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Durdona NAJMIDDINOVA,
PhD Student, Department of Physics, National University of Uzbekistan
E-mail: najmiddinovadurdona@icloud.com, ORCID: 0009-0004-6388-9377
Karamat MIRTADJIYEVA,
Head of Laboratory, Astronomical Institute of the Academy of Sciences of the Republic of Uzbekistan, D.Sc. in Physics and Mathematics, Professor
E-mail: mkt1959@mail.ru, ORCID: 0000-0002-1172-9054

Reviewed by Yu.Muslimova, Cand.Sci.(Phys.-Math.), Associate Professor, UzNPU.

ANALYSIS OF THE CLASSIFICATION OF PHYSICAL RING-LIKE GALAXIES

Annotation

This article revisits the classification of physical ring-like galaxies using modern observational data. The study examines a catalogue of 8,052 ring-galaxy candidates identified using data from the DESI Legacy Imaging Surveys DR9. Based on a detailed analysis of observational images and morphological features, 2,774 objects were selected as physical ring-like galaxies. This sample was combined with objects investigated in previous classification studies, resulting in a consolidated sample of 4,144 physical ring-like galaxies. The correspondence of the objects to the existing classification groups was subsequently analysed. The classification was provisionally extended to ten groups through the introduction of an additional R10 group. The analysis revealed that galaxies with a central nucleus surrounded by a ring constitute the most numerous group.

Keywords: ring-like structure, morphological classification, physical ring, bar, nucleus.

HALQASIMON GALAKTIKALARNING KLASSIFIKATSIYA MASALASI TAHLILI

Annotatsiya

Mazkur maqolada zamonaviy kuzatuv ma’lumotlarini hisobga olgan holda fizik halqasimon galaktikalarni tasniflash masalasi qayta tadqiq qilindi. Ishda oxirgi yillarda kuzatilgan 8052 ta yangi halqasimon galaktika nomzodlari ro‘yxati ko‘rib chiqildi. Kuzatuv tasvirlari va morfologik belgilarni tekshirish natijasida ular orasidan 2774 ta obyekt fizik halqasimon galaktika sifatida saralandi. Ushbu tanlanma avvalgi tasniflash ishlarida o‘rganilgan obyektlar bilan birlashtirilib, 4144 ta fizik halqasimon galaktikadan iborat umumiy jamlanma shakllantirildi. Shakllantirilgan umumiy jamlanmadagi obyektlarning mavjud klassifikatsiya sinflariga mansubligi tahlil qilindi. Natijada fizik halqasimon galaktikalar 10 ta sinfga ajratildi. Tasniflash jarayonida markazida yadro va uning atrofida halqa kuzatiladigan galaktikalar ko‘pchilik guruhni tashkil etishi aniqlandi.

Kalit so‘zlar: halqasimon struktura, morfologik tasnif, fizik halqa, bar, yadro.

АНАЛИЗ ПРОБЛЕМЫ КЛАССИФИКАЦИИ КОЛЬЦЕОБРАЗНЫХ ГАЛАКТИК

Аннотация

В данной статье с учётом современных наблюдательных данных повторно рассмотрена проблема классификации физических кольцеобразных галактик. В работе был проанализирован список из 8052 новых кандидатов в кольцеобразные галактики, выявленных по результатам наблюдений последних лет. На основе проверки наблюдательных изображений и морфологических признаков среди них было отобрано 2774 объекта, классифицированных как физические кольцеобразные галактики. Данная выборка была объединена с объектами, исследованными в предыдущих работах по классификации, в результате чего была сформирована общая совокупность, включающая 4144 физические кольцеобразные галактики. Была проанализирована принадлежность объектов сформированной совокупности к существующим классификационным классам. В результате физические кольцеобразные галактики были разделены на десять классов. Установлено, что наиболее многочисленную группу составляют галактики, в центре которых наблюдается ядро, окружённое кольцом.

Ключевые слова: кольцеобразная структура, морфологическая классификация, физическое кольцо, бар, ядро.

Introduction. The study of the morphological structure and evolutionary development of galaxies is one of the important research areas in modern observational astronomy. The relative arrangement of nuclei, bars, spiral arms, and ring-like components within galaxies provides valuable information about their formation processes and internal dynamics. Physical ring-like galaxies, in particular, are of special scientific interest because of their distinctive structures.

In previous studies, Mirtadjiyeva and Nuritdinov classified physical ring-like galaxies into nine groups [1]. Polar-ring galaxies and objects exhibiting apparent ring-like structures caused by projection effects were not included in this classification. In the present study, this classification was adopted as the basis for analysing a list of 8,052 ring-galaxy candidates identified using data from the DESI Legacy Imaging Surveys DR9 [2]. Based on a comparison of the visible structural features of these objects, an improved classification of physical ring-like galaxies consisting of ten groups is proposed.

Review of the relevant literature. De Vaucouleurs was among the first researchers to draw attention to the presence of ring-like structures in galaxies. In his classification of spiral galaxies, he introduced specific symbols to denote different structural

features. In particular, the symbol “s” was used for galaxies with spiral arms, “r” for ring structures, and “rs” for intermediate forms [3]. This approach represented one of the earliest attempts to identify ring structures as a distinct morphological feature of galaxies.

Vorontsov-Velyaminov was one of the first researchers to consider ring galaxies as a separate class of structural objects. He emphasized that ring galaxies should be studied not merely as ordinary forms of spiral galaxies, but as a distinct morphological sequence [4]. Subsequently, Kostyuk compiled a list of galaxies with outer ring structures based on the Palomar Sky Atlas and divided them into several groups [5,6]. These studies constituted an important stage in the cataloguing and initial classification of ring galaxies.

The *Catalog of Southern Ringed Galaxies*, compiled by Buta, played an important role in the large-scale systematization of ring galaxies. The catalogue provides morphological descriptions of numerous ringed galaxies located in the southern celestial hemisphere [7]. Buta and Combes analysed the mechanisms responsible for ring formation and demonstrated that rings may arise as a result of resonance processes or interactions and collisions between galaxies [8]. This approach substantiates the need to study ring structures not only in terms of their observable morphology, but also from the perspective of their formation mechanisms.

Fernández et al. conducted a statistical analysis of ringed spiral galaxies using observational data from SDSS DR14. The authors identified 1,868 ringed galaxies and classified them into inner-ringed, outer-ringed, nuclear-ringed, inner-and-outer-ringed, and partial-ring types [9]. According to the results of the study, bars occur more frequently in ringed galaxies, whereas their star-formation activity is lower than that of non-ringed galaxies. These findings confirm that ring structures have a significant influence on the internal dynamics and evolutionary development of galaxies.

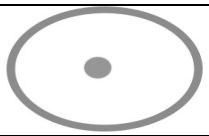
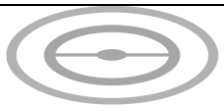
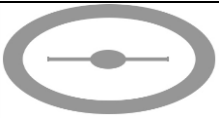
Research methodology. In this study, the classification of ring-like galaxies was investigated on the basis of modern observational catalogues and existing classification approaches. At the initial stage of the research, the catalogue of 8,052 ring-galaxy candidates compiled by Zhang et al. using data from the DESI Legacy Imaging Surveys DR9 was examined. For each object, the catalogue provides the catalogue version, BrickID, ObjID, equatorial coordinates (α, δ), spectroscopic redshift, and flux measurements in the g, r, and z photometric bands [2]. These data were adopted as the primary observational material for the present study.

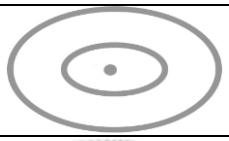
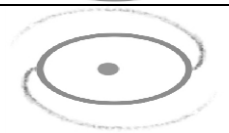
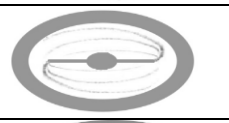
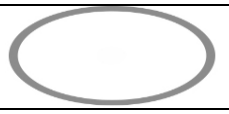
During the preliminary verification stage, the objects listed in the catalogue of Zhang et al. were cross-matched with the data from the Buta catalogue. The comparison was performed using the equatorial coordinates of the objects, namely their α and δ values. The coordinate-based analysis revealed no exact matches between the two catalogues. Therefore, the list of 8,052 ring-galaxy candidates compiled by Zhang et al. was treated as an independent observational sample.

At the next stage, additional information on the catalogue objects was obtained from several astronomical databases. In particular, HyperLEDA, SDSS, and the NASA/IPAC Extragalactic Database were used to verify the galaxy names, morphological types, presence or absence of a bar, whether a ring structure had been recorded, T-type parameters, absolute magnitudes, and observational images. During this process, the numerical catalogue data were compared with actual observational images of the galaxies, and each object was individually assessed to determine whether it exhibited a ring-like structure.

The nine-group classification of ring-like galaxies developed by Mirtadjiyeva and Nuritdinov was adopted as the principal classification framework of the study [1]. In this system, ring-like structures are treated as independent structural components alongside other galactic components, including the nucleus, bar, and spiral arms. A ring is denoted by (R), a bar by (B), a nucleus by (N), an off-centre nucleus by (NL), and spiral arms by (s). When the components are spatially separated, a hyphen is placed between their symbols; conversely, when they are connected, the symbols are written without a hyphen (Table 1). This notation system makes it possible to represent the visible structure of ring-like galaxies in a concise, precise, and systematic manner.

Table 1. Groups of physical ring-like galaxies in the original Mirtadjiyeva–Nuritdinov classification.

№	Classification classes		Brief description	%
1		**R-N; R-NL**	Pure ring-like galaxies with a nucleus. In some cases, the nucleus is lopsided or displaced from the centre (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**	Pure two-ringed galaxies with a nucleus and an internal bar. Typical examples: NGC 2859, NGC 3821, ESO 160-16	**12.5**
4		**R-BN**	Pure ring-like 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 connected to the ring. Typical examples: CSRG 131, NGC 4340	**7**

6		**R-R-N;** **R-R-NL**	Two-ringed galaxies with a nucleus. In some cases, the nucleus is lopsided or displaced from the centre (R–R–NL). Typical examples: ESO 87-51, NGC 7020, IC 5287	**5.5**
7		**R-N(s);** **R-NL(s)**	Ringed galaxies with a nucleus and external spiral branches. In some cases, a lopsided or off-centre nucleus is observed (R–NL(s)). 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, NGC 1269, NGC 1291	**4.5**
9		**R**	Pure ring-like galaxies without a nucleus. Typical examples: Arp 146, Arp 147	**2**

The observational images of the selected objects were analysed according to these classification criteria. Each object was assessed on the basis of the presence of a ring, nucleus, bar, and spiral arms, as well as their relative spatial arrangement. Particular attention was paid to whether the observed ring-like feature appeared as an independent physical structure within the galaxy.

During the analysis, it was found that some objects could not be fully described within the existing nine-group classification. In these galaxies, the relative arrangement of the ring, nucleus, bar, and spiral arms differs from the configurations represented in the previously defined groups. Therefore, using the Mirtadjiyeva–Nuritdinov classification as the basis, the newly observed objects included in the catalogue of Zhang et al. were analysed, and the need to expand the existing classification was substantiated. As a result, the introduction of an additional R10 group was proposed in order to provide a more complete representation of ring-like galaxies.

Analysis and results. During the study, an independent observational sample was initially constructed from the catalogue of 8,052 ring-galaxy candidates compiled by Zhang et al. Information on the object names, morphological types, presence of bars and rings, T-type parameters, absolute magnitudes, and observational images was verified using the HyperLEDA, SDSS, and NASA/IPAC databases. Objects for which no image was available, whose ring-like structure was not clearly visible, or whose apparent ring-like morphology resulted from strongly wound spiral arms were excluded from the sample [10]. As a result, 2,774 of the 8,052 ring-galaxy candidates listed in the catalogue of Zhang et al. were selected as physical ring-like galaxies. These objects were grouped according to their morphological types, and their quantitative distribution was analysed using statistical diagrams.

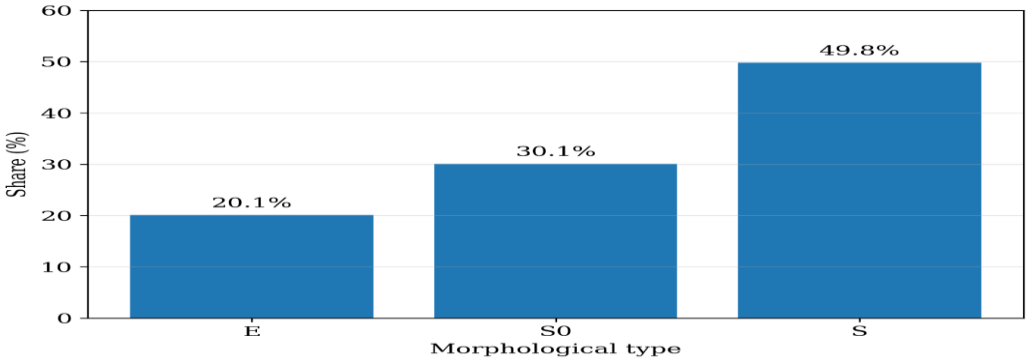


Figure 1. Percentage distribution of 2,774 physical ring-like galaxies by morphological type.

Figure 1 presents the percentage distribution of the selected 2,774 physical ring-like galaxies by morphological type. According to the results, 49.8% of the objects are spiral galaxies, 30.1% are lenticular galaxies, and 20.1% are elliptical galaxies. This finding indicates the predominance of disk galaxies in the analysed sample.

At the next stage, these 2,774 objects were combined with the sample of physical ring-like galaxies previously studied by Mirtadjiyeva and Nuritdinov. Before merging the two samples, the objects were cross-matched using their equatorial coordinates and redshift values, and no overlapping objects were identified on the basis of these parameters. As a result, a consolidated sample comprising 4,144 physical ring-like galaxies was formed for the overall analysis. Using this consolidated sample, a statistical analysis was performed according to the galaxies’ morphological characteristics and the R1–R10 classification groups. For the statistical analysis, the classification groups were conventionally designated as R1–R10. The R1–R9 groups correspond to the classification classes listed sequentially in Table 1, whereas R10 represents the new structural group proposed in the present study.

According to the results of the analysis, the 4,144 physical ring-like galaxies were distributed among ten groups (Figure 2). The largest proportion belonged to the R1 group, which accounted for 52.6% of the total sample. This result indicates that galaxies with a clearly distinguishable ring and central component constitute the dominant class in the consolidated sample. The next largest proportions were found in the R2, R5, and R4 groups, accounting for 11.1%, 10.3%, and 9.1%, respectively. The R3 group comprised 5.7% of the objects, while R7 and R6 accounted for 4.5% and 4.2%, respectively. The R8, R9, and R10 groups represented relatively rare classes, with proportions of 1.7%, 0.7%, and 0.1%, respectively.

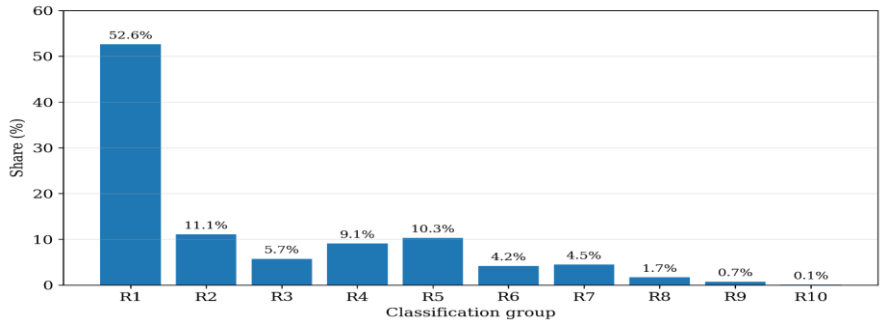


Figure 2. Percentage distribution of 4,144 physical ring-like galaxies across the R1–R10 classification groups.

These results demonstrate the predominance of ring-like galaxies with less complex visible structural configurations, particularly those characterised by a clearly visible ring and central component. Galaxies with more complex structures, including double rings or intricate connections between the bar, ring, and spiral arms, occur less frequently. Nevertheless, the presence of groups with small percentages is important from a classification perspective, as they reflect the structural diversity of ring-like galaxies.

The principal result of the present study is that the nine-group classification developed by Mirtadjiyeva and Nuritdinov was tested and extended using new observational data. The original nine groups provided an important framework for describing the principal structural configurations of ring-like galaxies. However, among the newly selected objects obtained from the initial sample of 8,052 ring-galaxy candidates, several structural configurations were identified that could not be fully represented within the existing groups. Therefore, the classification was provisionally extended by proposing an additional R10 group.

The objects assigned to this group contain a nucleus at the centre of the galaxy, with spiral arms emerging directly from the nucleus, while the ring-like structure is located in the outer region and remains spatially separated from the spiral components. In this configuration, the ring is not directly connected to either the nucleus or the spiral arms and appears as an independent outer ring component. Unlike objects in the R8 group, galaxies in the R10 group do not exhibit a bar; their spiral arms originate directly from the nucleus, whereas the outer ring is located as an independent component detached from the spiral structure. For this reason, these objects were provisionally classified as the R10 group.

The preliminary analysis assigned PGC 1783974, PGC 213617, PGC 1822881, NGC 5528, and PGC 1646069 to the R10 group. Although this group constitutes only a small fraction of the total sample, its identification provides an important basis for further refining the classification of ring-like galaxies. A detailed morphological and photometric analysis of the objects belonging to the R10 group will be addressed separately in future studies.

Conclusion. In this study, the classification of physical ring-like galaxies was reconsidered using modern observational data. The catalogue of 8,052 ring-galaxy candidates compiled by Zhang et al. from the DESI Legacy Imaging Surveys DR9 was analysed, and 2,774 objects were selected as physical ring-like galaxies on the basis of their observational images and morphological characteristics. These objects were combined with the sample of physical ring-like galaxies previously studied by Mirtadjiyeva and Nuritdinov, resulting in a consolidated sample of 4,144 objects.

The results confirmed the scientific significance of the nine-group classification proposed by Mirtadjiyeva and Nuritdinov for describing the principal structural configurations of physical ring-like galaxies. At the same time, several objects in the new observational material could not be fully characterised within the existing groups. Therefore, it was proposed to extend the classification to ten groups on the basis of the relative arrangement of the ring, nucleus, bar, and spiral arms.

The statistical analysis of the consolidated sample of 4,144 objects showed that the R1 group was the most common class, accounting for 52.6% of the total sample. The obtained results demonstrate the structural diversity of ring-like galaxies and confirm the importance of studying ring structures in relation to galactic nuclei, bars, and spiral arms.

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