GALAXIES AND THEIR NUCLEI

Our Extraordinary General Assembly is devoted to the memory of one of the greatest men of science, the great Polish astronomer Nicolaus Copernicus. The main service of Copernicus which made his name immortal was in finding the correct interpretation of the planetary motions we observe. Instead of geocentric concept, which proved unable to explain the accumulated bulk of empirical data on the apparent motions of planets he has put forward and advocated the concept of *solar system*. The scientific revolution started by him was continued by Galileo and Kepler and was crowned with the great theoretical generalizations of Newton. A foundation has been created for the exact theories of motions in the solar system which have been developed during the next centuries. These theories in their modern form solve all the problems concerning the orbital motions of spaceships as well.

At this stage we can hardly boast that in the study of nuclei of galaxies and their activity we have reached a level comparable with the level of planetary astronomy before Newton. Only 15 years elapsed from the first attempt to formulate the idea of activity of nuclei of galaxies (Ambartsumian, 1958). During these years discoveries of greatest importance have been made. New unexpected discoveries occur almost each year. These discoveries influence decisively our ideas on the diversity of objects and phenomena in the distant space, but they are still insufficient for the construction of adequate theories. Penetration into the nature of nuclear phenomena requires new observations, new measurements and new data. And if some optimists imagine that the time is ripe to build a general theory of these phenomena, cautious astronomers would consider a tremendous success merely a satisfactory systematization of observational data concerning external physical processes accompanying activity of the nuclei.

These external processes often reach such a large scale that they influence the appearance and integral parameters of the galaxies. Therefore the study of the nuclei and the study of the structure of galaxies with their evolutionary changes often can not be separated.

In this report we consider some properties of galaxies immediately connected with the activity of nuclei and ultimately with the nature of the nuclei themselves.

1. Soon after the birth of the concept of activity of the nuclei, observations have revealed some new forms of that activity. Now we can speak about considerable diversity of external forms of activity of galactic nuclei. The following we consider as more important:

(a) Ejection from the nucleus, and from the volume of the galaxy itself, of giant masses which transform into large clouds of relativistic plasma. Owing to this the galaxy transforms into a *radiogalaxy*.

(b) Enhancement of the optical luminosity of the nucleus. Due to this form of activity the galaxy passes into class 5 of the Byurakan classification (Ambartsumian, 1966) or becomes Seyfert. In case of a stronger increase of the luminosity we get an $N-$*galaxy*. The extreme form of the same kind of activity are the *quasars*, where the nuclei reach the absolute magnitude of 25 and even higher.

(c) Ejection and motion of gaseous clouds in and from the nuclei of Seyfert galaxies and from quasars.

(d) Great explosions which lead to the ejection of large gaseous masses of the order of $10^6\ M_\odot$, like the ejection that occurred in $M82$.

(e) Relatively small but recurrent explosions in nuclei which manifest themselves as increases in radioluminosity at the centimeter range of wavelengths.

2. There are many indications that along with the above forms of activity which we observe immediately, there exist also the hypothetical forms:

(f) Ejection of condensations from the nuclei of supergiant galaxies which are capable to transform into new galaxies (mostly into a satellite galaxy or a member of the group which surrounds the supergiant galaxy).

(g) Outflow of matter from the nucleus which can produce the spiral arms.

In the course of systematization of the data on galaxies and phenomena occurring in them it seems appropriate to assume that the forms f) and g) exist in reality. The possible (albeit improbable) fallacy of this assumption cannot discredit the results of such systematization.

3. Manifestations of the nuclear activity are very unusual physical processes and we are still far from understanding their real nature. Therefore it is too early to build models explaining them. The majority of known galaxies having active nuclei are very distant. The nuclei and much larger central volumes in which the most important processes take place usually remain unresolved by our instruments. In the majority of cases we are not convinced, that the radiation we detect is coming immediately from the central body which is the main source of activity. As a rule it is difficult to clarify *even the geometrical picture of the external processes*, leave alone the mechanism of the active source or the structure of true nucleus.

It seems that prior to construction of models a considerable amount of work must be done in order to find the empirical patterns. Such a work requires a correct classification of objects and phenomena founded on direct observations of the external manifestations of nuclear activity. Only after the study of external manifestations we may find the way to the essence and causes of phenomena in the nuclei of galaxies.

4. At this stage the *systematization* of data on external manifestations of nuclear activity must become an important aim. During the last twenty years I defended the opinion that each galaxy and its subsystems (the spherical component, disk, spiral arms) are the result of nuclear activity. In this sense systematization of the external manifestations of nuclear activity should include all accessible data on galaxies. However the first step can be a classification based on direct forms of nuclear activity.

During our century several systems of classifications of galaxies have been worked out and practically applied. In particular, classifications of Morgan and of Byurakan Observatory put considerable emphasis on the properties of the structure of central circumnuclear regions of galaxies.

The Hubble's system takes into account only the presence and strength of spiral arms. In this report we are going to consider only a partial question related to the classification of a rather special category of galaxies. Within this category we will consider the parameters and properties connected with nuclear activity.

5. Let us concentrate our attention on galaxies of which the spherical component only (Population **II**) has the total absolute magnitude $M_V < -21.0$ independently of the presence of other components (disc, spiral arms). If the stars of Population **I** are present, the total luminosity of such galaxy will exceed the given limit $M_V = -21.0$. Thus we consider the galaxies of highest luminosity and mass.

These supergiant stellar systems are special in many respects, particularly in properties which depend on the activity of their nuclei. Our aim is to specify here some parameters which are essential characteristics of these systems and to consider the possibility of classification based on such parameters.

We remark that though among all galaxies the supergiants are rare, their total mass represents a considerable part of the total mass of all galaxies (Ambartsumian, 1962).

6. We will consider the following parameters:

(a) *Radioluminosity* L_R. Radiogalaxies are defined as systems emitting strong radioemission with radioluminosity $L_R > 10^{41}$ erg s^{-1}. At the same time they have high optical luminosities. Therefore all radiogalaxies belong to the category of galaxies under consideration. Curiously enough, choosing the galaxies according to the criterium $L_R > 10^{41}$ erg s^{-1} yields a sample for which the dispersion of optical luminosities is much smaller than the dispersion of radio luminosities.

For spiral galaxies which are sources of radioemission the radioluminosity is always lower than the indicated lower limit. Therefore the radiogalaxies are always E–systems. However they sometime contain significant quantities of dust and Population **I** stars.

(b) *Optical luminosity of the nucleus.* This is the second important parameter. The nuclei of galaxies in our category range from optically weak ($NGC4486$ where $M_n > -15$) to the mini–quasars (the nuclei of N galaxies) and can even contain quasars with absolute magnitude reaching $M_n = -27.5$. Thus the range of optical luminosities of nuclei of systems under consideration is of the order of 10^5.

(c) *Presence, strength and degree of development of spiral arms* and generally the relative strength of stellar Population **I**. It is disirable to choose again one numerical parameter, perhaps the ratio of the mass of neutral hydrogen in the given galaxy to its total mass. The use of another important parameter — the ratio L/M which according to the work of the Meudon group (Balkowski *et al.*, 1973) changes abruptly when we pass from spiral and lenticular galaxies to ellipticals, seems not very practical. Probably the value of $B - V$ of the galaxy can be of some use.

(d) *Presence, intensity and the degree of development of the bar.* According to the surface photometry of giant SB galaxies (Kalloghlian, 1971) the surface brightness of the bar has some preferred value (the mean photographic surface brightness along the axis of the bar is about 21 magnitudes per square second of arc). Therefore very roughly we can consider this parameter as attaining only two possible values (0 or 1 depending on the absence or the presence of a bar).

(e) Diameters of the spherical components of populations (which in the case of E systems coincide with the galaxies) can vary greatly. For high luminosity systems, this implies different surface brightness. This corresponds to the division of supergiants according to the *degree of compactness*. At this stage it will be convenient to consider three types of galaxies: extended systems (with a diameter larger than 40000 pc), normal systems (with a diameter between 15000 and 40000 pc), and compact galaxies (diameter less than 15000 pc). To make the division more exact one must add to this some definition of the diameter of a galaxy.

Zwicky has suggested the mean surface brightness as additional numerical parameter describing the degree of compactness. However it is evident that the average

$$< i >_0 = \frac{\int i\, ds}{\int ds},$$

where i is the surface brightness, is not suitable since the domain of integration remains uncertain. One can propose instead a weighted average of the surface brightness, for example

$$< i >_1 = \frac{\int i^2\, ds}{\int i\, ds}.$$

However in this case the relative role of the central region becomes too large and therefore it is necessary to know sufficiently well the exact behaviour of i near the centre of the galaxy, which is difficult since the angular resolution by photometric measurements is low. Probably the best practical alternative is to adopt an average of the type

$$< i >_2 = \frac{\int i\, f(i)\, ds}{\int f(i)\, ds},$$

where $f(i) = i_0$ when $i > i_0$ and $f(i) = i$ when $i < i_0$. Here i_0 is some conventional, fairly high surface brightness, for example 22th mag. from a squared second of arc.

Since the degree of compactness must be closely related to the ratio of the absolute value of gravitational energy of the system to the square of its total mass (this ratio is proportional to the radius of the system) it is clear that this degree of compactness must depend on the mechanism and conditions of formation of the spherical component of the galaxy, particularly on the mean kinetic energy of the member stars.

7. Compact galaxies attracted much attention after Zwicky's studies. He even discovered several clusters consisting of compact galaxies (Zwicky, 1971).

Recently Robinson and Wampler of the Lick Observatory have shown that the cluster Shakhbazian 1 is a *compact group of compact galaxies*. Shakhbazian (1973) has presented a list of similar groups consisting of compact galaxies.

Zwicky has expressed the view that quasars are the extreme cases of highly compact systems. There are now fairly good evidences that quasars generally have underlying galaxies. These underlying galaxies often are extended objects. Therefore the fifth (compactness) and the second (the luminosity of the nucleus) parameters should be considered separately. The question of statistical correlation or anticorrelation between them must be solved using observations. *One of these characteristics describes the distribution of stellar population, the other — the state of the nucleus.*

8. The class of systems in question includes spirals with sufficiently luminous spherical subsystems. It is known that the ellipticals, which consist only of spherical subsystems have an L/M ratio four times smaller than the spirals. This means that in order to have a spherical subsystem of absolute magnitude $M_V = -21.0$ a spiral must have a total visual magnitude not lower than -22.5.

There are many ellipticals of that high luminosity but the spiral systems with $M_V < -22.5$ are very few indeed. Among the possible candidates for this category is Markarian 10, for which $M_V \sim -23.0$. However in order to place it into the category of systems we consider, it is necessary to show that its spherical subsystem has in fact a partial luminosity of $M_V < -21.0$. It may happen that the real number of such spirals is very small or they do not exist at all. In the latter case our conclusions are liable to some changes.

9. We see that the supergiant systems depend on at least five different parameters.

The question arises wether all possible combinations of different values of these parameters are represented among the real galaxies. We simplify this complex problem by means of very rough discretization:

(a) If the radioluminosity of a galaxy $L_R > 10^{41}$ erg s^{-1} we put $\alpha = 1$. If $L_R < 10^{41}$ erg s^{-1} we put $\alpha = 0$. For all radiogalaxies $\alpha = 1$. For all other galaxies $\alpha = 0$.

(b) If the nucleus of a galaxy has an absolute photographic magnitude $M_{pg} > -21$ we put $\beta = 1$. If the nucleus is fainter than $M_{pg} = -21$ we put $\beta = 0$. For all other galaxies $\beta = 0$.

(c) If on the plates of sufficient resolution and density in photographic light a galaxy has noticeable spiral arms we put $\gamma = 1$. If they are unnoticeable, then $\gamma = 0$.

(d) If on the plates of sufficient resolution in photographic light a galaxy has a discernible bar we put $\delta = 1$. In the opposite case we put $\delta = 0$.

(e) If a galaxy is compact, i.e. if on the maps of the Palomar Sky Survey or equivalent, its radius is less than 15000 pc, we put $\varepsilon = 1$. In the opposite case $\varepsilon = 0$. Incidentally, this definition of compactness based on diameter is correct only for high luminosity galaxies. For less luminous galaxies the limiting value of diameter must be smaller.

10. The five–digit binary number $S = \alpha\beta\gamma\delta\varepsilon$ roughly describes the state of a given galaxy. Correspondingly in decimal numeration the state of a galaxy can be given by one of the numbers from $S = 0$ to $S = 31$. For example, $S = 0$ means a radioquiet noncompact galaxy with no quasar in its centre, no spiral arms and no bar. *It is simply a normal elliptical galaxy.*

We can discuss the problem of independence of our parameters in two different ways.

(A) Do all 32 values of S have their counterparts among the galaxies? In other words, are all combinations of discrete quantities α, β, γ, δ, ε realized in the Universe? We have seen above that the combination 00000 corresponds to a normal elliptical and therefore is very frequent. On the other hand, some combinations for example 10100 ($S = 20$) never occur. Unfortunately we do not know whether the combination 11111 ($S = 31$) is realized anywhere, i.e. if there are quasistellar radiosources for which the underlying galaxy is of SB type and the spherical subsystem is compact.

(B) Can we represent the distribution function P_S of the values of S for galaxies in a unit volume as a simple product

$$P_S = \varphi_1(\alpha)\,\varphi_2(\beta)\,\varphi_3(\gamma)\,\varphi_4(\delta)\,\varphi_5(\varepsilon),$$

where $\varphi_1(\alpha)$ is the probability of the given value of α, and φ_k-s have a similar meaning?

Evidently the answer is negative. This follows from the fact that for some values of S we have $P_S = 0$. But this means that at some value of its argument at least one of the functions φ_i must vanish. But this cannot be the case, since this would mean that one of the two values of that argument is not realized in the Universe at all, while we have introduced our parameters on the ground that both values have been observed.

11. As regards the problem (A), we can confine ourselves to the simpler question of compactibility of values of pairs of parameters (for example of α and β). From Table I containing the data on four extragalactic objects we can see that all four combinations of values of α and β exist in the Universe.

Table I

Object	parameter α	parameter β
NGC 4889	0	0
Ton 256	0	1
NGC 4486	1	0
$3C$ 371	1	1

This statement means that both the presence or absence of strong radioemission are compatible with the presence or absence of a quasar (or of miniquasar) in the centre of a galaxy.

Apparently we have a similar situation for the parameters β and ε, i.e. the presence of a quasistellar source and the compactness. This may be seen from Table II.

However, statistically the compactness of a galaxy is rather anticorrelated with the presence of quasistellar objects in its central region.

The situation is more complicated for α and ε. Among the radiogalaxies there are both extended stellar systems and systems of normal size. But we do not know any compact radiogalaxy (with the diameter less than 15000 pc) nearer than 500 Mpc. Thus if $\alpha = 1$ we have $\varepsilon = 0$. But if $\alpha = 0$ the quantity ε can be equal either to 1 or to 0. Thus between the values of our two parameters no one–to–one correspondence exists.

Table II

Object	parameter β	ε
$NGC\,4889$	0	0
$IZw\,94$	0	1
$Ton\,256$	1	0
$Zw\,0039 + 4003$	1	1

We cannot exclude also the possibility that among the very distant (more than 500 Mpc) radiogalaxies there are compact systems which have the external appearance similar to quasars. Therefore before making any final conclusions we must wait for more refined data about the sizes of the optical images of quasistellar radiosources.

The survey of external forms of radiogalaxies shows that none of them has developed any regular spiral arms. Strictly speaking this means that the values $\alpha = 1$, $\gamma = 1$ are incompatible. On the other hand, the radiogalaxies NGC5128 and 2175 show the presence of dust, gas and of stellar Population I. This is not equivalent to the presence of developed and regular spiral arms. Therefore in this case too we cannot write $\gamma = 1$ or $\delta = 1$. Probably these cases indicate that the radiogalaxy phase precedes the phase of evolution of supergiant galaxies at which the developed spiral arms are formed.

12. Wfrom the fact that the combination $\alpha = 1$, $\gamma = 1$ never occurs, that the value of γ is determined by the value of α. In fact, when $\alpha = 0$ both cases $\gamma = 0$ and $\gamma = 1$ can happen. Again we have no one–to–one correspondence.

In fact all five parameters in question may have correlations and statistical dependencies. We shall not discuss this further.

The question arises on the evolutionary interpretation of the chosen parameters and their combinations.

13. Probably the diversity of forms and states of the galaxies is due to (a) differences of age and (b) differences of initial conditions. Among the initial conditions such quantities as the mass of a system, its total internal energy and the rotational momentum play an important part. Some significance can be attached also to the differences in the initial chemical composition. However there is no doubt that during the life of a galaxy the chemical elements in it undergo essential evolutionary changes. If the initial dominant state of matter was of atomic type (and not of the type of nuclei or particles having masses of stellar or larger order), the simplest assumption would be the similarity of initial chemical composition. If in the beginning the nuclear phase was predominant (of the type of the baryon star structures), it is probable that after the transition to atomic structure of matter approximately the same chemical composition emerges. Therefore it seems possible to disregard the possibility of differences of the initial chemical composition.

For supergiant galaxies and systems which have masses of about the same order of magnitude the remaining three parameters are (a) the age, (b) the total energy, and (c) rotational momentum.

Thus we have a situation where the number of empirically determined parameters, which specify the different states of the systems, is larger than the number of parameters related to the diversity of initial conditions.

However, the activity of a nucleus takes sometime such intense and cataclysmic forms that in a short time it can cause essential changes in the properties of the galaxy and even originate new temporary properties which should be described by new values of parameters.

This happens for example in the case of a sudden appearance of strong radioemission (formation of large clouds of relativistic charged particles), or X–ray emission or of strong nonstellar optiocal emission (quasars).

The intervals of time during which different new properties are maintained can overlap. If for two given properties A and B there is partial overlap of time intervals τ (for example the interval τ_B begins somewhere in the middle of τ_A), then the following cases are possible: (1) both properties are present in a galaxy, (2) a galaxy has only one of them, (3) a galaxy have none of the two. This exactly happens for the pairs α, β and β, ε.

If the intervals do not overlap, both properties never meet in the same system. However from the absence of one of the two we cannot conclude about the presence of the second. Exactly such a situation we have for α, γ, i.e. the presence of spiral arms is incompatible with strong radioemission, but the absence of radioemission does not mean necessarily the presence of arms.

We can hope that further work on the classification of galaxies and measurements of the essential parameters will allow us to determine the lengths of time intervals in which the properties of interest are maintained.

14. As regards the galaxies for which the spherical subsystem is considerably fainter than $M = -21.0$, we make the following remarks.

(a) Such galaxies are never strong sources of radioemission. But they can emit weak (normal spirals) or moderate radioemission (some Seyfert galaxies, for example $NGC1068$ or the irregular $M82$). For them always $L_R < 10^{41}$ erg s^{-1}.

(b) Such galaxies frequently have spiral arms.

(c) In this category, moderate radio–emission and presence of spiral arms are compatible.

(d) Many examples of Seyfert and Markarian galaxies show that these low luminosity objects can have nuclei of relatively high luminosity. Such objects are sometimes the galaxies that host radio–quiet quasars. However, many radio–quiet quasistellar objects have high luminosity host systems, i.e. supergiant galaxies.

(e) Definitely there is a lower limit for the integral luminosity of the spherical component of galaxies capable to form spiral arms of more or less regular shape. The exact value of this limit is not known but probably it is near $M = -14$. The galaxies with still fainter spherical subsystems can have some stellar Population I and interstellar material of appreciable density. However, in such cases they have irregular shapes.

15. Taking as starting point the assumption that the formation of spiral arms is the result of nuclear activity, we resume these facts in the following way:

(a) If the spherical component has an integral absolute magnitude $M_V < -21.0$, then the nucleus is capable to form large radioemitting clouds, but rather seldom regular and bright spiral arms.

(b) If the luminosity of the spherical subsystem is within limits

$$-21.0 < M < -14.0$$

then the nucleus of such galaxy never forms strong radioemitting clouds but frequently forms regular spiral arms.

(c) For $M > -14$, the nucleus cannot form regular spiral arms but still is able to produce relatively abundant population I.

16. According to observations, the type of nuclear activity depends on the absolute magnitude and therefore on the mass of the spherical subsystem. On the other hand, it is clear that the spherical component of the galaxy can hardly have any direct influence on the properties of the nucleus. Therefore there remain two possibilities:

(a) The spherical component itself is the result of the nuclear activity. Therefore it is in strong correlation with the other external manifestations of the same activity.

(b) The nucleus and the spherical subsystem have been formed together. The properties of the nucleus and the mass of the spherical component are determined by the integral mass of the galaxy.

At this stage it is difficult to decide which of these alternatives corresponds to reality. However the general considerations concerning the universal role of nuclear activity make the first possibility more likely.

17. No compact galaxies displaying strong radioemission are known. But compact galaxies sometime possess considerable population of type I and even form ejections and plumes which are similar to the spiral arms. As an example we have the galaxy $NGC1614$. A very preliminary survey of *compact groups of compact galaxies* carried out in Byurakan has shown that some of them contain blue compact galaxies. Usually these blue members have almost elliptical appearance somewhat disturbed by the presence of absorbing matter. A study of color distribution in such galaxies may bring interesting results.

18. The study of clusters and groups of galaxies inevitably brings to the conclusion that *the supergiant galaxies play a particularly important role in the Universe*. Quoting from a recent paper of Sandage (1972): "The luminosity of the brightest cluster member does not depend strongly, if at all, on the luminosities of the fainter cluster members". The dispersion of absolute magnitudes of the brightest cluster members is of the order of 0.25 mag.

Except for a few compact groups, each cluster contains at least one member having a mass of the order of $5 \times 10^{12}\ M_{\odot}$. How can the theory of formation of clusters of galaxies from a large cloud of diffuse matter explain the existence of definite upper bound for the masses of the parts into which the cloud splits and at the same time the existence of at least one part with mass of the order of that bound?

Under the alternative hypothesis of fragmentation of an initial dense and massive body, it is quite natural to suppose that during each step of such fragmentation a body divides into several pieces having masses of equal order. In this way at some stage dense bodies with masses of the order of $5 \times 10^{12}\ M_{\odot}$ will be formed. Then for some reason the division into almost equal masses stops and each part behaves as an active nucleus. Perhaps at this stage it is better to say "protonucleus". This means that each such part forms around itself a galaxy, consisting of stellar populations of different kinds. Moreover, ejection of secondary nuclei of smaller masses ($10^{11}\ M_{\odot}$) is possible. Thus the nucleus of a supergiant galaxy contributes to the formation of the less massive galaxies of the cluster.

19. Zwicky has established the existence of several large *clusters consisting of compact galaxies*. Since it is difficult to judge the compactness of faint members, it is more correct to say that a number of bright galaxies in each such cluster are compact.

Among these clusters is $Zw\,Cl\,0152 + 33$ which has the angular diameter of about one degree. Since the distance must be of the order of 5×10^{8} pc (this corresponds to the radial velocity $V_r = 26300$ km s^{-1} determined by Sargent (1972)) the linear diameter is of the order of 10^{7} pc. Since the dispersion of radial velocities is of the order of 1000 km s^{-1} we arrive to the conclusion that to cross the cluster a galaxie need time of the order of 10^{10} yr. Therefore one can suppose that the differences in the ages of galaxies in a cluster are of this same order of magnitude. This means that compactness is not a transient property of a galaxy and lasts at least hundred of millions, perhaps billions of years. This implies that these galaxies are in a stable state. It follows that these systems *will remain compact* also in the future, during the lifetime of stars from these systems.

Perhaps somewhat extrapolating we can suppose that compact galaxies as a rule are born and remain compact during their lifetime. In any case they are systems *sui generis* rather then some stages of evolution of normal galaxies.

The division of clusters and groups of galaxies into systems consisting of normal galaxies on one hand and of compact galaxies on the other is fundamental. This division must be intimately connected with the mechanism of formation of galaxies in clusters. It is very difficult to explain such a division on the basis of hypothesis of formation of galaxies from diffuse matter.

20. *Compact groups of compact galaxies* are of great interest. Such systems usually have from half a dozen to two dozen members, though there are richer groups too. Typical representatives of such groups are No. 1 and No. 4 of Shakhbazian's list which will be published shortly. The first consist of 17, the second of 7 members. The linear size of these groups are of the order of 2×10^5 pc.

The first group has been found at Byuracan in 1957 (Shakhbazian, 1957) during the study of the Palomar Sky Survey maps. Due to compactness of its members and of the group itself it looks very different from other groups of galaxies. This was the reason that after some hesitation we first supposed that it was a stellar cluster situated at some distance from our Galaxy. Later Kinman and Rosino (1962) found on large scale plates that some members of the group are galaxies. Since the other members looked like stars, they concluded that the group was a chance agglomeration of galaxies and stars on the sky. Only recently Robinson and Wampler (1973) have found from spectral observations that it is a physical group of compact galaxies. Meanwhile new groups of similar type have been found at Byurakan.

The group Shakhbazian 1 has the redshift $z = 0.1$, i.e. it is at a distance of six hundred million parsecs from us. The brightest centrally located member of the group has an absolute magnitude of the order of $M_V = -23$. It is interesting that the brightest member of Zwicky cluster $0152 + 33$ has roughly the same luminosity.

Determination of dispersion of radial velocities of the members of Shakhbazian 1 from redshifts and application of the virial theorem has shown that the M/L ratio expressed in solar units is of the order of unity.

Thus in this case the virial theorem gives too small masses. In this sence the situation is opposite to what we have in usual clusters of galaxies.

However not in all similar compact groups of compact galaxies the dispersion of radial velocities is that small. According to unpublished observations by Khachikian[1] the dispersion of radial velocities in the remarkable compact group Shakhbazian 4 is of the same order of magnitude as in usual clusters. Probably in this case we have again an expanding group.

The compact clusters of compact galaxies differ from usual clusters (as catalogued by Zwicky and Abel) in that the integral magnitudes of member–galaxies are contained in a narrow interval of stellar magnitudes and the difference of magnitudes between the first and the second brightest galaxies is relatively small.

The search for new groups of Shakhbazian 1 type is now in progress at Byurakan. The number of groups already found reaches several dozens. The very preliminary statistics shows that the number of such clusters with 18.5 red mag. for the brightest member must exceed one thousand.

Thus the compact groups of compact galaxies (CGCG) represent *one of the important constituents of the Metagalaxy.*

[1]E.Ye. Khachikian, C. R. Linds, A. Amirkhanian, IAU Colloquium, No. 124, 1990

21. We conclude that the study of compact galaxies and their clusters may shed some light on the problem of the origin and evolution of galaxies and the nature of the activity of their nuclei.

The compact galaxies are not strictly isolated from the world of normal galaxies. Quite the opposite: there are cases when it is difficult to class a given galaxy as compact or normal. It seems that the attention given to such intermediate cases will be rewarding.

The groups included by Shakhbazian in her first list contain almost exclusively compact galaxies. This is the result of intentional selection. If mixed systems exist, their study will help us understand the oppositing phenomena in the extragalactic world.

22. It is natural to suppose, that there exist systems for which the ratio M^2/H, where H is the total internal energy, is smaller than what has been measured by now. Such systems would appear as less extended, compact galaxies. However it is remarkable that:

(a) There exist rich clusters of galaxies containing dozens of compact but no extended systems of high luminosity.

(b) In the observable part of Metagalaxy there are thousands of compact groups of compact galaxies containing from five to ten compact systems but lacking normal or extended galaxies.

(c) Despite the differences in the nature of compact and normal galaxies and probable differences in the values of M/L (perhaps more than ten times), the upper limit of luminosities for the normal galaxies ($M_V = -23.7$) is apparently a sufficiently exact upper limit for the compact galaxies as well.

(d) The colours of compact galaxies apparently are not very different from the colours of some normal galaxies. However, no detailed study of the colours of compacts has been done.

23. Compacts apparently comprise only a small percentage of all galaxies. The nearest compact galaxies of high luminosity are at distances not less than 50 million parsecs from us. I am not quite sure that Shapley–Ames catalogue contains even one high luminosity compact. However, beginning with $m = 13.0$ they appear. Due to their high surface brightness, the compact galaxies of 13th or 14th apparent magnitude must have diameters smaller than $20''$. Therefore their detailed morphological study will be difficult.

At the same time I should like to warn you against unfounded pessimism. During the time after Copernicus astronomy has overcome the distance barrier from 10^{-4} pc to some billions in parsecs. At least at distances of 800 million parsecs a contemporary extragalactic astronomer feels almost at home.

Now it is necessary to overcome the barrier of low angular resolution in optical observations.

This can be achieved by combination of optical interferometry with the use of observations from the outer space. The fall of these barriers will open new prospects in extragalactic research.

24. Finishing this discourse I would like to pay tribute to some astronomers who contributed to the above problems.

By tremendous observational work *Sandage* has reached the final conclusion that quasars are nuclei of supergiant elliptical galaxies. After he understood the significance of high luminosity E–

systems in the Metagalaxy he established the regularities concerning the brightest objects in a cluster of galaxies.

Essentially I agree with his important conclusions and they have been used above.

By his studies of compact galaxies *Professor Zwicky* has opened a new page in extragalactic astronomy. Every compact galaxy which has emission lines in its spectrum is of great individual interest as is the case of quasars and Markarian's galaxies. However the totality of compact galaxies (the majority of which have no emission lines) presents much deeper interest and significance.

By attracting the attention of astronomers to the compact galaxies, Zwicky has shown once again how far from reality are those who think that we already know the composition and the structure of Universe, and that it is up to the theoreticians to put the last touches to their models. New types of objects and new kinds of processes in the Universe, literally compel us not to follow such oversimplified views.

The idea of inexhaustibility of the Universe has led modern astronomy to its great discoveries. This idea will perhaps remain the source of inspiration despite the increasing difficulty and deepness of the arising problems. Then astronomers of 2473 celebrating the thousandth anniversary of Copernicus will admit that the generation which lived halfway was not always sitting idle, but was sometimes unrestrained and fearless in the search of the unknown properties of the Universe.

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