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Comparison of bulge characteristics in lenticular and spiral galaxies

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We conduct a comparative study of bulges and global properties in a sample of spiral and lenticular galaxies. Our sample consists of 1322 lenticular and spiral galaxies. We classified the bulges of these galaxies into five categories based on their photometric images. Additionally, this article explores the reasons why classical bulges are more common in lenticular galaxies than in spiral galaxies. The main processes of bulge formation, their evolutionary features, and the effects of various types of galaxy interactions and mergers are analyzed. Based on observational data and theoretical models, we investigate the differences in the formation and evolution mechanisms of bulges in lenticular and spiral systems.

Keywords: Bulges, lenticular galaxies, spiral galaxies, galaxy mergers, galaxy structure

1 Introduction

Bulges are among the most interesting structures in the central regions of disk-shaped galaxies. These convexities, primarily composed of old stars, can occupy a significant portion of the central area of a galaxy. Bulges play a crucial role in understanding the dynamics and evolution of the galaxy, as they result from complex formation processes and interactions in galactic centers (Kormendy and Kennicutt (2004); Fisher and Drory (2016)). Observational data show that classical bulges (spheroidal, compact structures) are significantly more common in lenticular galaxies (S0) than in spiral galaxies (S). This article examines the reasons for this phenomenon from the perspective of galaxy evolution and the processes that influence the formation of these structures.

Lenticular galaxies (S0) are characterized by the absence (or very weak presence) of spiral arms in their disks. Traditionally, they are considered an intermediate class between elliptical and spiral galaxies on Hubble's tuning fork diagram. The formation and evolution of S0 galaxies remain an active area of research, with some authors

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(Barsanti et al. (2021), Barway et al. (1991)) suggesting that they are transformed spiral galaxies.

Advances in space- and ground-based observational methods have provided a comprehensive understanding of the structure of S and S0 galaxies, the most abundant galaxy types in the Universe. Their central bulges exhibit convex subsystems. For many years (Jarvis and Freeman (1985), Botirov and Nuritdinov (2021), Fisher and Drory (2011), Barentine and Kormendy (2012), Kormendy et al. (2010), McConnell and Ma (2013)), it was believed that bulges in S and S0 galaxies often have a dome-like shape. For example, our Milky Way also features a nearly dome-shaped bulge in its central region (see, e.g., (Fisher and Drory (2011), Barentine and Kormendy (2012), Kormendy et al. (2010), McConnell and Ma (2013), Botirov et al. (2023)).

Interestingly, some authors argue that bulges can also be identified in elliptical galaxies. However, since elliptical galaxies themselves are convex, there is currently no clear definition of bulges in these galaxies. Therefore, this study focuses on the observational properties of bulges only in S and S0 galaxies.

Classical bulges are more common in S0 galaxies than in spiral galaxies due to differences in their evolution and structural characteristics. They are typically older and exhibit less active star formation compared to spiral galaxies, which often feature young stellar disks and prominent spiral arms. This results in S0 galaxies that accumulate more old stars, forming classical bulges.

To investigate this, we compiled various samples of bulges in spiral galaxies and merged them into a composite catalog, which we update almost monthly. Below, we present the results of our analysis of this catalog.

2 Bulge formation in lenticular and spiral galaxies

The main differences in the frequency of classical bulges in lenticular and spiral galaxies are linked to their formation and evolution mechanisms.

2.1 The role of mergers and interactions

Lenticular galaxies may form through mergers of smaller galaxies. These events can significantly alter the dynamics of a galaxy's central region, leading to the formation of bright, compact bulges. During mergers, stars and gas mix, promoting the concentration of matter in the central areas and creating denser, more compact bulges (Naab and Trujillo (2006)). Additionally, mergers can increase rotational velocity and turbulence in the central regions, enhancing accretion and matter redistribution processes. In contrast, spiral galaxies, especially those not subjected to strong external influences, experience fewer mergers. Their centers remain more stable, and bulges develop more slowly and on smaller scales. Spiral arms continue to be active star-forming regions, further limiting bulge growth.

2.2 Turbulence and accretion

Lenticular galaxies exhibit high turbulence in their central regions, facilitating matter redistribution and the formation of compact structures. Turbulent gas and dust

flows in these galaxies can accelerate accretion processes in the central bulge, leading to classical bulge formation. Active accretion processes, where central black holes consume matter, are often observed in lenticular galaxies, creating high-density bulges (Meidt et al. (2013)). In spiral galaxies, where star formation is more active in the arms, such processes are less common.

2.3 Age and stellar population composition

Bulges in lenticular galaxies are typically composed of old stars, reflecting a later stage of evolution. In contrast, spiral galaxies may retain younger stellar populations in their central regions and spiral arms, resulting in less pronounced bulges with stars of varying ages (Kormendy and Fisher (2008)). This difference is also tied to their star formation histories: in lenticular galaxies, star formation occurs more slowly and primarily in the central regions, while in spiral galaxies, it is more evenly distributed.

3 Observational data analysis

Observations from space telescopes confirm that bulges in lenticular galaxies are often brighter and more compact. For example, studies using high-resolution instruments like the Large Microwave Telescope show that lenticular galaxies have more distinctly defined bulges, whereas spiral galaxies exhibit less prominent ones.

Our study focuses exclusively on bulges in S and S0 galaxies, as they may represent structures with fundamentally different properties and origins.

Figure 1 shows a histogram of the total number of 1322 galaxies classified by bulge type: 1) classical bulges; 2) disk-like bulges; 3) box-shaped bulges; 4) peanut-shaped bulges; 5) pseudo bulges.

Figure 1 shows that classical bulges are the most common, followed by disk-like and then box-shaped bulges (when excluding pseudo bulges), while peanut-shaped bulges are the least frequent. Of these, classic bulges are 440 (∼33%); disk-like bulges, 209 (∼16%); box-shaped bulges, 130 (∼9%); peanut-shaped bulges, 39 (∼3%); pseudo bulges (not yet precisely classified), 504 (∼38%).

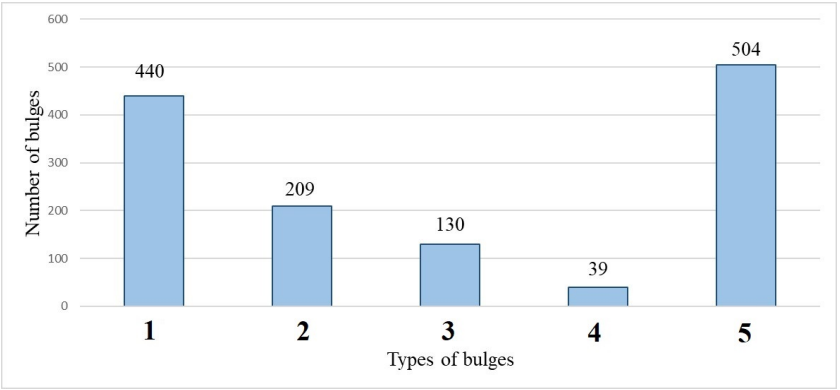


Figure 1 Histogram of the total number of galaxies by bulge types.

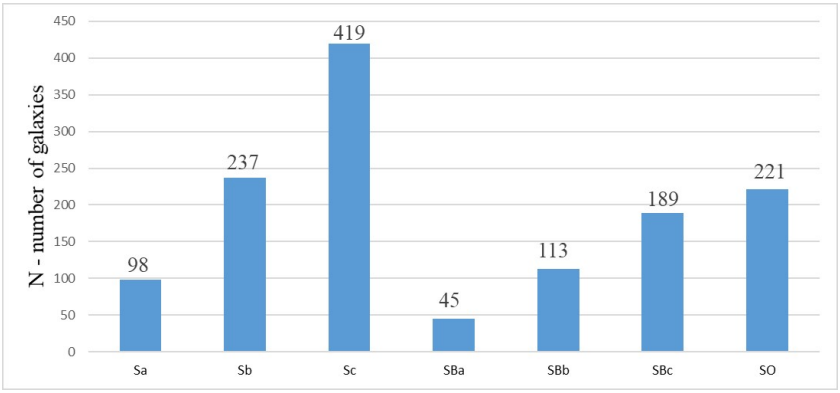


Figure 2 Histogram of the number of galaxies by morphological type.

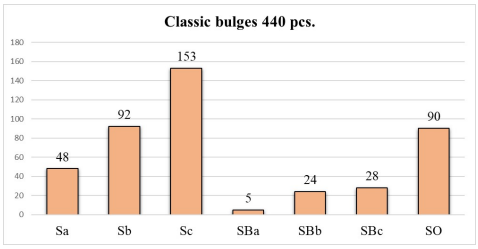


Figure 3 A histogram showing the distribution of galaxies with classical bulges.

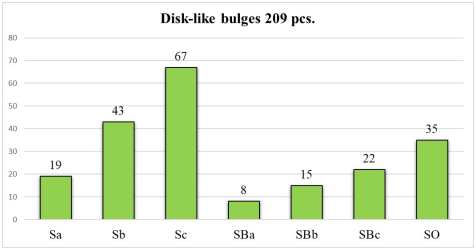


Figure 4 Histogram of the number of galaxies by type for disk-like bulges.

It would also be interesting to determine which types of spiral galaxies are most prevalent. The answer to this question could play a crucial role in understanding bulge formation mechanisms in spiral galaxy disks. Additionally, investigating the influence of bar-like structures is of particular interest. For this purpose, we have constructed the corresponding histogram (Fig. 2).

From this, it is evident that a significantly large number of galaxies correspond to the morphological types Sc and SBc, while the smallest number corresponds to Sa and SBa. The distribution of galaxies with classical bulges is shown in Fig. 3. Similar distributions for disk-like, box-shaped and pseudo bulges by galaxy morphological types are given in Figs. 4–6.

Our study shows that for all types of bulges, as the degree of twist in spiral arms decreases, the number of galaxies consistently increases. This implies that the less tightly wound (open) the spiral arms are, the easier (more) it is to observe the bulge. Thus, we can conclude that classical bulges are more commonly found in lenticular galaxies (which lack spiral arms) than in spiral galaxies. The higher frequency of classical bulges in lenticular galaxies can be attributed to several factors: 1) Lenticular galaxies (S0) are considered an intermediate stage between spiral and elliptical galaxies. They may form from spiral galaxies that have lost their gas and dust, halting star formation and transforming into lenticular galaxies. During this evolution, classical bulges may be preserved or even strengthened. 2) In lenticular galaxies, stars

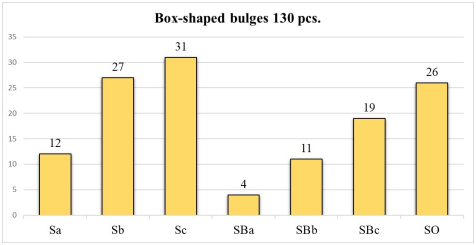


Figure 5 histogram of the number of galaxies for box-shaped bulges.

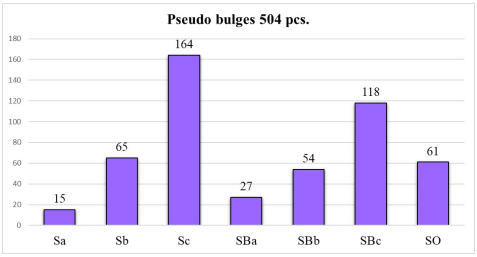


Figure 6 A histogram of the number of galaxies for pseudo bulges.

in the bulge have more chaotic orbits, leading to classical bulge formation. In spiral galaxies, stars in the bulge may have more ordered orbits, resulting in pseudo bulges. 3) Lenticular galaxies may form through galaxy mergers, promoting classical bulge formation. In spiral galaxies, mergers are less frequent or less disruptive, leading to pseudo bulges.

4 What are the main differences between the bulges of lenticular and spiral galaxies?

The main differences between the bulges of lenticular and spiral galaxies are related to their morphology, evolution, age of star populations and the formation mechanism. We consider these differences in more detail:

The bulges of lenticular galaxies often have a compact, well-defined spheroidal or ellipsoidal shape. They may be denser and expand only slightly beyond the central region. In these galaxies, bulges are frequently the result of more aggressive evolution, such as galaxy mergers, which makes them more compact and prominent against the rest of the structure. In contrast, the bulges of spiral galaxies tend to be more elongated and less pronounced compared to those in lenticular galaxies. They are often less luminous and blend more smoothly into the rest of the galaxy. Spiral galaxy bulges are typically less dense and may have a more varied structure due to a mixed population of older and younger stars.

Bulges in lenticular galaxies typically consist predominantly of old stars. These stars have low metallicities, indicating the older age of the bulges. Lenticular galaxies have often undergone several stages of mergers and accretion, which contributed to the concentration of old stars in their central regions. In spiral galaxies, bulges may include both old and younger stars, as star formation continues actively in the spiral arms, influencing the structure of the central region. The bulges of spiral galaxies can be more diverse in terms of stellar population ages.

The bulges of lenticular galaxies often arise from mergers or strong interactions with other galaxies, leading to significant changes in structure and the formation of dense central regions. These processes are frequently accompanied by high turbulence and accretion, promoting the rapid formation of compact bulges. In spiral galaxies, bulges form more slowly and under less extreme conditions. Star formation in the spiral arms occurs regularly and is more evenly distributed throughout the galaxy.

The bulges in these galaxies often develop more smoothly and are not subject to such strong transformations as in lenticular galaxies.

Bulges in lenticular galaxies are usually brighter and denser. They can make up a significant portion of the entire galaxy, especially if the galaxy has experienced multiple mergers. Such bulges may also be surrounded by a flat disk, but their central part is significantly denser and less differentiated. In spiral galaxies, bulges may be less bright and not as dense as in lenticular ones. In these galaxies, bulges often do not constitute a large part of the galaxy, as most of the matter is concentrated in the disk and spiral arms. The central bulge is usually less prominent and not as bright.

The kinematics of stars in the bulges of lenticular galaxies are often more chaotic and heterogeneous. This is due to the effects of mergers and strong gravitational interactions, which can disrupt the more ordered motion of stars characteristic of other galaxy types. In spiral galaxies, stars in the bulges tend to move more orderly, and their orbits are usually more circular or elliptical. This is because, in spiral galaxies, the processes of star formation and accretion are less turbulent, and the central regions remain more stable.

In lenticular galaxies, bulges occupy a central position and dominate the galaxy's structure, whereas in spiral galaxies, bulges may be less pronounced and occupy a smaller part of the central region.

5 Conclusion

Thus, the reasons why classical bulges are more common in lenticular galaxies than in spiral ones are related to differences in their evolution and formation mechanisms. Lenticular galaxies, undergoing more intense mergers and interactions, create conditions for the formation of bright and compact bulges. In spiral galaxies, where star formation occurs in the spiral arms and the central regions remain less active, bulges develop more slowly and are less prominent. These differences highlight the importance of galaxy interactions and mergers in the process of their evolution and the formation of key structures.

The main differences between the bulges of lenticular and spiral galaxies are their shape, the age of stellar populations, formation processes, and brightness. The bulges of lenticular galaxies are usually brighter, more compact, and predominantly composed of old stars, whereas in spiral galaxies, they may be more elongated, less dense, and contain both old and young stellar populations. These differences are directly linked to the distinct evolutionary histories of these galaxy types, as well as the intensity of interactions and mergers in their centers.

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