum. The light cycles usually have periods of a few hours or a few days. When studying similar stars whose true brightness was known, Miss Leavitt of Harvard Observatory discovered the fact that the longer the period of light variation the greater the intrinsic luminosity of the star. This relation was well established for the less distant stars, and it seemed so logical to expect stars with identical characteristics to obey the same law whether near or far, that it has been applied to stars in these remote galaxies. From a series of photographs, the period of light variation is found, then the established relation gives the true luminosity, and this, together with the apparent brightness on the photographs, gives the necessary data for calculating the distance.

It was by this method that Hubble determined the distance of the Great Nebula in Andromeda (Fig. 3) to be more than nine hundred thousand light-years. Another very large, bright spiral in the constellation of Triangulum was found by similar means to be at about the same distance. It is believed, however, that the thousands of fainter spirals are very much more distant. In Figs. 1 and 2 are shown two of the spirals in the region of the heavens designated by the constellation name Coma Berenices. Here, and in the adjacent region of Virgo, spiral nebulae are richly strewn on photographic plates of long exposure, and both Hubble and Shapley have estimated for some of these no less a distance than a hundred million light-years.

[*Photo, Mt. Wilson Obsy.*

FIG. 5.

THE WHIRLPOOL NEBULA (N.G.C. 5194-5).

This spectacular spiral in the constellation Canes Venatici was first carefully observed by Lord Rosse and seen to be not merely a mass of glowing gas, but an aggregation of many stars.

In spite of these tremendous distances much can be learned about the island galaxies, though, of course, the further away a galaxy is, the less up to date will be the news which the light brings. Thus, in the case of the Andromeda Nebula, approximately one million light-years distant, the rays of light which produced the image on the negative of Fig. 3 had been travelling through space for a million years, and consequently the picture we see is not Andromeda Nebula as it is to-day, but as it was one million years ago.

Just what it is like now we can only conjecture—probably not so very different from the picture, for one million years is less in the life of a star than one second of time in the average life of a man.

The radial velocities of the brighter nebulae can be determined by means of the spectroscope, and show that they are moving through space with great velocities. The Andromeda Nebula is approaching our galaxy with a velocity of 300 kilometres per second. Most of the spirals, however, are receding at speeds averaging 600 kilometres per second.

There are two ways of endeavouring to find out the total mass of a galaxy, and when two quite independent methods lead to results which are in good agreement the astronomer feels considerable confidence in the reliability of his calculations. The first method is based upon a speculation regarding the ratio of luminous to non-luminous matter in a galaxy and the theory that the luminosity is determined by the mass. When the absolute luminosity of a galaxy is known, its total mass can therefore be calculated. This method has been used by Opik, and gives for the Andromeda Nebula a mass nearly two thousand million times the mass of an average star like our sun. The second method depends upon the spectroscopic determination of the line of sight velocity of opposite edges of the nebula. If one side be found to be approaching and the other side receding, the only logical conclusion is that the whole nebula is rotating. Now a rotating mass will fly asunder by centrifugal force unless some equal and opposite force hold its members together. If gravitation, acting towards the centre of the nebula, provide this balancing force, it is possible to calculate the total mass necessary to give rise to the restraining force required. The period of rotation of the Andromeda galaxy was found to be 17,000,000 years. From this its mass was calculated, giving just over three thousand million suns. The agreement with Opik's result is satisfactory.

Our picture of this best known island galaxy can be briefly summed up in a few words: A thousand million stars—like those in our own galaxy, some larger and some smaller than our sun—and much uncondensed gas, all forming the giant spiral nebula travelling through space at least 300 kilometres per second, and as it travels slowly expanding and unwinding its spiral arms, while as a whole it is turning round with solemn, majestic deliberation.

The Einstein Universe.

Men of science throughout all the ages have been obsessed with the idea that there is order in the Universe.* When the great wave of agnosticism passed over Europe, threatening to sweep the thoughts of men from all moorings, this fundamental tenet of scientific faith was the sheet anchor which saved mankind. So deeply implanted is this belief in natural law and order, that when some facts of astronomy and physics appeared to be incompatible with the current conception of the Universe, based as it is on the stately geometry of Euclid and the Newtonian mechanics, men of science were willing to consider throwing over the old conception and adopting a new conception suggested by Einstein. This willingness is the more remarkable when it is remembered that, to the non-mathematical mind, the four-dimensional spacetime universe of Einstein seems mysterious, fantastic, and unreal. Yet there is already considerable evidence in its favour, and so, generalizing from his detailed study of 400 galaxies, Hubble proceeds to evaluate the radius, volume, and mass of the Einstein Universe.

He calculates first the average density of space. If the matter forming all the stars and gaseous nebulae in our galaxy and in the 400 other galaxies studied by him were to be spread evenly throughout the space occupied by these galaxies, there would be a density of matter equivalent to one atom of hydrogen in every 300 cubic feet. He then evaluates the radius of curvature of spacetime, which, according to Einstein, depends only upon this average density and two constants, the velocity of light and the gravitational constant. This radius comes out to be five thousand billion astronomical units (5×10^{15} times the sun-earth distance). This value is a thousand times greater than that calculated by Silberstein from other relations and other data available three years ago.† Here in reality, as always metaphorically, the horizon recedes as knowledge increases.

What then is the total amount of matter distributed as stars and nebulae, in clusters and in galaxies, throughout this vast yet finite Universe? To express these figures in words is far too cumbersome, and so we set them forth in the elegant shorthand used always by the physicist and the astronomer—If M be the total mass of matter in the Einstein Universe, then

$$M = 1.8 \times 10^{57} \text{ gms.}$$
$$= 9.0 \times 10^{22} \text{ suns}$$
$$= 3.5 \times 10^{15} \text{ normal galaxies.}$$

In other words, there are about a thousand octillion (10^{51}) tons of matter, and were this to consist only of hydrogen there would be 10^{81} atoms.

How much real value these stupendous figures have, it is impossible to say. Firstly, they involve the Einstein conception of the Universe, not yet indisputably established. Secondly, they are conclusions regarding a Universe not one ten-millionth of whose volume can be explored by even the giant telescope at Mt. Wilson Observatory. If the distance of a galaxy exceed only one six-hundredth of the radius of curvature above mentioned, no telescope yet constructed can detect it. But a man will judge the world of humanity, their habits and characteristics, their comings and goings, by his knowledge of a few score individuals and his passing glimpses of a few thousand, and his conclusions will not be entirely valueless. So, too, the astronomer, with reliable knowledge of hundreds of stars and many nebulae, and glimpses of thousands yet more distant, will not refrain from speculation regarding the vast regions as yet beyond his ken—the ocean of space-time studded with a thousand billion glorious Island Galaxies.

* An interesting treatment of this subject may be found in "Science and the Modern World," by Dr. A. N. Whitehead.

† See "Measuring the Universe," *Discovery*, September, 1924.

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