INTRODUCTION TO "NUCLEI OF GALAXIES"

1. The great majority of galaxies have a density–maximum somewhere near to their centre of inertia. We prefer to call this region of maximum density *the central part* of a galaxy.

In the astronomical literature this *central part* is sometimes called the *nucleus* of the galaxy. We are going to avoid such usage. It is not this maximum density region with very indefinite borders which we are going to discuss.

In some nearer galaxies, for example $M31$, $M32$, $M33$, we see that there is a starlike, or almost starlike, image supperposed on this region of maximal density. In many distant galaxies the limits of angular resolution do not allow us to see similar starlike formation. They become lost in the bright background of the central part. However, in some distant galaxies these superimposed starlike formations have sufficient luminosity to be observed even in the cases when the angular resolution of photographs are moderate ($1'' — 3''$). This is for example the case in Seyfert galaxies. Similar, but less prominent starlike formations we observe in the photographic images of many other (mostly spiral) galaxies. It is much more convenient to apply the term "nucleus" just to these formations, since they display a number of exceptionally interesting phenomena, the discovery of which affected the whole outlook of modern extragalactic astronomy.

2. The spectroscopic study of the more prominent nuclei shows that there are processes within the nuclei differing from the phenomena in the other parts of galaxies. We are going to speak about these processes a little later. Let us mention here only some of them: the violent motions of gaseous clouds, considerable excess of radiation in the ultraviolet, relatively rapid changes of brightness, expulsion of jets and condensations.

The presence of at least one of these processes is described by the term *activity* of the nuclei. There are cases when no starlike discrete image is seen at the center of a galaxy, but there are clear signs of the nuclear activity. It is natural to assume in such cases that a nucleus exists, but its total luminosity in the visible light is so low that its image is not resolved due to the bright background of the ordinary stellar population. In such cases higher resolution could probably reveal the presence of a small nucleus.

Nevertheless no sign of a nucleus has been found in some of the *nearest* galaxies. Examples: SMC and the Sculptor System. We can only speculate on possible presence of nuclei in the past history of these systems or on remnants of what at some time was the nucleus of a galaxy.

At the same time the existing data make it almost certain that all spiral galaxies as well as all ellipticals of high and intermediate luminosity have nuclei of different prominence. Putting it in another way, we can say that almost all galaxies of high and intermediate luminosity have nuclei, but it is possible that a large proportion of dwarf galaxies are deprived of nuclei.

Of course we do not know exactly where the boundary lies between the galaxies with and without a nucleus. There is no clearcut border and the difference is only in the luminosity and significance of nuclei of different galaxies. In any case here is a problem for study which is very difficult.

3. There is a degree of similarity between quasars or *QSRS*s and active galactic nuclei. Parallel to *QSRS*s, which are comparatively rare objects, we also observe optical *QSO*s. According to *SANDAGE* and his collaborators the number of *QSO*s of *a given apparent magnitude* is more than a hundred times larger than the number of quasars of the same apparent magnitude.

The ratio is much higher when we take the corresponding spatial densities of the same objects. We know that quasars have optical (photographic) luminosities between -24 and -26 absolute. The *QSO*s have apparently a somewhat larger dispersion of luminosities and their average luminosity must be of the order of -23. This makes it very probable that the spatial density of *QSO*s is more than one thousand times higher than that of quasars. This means that the optical *QSO*s are in some respects much more important than quasars. We can formulate the situation in the following way:

The QSOs have considerable dispersion of luminosities. The most luminous of them are also emitting intense radio–frequency radiation and are known as Quasars.

Such a large population of *QSO*s in the uninverse is an evidence against their short lifetime. It seems to me that the assumption that on the average *QSO*s live less than 10^9 years will imply many difficulties. However, if we consider the state of quasars as a special active phase in the evolution of *QSO*s then it is possible to suppose that the total duration of such phase is much shorter (of the order of 10^7 — 10^8 years, but hardly less).

For a *QSO* or a quasar of high luminosity ($M = -25$) such a long lifetime means that the total amount of energy emitted in the form of electromagnetic radiation including the strong infrared radiation must be of the order of 10^{63} ergs, which is equivalent to about $5.10^8 M_\odot$. If we suppose that the lifetime of very *high luminosity QSO*s is shorter than 10^9 years, then even in the case of objects with $M = -22.5$ the problem of the energy sources will remain.

4. One of the most important things to be done in the studies of active nuclei and of *QSO*s is to understand the interconnection between the different forms of activity.

The study of radio–galaxies has opened the way to discovery of the phenomena we are now discussing. The radio–sources form only a small part both of galaxies with active nuclei and of *QSO*s. At least this is the case when we speak about strong radio–sources. It is quite possible that all active nuclei emit in radio–frequencies, but apparently we are not able to detect such weak sources.

The activity of many galactic nuclei manifests an excess of ultraviolet radiation of non–thermal and *non–stellar origin* and the presence of emission lines. In almost all cases the strong emission lines originate by means of fluorescence processes similar to that in gaseous nebulae of our own galaxy. Therefore let us concentrate on the continuous emission in the ultraviolet. In the case of *QSO*s, due to very large redshiflt the presence of ultraviolet excess is quite clear. However, for the majority of galaxies the total radiation of the nucleus is weak (both absolutely and apparently) and only a small part of galaxies shows an ultraviolet excess coming from the nucleus. A careful search for galaxies with bright ultraviolet continuum covering several thousands of square degrees has been made at Byurakan Observatory. It has been found that about 2% of galaxies in the interval of apparent magnitudes 13.5 and 17.5 have comparatively bright ultraviolet continuum. About 400 of such "ultraviolet" galaxies have been already found by *MARKARIAN* and a list comprising 300 galaxies with u.v. excess has been already published. About one hundred galaxies of that number were already observed by other observers (*KHATCHIKIAN, WEEDMAN, SARGENT, ARAKELIAN, DIBAJ, ESIPOV*) and it is now clear that not less than 80% of *MARKARIAN*'s galaxies have strong emission lines. Thus the observations support the idea that the strong emission lines are strongly correlated with u.v. excess.

There is every reason to believe that the near–ultraviolet excess observed in these galaxies expands to the far–ultraviolet, as in the case of QSOs and that there exists a maximum of spectral intensities in wavelength scale $[I(\lambda)]$. We connect this fact with the observations of galaxies made by orbital astronomical observatories launched by the Americans. They have indicated that some normal galaxies (for example $M31$) show an increase of intensity to the far ultraviolet, which suggests a maximum of intensity beyond 2000 Å. We can guess that the nuclear region of every galaxy is a source of non–thermal and non–stellar radiation, which has its maximum in the far ultraviolet. What we observe from the earth's surface is only a relatively faint wing of this radiation. In the cases when the excess is *large* (as in the case of Seyfert or of some N–galaxies) we can detect this wing. However, in the majority of cases the u.v. excess is faint and its near–ultraviolet wing is still fainter and we cannot detect it.

If this extrapolation is valid, we may suppose that all nuclei emit this kind of u.v. radiation, but in galaxies with active nuclei such emission is much more intense. It seems therefore that the observation of radiation of nuclei in the far ultraviolet is rather important.

All these questions are connected with the problem of low–level activity of the nuclei of normal galaxies. But even in normal galaxies violent events occur from time to time. The Duch astronomers have shown recently using 21 cm observations that there are outward motions of some isolated clouds directed from the nucleus of our Galaxy at a considerable angle to the galactical plane.

As regards the source of ultraviolet radiation, there is no doubt that this continuum usually comes from a source of small diameter (less than 10^{17} cm) and very characteristic irregular variations speak in favour of this. How can we explain these variations? If the mechanism of radiation is of synchrotron nature, then probably the variations of radiation intensity are caused by variation in the flow of particles which are ejected from a central body which has a still smaller volume.

The infrared emission represents another very important form of activity of some nuclei. There are evidences that dust is present in the nuclei of some of Markarian galaxies. However the dust is not the real cause of infrared emission.

5. Another form of nuclear activity is the ejection of gaseous clouds. In the case of less active nuclei we have apparently stable outflow of matter from the nucleus. The loss of mass by active nuclei can be estimated.

In the case of *NGC*4151, *ANDERSON* and *KRAFT (Ap. J. 158, 859, 1969)* have calculated that the loss of mass is somewhere between 10 and $1000 M_\odot$ per year. If we suppose the duration of the Seyfert phase to be $5 \cdot 10^7$ years and take the lower value for the loss per year, we obtain the total loss of the order of $5 \cdot 10^8 M_\odot$. Thus the activity must be connected with great changes in the state of the nucleus.

Another example is *NGC*1275. Apparently the giant filamentary gaseous structure which we observe in this galaxy has a mass of the order of several times $10^8 M_\odot$.

Thus the outflow of gas from nuclei in the form of either clouds or shells, indicates essential evolutionary changes in the masses of nuclei. At the same time we must suppose that at the initial stage of evolution the mass of the active nucleus forms a considerable part of the mass of the whole galaxy.

We can only guess about the further history of the gas. If the motions are extremely violent (more than 1000 km/sec) the galaxy loses the gas. In the case of low velocity outflow the gas can form some system of clouds around the nucleus.

Perhaps the constant escape of mass from such galaxies as *NGC*4151 and Markarian 9 is the cause of the extreme faintness of the envelope surrounding the nuclei of these galaxies.

By definition, for Seyfert galaxies the width of allowed lines is much larger than the width of forbidden lines (N_1 and N_2). However, if the emission line spectra of Seyfert galaxies is explained as summary radiation of many gaseous clouds ejected from the nucleus, then the just mentioned spectral property means that a considerable part of the emission line radiation comes from clouds of small masses. An expanding cloud of small mass can give an appreciable amount of radiation only when it is dense, since the luminosity is proportional to M^2/V.

But by high density and small volume the forbidden lines cannot appear. When the density diminishes due to expansion the total radiation is too faint to be observed. Thus in such clouds we do not see any forbidden lines. For the massive clouds the opposite is true. When we have only massive clouds, then we observe both the allowed and forbidden lines. Everything depends on the velocity of expansion of these large clouds. If they have low velocity of escape, they produce narrow forbidden lines. If their expansion velocity is high we must observe wide forbidden lines. Now it is important that *there is a group of galaxies which show both the allowed and forbidden lines equally widened*. Examples are Markarian 3, 6 and 39. But this is exactly opposite to what we have in the case of Seyfert type spectra. At the same time the physical causes are the same. Only the values of the masses of the clouds are different. Thus many non–Seyfert galaxies have active nuclei of the same kind as the Seyfert galaxies.

Many galaxies with Seyfert spectra are similar in their structure to *N*–galaxies introduced by Professor *MORGAN*. Therefore it seems more appropriate to discuss their morphology in connection with morphological properties exhibited by *N*–galaxies. Professor *MORGAN* has some important new ideas on this matter and I hope that he will tell us more on this later. In this connection I would like to discuss only one point which has been emphasised by *MARKARIAN* and *ARAKELIAN* recently.

In his survey *MARKARIAN* has divided all UV objects in two classes. First, the s–galaxies which are strongly concentrated objects of spheroidal form, which have a spectral distribution like *QSO*s. Second, the d–objects: they have diffuse borders, as sources of emission lines, they occupy large volumes in the corresponding galaxies.

The redshifts of 42 *CS* objects (concentrated, spheroidal) are known at this stage; 25 of them have been measured photoelectrically. For the latter we can determine the absolute magnitudes.

For the mean absolute magnitude and colour of *CS*–s *MARKARIAN* and *ARAKELIAN* give $M_B = -19.2$, $B - V = +0.57$, $U - B = -0.28$ compared with published mean values for N–galaxies $M_B = -21$, $B - V = +0.9$, $U - B = -0.27$.

The s–galaxies of *MARKARIAN*, though generally much nearer to us than N–galaxies, as a rule were not observed as radio sources.

Therefore we can say that the *CS*–s of *MARKARIAN* together with N galaxies form one major class of objects. Optically the most luminous of these objects often are radio galaxies. The number of *CS*–s in a given volume is several hundred times larger that the number of N–galaxies.

We have the same situation in the case of *QSO*s, *QSR*s, $D - E$ galaxies and corresponding radio sources.

6. *Radio–frequency emission.* Here we have one of the most important problems. We understand that a strong radio–frequency emission is always connected with the activity of nuclei. But the nature of this connection must be different in different cases.

In the cases of Quasars and N–galaxies the connection is apparently a direct one since the optical radiation in these cases comes from the nucleus. In the case of D or E radio galaxies, the radio emission often comes from the clouds of relativistic gas outside the galaxy and the optical luminosity is caused by the light of the stellar population. In these cases the connection is indirect and the explanation should be in the interconnection between the nucleus and the stellar population of the whole galaxy. Any theory aimed of explanation of the activity of the nuclei and the origin of radio galaxies must explain these simple facts.

Another important question is formation of clouds of relativistic electrons. The models supposing that the clouds were ejected directly from the nucleus meet some difficulties. Alternatively, we can suppose that the clouds have been formed by coherent bodies ejected from the nucleus. In this case we must assume that each of these ejected bodies behaves as an active centre emitting relativistic electrons. Here is a challenge for theoreticians.

7. *Dense bodies ejected from nuclei.* On several occasions I have had the opportunity to speak on jets originating in the nuclei of some giant galaxies. The galaxy *NGC*4486 is only one example. The jets in *NGC*3561 and *IC*1182 are similar in form but consist mainly of classical gas. The condensations in these jets have strong ultraviolet excess and emission lines. In this respect they resemble compact galaxies with active nuclei. There are some other condensations of this type, which differ from these examples only by absence of the jet which connects the condensation with the nucleus of the primary galaxy. Some of them show spectra similar to that of condensation in the jets of the above mentioned two galaxies.

It is possible to argue that we have no direct evidence that these objects (condensations) are of the same nature as active nuclei of galaxies. But it seems that such an argument is not too strong: any two stars which have the same spectral properties should be physically identical.

Therefore we must consider as very probable that these small blue objects have at least some (if not all) properties of active nuclei of galaxies.

We know that a nucleus can develop gaseous envelope around itself. In the case of our Galaxy we are almost certain that the interstellar gas enriches itself by the flow coming from the nucleus of the Galaxy. Therefore it is quite natural that we observe emission lines in these condensations.

Thus we come to the idea of fragmentation of nuclei and formation of new galaxies.

8. In order to explain the inconsistently large masses of galaxies, which we obtain by applying the virial theorem to clusters and groups of galaxies, a suggestion was made that the latter objects originate by means of successive fragmentation of some initial body and that the corresponding clusters and groups are systems with positive energy. During 15 years that elapsed after this suggestion several attempts have been made to postulate presence of some hypothetical matter (for example neutral hydrogen) in the clusters. However, these attempts were not successful. Therefore, my original suggestion remains valid. I have nothing to add to the original arguments except for the fact that both the fragmentation and the activity of nuclei concepts were closely connected and now, when the second concept is confirmed by direct observation, it is time to discuss the fragmentation concept very carefully.

But if we ascribe some kind of universality to the activity of nuclei, I think we must admit that each nucleus builds an environment by means of activity.

In this case the formation of globular clusters and generally of the type II population is one of the kinds of nuclear activity. We can suppose the same as regards the origin of spiral arms.

I would like to emphasize here that the risk connected with such a hypothesis is much less now than when we had had no idea about the energetics of nuclei. Usually the kinetic energy of the stars in a galactic system is of the order of 10^{59} ergs. Energies higher by one or two order of magnitude are sometimes released by the nuclei.

9. What we observe is only a number of external manifestations of the activity of some massive bodies which lie hidden in the very centers of the nuclei. The long duration of active processes in nuclei makes it quite clear that no processes of collapse or accretion can explain such a continuous activity.

At the present stage we know almost nothing about these central bodies. The only thing which is certain is that they are capable of producing very large amounts of energy both in the form of discrete portions and of continuous flow.

These bodies are apparently unstable, they change their physical state easily, but at the same time persist during a very long time. They eject sometimes great masses of the order of $10^8 M_\odot$, but after such ejection they continue their activity, perhaps in a less pronounced way. These central bodies of nuclei of galaxies and of QSOs represent a challenge to theoreticians.

10. As usually happens in astronomy when great new discoveries are made, the theoreticians try to give the explanation of new facts almost immediately. This time however we deal with very complex phenomena. It is even difficult to understand what is going on in the external parts of a nucleus which are transparent and open to observations. Therefore some patience is necessary.

At this stage the problem is to understand better the external manifestation of the activity of nuclei and to obtain a correct general picture of the processes. Then will come the second stage when the theoreticians will give the explanation of the deep processes and of the physics of energy generation.

To make the first stage shorter we must put the emphasis on the observations and on the systematization of the results of observations.

The systematization and classification of objects is as important as the classification of relations we discover between different facts and forms of activity.

Nature is much more complicated and diverse than it seemed to us, who until recently had no idea about these wonderful processes. Let us study them with patience and base our conclusions mainly on the observational data.