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Galaxies with Binary Nuclei

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Abstract. It is known that among active galaxies (AG) with strong emission lines (UV-galaxies, Sy1 and Sy2, Markarian and Kazarian galaxies, radio-galaxies, QSOs host galaxies and so on) there is a large percentage of objects with double and multiple (or complex) nuclei. The common sizes of these nuclei are of the order of a few hundred parsecs or kiloparsecs. We shall discuss the results of morphological and spectroscopic observations of a number of "active galaxies" carried out with the 5m Palomar telescope, 2.6m telescope of Ambartsumian Byurakan Astrophysical Observatory, 6m telescope of Special Astrophysical Observatory in Russia, and newer Hubble Space Telescope data.

Keywords. galaxies: active – galaxies: nuclei – galaxies: structure – galaxies: interactions

1. Introduction

The problem, connected with the nature of double and multiple nuclei, actually began since the discovery (identification) of radio galaxies by Baade and Minkowsky (1954) in the 1950s. They advanced the idea that the energy of strong radio galaxies was related to galaxies showing double nuclei as a result of collisions between two galaxies (mergers).To explain the nature of energy of the radio radiation they pointed out radio galaxies like Cygnus A, Cent A, Persei A (NGC1275).

This gave them the idea that radio radiation of these galaxies was the result of colliding galaxies and this led to the suggestion that the strong radio emission was due to galaxy mergers.

At the same time Ambartsumian (1958) was developing the concept of the activity of the nuclei of galaxies (AGN). At the physics Solvay conference in 1958 and at the University of California at Berkeley, he described the AGN phenomenon with the following forms of activity:

- outflow of ordinary gas matter (in the form of jets or clouds) from the nuclear regions with velocities of up to hundreds of kilometers per second,
- continuous emission of the flux of relativistic particles or other agents,
- eruptive ejections of gas matter (M 82 type),
- eruptive ejections of concentration of relativistic plasma (AGN 4486, 5128, etc.), and
- ejection of compact blue condensations with an absolute magnitude on the order of the luminosity of dwarf galaxies (AGN 3561, IC 1182). Here the division of the nucleus into two or more comparable components is also assumed possible, initiating the formation of multiple galaxies.

Soon Baade and Minkowski identified one of the powerful radio sources in Cygnus A with an optically rather faint galaxy with two nuclei. Another similar important object with two nuclei was the strong radio source NGC1275.

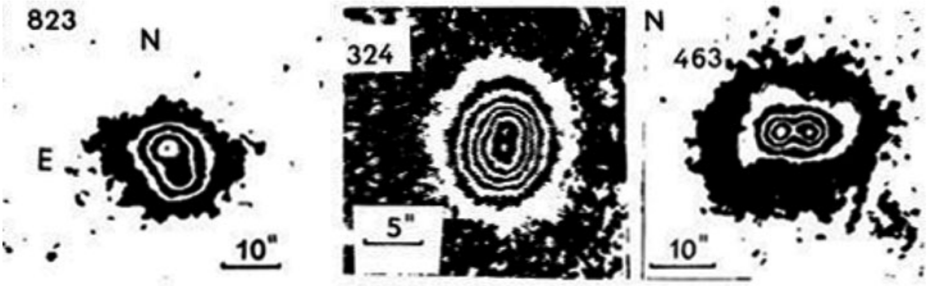

Figure 1. Isophots of double nuclei galaxies M823, M324 and M463.

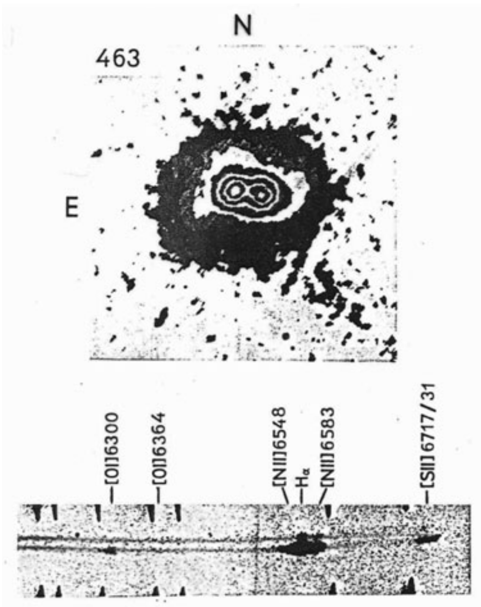

Figure 2. Densitometry of double nucleus galaxy Mrk 463 (top) and registration of spectra of both nuclei in the Hα region (bottom).

Thus, the first observed radio galaxies were extremely unusual from the standpoint of morphology: they had two nuclei. A mechanism involving a random collision of two giant galaxies was proposed in order to explain these unusual galaxies. This hypothesis was advanced by Baade and Minkowski, with their great scientific authority, and it was widely accepted at that time. Although the collision hypothesis was attractive for its simplicity, it did have some deficiencies, as first pointed out by Ambartsumyan. In a series of papers beginning in 1954, he convincingly showed that a collision is not taking place in the radio galaxies, but rather an explosion in their nuclei, which resulted in some cases to splitting of the nucleus and the ejection of large bursts of matter from it. Later well-known US theoretician G. Burbidge (1959) calculated that the collision energy of two galaxies is considerably smaller (by two or three orders of magnitude) than the energy of these radio galaxies. The collision theory was no longer tenable and Ambartsumyan concluded that the radio galaxies develop because of strong critical phenomena which take place during the galaxies' internal development.

Thus the problem has been the nature of the double and complex nuclei (see Fig. 1, 2 and 3).

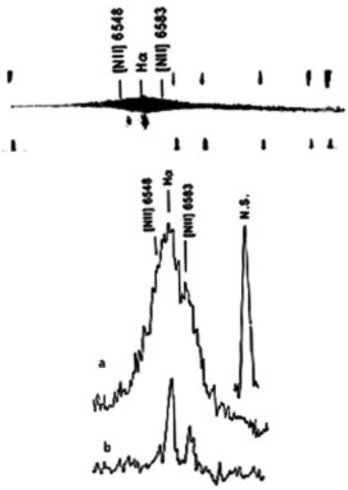

Figure 3. The spectra of double nuclei galaxy Mrk 739 (top) and the spectra of both nuclei in the Hα emission line (bottom). N. S. is the registration of the night sky emission line for the comparison of line widths.

They are either due to galaxy collisions and mergers, or due to some unknown monster nuclear activity. At the time Allan Sandage said: "No astronomer would deny today the mystery of the nuclei of galaxies, and Ambartsumian was the first who understood what a rich reward is contained in this treasury".

2. Morphology and spectrophotometry of UV-excess galaxies with double nuclei

Galaxies having double and multiple nuclei are an important class of objects for the investigation and explanation of the physical processes going on in AGNs. Many objects of this type are found among the Markarian and Kazarian objects, which have been discovered by their strong UV excess, and among ultra luminous infrared galaxies. Some studies of individual objects of this class have been done and more attention has been paid to Markarian galaxies with double nuclei (Khachikian 1972; Khachikian *et al.* 1974; Petrosian *et al.* 1978; Khachikian *et al.* 1980; Khachikian & Kazarian 1977; Mazzarella *et al.* 1991; Mazzarella & Boroson 1993; Nordgren *et al.* 1995). Many of these works aim to test the "merger hypothesis". Some of the questions addressed are the physical processes involved, and which are predominant in the generation of double nuclei in disk galaxies or any other type of galaxies? Is there any correlation between the properties of double nuclei and those of their host galaxies? Are there any systematic differences (or similarities) between component nuclei? Do the nuclei occupy any preferential place within the host system?

As far back as 1969 it was noticed that UV galaxies do not form a homogeneous group of galaxies and among them there are different types of galaxies from Zwicky objects to Hubble type's galaxies (Weedman and Khachikian 1969).

We have to distinguish the morphology of UV objects in general, and morphology of their central parts in particular. In 1979 it was shown that the form of activity of central parts of UV galaxies is not correlated with the morphology of the whole galaxy (Khachikian 1979).

Table 1. Parameters of 6 representative UV galaxies with double nuclei.

Mrk No.	$\mathbf{m}_{pg}$	$\mathbf{M}_{pg}$	**d (")**	**d (kpc)**	$\mathbf{V}_r$ **(km/s)**
266	17.5	-17.8	12.0	6.5	127
	17.8	-17.5			
273	17.5	-18.4	4.3	3.2	–
	18.2	-17.7			
463	17.0	-19.5	4.5	4.3	50
	17.2	-19.3			
673	16.2	-19.6	5.3	3.7	166
	16.2	-19.6			
739	16.2	-19.1	6.6	3.8	85
	17.0	-18.3			
789	16.0	-19.5	4.1	2.5	2

Following Ambartsumian, in terms of their morphology the nuclei of galaxies with a UV excess can be divided into five groups (Khachikian 1987):

- Star shaped nuclei (Mrk 9, Mrk 10, Mrk 305, Kaz 73, Kaz 102);
- Binary nuclei (Mrk 739, Mrk 930, Mrk 212, Mrk 266, Mrk 306);
- Multicomponent nuclei (Mrk 7, Mrk 8, Mrk 171, Kaz 5);
- Nuclei with jets (Mrk 273, Mrk 773, Kaz5, Mrk 423);
- Nuclei in the form of a bulge (Mrk 1, Mrk 474, Mrk 489).

Clearly, the classification of a galaxy in any of these groups depends not only on the galaxy itself but also on the size of its image on the plate and the resolution. Nevertheless, we have good examples of these groups among UV galaxies.

This very interesting group of galaxies was studied in detail by Khachikian *et al.* (1978, 1979, 1981). The observations show that both nuclei are not always spectroscopically identical and sometimes differ both in the intensity of the continuum and the lines (Fig. 3). Interestingly, Seyfert galaxies are also encountered among double nuclei galaxies (Mrk 266, 463, 673, 739, 789) (Khachikian, Petrosian and Sahakian 1978b, 1980a). It is very significant that among them there are galaxies in which both nuclei show Seyfert-type spectra. In Table 1 the apparent and absolute photographic magnitudes of the components of the nucleus, distances between components in arcseconds and kpc, and radial velocity differences are presented for some galaxies with double nuclei (H = 75 km/s Mpc). "d" is the distance between the nuclei (in arcseconds and kpc), "V_r" is the redshifts differences between the nuclei in kilometers per seconds.

A good example of this group is Mrk 273 (Fig. 4) and Kaz 5 (Fig. 5) with jets. The morphological and spectroscopic investigations of four galaxies of this type (Mrk 423, 739, 773 and 984) have been carried out by Khachikian *et al.* (1985). Some approximate data about these galaxies are presented in Table 2.

Detailed studies of objects whose central regions consist mainly of several densifications of the superassociation type are of great current interest. First of all, it is necessary again to consider a very interesting system of extragalactic objects in the neighborhood of the galaxies Mrk 261 and 262, which most likely consist of a physically coupled system within a small relative volume on the order of the size of our galaxy (z = 0.03) Arp, Khachikian, and Heidmann (1974).

Fig. 5 is a photograph of this system taken at the primary focus of the 5m Palomar telescope.

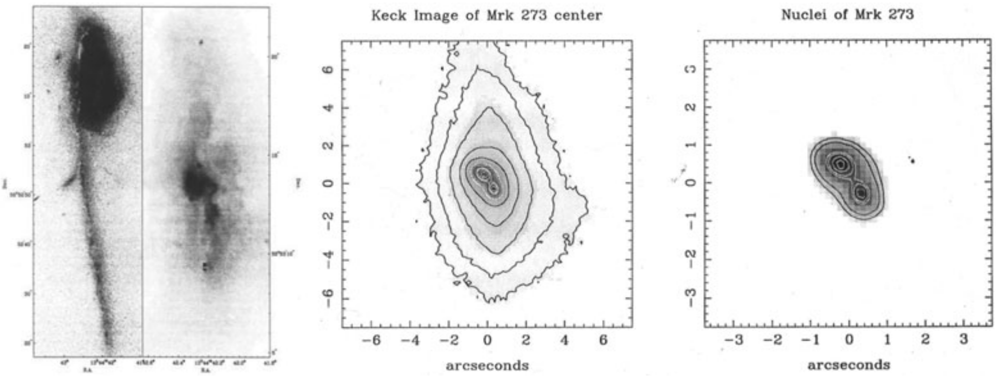

Figure 4. Mrk 273.

Table 2. Parameters of 4 representative UV galaxies with jets.

Mrk No.	Component	m_{pg}	M_{pg}	Sizes (arcsec)	Sizes (kpc)
423	integral	14.9	-20.6	42 × 24	26 × 15
	nucleus			3.0	1.9
	jet			7.6 × 2.6	4.7 × 1.6
739	integral	14.8	-20.6	30 × 27	16.9 × 15.2
	E-nucleus	17.0	-18.4	5.3	3.0
	W-nucleus	16.2	-19.2	4.1	2.3
	jet			11 × 4.5	6.2 × 2.5
773	integral	14.1	-16.2	30 × 24	1.7 × 1.3
	SE-nucleus	17.5	-12.8	5.7	0.32
	SE-jet			7 × 4	0.4 × 0.2
	its knot	16.0	-14.3	4.3	0.2
	NW-nucleus	17.5	-12.8	6.2	0.35
	NW-jet			23 × 2.2	1.3 × 0.1
	its knot	18.5	-11.8	3.4	0.2
984	integral	15.1	-21.9	84 × 48	80 × 46
	nucleus	17.0	-20.0	3.2	3
	jet			15.6 × 3	14.8 × 2.8
	I knot	18.5	-18.5	3.2	3.0
	II knot	19.5	-17.5	3.0	2.8

These blue objects are located at a distance of about 2' to the north of Markarian 261 and 262. In blue light they appear in the form of two compact condensations joined together by means of two bars. In red light the bars become barely visible. The distance between the "twin" objects is about 4 kpc in projection. Both objects have very strong emission line spectra.

A notable peculiarity of this system is the great similarity of the components; their shapes, dimensions, radial velocities, luminosities and spectra are nearly identical. Because of their faintness (m_{pg} = 18.5) they have not been included in the first Byurakan Spectral Survey, but they will be in the second one.

On the one hand, the "twin" objects are a double nucleus galaxy without any stellar environment or common diffuse envelope; on the other hand, there are pairs of isolated SA's. Actually we may have the origination of two particular galaxies, consisting of hot stars and surrounding gas envelope. Recently Shaver and Chen (1985) published data on four objects of this type discovered on objective prism plates taken with UKST. These four objects are also double. Very likely these most isolated HII giant regions are double.

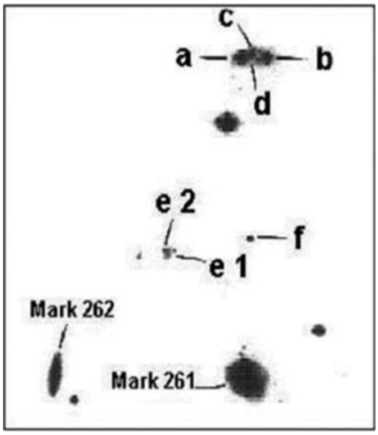

Figure 5. The photograph of the system of galaxies in the neighborhood of Mrk 261 and 262 obtained at the Prime focus of the 5m Palomar telescope (USA).

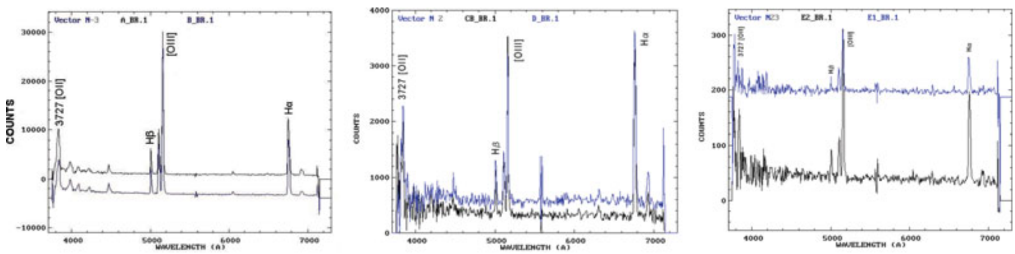

Figure 6. a) The registration of spectra of both objects “a” and “b” in the Hα region, obtained with the 6m telescope of Russia. b) The registration of spectra of both objects “c” (black) and “d” (blue) in the Hα region, obtained with the 6m telescope of Russia. c) The registration of spectra of both objects “e1” (blue) and “e2” (black) in the Hα region, obtained with the 6m telescope of Russia.

Very few spiral galaxies with jets are known – maybe only NGC 1097 (Arp 1976) and UGC 3995 (Keel 1985). We found two more: Mrk 423 and 984. It is interesting to note that knots in jets have different physical properties: the knots in M87 have continuum spectra only, while in NGC 3561, IC 1182 (Stockton 1972) and 3C 277-3 (Breughel 1981) the spectra of knots look like the spectra of superassociations.

The majority of Seyfert galaxies with jets are of high luminosity. Mrk 773 is an exception. None of the jet galaxies is a strong radio source.

Mrk 423 is a Seyfert 2 galaxy (Afanas’ev *et al.* 1980) with the morphological type Sa (Osterbrock 1981). The jet begins to be visible at a distance about 4” from the nucleus ($\sim$ 2.5 kpc).

Mrk 739 is a double nucleus galaxy: the East nucleus has very strong Sy 1 properties; the West one is a superassociation (Khachikian *et al.* 1979b). The jet starts in the region between the nuclei.

Mrk 773 looks like a double-nucleus galaxy. Almost perpendicular to the line joining the nuclei, in two mutually opposite directions from the centre two jets are seen. The SW is short and ends with a star like knot. The NE jet is longer and also has a knot just in the middle of it. Both nuclei and knot in the SW jet show emission-line spectra.

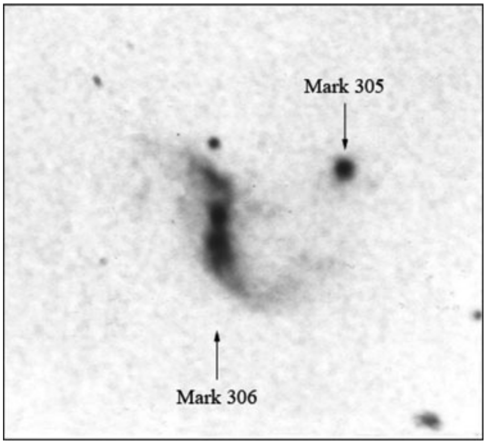

Figure 7.

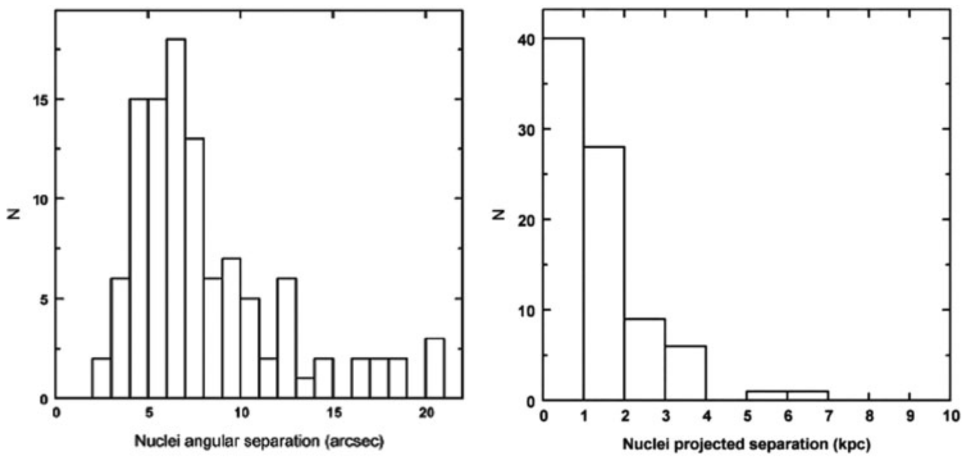

Figure 8. a) Nuclei angular separation (in arcsec). b) Nuclei projected separation (in kpc).

3. Summary

The principles of selection of double and multiple nuclei are described in Khachikian *et al.* (1981). The issue of AGNs with double and multiple nuclei remains of great interest, but their origin is not yet conclusively clear. It could be that we are witnessing the result of merging galaxies perhaps each with supermassive black holes, or some unknown physical process is taking place in the nuclei of AGNs that makes the nucleus break into two or more components and creates energetic jets and other disturbances. It is also possible to think that a single galaxy may form two supermassive black holes and their interaction may be causing the nuclear activity.

However, some think that mergers are improbable and that there is another explanation. It is difficult to make conclusions from existing images. We need very high resolution images to study the central structures. Nevertheless galaxy mergers do occur and that hypothesis cannot be ruled out. For investigating the double nuclei in the central parts of AGNs it is very important to observe with high resolution. Recently important high-resolution images have been made with the Hubble Space Telescope of the cores of three active galaxies: Mrk 348, Mrk 516, and Mrk 789 by Gorjian (1995). Results are shown on Fig. 9.

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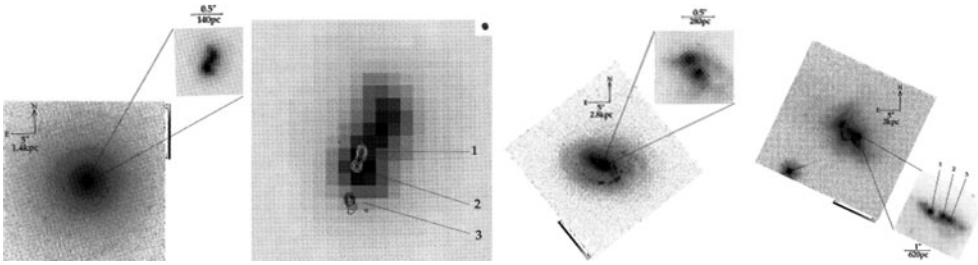

Figure 9. a) Mrk 348 is presented with a log scale (lower left), while the nucleus (upper right) is presented with a linear scale to bring out greater detail. The length of the east bar is equivalent to 5”. b) VLBI image of Mrk 348 superposed on the optical image by aligning the brighter optical source with the inverted spectrum radio component. The beam size for the radio map is shown on the upper right. Each pixel is 0.046” on a side. c) Mrk 516 is presented with a log scale (lower left), while the nucleus (upper right) is presented with a linear scale. d) Mrk 789 is presented with log scale (upper left), while the nucleus (lower right) is presented with a linear scale.

From the above images the majority suggest complex nuclear activity. In other words, if we observed double nuclei AG with jets we are thinking at once about the physical processes going on in the center of galaxy. In addition, from the point of view of mergers, it is not so clear from the images what kind of objects are merging.

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