INVITED DISCOURSE C

given to participants in the General Assembly at 20^h00^m on Monday 21 August 1961 in the Auditorium of Wheeler Hall on the Berkeley Campus of the University of California by

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on

PROBLEMS OF EXTRA-GALACTIC RESEARCH

INTRODUCTION

The present report deals with the basic facts of extra-galactic astronomy. It should be noted that a true picture of the outer stellar systems (galaxies) was formed in astronomy only about forty years ago. As a result, most basic problems concerning the outer galaxies remain unresolved. We, therefore, formulate in the present report a number of problems which, in our view, seem to constitute the most essential points in the further exploration of the outer galaxies. We shall try to keep as close to the facts as possible and handle, primarily, those problems the solution of which may seem possible in the near future with the means available to us.

It is known that extra-galactic astronomy comes in close contact with cosmology, that is with the theories attempting to describe the universe as a whole. These theories are, undoubtedly, of definite usefulness insofar as several solutions of the equations of Einstein's theory of gravitation are considered, and the question is raised as to the applicability of these solutions to the observed part of the universe. At the same time some of these theories contain rough simplifications and unbounded extrapolations. It is beyond the scope of the present report to make an analysis of these theories and discuss the problems of their further development, although a critical review of the work carried out in this field should be extremely valuable. None the less the facts and the problems discussed below should be of importance to cosmological theories as well.

I. THE PRINCIPAL FACTS ON THE DISTRIBUTION OF MATTER IN EXTRA-GALACTIC SPACE

That the majority of the matter observed in space is concentrated in the stars constitutes one of the properties of the surrounding world. Other bodies contain but a small part of the mass observed.

In the overwhelming majority of cases the observed stars enter, in their turn, into giant stellar groups called galaxies. This is a most significant fact of extra-galactic astronomy.

The stellar population and the dimensions of the galaxies vary over an unusually wide range. The super-giant galaxies of the type of the two brightest galaxies in the centre of the Coma cluster (NGC 4874 and NGC 4889) attain a photographic absolute magnitude of the order of -22. They contain hundreds of thousands of millions of stars, while the dwarf systems of the type of the nearby galaxy in Sculptor are of absolute magnitude $-11{\cdot}0$ and apparently contain only several million stars. However, stellar systems of much lower luminosity exist and might be called sub-dwarf galaxies. The galaxy in Capricorn of absolute magnitude $-6{\cdot}5$, discovered by Zwicky, is an illustration in point. This group seemingly comprises, at most, several tens of thousands of stars and is more than ten million times poorer than some super-giant galaxies. Moreover, it is inferior in population to many globular clusters.

The diameters of the galaxies, as a rule, are included in the range 50 000 pc for super-giants to 500 pc for sub-dwarfs.

The giant and the super-giant galaxies with diameters ranging from 5000 pc to 50 000 pc invariably possess high surface brightness (over 24·0 per square second of arc) and also show an extensive concentration of luminosity towards the centre.

In dwarf galaxies objects with low surface brightness are encountered alongside those with high surface brightness. However, in addition to the systems with high gradient of surface brightness from the border to the centre, there exist also dwarf galaxies with very low gradient, so that such systems look in pictures almost like uniform disks.

Examples of galaxies with low density gradient in the local group are the dwarf stellar systems in Sculptor and Fornax discovered by Shapley. The surface luminosity of these systems is exceedingly low. Later, Baade showed that the galaxies NGC 147 and NGC 185, belonging to the Local Group, also contain a low density gradient. The surface luminosity of these two galaxies is considerably higher than that of the systems in Sculptor and Fornax. Of intermediate surface brightness are two other members of the Local Group: Sextans B ($9^h 57^m{\cdot}3$, $+5°34'$; 1950·0) and Leo 2 ($10^h 05^m{\cdot}8$, $+12°33'$; 1950·0). They also have a very low density gradient. Many objects of low surface brightness and low density gradient are met with in the Virgo cluster. Their linear dimensions sometimes are of the same order as those of the galaxies of average luminosity. For instance, galaxy IC 3475 in addition to its very low surface brightness has a negligible density gradient while its diameter attains 5000 pc. Thus, by dimensions, this galaxy is by far superior to similar objects in the Local Group.

However, it is worthwhile to note that objects of relatively large dimensions with a small density gradient and a low surface brightness are very rare. For instance, in the well-known cluster in Cancer, the largest of such galaxies has a linear diameter of about 2500 pc.

The fact that the absolute majority of stars belong to the galaxies becomes of primary importance if we take into account that the galaxies are, roughly speaking, systems isolated one from another. Usually the distance between neighbouring galaxies exceeds by far the diameters of their central, denser parts. At the same time, external rarified parts of galaxies often penetrate into one another. Besides this topographical isolation, we must also indicate the mutual dynamical independence of the galaxies as stellar systems. The term 'dynamical independence' implies the property under which the motion of the stars in each galaxy is determined, in the main, by its interaction with the other members of the same galaxy. It should also be pointed out that this condition of dynamical independence holds usually only to a certain approximation. The mutual perturbations of two neighbouring stellar systems, the ejections from the central parts of the galaxies, which will be properly considered below, are, to a greater or lesser extent, cases of the violation of this independence.

As the stars belong to the galaxies, likewise the latter, in their turn, form part of such systems of galaxies as the clusters, the groups and the multiple clusters.

Two decades ago it was assumed that in addition to the clusters and the groups of galaxies there exists a general field comprising the greater part of the galaxies—similar to the general star field in our stellar system which is overspread with stellar clusters and associations. Now the existence of the general field itself is in doubt. At any rate, it can be asserted that the clusters, the groups and the multiple systems contain the overwhelming majority of the galaxies of high luminosity.

The clusters we observe can be classed under two types: spherical clusters with a regular, symmetrical distribution of the galaxies about the centre; and loose clusters with an irregular distribution of galaxies. The giant and the super-giant members of the spherical clusters comprise chiefly elliptical galaxies. The irregular clusters contain a high percentage of spirals. Groups of galaxies such as the Local Group or the groups around M 101 and M 81 are, in this respect, very much like the irregular clusters.

For instance, the groups of galaxies associated with M 101 and M 81 virtually contain no elliptical galaxies whatever. They are made up of only spirals and irregular galaxies. A group in Sculptor, studied by de Vaucouleurs, contains only galaxies of the Sc type and some irregulars as well. Our Local Group does not comprise elliptical galaxies of high luminosity either, but it possesses elliptical galaxies of low and moderate luminosity.

It is also interesting to note that our Local Group consists, in fact, of two smaller groups approximately of the size of multiple galaxies. The first group contains our Galaxy, two Magellanic clouds and, apparently, some galaxies of the Sculptor type. The second group comprises the Andromeda nebula with its four satellites and M 33. However, such a division can be ascertained only for galaxies of high and moderate luminosity.

Referring to the dwarf galaxies, they might possibly fill in the space of the Local Group. It should be added that the full mass of the whole Local Group is determined, mainly, by two galaxies which form actually the centres of these sub-groups, that is M 31 and our own Galaxy. On the other hand, in some cases rich clusters of galaxies occur sometimes in twos and in threes, forming multiple clusters.

It has been mentioned above that the galaxies are, as a rule, stellar systems isolated one from another. However, there are cases when this isolation is not observed strictly. Let us indicate the following three categories of such objects:

(*a*) *Interacting galaxies*. This is the case when two galaxies are close to each other and the presence of the one deeply affects the structure of the other. Numerous instances of interacting galaxies are reproduced in the atlas of Vorontsov-Velyaminov. Two interpretations of the interaction under discussion are possible: (i) tidal interactions; and (ii) the division of one galaxy into two. In the latter case the 'interaction' observed should be regarded as the aftermath of the process of division.

(*b*) *Couples of galaxies* interconnected by means of bridges and filaments. Many illustrations of this kind are cited in the articles of Zwicky, who has shown that the filaments are made up of stars. In addition, there are jets flowing out from the central areas of some spherical galaxies. Such jets sometimes contain blue condensations which are known to be the dwarf galaxies. (The high luminosity galaxies NGC 3561 and IC 1182 possess jets containing condensations.)

It turns out that in this case, too, the jet joining the dwarf galaxy to the large one is a kind of filament. In such a case there remains no doubt that the dwarf galaxy has been detached from the main body of the principal galaxy. It seems more plausible, therefore, to regard the bridges and the filaments as resulting from the process of formation of two galaxies from one.

(*c*) *Radio galaxies.* It is known that the radio galaxies were assumed to be cases of accidental collision of a pair of independent stellar systems. It was also assumed that the kinetic energy of the collision of two gas masses, contained respectively in each galaxy, is the source of the energy of radio-emission. The facts, however, contradict this hypothesis. All the data support the view that the radio galaxies form some stage, possibly of short duration, in the process of the internal evolution of the galaxies of very high luminosity.

The radio-emitting activity of the galaxies is, evidently, closely associated with the new formations within them, such as jets and ejections coming from the centre (Virgo A), spiral arms and even complete new galaxies. In other words, in some cases a process of division of the main body of the galaxy and the emergence from it of a new one takes place. That is why radio galaxies often become very narrow pairs, consisting of the old galaxy and the new formation immersed in the old galaxy.

It is to be noted that all the cases of violation of the isolation of galaxies, as referred to above, taken together, constitute only a small percentage of the total number of galaxies. There is every reason to believe that these violations occur only at a certain stage of the evolution of the galaxies, namely when new galaxies come into being.

Notwithstanding the great gains scored in the study of space distribution of the galaxies, many important problems are still unsolved. Here are some of them: do clusters of galaxies form, in their turn, systems of higher order of the type of super-clusters or super-galaxies.

Our Local Group enters, no doubt, into a certain group of clusters with the great cluster of Virgo forming its main part. This great system was named the Super-galaxy by de Vaucouleurs; its dimensions are of the order of 20 million pc. However, nothing can be said so far as to the dynamical unity of this system or the existence of forces that might support such a unity.

It is interesting to observe that the existence of a great number of super-galaxies by no means becomes prominent while making a study of the distribution of galaxies in the sky. In considering this problem one of two possibilities must eventually be realized: (i) the mutual distances between neighbouring super-galaxies are great compared with the linear dimensions of the super-galaxies; or (ii) these mutual distances are of the same order of magnitude as the linear dimensions of the super-galaxies. In the former case a great many such super-galaxies must be clearly outlined in projection on the sky as isolated formations. In the latter case we could trace out only a small number of similar formations in projection on the sky, in the form of isolated systems, and unless we make a deep study of the problem it would be hard to draw conclusions regarding the occurrence of distant super-galaxies.

The observations reveal irregularities in the distribution of clusters and groups of galaxies, which can be accounted for, to a certain extent, by the occurrence of super-galaxies. At the same time it should be stressed that we observe only a few isolated cases of clouds consisting of a number of concentrations; for example, in the southern sky a vast cloud, extending from $l = 160^\circ$ to 240° when $b = -40^\circ$.

The irregularities in the distribution of the galaxies in the sky (independent of the absorption in our Galaxy) are clearly shown by the galaxies included in the catalogue of Shapley and Ames (limiting magnitude 13·0). This irregularity is stipulated mainly by the local Super-galaxy. The irregularities become more pronounced in the counts of Shane and Virtanen (limiting magnitude 18·4). The small-scale inhomogeneities are conditioned by the concentrations of the galaxies in clusters. But there are also inhomogeneities of greater dimensions brought about by the tendencies of the clusters to form groups similar to the super-galaxies discussed above.

According to Zwicky and other authors, the irregularities in the distribution of the galaxies extend up to the boundaries observable by the Palomar Schmidt telescope (almost to the 20th magnitude).

The huge clouds of galaxies in the region of the cluster in Corona Borealis are an illustration in point. However, an investigation of the distribution of the centres of the clusters of galaxies is of great interest when studying the tendencies of clustering of the clusters. Abel has made such a study on the plates of the Palomar Atlas. The results derived confirm the inhomogeneity in the distribution of the clusters.

Zwicky believes that the main cause in the inhomogeneity observed in the distribution of the clusters lies in the patchy distribution of the inter-galactic dust. The arguments he adduces in favour of inter-galactic absorptions in some directions are apparently convincing. Not all the deviations from homogeneity are accountable in this way. That is why the real irregularity in the distribution of the most distant galaxies is something that should be properly taken into account.

These two facts show that the second alternative is realized, that is the distances between the super-galaxies are of the same order as their diameters. Although the existence of independent super-galaxies is to be conceded, nevertheless the following questions remain open:

(*a*) *What percentage of clusters of galaxies enters into these systems of a higher order?* Is there an equally strong tendency towards a clustering of the clusters in the two familiar types of clusters (spherical and diffuse)? Only more detailed photometric and statistic studies could provide answers to these questions.

(*b*) *To what extent do galaxies of low luminosity repeat the space distribution of those of high luminosity?*

The concentration of galaxies in clusters is, as shown above, rather well established in respect to objects of high luminosity. However, beginning at a distance of several million parsecs, objects of low luminosity will be lost altogether among galaxies of remote background, and the solution of the problem will be beset with certain difficulties. Yet some conclusions as to the distribution of objects of low luminosity, especially galaxies of low surface brightness, can be made from the results of the work of Rijves. He established that the distribution of objects with low surface brightness in the Virgo cluster repeats roughly the distribution of galaxies with high luminosity. But we cannot assert whether the galaxies of exceedingly low surface brightness (systems of the Sculptor type or of the Zwicky object in Capricorn) make up one common metagalactic field or concentrate in clusters and groups.

(*c*) *The super-galaxies, referred to above, are objects with a diameter of the order of 20 million parsecs.* If they constitute the greatest inhomogeneities in the distribution of the galaxies, space cells, 50 to 100 million parsecs in dimensions, are to be expected to contain approximately equal numbers of galaxies.

It is possible, however, that inhomogeneities of a larger scale occur. The question can be settled only by investigating the distribution of the faintest clusters of galaxies (up to $m = 21$), or by studying the distribution of extra-galactic radio sources. The solution of this problem is extremely important for cosmological theories. For the time being there is no evidence to justify the postulate of homogeneity usually introduced by the cosmologists.

(*d*) *It has already been said above that there are sound proofs in support of inter-galactic dust.* In this connection, the expediency of studying all types of inter-galactic matter is to be underlined. Even already, some species of inter-galactic matter seem to be established as real:

(i) The bright inter-galactic matter, sometimes filling up the central part of the volume, occupied by a cluster of galaxies. All the data testify to the bright matter, as well as the frequently observable bridges and filaments, being made up of stars.

(ii) Inter-galactic globular clusters, some of which are encountered at a distance of over 100 000 parsecs from us.

https://doi.org/10.1017/S0251107X00022355 Published online by Cambridge University Press

(iii) Huge clouds of relativistic electrons ejected from the interior of the galaxies. For instance, the radio source of Centaurus A consists of three such clouds, while the source Cygnus A consists of two. Each of these clouds surpasses in dimensions the normal galaxies. Doubtless, most of the clouds of this type have already dispersed in inter-galactic space.

(iv) Absorbing dust. However, we have no data on the dimensions of separate dust clouds.

(v) Neutral hydrogen, which is only so small in amount that the radiation emitted (in the line $\lambda = 21$ cm) has not been so far detected with certainty.

There is no doubt that each of the types of inter-galactic matter deserves a special study.

II. THE BASIC FACTS REFERRING TO THE KINEMATICS AND THE DYNAMICS OF THE SYSTEMS OF GALAXIES

Our knowledge of the motions in the world of galaxies is restricted to the radial velocity of about one thousand galaxies. We have no data on transverse velocities. None the less, the data on radial velocities, obtained almost exclusively at the observatories of Mount Wilson, Palomar and Lick, raise the most difficult problems ever dealt with by astronomy.

The whole complex of the galaxies observed represents one part of a grandiose system which we name the Metagalaxy. This concept of a Metagalaxy is of significance, irrespective of whether there exist galaxies outside this system or not. The fact of the expansion of the Metagalaxy, constitutes an important inference made from our knowledge of the radial velocities of the galaxies. Hubble's law

$$V_r = Hr$$

deduced from the empirical data, holds good for values of r, up to almost two thousand million parsecs. This circumstance signifies the approximate homogeneity of the observed expansion.

All efforts to find an explanation for the redshift, other than the Doppler effect, have been futile. That is why, when treating the large scale properties of the Metagalaxy, the phenomenon of expansion should be given proper consideration.

Of course, Hubble's law is correct only for mean velocities. In addition to the velocity, as defined by Hubble's formula, every cluster and every galaxy has its own peculiar velocity. Thus, in the Local Group, where the distance between the galaxies is small, the relative velocities are mainly determined by the peculiar motion of individual members. But even the nearest clusters of galaxies and groups are receding from us, which is evidence of the smallness of their peculiar velocities in comparison to the regular velocities of recession given by Hubble's formula.

The numerical value of the constant H is of great importance, since a knowledge of it enables us to determine the absolute distance of the remotest clusters. Unfortunately, its precise value is unknown. It is very likely to be somewhere within the limits of

$$60 \text{ km/sec/megaparsec} < H < 140 \text{ km/sec/megaparsec}$$

and we can assume, with some risk, that it is included in the narrower interval

$$70 \text{ km/sec/megaparsec} < H < 100 \text{ km/sec/megaparsec}$$

in conformity with the results of Sandage (1958). We shall not discuss here the difficulties involved in the determination of the value of H; we do point out, however, that in any case Hubble's law makes it possible to give a correct estimate of *relative distances*.

The second important fact regarding the motions of the galaxies is the occurrence of some dispersion of the velocities in each cluster, related to the internal motions of the galaxies within them.

If the clusters are in a steady state, or are going to become steady, then their total energy E must be negative

$$E = T + U < 0$$

where T and U represent respectively the kinetic and potential energies of the system. On the other hand, if $E > 0$, then such a system cannot come to a steady state and, at least, some of its members must escape from it.

Recent investigations have shown that, for certain groups and multiple systems, the kinetic energy of internal motions determined from the radial velocities exceeds by far the probable value of the absolute magnitude of the potential energy, calculated on the assumptions that the whole mass of the cluster (or group) is concentrated in its galaxies and that the ratio of mass to luminosity $f = M/L$ for the given type of galaxies is of the same order that is found from the rotation of galaxies. It follows therefrom that some groups and clusters possess positive total energy and will be dispersed into space. Such a conclusion has been arrived at, for example, for the clusters in Virgo and Hercules, and also for the nearby group of galaxies in Sculptor. The latter case, analysed in detail by Vaucouleurs, is outstanding, for the kinetic energy exceeds the calculated absolute value of the potential energy by one and a half or two orders of magnitude.

Insofar as the positive energy must lead to the escape of some members and, at times, to the total disintegration of the cluster, it can be presumed that there is something common between the instability of the cluster, on the one hand, and the expansion of the Metagalaxy, on the other.

In this respect an intermediate part is to be played by the systems of the type of Local Super-galaxy. Its component parts are known to recede from one another. For instance, the cluster in Virgo or the M 81 group recede from the Local Group of galaxies.

What has been said about the sign of the absolute internal energy of the clusters of galaxies holds good for multiple systems as well. Apparently some multiple systems also have a positive total energy. All these facts force us into the belief that the corresponding galaxies are comparatively young—their ages being of the order of 10^9 years.

However, one more peculiarity of the assembly of multiple galaxies (triples, quadruples, etc.) engages our attention, regardless of the sign of the total energy. It is known that the great majority of the *multiple stars* have configurations of the 'usual' type, while the configurations of the 'Orion Trapezium' type make up an insignificant percentage ($< 10\%$). On the other hand, nearly half of the *multiple galaxies* have trapezium-like configurations. As the trapezium-like systems are, as a rule, unstable we can infer that the time, elapsed since the formation of these multiple groups, is not greater than a few periods of revolution of such a multiple system, which, in its turn, is of the order of 10^9 to 5×10^9 years.

Finally, the assumption of negative energy for all double galaxies sometimes entails improbably great values for the mass of the components (Page); hence there is reason to believe that some of the double galaxies also possess positive energy.

In very close pairs, such as the radio galaxies, considerable differences in the velocities of the components are noticed; thus in the radio galaxy Perseus A this difference reaches 3000 km/sec. In this way these pairs also possess positive energy. We apparently observe in this case the formation of such a pair out of one galaxy.

Further accumulation of data on the radial velocities of galaxies will make possible the solution of many unresolved questions of their kinematics and dynamics. Some of these questions are listed below:

(*a*) *A more precise determination of the constant of the redshift law.* This will provide the scale of extra-galactic distances.

(*b*) *A determination of the character of the redshift law for very large distances.* We must observe, no doubt, a violation of linear dependence. The sign of the deviation from the linear relation and whether the magnitude of this deviation is independent of direction are important factors in the basic problems of cosmology.

(*c*) *It is of significance to determine the peculiar velocities of the centres of gravity of the separate clusters of galaxies*, that is the deviations of their observable velocities from Hubble's formula. This is of great importance for the solution of problems connected with the possible genetic relations between neighbouring clusters. But to determine these deviations it is essential to develop further the methods of precise determination of the distances of the remote clusters, independently of Hubble's law.

(*d*) *To solve many questions of the dynamics of multiple galaxies and of clusters it is essential to determine their masses.* Unfortunately, in the case of distant galaxies entering into the above-mentioned systems, we determine the masses statistically, assuming negative energy and also the applicability of the virial theorem.

It is necessary to determine the masses of the galaxies, at least in the nearest clusters, irrespective of this assumption. At the same time, means should be found to enable us to evaluate, at least, the upper boundaries of the probable inter-galactic mass in each system (clusters or groups).

(*e*) *The inconsistency between masses of systems, defined by the virial theorem, and masses, determined from the luminosities of the individual members of the system, is most prominent for some irregular clusters and groups of galaxies* (clusters in Virgo, Hercules, the group of galaxies in Sculptor, in Leo etc.). On the other hand, according to Zwicky, rich spherical clusters show no signs of expansion.

To reach a final decision on these problems a greater number of radial velocities in some of the nearest rich spherical clusters should be obtained.

III. SOME FACTS ON THE NATURE OF GALAXIES AND THEIR CLUSTERS

Observations show that a great diversity of form and internal features are encountered in the galaxies. To gain a fuller insight into their nature, it is important to have a complete, but simple, system of classification of galaxies. It is quite evident that the deeper the physical meaning of the criteria forming the basis of the classification, the more useful it will prove in solving problems of extra-galactic astronomy.

The wide-spread classification of Hubble is based only upon a study of the outer forms of the observed galaxies. It turned out to be of extreme usefulness for, until quite recently, all our information concerning the overwhelming majority of the galaxies was confined to data on the form, the integral brightness and the apparent diameter. The last two parameters do not, by themselves, constitute characteristics of the system in so far as the distance remains unknown. In recent years, however, we have succeeded in judging approximately the absolute brightnesses and the linear diameters of a great many galaxies entering into rich clusters, as it became known that the brightest members of these clusters are always super-giants with an absolute magnitude of order of $-21{\cdot}0$. If we compare this value with the apparent magnitude of the brightest members, we can make a very rough estimate of the distance and, thereby,

https://doi.org/10.1017/S0251107X00022355 Published online by Cambridge University Press

of the luminosity and the absolute dimensions of all the remaining members. It was stated at the beginning of this report that the range of the luminosities of the galaxies within the clusters is very great. Gradually, it became clear that the attribution of a given galaxy to the category of super-giants, giants, objects of moderate luminosity, dwarfs and objects of extremely low luminosity (of the type of the Zwicky object in Capricorn) is in most cases much more essential than the recognition of its form. Let us recall once more that a super-giant galaxy contains millions of times more stars than any galaxy of extremely low luminosity.

To understand better the properties of the galaxies, it is substantially significant to study their central parts and particularly to verify the existence of dense central nuclei of small dimensions. It is also desirable that new attempts of classification should give a proper consideration to luminosity criteria. The assignment of the class should take into account the role of the central parts and possibly of the nucleus itself. Probably there are also other, so far unknown, parameters which are extremely important in describing the state of the galaxy.

The classification suggested recently by Morgan, which takes into account the degree of concentration of luminosity, is, to a certain extent, in line with one of these desiderata; but the assignment of a Morgan class leaves the luminosity indefinite. Recently Van den Bergh has made an attempt to construct a parameter determined by the observable forms of the galaxy which, in essence, defines its luminosity. This is a valuable principle. However, Van den Bergh's classification is not universal and involves only late-type spirals. It is to be assumed, therefore, that new classifications will be proposed in future which will take into account the most important parameters of each galaxy.

The concepts of the existence of sub-systems in galaxies and of various types of stellar population is a remarkable achievement of the second quarter of our century (Lindblad, Kukarkin, Baade). In a number of galaxies, such as the systems of the type EO, we notice rather a high degree of homogeneity of the population; in such cases it can be maintained that the whole galaxy is composed of only one sub-system. This is true particularly for such members of the Local Group as the one in Sculptor, and galaxies M 32 and NGC 147. Unlike the view expressed sometime ago by Baade, we do not observe systems in nature consisting wholly of populations of the first type (the population of the spiral arms). In most cases, the galaxies represent superpositions of two or more sub-systems, containing various types of population.

Thus the lenticular galaxies (SO) consist of two sub-systems, made up of stellar populations of both the spherical component and the disk. The giant spirals of the M 31 type are composed of the spherical component, the disk and the spiral arms. Possibly a more detailed division is needed; but at this place we should like to emphasize *the phenomenon of superposition* of the various sub-systems.

The data available indicate that the various sub-systems follow different paths of evolution. There is reason to believe that the average age of the stars of different sub-systems varies too. It turns out that, if the dynamical interaction is not considered, each of the sub-systems leads its own life. It is exactly this factor that assumes importance in describing the galaxies as composite systems, resulting from the *mere superposition of the sub-systems*.

There is no correlation between the degrees of development of the different sub-systems of the galaxies. This verifies the relative independence of the different sub-systems entering into the same galaxy.

Thus the spherical sub-system of M 31 does not sensibly differ in its richness and dimensions from the normal galaxy of EO type of absolute magnitude about $-19{\cdot}0$. Nevertheless the latter has no population whatever of a flattened sub-system and spiral arms, whereas M 31 possesses powerful spiral arms and a rich disk population.

Systems of an intermediate position are also of interest from this standpoint; in such systems one of the sub-systems is quite well developed while the other is comparatively poor. A striking illustration is offered by NGC 5128 (radio source Centaurus A) which on over-exposed plates looks like an elliptical galaxy but, as a matter of fact, contains in its central part a poorly developed flattened sub-system, including a lot of absorbing matter. The work of the Burbidges, based on measurements of radial velocities in this flattened sub-system, has revealed that the equatorial plane of the latter is nearly perpendicular to that of the elliptical sub-system; this bears testimony to the independence of the sub-systems. NGC 3718 is another interesting illustration. The spiral arms of this galaxy are of small power but, unlike NGC 5128, extend far beyond the boundaries of the volume occupied by the spherical sub-system; the plane of concentration of the dark matter is inclined at about 25° to the equatorial plane of the elliptical sub-system, which is further evidence in favour of the independence of the sub-systems.

Opposite examples might also be produced in which the spherical system is under-developed while the flattened system is very prominent. The Large Magellanic Cloud could apparently serve as an example; that there is a spherical sub-system in this cloud is inferred from the existence of at least three dozen globular clusters similar to those in our Galaxy and in M 31. Unfortunately, other objects of the spherical sub-system are very hard to uncover against a background consisting of the population of the flattened sub-system. It is therefore difficult to say which type of elliptical galaxy resembles the spherical component of the Large Magellanic Cloud; judging by the number and distribution of globular clusters this must be an elliptical galaxy of moderate luminosity ($M \sim -16$), having a low density gradient. It is well known that when passing from the super-giant elliptical galaxies to those of moderate and low luminosity, objects with low density gradient become more frequent.

Mention has been made above of the comparative independence of the various sub-systems entering into the same galaxy. But in one respect the bond between the sub-systems is always observed with great strictness. We have in mind the common centre. The centre of the spherical sub-system coincides with that of the disk and also with the region out of which the spiral arms emerge. As is evident from observations of the nearest galaxies of high luminosity, this centre is usually the location of a nucleus only several parsecs in dimensions (less than the diameter of the common globular cluster). It seems natural, therefore, that the formation of separate, almost independent sub-systems is somewhat linked with the occurrence of the above-mentioned nuclei.

No traces of nuclei have been reported in a number of galaxies; such is the case, for example, with NGC 185 and with Sculptor. But let us consider the luminosities of the nuclei. The absolute photographic magnitude of the nucleus of M 32 is $-11{\cdot}6$; in M 31 it is $-11{\cdot}1$ and in M 33 it is $-10{\cdot}3$. In NGC 147 it is $-5^{m}{\cdot}0$. One gathers the impression that the luminosity of the nucleus decreases with the diminution of the density gradient. It is to be expected, therefore, that in NGC 185 and in the systems of the Sculptor type, as probably in the Magellanic Clouds, the nucleus must have a still lower luminosity than in the NGC 147. If it is of order -2, it is evident that the nucleus will be lost among the stars. Let us note that in the Magellanic Clouds the nucleus may remain unnoticed even if it is of magnitude -5; it is therefore premature to insist on the absence of nuclei in these systems. But if the nuclei do exist they must be of small power.

It has been noted above that usually the concentricity of the sub-systems in each galaxy is observed very strictly. However, there are cases of deviation from this rule; NGC 4438, in the Virgo cluster, is a pertinent example where the two sub-systems are clearly shifted in respect to each other.

There is a certain similarity between the galaxies and the clusters. This lies in the fact that the member galaxies in clusters can be attributed to two different types of population, just like the stars in galaxies. To the first type belong the spiral galaxies and the irregulars, while to the second belong the elliptical and the lenticular galaxies (SO).

Large spherical clusters of galaxies, such as the one in Coma, are rich in populations of the second type. The loose clouds of galaxies like the Ursa Major Cluster, one of the nearest to us, have almost no elliptical galaxies of high luminosity. The nearest to us, a group of galaxies in Sculptor ($m-M = 27{\cdot}0$) studied by de Vaucouleurs, is not only deprived of elliptical galaxies but contains no galaxies of So, Sa and Sb types either. Only spirals of late subdivisions are included in this group. The large irregular cluster in Virgo contains giant elliptical galaxies as well as giant spirals.

Then comes the question: *is it possible to speak of the superposition of different sub-systems of galaxies in one cluster?* It must be admitted that combination of two quasi-independent sub-clusters into one are not observed; nevertheless, certain observations clearly favour this view. Thus in the Coma cluster one of the central galaxies (NGC 4874), which is a supergiant of the So type, is apparently surrounded by a symmetrical cloud of elliptical galaxies of lower luminosity. Externally this group is very much like galaxy NGC 4486, surrounded by globular clusters. In this case, however, the latter are replaced by elliptical galaxies of moderate luminosity; and this dense group of elliptical galaxies, with NGC 4874 in the centre, overlies a large cluster of galaxies, possessing a small density gradient.

For irregular clusters of galaxies we can presumably discover many more phenomena testifying to the superposition of separate groups. The chain of bright galaxies M 84, M 86, NGC 4435, 4438 and others in the Virgo cluster is an example in point; this chain is not an accidental formation, as stated by Markarian a few years ago, but overlies the Virgo cluster as an independent group.

It is highly probable that the irregular clusters of galaxies generally represent results of combination and superposition of a number of more-or-less independent groups, out of which their irregular form arises.

It must be recalled, in this connection, that there exist clusters (or groups) made up of one central galaxy surrounded by a smaller or greater number of objects of low luminosity. The group around M 101, for example, belongs to that category. We emphasize this fact because, in such cases, the common origin of the central galaxy and its faint satellites admits of no doubt. However there are, in addition, groups consisting almost exclusively of super-giants; Stephan's Quintet is a pertinent example. Unlike the M 101 group, no galaxies of low luminosity appear around these super-giants. Of course, it is possible that here we have a case of discontinuity of the luminosity function, and that this system contains some galaxies with an absolute magnitude fainter than the detection limit. The facts mentioned above, in conjunction with what has been said about the exceptional position of M 31 and our Galaxy in the Local Group, emphasize the great cosmogonic significance of the super-giant galaxies in clusters and in groups.

It is also clear from the foregoing that, besides investigating rich clusters of galaxies, it is very important to have as much data as possible for the comparatively poor groups. In particular, it is essential to find out whether there exist many isolated groups, composed exclusively of galaxies of low luminosity; if such groups are not abundant this would signify that the cosmogonic processes going on in a galaxy of high luminosity are essential for the formation of surrounding dwarfs.

In spite of certain gains achieved in the investigation of the character of the stellar population of galaxies and various sub-systems, it is to be admitted that only the first steps have been taken in this direction.

We are in urgent need of further data on the composition of the population based on spectroscopic evidence (on the lines contemplated by Morgan and Mayall) and also on the quantitative analysis of the continuous spectrum (Markarian *et al*).

Another question of importance is the analysis of the nature of the arms of galaxies. Among galaxies with arms of the same degree of openness and length we find objects both very rich and very poor in O-associations. To discover a correlation between the nature of the arms and the other parameters of the galaxies would get close to realizing the cause of these differences.

Of particular interest are the barred spirals (SB). To our regret, we do not fully realize the difference between the population of the bars and the arms. It is only known that usually the colour of the bars is considerably redder than the colour of the arms and that the latter, therefore, contain a larger number of stars of recent formation. It is especially important to find out to what extent the bars are rich in open clusters and super-giant stars.

IV. AN EXTENDED UNDERSTANDING OF THE PHENOMENA OF SUPERPOSITION

We have already spoken of the particular cases in which the centres of the sub-systems comprising the giant galaxy are shifted relative to one another. However, we know of other galaxies which are double but are in fact linked together by means of a material medium and can, therefore, be regarded as single systems. M 51 and NGC 7752–7753 are good examples. It is natural to think that in these instances we are concerned with diverging centres of sub-systems of one single galaxy. In the case of IC 1613, on one side of the main mass of the galaxy, there is a super-association which can be regarded either as part of the main galaxy or as a separate satellite galaxy. It is highly probable that this super-association, consisting of hot giants, was formed much later than the remaining galaxy. (We have almost the same situation in galaxy IC 2574. To the north of the main part of this galaxy is a bright super-association, connected with it by means of a faint arm.) It can be presumed in this connection that the evolution of the galaxy is stipulated by the consecutive formation of the various sub-systems. One or other of the sub-systems, and sometimes the group of the sub-systems itself with a new centre, may become the satellite of the principal galaxy. This view leads to the idea that the formation of the satellite, and the origin of the new sub-system within the limits of the given galaxy, are related phenomena. Moreover, these phenomena can supposedly accompany one another. Thus, where the spiral arms join the centre of the given galaxy to the satellite it is natural to assume that the formation of the spiral arm and the satellite coincide in time.

After all, a satellite, of the type of the dwarf system in Sculptor, revolving around some giant galaxy differs but little in scale, and nature of population, from a globular stellar cluster which doubtless evolves from inner processes within the galaxy. Therefore, it is natural to assume that satellites of the Sculptor type have a similar origin.

V. PHENOMENA OF INSTABILITY IN THE GALAXIES

Up to the present we have spoken of the galaxies as stable formations. But unstable phenomena of great interest also take place in galaxies, particularly in the super-giants.

We do not refer here to the processes of star formation in associations, although they are sometimes pronounced; we mean more rapid, readily-observable changes. It is interesting to note that the greater part of these unstable phenomena is linked with the nuclei of the galaxies and can even be regarded as the manifestation of activity of these nuclei.

(*a*) *Neutral hydrogen flows out from the central part of our Galaxy.* This phenomenon was uncovered by the Dutch astronomers through observations made at 21 cm. A similar phenomenon of gas outflow from the nucleus of M 31 was detected by Munch, following an investigation of the line λ 3727. In both cases the outflowing mass is of the order of one solar mass a year; oddly enough, this result is difficult to reconcile with the data on the mass of the galactic nuclei in question (of the order of $10^7 M_\odot$).

(*b*) *In a number of galaxies, with nuclei of high luminosity as stated by Seyfert, the emission line* λ *3727 is remarkably widened.* This corresponds to velocities of motion of the order of several thousand kilometres a second; these velocities exceed those of escape. This is why we are concerned with a powerful outflow of gas, ejected with high velocity from the centre and then dispersing into infinity. Here, the amount of the outflowing gas supposedly far exceeds the corresponding amount for our Galaxy and M 31. The blue galaxies of Haro, in which the emission lines are intensive around the region of the nucleus, are expected to be of a similar nature.

(*c*) *In the very centre of the radio-galaxy NGC* 4486 *we also observe* λ 3727 *and deduce rather a heavy outflow of gas with a velocity of about* 500 *km/sec.* If we compare this with the radial jet, springing up from the centre of the galaxy and containing condensations radiating in intensive radio-emission, we come to the conclusion that these condensations are ejected with high velocities from the central nucleus of the galaxy. The polarization of light in these condensations points to the presence of high-energy electrons. These condensations are formations of much larger scale than the Crab nebula; the power of their radio-emission, measured in absolute units, is tens of millions of times greater. If we visualize that the duration of the radio-emission, must be, in this case at least, a thousand times more, we conclude that the supplies of energy in these condensations exceed the total supply of the energy of the Crab nebula by thousands of millions of times. In other words, by their energy and masses, these condensations must be objects representing smallscale galaxies, in agreement with their photographic absolute magnitudes.

Were these condensations ejected from the nucleus of the galaxy as real clouds of relativistic electrons or, which is more probable, were objects ejected from the nucleus, forming continually new currents of such electrons? This is another question. However, the very fact that such large-scale condensations may burst out from the nucleus of the giant galaxy is of great interest. This can hardly conform with our information about the masses of the nuclei of the galaxies.

(*d*) *The position in other radio galaxies is much more difficult to interpret.* Even the galaxy NGC 1275 (Perseus A) is known to belong to the class of Seyfert galaxies in which the line λ 3727, observed in the central regions, is widened. In other words, there is, in this case too, an intensive outflow of matter from the nucleus. The existence of two nuclei in the radio galaxy Cygnus A points seemingly to a process of nucleus division that took place recently; in connection with the views expounded above this will lead to the formation of sub-systems with various centres, with a consequent formation of a double galaxy.

In any case NGC 5128 (Centaurus A) also demonstrates that the nuclei of galaxies are able to eject either huge clouds of relativistic electrons or some condensations of matter capable of giving rise to such clouds in the future. One way or another, the radio galaxies are systems in which the central nuclei exhibit tremendous activity—including sometimes the formation of new condensations, new sub-systems and probably new galaxies. We can, therefore, assuredly speak of the *cosmogonic activity of the nuclei* although we are unaware at the expense of which masses such an activity is displayed.

(*e*) *We know of giant galaxies with jets bursting out from the central regions.* In some cases these jets contain *blue galaxies* of absolute magnitude of order −15, that is of higher luminosity than the condensation in NGC 4486. NGC 3561 and IC 1182 serve as examples of such galaxies. The ejection of these condensations is one more form of the cosmogonic activity of the nuclei of the galaxies.

(*f*) *That the spiral arms arise from the nuclei of the galaxies proves that their formation is also directly connected with the nucleus.*

(*g*) *Radio observations of the centre of our Galaxy, made by Parijsky and others, show that the state of the nucleus, known to be composed mostly of late-type stars, differs markedly from the state of other groupings of similar stars* (*such as the globular clusters*). The nucleus of our Galaxy is the source of thermal radio-emission while the surrounding region, with a diameter of the order of 500 parsecs, is the source of a heavy non-thermal emission. These facts indicate that the physical state of the nuclei is quite different from that of common stellar groupings.

One of the important problems confronting us in the study of the outflow of matter and ejections from the nuclei of the galaxies is the quantitative evaluation of the ejected masses. This refers equally to those galaxies, of which the central parts show emission lines, to the radio galaxies and to other examples with discrete ejections.

The few facts at our disposal show that these data may conflict with the law of conservation of energy (and matter) in its present form, and may perhaps require a generalization of this law.

VI. CONCLUSION

We note that the activity of the nuclei determines the most important processes in the life of large galaxies. This activity assumes several different forms as discussed above; however, two of them deserve special mention. One concerns the formation of the spiral arms, while the other is concerned with the formation of the stars and the stellar clusters of the spherical components. These phenomena seem to occur at different stages of development and are accompanied by corresponding changes in the nuclei. It is to be noted, at the same time, that the very process of formation of a given type of sub-system must vary under different circumstances. Thus M 32 does not apparently contain globular clusters while another satellite of the Andromeda nebula (NGC 205) comprises at least nine globular clusters. It is most surprising that globular clusters occur in the galaxies with a low density gradient. If we take for granted the hypothesis of the formation of galaxies from initially diffuse clouds, it would seem natural that dense formations, such as the globular clusters, should originate in systems with very high density regions, that is where high density gradients exist. Nonetheless, such qualitative reasoning cannot, of course, be considered quite adequate. *The number of globular clusters, per unit of luminosity of the spherical population, varies in different systems.* We have, therefore, an additional parameter to characterize the spherical systems and sub-systems. How this parameter is related to others of the same system (integral luminosity, density gradient) will become evident from observations.

Statistical data concerning multiple galaxies and clusters of galaxies show that these systems could not form by the capture of formerly independent galaxies. Hence a common origin is to be ascribed to the components of these systems. This problem was dwelt upon in detail in our Solvay report of 1958.

In the light of the data on the ejection from the nuclei of condensations, later on becoming complete galaxies of moderate or low luminosity, and also on the division of the nuclei, one can presume the formation of multiple systems and whole groups consequent upon the splitting of one initial nucleus into several. This division is likely to recur consecutively.

Where there is a central galaxy of high luminosity in the group, the formation of faint galaxies must be related mainly to the activity of the nucleus of the high luminosity galaxy.

That there is high activity of the nuclei of super-giant galaxies is proved by the fact that radio galaxies usually form one of the brightest members of the cluster to which they belong. If there is one dominant galaxy in the corresponding cluster this must be the radio galaxy itself.

Observations reveal that, although all the large clusters contain super-giant galaxies, only a small part of the latter are radio galaxies. Thus the radio-emitting activity must be a relatively short-lived phase in the evolution of the galaxies. The ejection of the radio-emitting agents is apparently a phenomenon accompanying the outflow from the nuclei of more powerful masses, and possibly taking place at a certain stage of the particular cosmogonic process.

Although extra-galactic astronomy has already explored certain forms of the activity of the nuclei, our information on the various types of this activity is scanty. Still smaller is our knowledge of the parameters characterizing the integral properties of these nuclei—luminosity, mass, colour, dimensions, rotation; after all, we know nothing about the internal structure of these nuclei. In this respect, there is open the widest range of exploration in the field of extra-galactic astronomy. Here are some of the questions and problems still outstanding:

(*a*) *Do all the galaxies possess nuclei? If not, which are then the features that characterize the non-nuclear galaxies?*

(*b*) *The determination of the integral characteristics of the nuclei for a possibly large number of galaxies.* The practical difficulty of doing this for galaxies of high density gradient should be properly visualized. At the same time, it is pointed out that the nucleus of most galaxies of the Sc type are of such prominence that they can be explored without considerable influence from the peri-nuclear central condensation.

(*c*) *The determination of the correlation of the integral parameters of the nuclei with those of the galaxies.*

(*d*) *An exploration of the spectra of the nuclei in galaxies, showing emission lines, phenomena of rotation and outflow.*

(*e*) *An investigation of the inter-relationship between the nucleus and the bar in barred galaxies and of the relation between the bar and the phenomenon of outflow from the nucleus.*

(*f*) *The investigation of galaxies with multiple nuclei; and a study of the radial velocities of the separate components of such nuclei.*

(*g*) *The dependence of the total number of globular clusters upon the nature of the nucleus of the galaxy.*

Although we have formulated some conceptions concerning the formation of the galaxies, nevertheless we have attempted to adhere to the facts and to refrain from unfounded speculations. The analysis of the facts indicates that the phenomena concerning the formation of the galaxies are so unusual that they could not be predicted on the basis of any theoretical preconceived proposition. Here we again meet an outstanding phenomenon being repeated in the history of astronomy. As one enters the realm of new phenomena, new qualitative regularities are found which overstep the limits of past conceptions. This makes every such realm more interesting. Therefore, we should bring together, still more minutely, facts and observations. The increase of observational data, the assembly of more precise information about the real objects, the accumulation of considerable information about the structure of the various parts of the galaxies, and a thorough analysis of this information, can help us in solving these difficult problems, some of which have been discussed here.