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Towards the classification problem of ring-like galaxies

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The classification problems of ring-like galaxies on the basis of modern observational data are considered. Here we did not take account of galaxies with the polar rings the nature of which is not connected in any way with the ring formations in the galaxy plane. A classification developed by us contains 9 groups concerning visible signs of physically ring structures in galaxies where the rings are not formed because of strong twist of spiral arms or their unusual projection to the picture plane. Thus in our classification the ring structures are considered on equal rights with other subsystems of galaxies, for example, with the bar or the spiral arms.

Keywords: Galaxies, ring-like structural formations, classification

1 Introduction

According to observations, many spiral galaxies comprise various types of ring-like structural formations. But there are also purely ring galaxies without spiral arms among which, for example, the combination of a nucleus and a ring is more often observed. Today we can assert that galaxies with ring formations differ from each other strongly enough, but also at the same time they sometimes have a number of naturally repeating signs, that obviously attests to a necessity of working out some classification.

It was E. Hubble (Sandage, 1961) and Vaucouleurs (1956) who noted the existence of ring structures in spiral galaxies for the first time. But these authors did not think about the ring classification yet. Vaucouleurs only described the ring structures in the Hubble tuning fork. Vorontsov-Velyaminov (1960) was the first who had attempted to classify the ring-like galaxies revealing various kinds of ringed galaxies by means of the Palomar Sky Atlas. He suggested considering these galaxies as the

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independent sequence parallel to the spirals entering three classes "a", "b" and "c". It was the first attempt to classify the ring-like galaxies. Further Kostyuk (1975, 1979) compiled the list of 143 galaxies and also as Vorontsov-Velyaminov she suggested dividing ring galaxies into three classes. However no one uses the proposals of Vorontsov-Velyaminov (1960); Kostyuk (1975, 1979) up to now as these three classes are rather conditional and do not cover many of the various observable kinds of ring galaxies. Hence, in work of Nuritdinov & Usarova (1989) one of the authors of this article compiled the list of 300 ring-like galaxies and in that work a wider preliminary variant of classification was also offered. However, today among many works on the morphology of ring galaxies it is necessary to note the work of Buta (1995) who made the remarkable catalogue of 3591 ring galaxies for the Southern hemisphere.

But Buta (1995) describes ring galaxies also as those ring-like structures which are formed due to strong twist of spiral arms, or are observed due to their unusual projections to the picture plane. Although it are not interested in general classification of the ring-like galaxies, but he has assigned to them complex symbolic notations, including every time the letter S, regardless of whether they contain spiral arms or not. Our analysis of the observational data shows that about 50 percent of the physical ring galaxies do not contain spiral arms in general, and they should be classified, not being associated with spiral galaxies. Below are the results of the analysis of observations of the ring-like galaxies and also has been offered their classification, based on the selection of physical ring cases.

2 Analysis of the observational data

It should be noted that here we do not consider the polar rings, thinking that their origin is in no way connected with the inner ring structure. As we mentioned above, Vaucouleurs (1956) was the first to distinguish between spiral galaxies, not only by the presence or absence of bars and degree of twist of spiral arms, but also by the presence of ring structures. He suggested various notations for such objects. For example, if tonly spiral arms are present then in the notation of galaxies the index (s) is added, and if there is a ring structure, the index (r) is given. He also introduced transitional types with the index (rs) as well. Thus, Vaucouleurs not classifying ring-like galaxies introduced only certain notations for spiral galaxies having rings.

A classification of ring-like galaxies was first proposed by Vorontsov-Velyaminov (1960) by means of Palomar Sky Atlas. He considered in detail the galaxies that have features of purely ring formation without the bars and the spiral arms. Furthermore, it was proposed to denote galaxies with dominant ring structure as SR. at the same time for the transitional forms a sequence of letters means the predominance of one or another structure, such as SBR or SSR, SRB or SRS. Analysis of the images of galaxies has shown that there is a continuous transition from these ring galaxies to SO, S, SB and some other spiral galaxies. Besides the rings as well as spirals are divided into following subclasses as a, b and c. And it takes into account not the degree of twist but the grain of structure. The most important conclusion of Vorontsov–Velyaminov, in our opinion, is that the ring formations of galaxies should be regarded as an independent structure and as equal with bars, spiral arms, and

others. In addition, in the present work some galactic formations without spiral arms also have been described.

In Kostyuk (1975, 1979), a list of 143 galaxies with external ring-like structure was compiled on the material of the Palomar Sky Atlas of the Northern hemisphere. Here, the external ring structure, which is isolated from the inner spheres of the galaxy, served as the criterion of selection. Collected in this way ring-like galaxies were classified into three types:

- RS – normal and bar-like galaxies, where the ring-like structure is clearly determined by its appearance and location of the spiral arms. In this list the number of these galaxies is equal to 114. It was clarified that the distribution of galaxies of this type on the celestial sphere does not show a tendency to crowding.
- RH – in these galaxies in the external ring there is no sharp border, which is continued by quite extended light.
- R – galaxies of this type take a toroidal shape, or have noncentral nucleus, which is sometimes located on the ring.

Moreover, Kostyuk (1975, 1979) concluded that the ring-like galaxies belong to the early morphological types at Hubble sequence, and they have more extended disc, in comparison with earlier types of galaxies without rings.

It should be noted that these classifications proposed by Vorontsov-Velyaminov (1960); Kostyuk (1975, 1979) do not take into account many other types of ring-like galaxies and their obvious features. Therefore, in the work of Nuritdinov & Usarova (1989) one of the authors of the present paper started the development of more detailed classification of the ring-like galaxies, based on about 300 such objects gathered in 1988. However, currently there have been already published a series of new lists and catalogues of ring-like and other adjacent galaxies. In this way new ring-like galaxies data are revealed which are needed for the establishment of the real nature of these mysterious objects. That is why the study of physics of ring-like galaxies should be continued. It is important to note that at the present time for the Southern Hemisphere of the sky R. Buta created a catalog of ring-like galaxies (Buta, 1995). This catalog contains 3591 ring-like galaxies. Analysis of this catalog shows that according to the designation of Buta there are 2582 single-ring, 978 two-ring and 31 three-ring galaxies.

Figure 1 shows a histogram of the distribution of galaxies, containing single-ring structures. As follows the most frequently found galaxies type is SB(r) with a bar and ring-like structure (the quantity is 273). Next is transitional between the normal and the bar-like spiral galaxies type SX (rs) with a total quantity of 247 units and etc. It should be noted that here we mainly follow the notations introduced by Buta (1995), in particular, r- are inner rings, the size of which are approximately equal to the size of the bars and slightly elongated along them; R is outer ring, size of which is significantly larger than the size of the bar where the semi-major axis is twice the size of the bar; R1 is an eight-shaped outer ring, which is formed from a compound of the spiral arms with the bar, twisting by 180 degrees, i.e. semi-major axis of the ring is perpendicular to the semi-major axis of the bar; R2 is also an outer ring, which is formed from a compound of widely open spirals, twisting by 270, i.e. semi-major axis of the ring is located along the semi-major axis of the bar etc. An interesting fact, however, is that the histogram of the distribution of galaxies, containing a single-ring

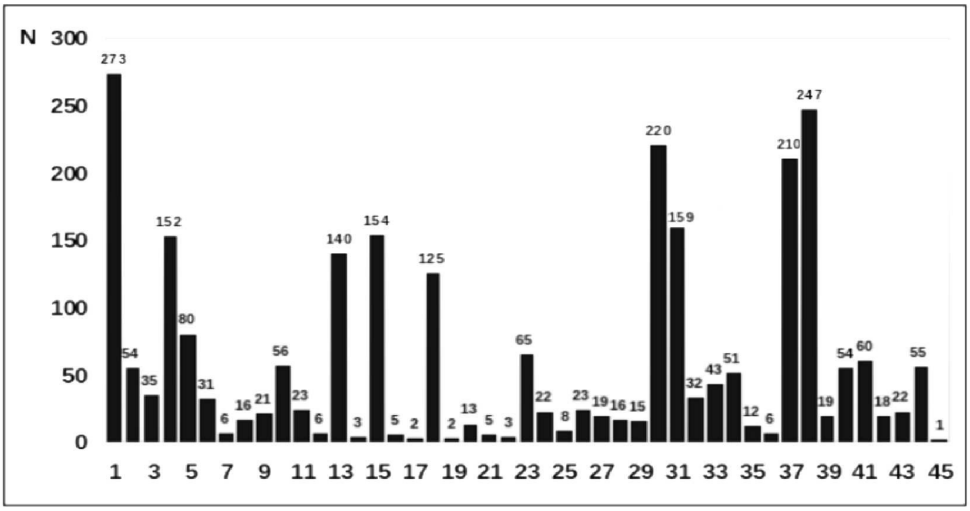


Figure 1 Distribution histogram of the one-ringed galaxies from the Buta catalog.

structure, indicates the existence of 45 species, differing from each other by concrete features (Table 1). If we build relevant histograms for two- or three-ring galaxies as well, the total number of types of ring-like galaxies will consist of 68 types in the catalog (Buta, 1995). It is evident that the catalog also contains, in addition to physical ring galaxies, galaxies in which the rings are formed due to the projection of the spiral arms on the picture plane or due to strong twisting of the arms.

We are also interested in, first of all, those galaxies where ring structures could be formed as a result of a global dynamical evolution, in particular, because of the gravitational instability of some oscillation modes on the background of non-stationary models of disk-like self-gravitating systems. In particular, the physical ring galaxies can be also formed because of an external impact and some merging effect. These ring-like structures can be considered as equal with other subsystems of galaxies, for

Table 1 Specific single-ring structures notations corresponding to the numbers on the horizontal axis of Fig. 1.

#	View	#	View	#	View	#	View	#	View
1	SB(r)	10	(R1)SB	19	(RP)SB(l)	28	(R)S	37	SX(r)
2	SB(r)p	11	(R)SB(l)	20	(RL)SB	29	(RP)S	38	SX(rs)
3	SB(rl)	12	R1P)SB(l)	21	(RL)SB(s)	30	SA(r)	39	SX(rl)
4	SB(rs)	13	(R1P)SB(s)	22	(RL)SB(l)	31	SA(rs)	40	(R)SX
5	SB(rs-)	14	(R2)SB	23	(R)SB	32	SA(rl)	41	(RP)SX(s)
6	SB(rs+)	15	(R2P)SB(s)	24	(R)SB(s)	33	(R)SA	42	(RL)SX
7	(L)SB(r)	16	(R2P)SB(l)	25	(R)SBp	34	(RP)SA(s)	43	(R1)SX
8	(R1)SB(l)	17	(R2PL)SB(s)	26	(R)SB(l)	35	(RL)SA	44	(R2P)SX(s)
9	(R1)SB(s)	18	(RP)SB(s)	27	S(r)	36	(L)SA(r)	45	(R) Im?p

example, with a bar or spiral arms. Such rings may be revealed, for example, in the form of the inner ring, the size of which approximately coincides with the size of bars, or may occur as the external ring with dimensions substantially larger than the bar. But the rings can also be found in some galaxies without bars and nucleus (Vorontsov-Velyaminov, 1960; Buta, 1995). There are galaxies that have both an internal and an outer ring at the same time. Analysis of observational data about ring-like galaxies has also shown that in some of them there is an effect of lopsidedness, i.e. the nuclei of these galaxies are shifted relative to the geometric center of the system.

Thus, we have carefully studied the various types of ring-like galaxies (Sandage, 1961; Kostyuk, 1975, 1979; Nuritdinov & Usarova, 1989; Buta, 1995) and have selected from them 1370 physically ring objects. Only after that we were able to classify these galaxies.

3 Classification of ring galaxies

Selected ring galaxies were classified by us according to their various structures and forms (Table 2). In our classification, we have introduced new notations so that they would ensure each case in its application and at the same time would allow us to put new theoretical problems related to the ring-like galaxies. Thus, we offer the following notations: R is a ring, B is a bar, s is two-arm spiral, N is a nucleus, NL is a lopsided nucleus. Also dashes are inserted when the structures are separated from each other and if they are connected to each other then there is no dash.

As a result, the classification developed by us includes 9 groups (classes), where are collected in one class ring-like galaxies that have almost similar features in their structure. For example, here we have grouped in one class lopsided galaxies and galaxies with a central nucleus.

It is revealed that the most numerous (rich) classes are ones of R-N (26.5%) and RBN(s) (26%). The first is purely ring galaxy and contains a ring with central nucleus. The second (RBN(s)) contains a ring, a bar, a nucleus and two-armed spiral. In five cases of the nine there are bars. And the spiral arms are observed only in three cases.

4 Conclusions

- On the basis of the observational data physical ring galaxies were selected in which these structures are observed as equal with other subsystems, such as a bar or spiral arms.
- For the first time a classification of ring-like galaxies is developed based on the analysis of the observational data that contains nine groups relative to the visible features of ring structures in galaxies.
- It is revealed that the most frequently observable cases are ones when we have purely ring galaxies with a nucleus and also the next most frequently observable cases have a ring, a bar, a nucleus and two-armed spiral.
- It turned out that in our classification the bars are observed in 5 cases out of 9, and the spiral arms are found only in 3 cases.

Table 2 Suggested by us a classification of physically ringed galaxies.

#	Suggested classes		Brief description	%
1		R-N; R-NL	Purely ring galaxies only with a nucleus. Sometimes the ring is lopsided (R-NL). Typical examples: ESO 316-30, CSRG 795, PGC 54559	26.5%
2		RBN(s)	Ringed galaxies with a bar, a nucleus and external spiral branches. Typical examples: UGC 12646, ESO 245-12, ESO 499-41, ESO 160-20	26%
3		R-RBN	Purely two-ringed galaxies with a nucleus and internal bar. Typical examples: NGC 2859, NGC 3821, ESO 160-16	12.5%
4		R-BN	Purely ring galaxies with a nucleus and a bar separated from the ring. Typical examples: NGC 3237, CSRG 1123, CSRG 95	11%
5		RBN	Ringed galaxies with a nucleus and a bar reached the ring. Typical examples: CSRG 131, NGC 4340	7%
6		R-R-N; R-R-NL	Two-ringed galaxies only with a nucleus. Sometimes the nucleus is lopsided (R-R-NL). Typical examples: ESO 87-51, NGC 7020, IC 5285	5.5%
7		R-N(s); R-NL(s)	Ringed galaxies with a nucleus and external spiral branches. Typical examples: ESO 150-9, ESO 121-11	5%
8		R-SBN	Ringed galaxies with a nucleus, a separated bar and internal spiral branches. Typical examples: ESO 119-21, MCG 1269, NGC 1291	4.5%
9		R	Purely ring galaxies without nothing. Typical examples: ARP 146, ARP 147	2%

It is necessary to note that we do not pretend to report the completeness of classification problem of ring-like galaxies as we selected only the cases which can be explained by mechanism of the gravitational instability of the ring oscillation modes. Of course, these physical ring galaxies can be also formed because of an external impact or by some merging effect.

Hereafter it is necessary to analyse, for example, the case of the ring galaxy type where there is a bar and a ring circled by external multiple spiral branches (typical examples are NGC 7329, NGC 2523, MCG+00-30-013). Their number is more than 720. It is difficult to determine whether it is a physical ring galaxy or if the ring is formed by dynamics of the spiral density waves.

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