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GALAXIES AND THEIR NUCLEI

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Our Extraordinary General Assembly is devoted to the memory of one of the greatest men of science to the genial Polish astronomer – Nicolaus Copernicus. The main service of Copernicus which has made his name immortal was in finding the correct interpretation of the planetary motions we observe. Instead of geocentric notions, which proved unable to explain the accumulated bulk of empirical data on the apparent motions of planets he has put forward and advocated the notion of a *solar system* thus presenting the true picture of the part of the Universe we live in. The scientific revolution started by him was continued by Galileo and Kepler and was crowned with the great theoretical generalizations of Newton. As a result a foundation has been created for the most exact theories of motions in the solar system which were developed during the next centuries. These theories in their modern form give also the possibility to solve all the problems concerning the orbital motions of spaceships.

At this stage we can not yet boast that in the study of nuclei of galaxies and their activity we have reached the level which existed in planetary astronomy even before the works of Newton. Only 15 years elapsed from the moment when the idea of activity of nuclei of galaxies was clearly formulated (Ambartsumian, 1958). During these years discoveries of the greatest importance have been made. New unexpected discoveries occur almost each year. These discoveries influence decisively our notions on the diversity of objects and phenomena in the distant space, but they are still insufficient for the construction of adequate theories. In order to penetrate into the very nature of nuclear phenomena we require new observations, new measurements and new data. And if some optimists imagine that the time has already ripen to build a general theory of these phenomena, the more cautious astronomers would like to consider a more or less satisfactory systematization of observational data concerning the activity of nuclei and the understanding of external physical processes accompanying it as a tremendous success.

These external processes reach often such a large scale that they influence the appearance and integral parameters characterizing the galaxies. Therefore the study of the nature and the activity of nuclei sometimes means to investigate the problems of the structure of galaxies and of their evolutionary changes.

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

1. Soon after the introduction of the concept of the activity of nuclei the observations have revealed some new forms of that activity. Therefore we can speak now about the considerable diversity of the external forms of activity of the nuclei of galaxies. Let us mention here some important forms:

Contopoulos (ed.), Highlights of Astronomy, 51–66. *All Rights Reserved*

(a) The 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 a galaxy transforms into a *radiogalaxy*.

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

(c) The ejections and motions 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 M 82.

(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 alongside with the forms of activity we have mentioned above, which we observe immediately, there are also the following *supposed* forms:

(a) The 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 under consideration).

(b) The outflow of matter, from the nucleus which can produce the spiral arms.

Of course in studying and classifying the manifestations of nuclear activity one must strictly differentiate the well established forms from the supposed forms we have just mentioned. However in the course of the systematization of the known data on galaxies and phenomena occurring in them it seems appropriate to assume that these forms also exist in reality. The possible (though at the moment improbable) fallacy of such an assumption cannot discredit the results of such systematization work since the concepts on the forms of nuclear activity serve only as suggestion for such work. Evidently we can choose as a basis for the work of systematization and classification of facts any consideration or idea about the nature of galaxies. Only the result of the work can show how fruitful the considerations chosen as a basis proved to be.

3. The 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. Owing to the fact that the majority of known galaxies having active nuclei are very distant, not only the nuclei themselves but the much larger central volumes in which the most important processes take place remain usually unresolved with our instruments. In the majority of cases we are not convinced, that the radiation we receive is coming immediately from the central body which is the main source of activity. Therefore, as a rule it is difficult to clear up *even the geometrical picture of the external processes*, not to speak about the mechanism of the active source or structure of the true nucleus.

It seems that before proceeding to the construction of models a considerable amount of work must be done in order to find the empirical regularities. For such a work the correct classification of objects and phenomena should serve a basis.

Evidently such a classification should be founded on direct observations. However, since only the external manifestations of nuclear activity are accessible for observations, the classification of processes and objects connected with the activity of nuclei is to be established from the observations of these external manifestations. Only after the study of external manifestations we may find the way to the very essence and true causes of phenomena taking place in the nuclei of galaxies.

4. Since at this stage the *systematization* of data on external manifestations of nuclear activity must be the most important aim we would like to emphasize the broad character of this problem. There is no doubt now that the nuclei sometimes can cause fundamental changes in the properties of the galaxy.

During the last twenty years the present reporter has defended the opinion that each galaxy including all subsystems of which it consists (spherical system, disk, spiral arms) is the result of nuclear activity. If so the systematization of data related to the external manifestations of nuclear activity means the systematization of all accessible data on galaxies. However we have in our view such systematization which takes into account *more direct* external manifestations of nuclear activity. The first step in this direction must be the classification based on the existing notions on different forms of nuclear activity.

Of course such a work is made easier by the fact that during our century several systems of classifications of galaxies have been worked out and practically applied. Two of these systems (classifications of Morgan and of Byurakan Observatory) put considerable emphasis on the properties of the structure of central circumnuclear regions of galaxies. As regards to Hubble's system – it takes into account only one of the parameters connected with the activity of the nuclei – the presence and strength of spiral arms. However the building of a classification system which takes into account different known kinds of nuclear activity is a difficult task. In the present report we are going to consider only a partial question related to the classification of a special category of galaxies. Thus our aim is rather *to consider the diversity of parameters and of properties which are connected with nuclear activity and by which galaxies of that category differ between themselves.*

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 integral luminosity of such galaxy as a whole will exceed the given limit $M_V = -21.0$ even more. Thus we have chosen the galaxies of highest luminosity and mass.

Having concentrated on those supergiant stellar systems we see that they are different in many respects and particularly in properties which depend on the activity of their nuclei. Our aim is to specify here different parameters which are essential characteristics of these systems and to consider the possibility of classification based on such parameters.

We shall have in mind that though the supergiant galaxies form only a small minority among all galaxies, their total mass in a given volume represents a considerable part of the total mass of all galaxies as it was indicated by us already in our report at Berkeley (Ambartsumian, 1962).

6. Among the parameters decribing the galaxies under considerations we shall consider as important:

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

It is known that spiral galaxies also are often the sources of radioemission, however their radioluminosity is always lower than the indicated lower limit. Therefore the radiogalaxies are always *E*-systems, which however sometime contain a significant quantity of dust and some number of Population I stars.

(b) *The optical luminosity of the nucleus*. This is the second important parameter. Alongside with optically very weak nuclei (NGC 4486 where $M_n > -15$) the galaxies of the category under consideration sometimes have intense nuclei (for example the nuclei of *N* galaxies, which were wittily called mini-quasars) and 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) *The presence, strength and the degree of development of spiral arms* and generally the relative strength of stellar Population I. It is clear that in this case it is very disirable for classification-purposes to choose again one definite numerical parameter. Perhaps as such a parameter one can use the ratio of the mass of neutral hydrogen in the given galaxy to its total mass. The use of another important parameter – of the ratio L/M which according to the work of the Meudon group (Balkowski *et al.*, 1973) changes abruptly when passing from spiral and lenticular galaxies to ellipticals seems not very practical. Probably as a substitute of the parameter under consideration the value of $B-V$ of the galaxy can be of some use.

Considering the question more precisely one must also take into account that apparently for the description of the spiral structure several independent parameters are necessary. Here we limit ourselves with one parameter since as a supplementary parameter we consider below the strength and the degree of the development of the bar.

(d) *The 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 prefered 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 having only two possible values (0 or 1 depending on the absence or the presence of a bar).

(e) Finally the spherical component of population (which in the case of E systems coincides with the galaxy as a whole) can have a great or a small diameter. Since we have confined ourselves to the high luminosity systems only, this means that they can have different surface brightnesses. This corresponds to the division of supergiants according to the *degree of compactness*. At this stage it will be convenient to consider three species 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). Of course to make the division more exact one must add to this some definition of the diameter of a galaxy.

When elaborating the question it will be expedient to introduce some more definite numerical parameter describing the degree of compactness. Zwicky has suggested that the mean surface brightness can serve as such. However it is evident that the simple average:

$$\langle i \rangle_0 = \frac{\int i \, \mathrm{d}s}{\int \mathrm{d}s},$$

where i is the surface brightness is not very suitable since increasing the domain of integration we can obtain as low value of $\langle i \rangle_0$ as we wish. One can propose instead a weighted average of the surface brightness for example

$$\langle i \rangle_1 = \frac{\int i^2 \, \mathrm{d}s}{\int i \, \mathrm{d}s}.$$

However in this case the relative role of the central region is very 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

$$\langle i \rangle_2 = \frac{\int i f(i) \, \mathrm{d}s}{\int f(i) \, \mathrm{d}s},$$

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 corresponding for example to 22th mag. from a square 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 (since this ratio is according to definition proportional to the radius of the system determined in some specific way) it is clear that this degree of compactness must depend on the mechanism and conditions of formation of the spherical component of the galaxy and particularly from the mean kinetic energy of the member-stars. If one assumes that the nucleus plays the fundamental part in the formation of the spherical component of the galaxy the degree of compactness may serve as one of external manifestations of the activity of the nucleus.

7. The importance of the degree of compactness as one of the properties of galaxies became clear when Zwicky had given attention to the existence of many compact galaxies, and having accomplished his valuable catalogue has even discovered several clusters consisting of compact galaxies (Zwicky, 1971).

At the start of this year Robinson and Wampler of the Lick Observatory have published a paper in which they have shown that the cluster Shakhbazian 1 is a *compact group of compact galaxies.* Immediately after that Shakhbazian (1973) has presented a list of similar groups consisting of compact galaxies. Owing to these studies the compact galaxies recently have attracted considerable attention from investigators.

However, commenting his studies on compact extragalactic objects 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 using the terminology used above we can assert than the fifth (compactness) and the second (the luminosity of the nucleus) parameters we have introduced are to be considered independently. The question of statistical correlation or anticorrelation between them must be solved from observations. *One of these characteristics describes the distribution of stellar population, the other – the state of the nucleus.*

8. Since within the category of systems we are considering among others enter spirals with sufficiently luminous spherical subsystems it is appropriate to make the following reservation. It is known that the ellipticals, which consist only of spherical subsystems have an L/M ratio four times smaller than in the case of 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 such 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 introduce it into the category of systems under consideration 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 don't exist at all. In the last case our conclusions are liable to some changes.

9. Thus we see that considering only supergiant systems, i.e. fixing the value of one of the important parameters (the luminosity) we see that the totality of states of galaxies depends 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 or some ot them depend on the values of others thus reducing the number of truly independent variables.

We shall simplify this complex problem by means of the very rough discretization of the values of parametes describing each galaxy. Namely:

(a) If the radioluminosity of a galaxy $L_R > 10^{41}$ erg s^{-1} we shall say that the corresponding discrete parameter $\alpha = 1$. If $L_R < 10^{41}$ erg s^{-1} we shall write $\alpha = 0$. 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 shall say that another discret parameter $\beta = 1$. If the nucleus is fainter than $M_{pg} = -21$ we shall write $\beta = 0$. 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 shall write that the corresponding discrete parameter $\gamma = 1$. If they are unnoticeable $\gamma = 0$.

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

(e) If a galaxy is compact, i.e. on the plates which are as effective in showing the faint peripheries as the maps of the Palomar Sky Survey, its radius is less than 15000 pc, we shall then write $\varepsilon = 1$. In the opposite case $\varepsilon = 0$. Incidentally this definition of compactness based on the value of the diameter is correct only for the high luminosity galaxies under our consideration. For the less luminous galaxies this limiting value of diameter must be smaller.

10. The five-digit binary number $S = \alpha\beta\gamma\delta\varepsilon$ determines a particular value of each of the parameters introduced above and describes roughly the state of the 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 – the case $S = 0$ means a radioquiet galaxy, without a quasar in its centre, without spiral arms and bar which is not compact. *It is simply a normal elliptical galaxy.*

Now we can discuss the problem of the independence of the introduced parameters in two different ways.

(A) Do all 32 values of $S = \alpha\beta\gamma\delta\varepsilon$ (in decimal system the numbers from 0 to 31) 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 (in the decimal notation $S = 20$) are not realised. Unfortunately we don't know whether the combination 11111 ($S = 31$) is realized anywhere, i.e., are there 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 the set of 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 $\varphi_i(\alpha)$ is the probability of the given value of α, and $\varphi_k - S$ 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 be equal to zero. But this cannot be the case, since this means that one of 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 somewhere in nature.

11. Returning to the first problem (A) we can confine ourselves with the simple question of the compatiblity of values of some pairs of parameters (for example of α and β). Thus from Table I containing the data on four extragalactic objects we can see that all four combinations of values of α and β are realized in the Universe.

TABLE I

Object	Parameter	
	α	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 equally compatible with the presence or absence of a quasar (or of miniquasar) in the centre of a galaxy.

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

TABLE II

Object	Parameter	
	β	ε
NGC 4889	0	0
I Zw 94	0	1
Ton 256	1	0
Zw 0039 + 4003	1	1

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 when we consider another pair of parameters: α and ε. Among the radiogalaxies there are both the extended stellar systems and the systems of normal size. But we don't 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 there is no one to one correspondence.

We cannot exclude also the possibility that among the very distant (more than

500 Mpc) radiogalaxies there are compact systems which will 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 and regular spiral arms. This means that strictly speaking the values $\alpha=1$, $\gamma=1$ are incompatible. On the other hand the radiogalaxies NGC 5128 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 also we cannot write $\gamma=1$ or $\delta=1$. But probably these cases indicate that the phase of radiogalaxy precedes the phase of evolution of supergiant galaxies at which the developed spiral arms are formed.

12. But also in this case form the fact that the combination $\alpha=1$, $\gamma=1$ never occurs we cannot conclude 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. Thus here also we do not have one to one correspondence.

Continuing these consideration we may show that all five parameters introduced are physically independent. But they may have correlations and statistical dependences which we shall not discuss further.

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

13. Evidently the diversity of forms and states of the galaxies we observe one should explain by (a) differences of age and (b) differences of initial conditions. Among the initial conditions such quantities as the mass of the 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. Therefore, if the dominant state of matter from the beginning 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 however 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 emerged. Therefore it seems possible to disregard the possibility of differences of the initial chemical composition.

Since we are considering such systems (supergiant galaxies) which have masses of about the same order of magnitude, there remain only three parameters: (a) the age, (b) the total energy, and (c) rotational momentum.

Thus we have the situation when the number of empirically determined parameters, which specify the different states of the systems, is larger than the number of parameters we can foresee from physical considerations related to the diversity of initial conditions.

However one must take into account that the activity of a nucleus takes sometime such intense and cataclysmic forms that in a short time it can not only cause essential changes in the properties of the galaxy, but even originate new temporary properties which should be described by the values of new parameters.

This can happen for example in the case of a sudden appearance of strong radio-emission (formation of large clouds of relativistic charged particles), or X-ray emission or of strong nonstellar optical emission (quasars). As we have seen the appearance of new properties in each case means that some parameter normally having a constant value (in the example just mentioned not much differing from zero), for some interval of time acquires new, sometime variable value.

The intervals of time during which different new properties are maintained can overlap. If for two given properties owing to the regularities of evolutionary processes there is partial overlap of intervals τ (for example the interval τ_B begins somewhere in the middle of τ_A), we shall observe (1) the cases when both properties are present in a galaxy, (2) the cases when galaxies have only one of them, of (3) the cases when a galaxy have none of them. This exactly happens in the case of the pair α and β or in the case of properties β and ε.

If the intervals don't overlap both properties never meet in the same system. However from the absence of one of them we cannot conclude about the presence of the second. Exactly such a situation is present in the case of the parameters α and γ, i.e. the presence of spiral arms is incompatible with the strong radioemission, but the absence of radioemission does not mean necessarily the presence of the arms.

We can hope that further work on the classification of galaxies and measurements of the essential parameters will allow us to determine the length of intervals during which the properties under consideration are maintained and will ascertain the circumstances that precede them.

14. If we will try to extend the above considerations to the galaxies for which the spherical subsystem is considerably fainter than $M = -21.0$ we will meet some important circumstances.

(a) Such galaxies are never strong sources of radioemission. But they can emit weak radioemission (normal spiral) or moderate as some Seyfert galaxies (for example NGC 1068) or the irregular M 82 do. But for them always $L_R < 10^{41}$ erg s^{-1}.

(b) Such galaxies have spiral arms more frequently.

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

(d) Many examples of Seyfert and Markarian galaxies show that these objects of low luminosity can have nuclei of relatively high luminosity. Moreover such objects are sometimes the galaxies that underlie the radio-quiet quasars. This does not exclude the fact that many radio-quiet quasistellar objects can have as their underlying galaxies high luminosity systems, i.e., supergiant galaxies.

(c) There is some definite lower limit for the integral luminosity of the spherical component of galaxies capable to form the spiral arms of more or less regular form. 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 forms.

15. If one takes as starting point the assumption that the formation of spiral arms is the result of nuclear activity one can resume these facts in the following way:

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

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

$$-21.0 < M < -14.0$$

the nucleus of such galaxy is unable to form strong radio emitting clouds but frequently forms regular spiral arms.

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

16. Thus according to observations the kind 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 hardly can 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 strongly correlated 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.

It seems that at this stage of our knowledge it is difficult to decide which of these alternatives corresponds to reality. Only the more general considerations concerning the universal role of nuclear activity make the first possibility more likely.

17. We have stated above that compact galaxies displaying strong radioemission are not known. But there is no doubt that the compact galaxies sometime are able to produce in themselves a considerable population of type I and even form the ejections and plumes which in some degree are similar to the spiral arms. As an example we have the galaxy NGC 1614. As a result of a very preliminary survey of *compact groups of compact galaxies* carried out in Byurakan it has been concluded that some of them contain a blue compact galaxy. Usually these blue members have almost elliptical appearances somewhat disturbed by the presence of absorbing matter. There is no doubt that the study of the color distribution in such galaxies will bring interesting results.

18. The study of clusters and groups of galaxies is extremely important for the understanding of processes of the formation and evolution of galaxies. Such studies inevitably bring the conclusion that *the supergiant galaxies play a particularly important role in the Universe.* For example let us quote one of the conclusions reached in the 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. The deviations from these rules happen in the specific cases of compact groups of galaxies.

Excluding for a moment such compact groups from our consideration we can say that each cluster contains at least one member having a mass of the order of 5×10^{12} $M_{\odot}$. If one adhers to the theory of formation of the clusters of galaxies from a large cloud of diffuse matter, the existence of definite upper limit for the masses of the parts into which the large cloud splits and at the same time the necessary formation of at least one part which has mass of the order of that limit is difficult to understand.

If in order to explain the origin of clusters of galaxies we consider 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 the dense bodies with masses of the order of 5×10^{12} $M_{\odot}$ will be formed inevitably. Then by some reason the division into masses of equal order of magnitude 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 the 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 population of the cluster of galaxies.

19. Zwicky has established the existence of several large *clusters consisting of compact galaxies.* Since however 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 galaxies cross the whole cluster during the time interval of the order of 10^{10} yr. Therefore one can suppose that the differences in the ages of galaxies in the cluster are of this same order of magnitude. This means that compactness is not a quickly passing property of a galaxy and lasts at least hundred of millions, perhaps billions of years. This requires that these galaxies are in a steady state. But from this follows that these systems *will remain compact* also in the future, during the life of stars which enter in these systems.

Perhaps somewhat extrapolating we can suppose that the compact galaxies as a rule are born as such and remain compact during the length of their life. In any case they are systems *sui generis* and not 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 other hand has therefore fundamental significance. This division must be intimately connected with the mechanism of the formation of galaxies in clusters. It is very difficult to imagine that one can explain such a division on the basis of hypothesis of formation of galaxies from diffuse matter.

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

The first of these groups has been found at Byarakan in 1957 (Shakhbazian, 1957) during the study of the Palomar Sky Survey maps. Owing to compactness of its members and of the group itself it looks very different from other groups of galaxies. This was the reason that with 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. But since the other members were seemingly stars they concluded that the group is 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 definite 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 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 the Zwicky cluster 0152+33 mentioned above according to rough estimates has the same luminosity.

The determination of dispersion of radial velocities of the members of Shakhbazian 1 from redshifts and the 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 as small. Thus according to unpublished observations by Khachikian 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 of first ranked and the second galaxy is relatively small.

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

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

21. From what has been said above one can conclude that the study of compact galaxies and their clusters will bring new conclusions, which may have close bearing to the problem of the origin and evolution of galaxies and the nature of the activity of their nuclei.

At the same time we shall not think that the phenomena connected with compact galaxies are strictly isolated from the world of normal galaxies. The opposite is true, and there are cases when it is difficult to know whether to relate a given galaxy to the compacts or normals. It seems that the attention given to such intermediate cases will be rewarding.

Though the groups of galaxies included by Shakbazian in her first list contain almost exclusively the compact galaxies this is the result of intentional selection. It may happen that there exist mixed systems and their study will help us understand the connection between opposite phenomena in the extragalactic world.

22. There is nothing astonishing in the existence of the compact galaxies and in their properties. It is natural to suppose, that any mechanism of the origin of galaxies must provide the possibility for formation of systems for which the ratio M^2/H, where H is the total internal energy, is smaller than for others. Such systems will appear as less extended, compact galaxies. However it is remarkable that:

(a) There are some rich clusters of galaxies each of which contains dozens of high luminosity compact systems and do not have any extended system of the same luminosity.

(b) In the observable part of the Metagalaxy there are thousands compact groups of compact galaxies containing from five to ten compact systems but don't contain normal or extended galaxies.

(c) Inspite of differences in the nature of compact and normal galaxies and of probable differences in the values of M/L among them (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 also for compact galaxies.

(d) The colours of compact galaxies apparently are not very different from the colours of some normal galaxies. However there was until now no extensive and precise study of the colours of compacts.

23. Aiming to the detailed study of compact galaxies and their clusters we shall keep in mind the difficulty of this problem. The compact galaxies 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 in the Shapley-Ames catalogue there is even one high luminosity compact. However, beginning with $m = 13.0$ they appear. But owing 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 is difficult.

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

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

Apparently this will be achieved by combination of optical interferometry with the use of observations from outer space. If these barriers will be conquered new prospects of extragalactic research and specially for investigations of compact galaxies will open.

24. Finishing this discourse I should like to pay tribute to the astronomers who have mostly contributed to the solution of problems considered above.

Owing to tremendous observational work *Sandage* has reached the final conclusion that quasars are nuclei of supergiant elliptical galaxies. Having understood the significance of high luminosity *E*-systems in the Metagalaxy he has established the regularities concerning the brightest objects in 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 arouses great interest individually as it happens in the case of quasars and Markarian's galaxies. But we insist that the totality of compact galaxies (the majority of which have no emission lines) presents much deeper interest and significance.

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 regularities of the structure of Universe, and that it is up to the theoreticians to put the last touches to their models. Nature showing us new types of objects in the Universe, and demonstrating new kinds of processes, literally compells us not to follow such oversimplified views.

The conviction of the inexhaustibility of the Universe has led modern astronomy to its great discoveries. And if we modestly recognize this inexhaustibility we shall continue to inspire ourselves with the increasing difficulty and deepness of the arising problems, and we can hope that astronomers of 2473 celebrating the thousandth anniversary of Copernicus will mention 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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