1. LARGE-SCALE STRUCTURE OF SPIRAL NEBULAE

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For a discussion of the large-scale structure of spiral nebulae, we should like, of course, to choose a stellar system which we are certain is similar to our own. Since we know that our own Galaxy is a spiral galaxy, this narrows our choice to the spiral galaxies and, of those, we can immediately eliminate the so-called barred spirals, as we know that our galaxy is not a barred spiral. Hence, we need only consider spirals of types Sa, Sb, and Sc on Hubble's system. NGC 4594 is an Sa system with a large central spheroidal system typical of these early-type spirals. Undoubtedly, our Galaxy does not have such a large spheroidal system since it would be obvious as a large bulge which simply has not been observed. Next, M 81 is typical of the Sb spirals in which the central system has shrunk considerably. Finally, M 33 is typical of the Sc spirals in which the central system has shrunk until it actually approaches a semi-stellar point.

There are a number of reasons to believe that our own Galaxy is a spiral of type Sb. Since we are eight or nine kiloparsecs from the galactic center, the picture taken by Mr Code with the Henyey-Greenstein camera gives a first impression of how our Galaxy would look from the outside if it were seen edgewise. In this picture, the galactic center regions and the flattening in the outer parts are visible. On the basis of such a picture alone, we would classify our Galaxy as an Sb spiral. In fact, it is very similar to the spiral NGC 891, also seen edge-wise. In addition to the structural data, we could introduce other evidence; for example, the strength of the nova phenomenon. This is very strong in the Sb spirals like the Andromeda nebula and M 81 and very weak in late spirals like M 101.

For this reason, I should like to describe the Andromeda nebula as an example of the spiral structure of Sb galaxies. We have every reason to believe that something similar, both in features and arrangement, will be found in our own Galaxy. Starting with the center, we have a tiny nucleus, quite sharply defined, with the dimensions, $2''.5 \times 1''.5$. It is an elliptical structure, oriented exactly like the major axis of the whole system. A very important feature is that the spiral structure, in the form of dust clouds, reaches right into the nucleus, on both sides. The first spiral arm comes out, swirls around, and then splits into two sections. One continues around, the other shoots further out. The first part of the innermost spiral arm is very disrupted. The clouds forming it are huge flares in a very turbulent state. The next spiral arm, number two, is barely visible because it is filled in with the light of the nucleus, but it shows a remarkable feature. Along one edge, in a dust lane, the first stars appear. These stars are all blue super-giants, and as soon as we find them we also find H II regions. Farther in, neither H II regions nor stars are observed. Hence, at a distance of about 3 kpc from the nucleus, the first stars and the first H II regions are observed in an otherwise dark spiral arm. The next arm is again essentially a dust arm, but everywhere along the outer fringes of this arm are super-giants which are associated with the arm. The huge star association NGC 406 is in the next arm. In this region of the Andromeda nebula the spiral structure is very complicated. The arm branches to form a loop of cloud complexes from this arm to the next. Spiral structure is never as regular as has been thought. Hubble concentrated most of his investigations on the next arm in a region about 50′ from the center of the Andromeda nebula. In front of darker material, this arm appears bright. It is full of giant and super-giant stars, by which it is essentially marked instead of by gas and dust. H II regions are present, but only in the dark lanes or along the edge of a few large dark clouds. Although in other areas there are plenty of O- and B-stars, the H II regions are restricted to these dark areas. Hence, we must conclude that elsewhere dust has already been converted into stars, and dust and gas are essentially absent. Where the arm crosses in front of the nebula, it appears simply as a dark lane. H II regions are present throughout the interior of the lane, thus showing evidence of star formation in the center of the dust lanes. The remaining arms are essentially star arms with relatively few emission nebulae. Skipping one arm, we come to the one about 1°5 from the center of the Andromeda nebula. It is very thin; most of the stars are blue super-giants with red ones among them. Extra-galactic nebulae shine through the arm in large numbers. There are only very few emission nebulae which are associated with O- and B-star associations. Nevertheless, the arm contains a large number of variable stars, many of them Cepheids. Going still farther out, we find the last arm at about 2° from the center of the galaxy. It is still thinner than the preceding one, but even in it an occasional emission nebula is found. Beyond this we find what are apparently remnants of former arms. For example, in a remnant 2° 14′

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978-1-107-51161-3 - Comparison of the Large-scale Structure of the Galactic System with that of Other Stellar Systems
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from the center, we find a little group of B-stars which are about 20 kpc from the nucleus of the Andromeda nebula.

The picture of the spiral structure can be summarized as follows: In the interior, we see the spiral arms essentially as dust arms, but soon, at a distance of about 3 kpc from the center, we can detect the first super-giants and the first emission regions. From there out, the spiral arms are dotted with super-giants and H II regions, but only at the outer fringes of the dust arms. The central parts of the arms still appear only as dust. By the time we reach a distance of about 7 to 8 kpc from the center, the arms appear essentially as arms formed by stars; dust and gas are still noticeable, but they become less and less conspicuous as we go to spiral arms beyond 8 kpc from the center. Beyond this, the arms are thin and primarily represented by stars. At a distance of nearly 2° from the center, far beyond what is usually considered the body of the Andromeda nebula, the outermost arm can still be traced. Of course, this entire spiral structure is embedded in a huge disk of population II stars which extends far beyond the spiral structure. In the region between NGC 205 and the Andromeda nebula, the whole field is covered with population II, including globular clusters.

Discussion

? : Do we know the near side of the Andromeda nebula definitely?

Baade: We conclude that one side is the near side from the orientation and the structure of the absorption lanes.

Oort: How good is the evidence that there are no blue super-giants nearer than 3 kpc to the center?

Baade: The only evidence is that I have been unable to find a single H II region there, although I have made every attempt to do so. I think they would be visible even against the bright background. Also, the structure of the inner spiral arm is very disrupted and gives the impression of being very turbulent.

Lindblad: If you assume that these clouds near the center of the Andromeda galaxy lie in its plane, and try to untilt them, they become extremely elongated along the minor axis. Thus it is interesting that there is fairly good evidence that the clouds do not lie exactly in the nebular plane but are well elevated.

Baade: Yes, there is certainly evidence that the spiral structure in the central region does not lie in the plane.

2. SOME REMARKS ON MULTIPLE GALAXIES

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(Read by Mrs Masevich)

Within each cluster of galaxies, the ratio of the number of multiple galaxies to the number of single galaxies is much higher than the ratio calculated under the assumption of statistical equilibrium. This fact leads, without any supplementary assumption, to the conclusion that the components of any given multiple galaxy have a common origin. In this respect the multiple galaxies are similar to the multiple stars of our stellar system.

The study of the configurations of the multiple galaxies in Holmberg's catalogue has shown that among 132 multiple systems in this catalogue, 87 systems (65 %) form configurations of the Trapezium type, while only 27 (20 %) belong to the type usual for multiple star systems. The remaining 15 % are intermediate in type with the ratios of the largest distances between components to the smallest ones between 2·5 and 3·0.

In this respect the class of multiple galaxies differs strongly from the class of multiple stars, in which the Trapezium type configurations form only a small minority.

The Trapezium type multiple galaxies are probably unstable, at least in the cases in which the masses of the components are similar. The very existence of such configurations makes it probable that many of them have positive total energies. This means that some of the multiple galaxies represent newly formed and expanding groups, but this assumption requires some independent proof.

From the differences in the radial velocities, Δv_r, between the components of the pairs of galaxies observed by Page and others, we can find the values of $\rho(\Delta v_r)^2$, where ρ is the projected linear distance between the components. These values of $\rho(\Delta v_r)^2$ are systematically much higher for the pairs in the multiple systems with three or more components than in simple double galaxies.

However, if all the systems have negative total energies, the average value of $\rho(\Delta v_r)^2$ will be proportional to the average mass of the systems. Thus, the assumption of negative total energy for all systems leads to the conclusion that the masses of the components of multiple galaxies are systematically greater (at least by multiples of two or three) than the masses of the components of double galaxies.

The only way to avoid this conclusion is to assume that some multiple galaxies have positive energies. Thus we have an indirect proof of the assumption introduced above.

The mean value of the ratio $f = M/L$, derived for multiple systems, assuming negative total energies, is much higher than the maximum value of the same ratio obtained from the rotation of individual galaxies. This may provide additional evidence in favour of positive total energies for some multiple galaxies.

If we assume the steady state of clusters of galaxies and apply the virial theorem, we obtain very high values for the ratio f. Thus we obtain $f = 2000$ for the Virgo cluster and $f = 5000$ for the Coma cluster, if we take the new value determined by Zwicky for the radius of the latter cluster (and not $f = 800$ as derived by Schwarzschild, who applied only the corrections which tend to minimize the mass and neglected the opposite corrections).

Though the evidence in favour of inter-galactic matter in clusters of galaxies is convincing, it seems improbable that the mass of this matter in a cluster can exceed many times the total mass of member galaxies. Instead, it seems that the nature of inter-galactic patches is similar to that of irregular galaxies in which the ratio f is very small. Therefore it is reasonable to assume *that some of the clusters of galaxies are systems of positive energy*. In this case the virial theorem is not applicable.

As Markarian has pointed out, the presence of a chain of bright galaxies in the dense part of the Virgo cluster is an evidence in favour of the non-steady state of this system. The chain includes the giant elliptic galaxies M 84 and M 86 and is one of the outstanding features of the cluster. In this respect there is a remarkable similarity between the irregular clusters of galaxies and the O-associations, in which chains of blue super-giants appear (for example, the Orion Belt).

If among the multiple galaxies we have systems of positive energy, it is also natural to expect the occurrence of such cases among double galaxies. A double galaxy of this type would represent a pair of mutally receding stellar systems. There is no configuration-criterion in the case of double systems. However, the question arises of the possibility of observing such pairs in the early stages when the mutual distance of the components is very small and the nucleus of one component is situated in the central part of the other.

Actually, we observe some such narrow pairs as radio-galaxies. It is easy to show, applying statistical considerations, that the galaxy NGC 5128 (Centaurus A) cannot be a result of the collisions of two previously independent galaxies. In the case of Cygnus A the collision hypothesis should be abandoned on the grounds of similar statistical reasoning. In the case of NGC 4486 (Virgo A) the division of the nucleus into the main mass and a jet was directly observed by Baade. Therefore, we may consider a radio galaxy as a result of the division of the nucleus of some primary system.

Discussion

Minkowski: Results of a detailed investigation of NGC 1275, reported at the Jodrell Bank Symposium, admit no other interpretation than that this system consists of two colliding galaxies.

3. A STUDY OF BRIGHT MEMBERS OF THE LARGE MAGELLANIC CLOUD

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(This is an abstract of the paper presented by A. D. Thackeray at the symposium. The full paper is in *The Observatory*.*)

A progress report on work on (*a*) spectral types and (*b*) radial velocities of twenty-eight members of the Large Cloud (mostly $m_{pg} = 11$ or brighter) will appear shortly in *The Observatory*. The commonest spectral types found lie between B 5 and A 2. A star with $M_{pg} = -10{\cdot}1$ has slightly narrower H-lines than the galactic A 2 super-giant HD 92207. [Fe II] emission appears in four of the stars, including recent spectra of S Dor.

The radial velocities exhibit the rotation of the Cloud about an axis in position angle 75° agreeing within 5° with de Vaucouleur's minor axis derived from the outer structure.

The angular velocity appears to be constant out to a projected distance of some 3 kpc. This central body rotates with a period about 180 million years.

The angular velocities of stars and diffuse nebulae appeared to be 3·3 times that of the H I gas, as suggested by the published radio data at the time of submitting the paper. The explanation of the discrepancy was offered that the complexity of 21-cm profiles might have led to underestimated velocities for the inner core. This explanation has been confirmed by verbal conversations at the Dublin General Assembly of the Union.

Discussion

Morgan: Can Dr Thackeray tell us the magnitude of, say, the fifth or tenth brightest of the A super-giants which he has observed in the Magellanic Clouds in order to give an idea of the nature of the bright end of the luminosity curve as compared with individual isolated members.

Thackeray: About tenth magnitude, apparent. I should say that these magnitudes are extremely unreliable. Most of these stars are variable and, if they are faint, they tend to show emission lines of forbidden iron.

Morgan: Are these A super-giants variable as a group?

Thackeray: Many of them are.

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* *Obs.* **75**, 216, 1955.

4. ON ROTATING RING ORBITS IN GALAXIES

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If ω is the angular velocity of circular motions in a stellar system depending on the distance R from the centre, and κ is the frequency of oscillation in the radius vector for an orbit in the equatorial plane which differs slightly from a circular orbit, we may show [1] that in a coordinate system of angular speed

$$\omega - \tfrac{1}{2}\kappa$$

the orbit in question is a closed oval, in the first approximation an ellipse, with two opposite vertices and with its centre in the centre of the system. The conditions are illustrated in Fig. 1, when AA is the apsidal line of an orbit. The expression for κ is

$$\kappa = 2\sqrt{\omega(\omega - A)},$$

where A is Oort's constant of differential rotation. If the distribution of matter in the stellar system may be approximated by a sum of concentric spheroids with one and the same plane of symmetry, the density increasing with decreasing dimensions of the spheroids, we should expect $\kappa = 2\omega$ close to the centre, whereas in the outermost regions we must expect that κ approaches to ω. It is therefore likely that $\omega - \frac{1}{2}\kappa$ does not change appreciably within the system. Fig. 2 gives the run of κ, ω, and $\omega - \frac{1}{2}\kappa$ for the galactic system according to the values of ω given by Kwee, Muller, and Westerhout [2]. In this case $\omega - \frac{1}{2}\kappa$ changes very slowly with R. A relative orbit has a quite important property, if $\omega - \frac{1}{2}\kappa$ is constant in the interval of R covered by the orbit. In this case, if the centre of gravity of a cloud of free particles follows the orbit, and if the velocity dispersion is small, the particles will pursue orbits which differ only slightly from each other and from the central orbit, but on the other hand there will in general be considerable differential motions along the central orbit. This orbit is therefore the curve in space along which a cloud of free particles tends to disperse. The process is similar to the dispersion of the meteoric particles of a comet along its orbit.

If we follow a piece of matter in its motion along a slightly oblong orbit of this kind, the amount of matter per unit of the central angle θ will vary

Cambridge University Press
978-1-107-51161-3 - Comparison of the Large-scale Structure of the Galactic System with that of Other Stellar Systems
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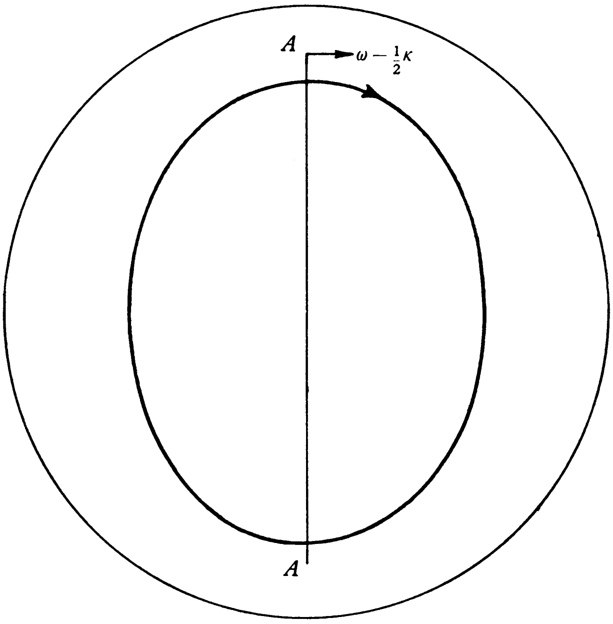

Fig. 1.

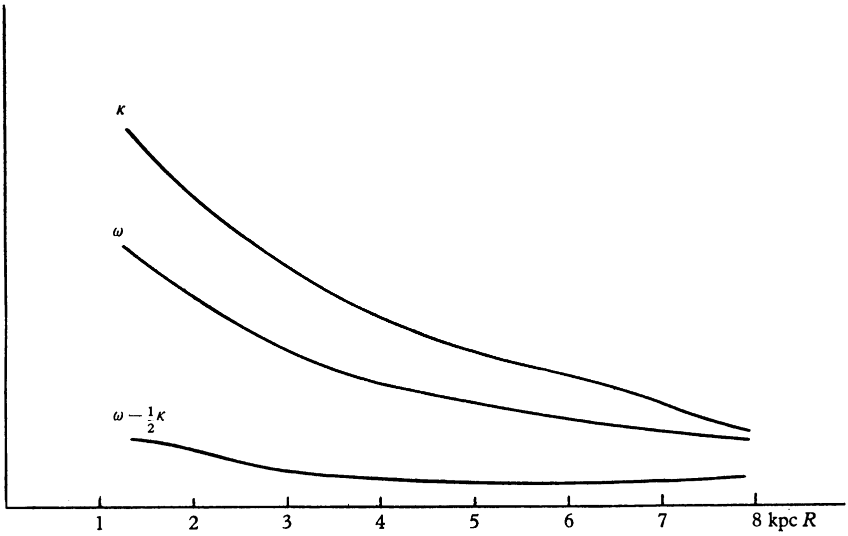

Fig. 2.

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due to the law of areas in the motion. In the case of a perfect mixing of matter along the orbit, which is of course an ideal case, but which will be approached as time increases, there will be steady maxima of density at the vertices (major axis) and steady minima at the ends of the minor axis. Due to this circumstance there will be secular disturbances of the motions in the ring, as well as on particles outside of the ring. In order to test this effect we have made computations on the motions of ring formations in a typical stellar system.

We assume as an interpolation formula in the interval of R considered a central force of the form

$$\frac{\partial\phi}{\partial R} = -\frac{aR}{1+bR^3}. \qquad (1)$$

It is easily found that in this case $\omega - \frac{1}{2}\kappa$ is nearly constant in a region about $R = R_0$, where

$$bR_0^3 = 2{\cdot}456.$$

If we choose $R_0 = 7$ kpc, we have

$$b = 0{\cdot}00716. \qquad (2)$$

The value ω_0 for $R = R_0$ may be chosen in accordance with the value derived by Kwee, Muller and Westerhout for $R = 7$ kpc in the galactic system, $\omega_0 = 0{\cdot}0323$ km/sec pc, which gives

$$a = 0{\cdot}003606. \qquad (3)$$

If we take as the unit of time 10^6 years, as the unit of distance one kiloparsec, and express ω in kpc/10^6 yrs kpc, we find

$$\frac{\partial\phi}{\partial R} = -\frac{0{\cdot}003768R}{1+0{\cdot}00716R^3}. \qquad (4)$$

The total mass of the stellar system is found to be of the order 100.10^9 solar masses.

At $R_0 = 7$ kpc we have

$$\omega - \tfrac{1}{2}\kappa = 0{\cdot}010454 \text{ kpc}/10^6 \text{ yrs kpc}. \qquad (5)$$

The orbit of a particle in the central field (4) in a co-ordinate system ξ, η rotating with the angular speed (5) has been computed starting with the initial values

$$\xi = 0,\ \eta = +7{\cdot}7,\ \dot{\xi} = +0{\cdot}12285,\ \dot{\eta} = 0.$$

The resulting orbit is very nearly closed. The positions and velocities in the first quadrant (ξ and η positive) were taken to define the orbital motion at intervals of time corresponding to 1/32 of a period. The values in the other quadrants were formed by symmetry. In this way we find the initial distribution of thirty-two points along the periphery of the ring as shown in Fig. 3.