WIKIPEDIA

Lenticular galaxy

A **lenticular galaxy** is a type of galaxy intermediate between an elliptical and a spiral galaxy in galaxy morphological classification schemes.[1] Lenticular galaxies are disc galaxies (like spiral galaxies) that have used up or lost most of their interstellar matter and therefore have very little ongoing star formation.[2] They may, however, retain significant dust in their disks. As a result, they consist mainly of aging stars (like elliptical galaxies). Because of their ill-defined spiral arms, if they are inclined face-on it is often difficult to distinguish between them and elliptical galaxies. Despite the morphological differences, lenticular and elliptical galaxies share common properties like spectral features and scaling relations. Both can be considered early-type galaxies that are passively evolving, at least in the local part of the Universe.

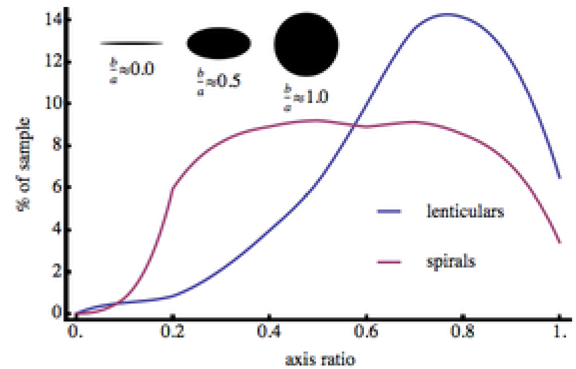
The Spindle Galaxy (NGC 5866), a lenticular galaxy in the Draco constellation. This image shows that lenticular galaxies may retain a considerable amount of dust in their disk. There is little to no gas and thus they are considered deficient in interstellar matter.

Contents

Morphology and structure

Classification

Lenticular galaxies are unique in that they have a visible disk component as well as a prominent bulge component. They have much higher bulge-to-disk ratios than typical spirals and do not have the canonical spiral arm structure of late-type[note 1] galaxies, yet may exhibit a central bar.[3] This bulge dominance can be seen in the axis ratio (i.e. the ratio between the observed minor and major axial of a disk galaxy) distribution of a lenticular galaxy sample. The distribution for lenticular galaxies rises steadily in the range 0.25 to 0.85 whereas the distribution for spirals is essentially flat in that same range.[4] Larger axial ratios can be explained by observing face-on disk galaxies *or* by having a sample of spheroidal (bulge-dominated) galaxies. Imagine looking at two disk galaxies edge-on, one with a bulge and one without a bulge. The galaxy with a prominent bulge will have a larger edge-on axial ratio compared to the galaxy without a bulge based on the definition of axial ratio. Thus a sample of disk galaxies with prominent spheroidal components will have more galaxies at larger axial ratios. The fact that the lenticular galaxy distribution rises with increasing observed axial ratio implies that lenticulars are dominated by a central bulge component.[3]



The percentage of galaxies with a particular axis ratio (minor/major) for a sample of lenticular and spiral galaxies. The inset is a visual representation of the profile of either at the specified minor (b) to major (a) axis ratios.[3]

Lenticular galaxies are often considered to be a poorly understood transition state between spiral and elliptical galaxies, which results in their intermediate placement on the Hubble sequence. This results from lenticulars having both prominent disk and bulge components. The disk component is usually featureless, which precludes a classification system similar to spiral galaxies. As the bulge component is usually spherical, elliptical galaxy classifications are also unsuitable. Lenticular galaxies are thus divided into subclasses based upon either the amount of dust present or the prominence of a central bar. The classes of lenticular galaxies with no bar are $S0_1$, $S0_2$, and $S0_3$ where the subscripted numbers indicate the amount of dust absorption in the disk component; the corresponding classes for lenticulars with a central bar are $SB0_1$, $SB0_2$, and $SB0_3$.[3]

Sérsic decomposition

While ellipticals and spirals tend to have somewhat well-defined Sérsic profiles, the surface brightness profiles of lenticular galaxies are often more difficult to quantify. The disk component of lenticular galaxies often has a very flat surface brightness distribution (Sérsic index of $n \approx 1$), especially in the outermost regions of the disk.[3] Also, there is typically an observed truncation in the surface brightness of lenticular galaxies at ~ 4 scale radii of the disk.[5] These features are consistent with the general structure of spiral galaxies. However, the bulge component of lenticulars is more closely related to elliptical galaxies in terms of morphological classification. This spheroidal region, which dominates the overall structure of lenticular galaxies, has a much steeper surface brightness profile (Sérsic index of $n \approx 4$, or that of a de Vaucouleurs profile) than the disk component.[5] Since the bulge component tends to dominate the galaxy, lenticular galaxy samples are often indistinguishable from elliptical galaxy populations in terms of their overall surface brightness profiles. However, galaxies are often assigned the S0 morphological class when they require multiple Sérsic indices to describe their surface brightness profiles, one to describe the bulge and one to describe the disk.[3] This implies that lenticular galaxies are a distinct morphological subclass of galaxies.

NGC 2787 is an example of a lenticular galaxy with visible dust absorption. While this galaxy has been classified as an S0 galaxy, one can see the difficulty in differentiating between spirals, ellipticals, and lenticulars. Credit: HST

Bars

Like spiral galaxies, lenticular galaxies can possess a central bar structure. While the classification system for normal lenticulars depends on dust content, barred lenticular galaxies are classified by the prominence of the central bar. $SB0_1$ galaxies have the least defined bar structure and are only classified as having slightly enhanced surface brightness along opposite sides of the central bulge. The prominence of the bar increases with index number, thus $SB0_3$ galaxies have very well defined bars that can extend through the transition region between the bulge and disk.[3] Unfortunately, the properties of bars in lenticular galaxies have not been researched in great detail. Understanding these properties, as well as understanding the formation mechanism for bars, would help clarify the formation or evolution history of lenticular galaxies.[5]

Content

In many respects the composition of lenticular galaxies is like that of ellipticals. For example, they both consist of predominately older, hence redder, stars. All of their stars are thought to be older than about a billion years, in agreement with their offset from the Tully–Fisher relation (see below). In addition to these general stellar attributes, globular clusters are found more frequently in lenticular galaxies than in spiral galaxies of similar mass and luminosity. They also have little to no molecular gas (hence the lack of star formation) and no significant hydrogen α or 21-cm emission. Finally, unlike ellipticals, they may still possess significant dust.[3]

Hubble image of ESO 381-12.[6]

Kinematics

Measurement difficulties and techniques

Lenticular galaxies share kinematic properties with both spiral and elliptical galaxies.[8] This is due to the significant bulge and disk nature of lenticulars. The bulge component is similar to elliptical galaxies in that it is pressure supported by a central velocity dispersion. This situation is analogous to a balloon, where the motions of the air particles (stars in a bulge's case) are dominated by random motions. However, the kinematics of lenticular galaxies are dominated by the rotationally supported disk. Rotation support implies the average circular motion of stars in the disk is responsible for the stability of the galaxy. Thus kinematics are often used to distinguish lenticular galaxies from elliptical or spiral galaxies. The distinction between spiral galaxies and lenticular galaxies is often simpler to analyze as the dividing line is often set at a particular bulge-to-disk ratio. Determining the distinction between elliptical galaxies and lenticular galaxies often relies on the measurements of velocity dispersion (σ), rotational velocity (v), and ellipticity (ε).[8] In order to differentiate between lenticulars and ellipticals, one typically looks at the v/σ ratio for a fixed ε. For example, a rough criterion for distinguishing between lenticular and elliptical galaxies is that elliptical galaxies have $v/\sigma < 0.5$ for $\varepsilon = 0.3$.[8] The motivation behind this criterion is that lenticular galaxies do have prominent bulge and disk components whereas elliptical galaxies have no disk structure. Thus, lenticulars have much larger v/σ ratios than ellipticals due to their non-negligible rotational velocities (due to the disk component) in addition to not having as prominent of a bulge component compared to elliptical galaxies.

NGC 4866 is a lenticular galaxy located in the constellation of Virgo.[7]

The kinematics of disk galaxies are usually determined by Hα or 21-cm emission lines, which are typically not present in lenticular galaxies due to their general lack of cool gas.[5] Thus kinematic information and rough mass estimates for lenticular galaxies often comes from stellar absorption lines, which are less reliable than emission line measurements. There is also a considerable amount of difficulty in deriving accurate rotational velocities for lenticular galaxies. This is a combined effect from lenticulars having difficult inclination measurements, projection effects in the bulge-disk interface region, and the random motions of stars affecting the true rotational velocities.[9] These effects make kinematic measurements of lenticular galaxies considerably more difficult compared to normal disk galaxies.

Offset Tully–Fisher relation

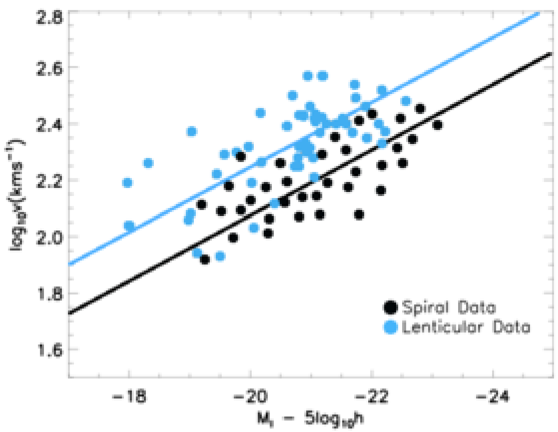
The kinematic connection between spiral and lenticular galaxies is most clear when analyzing the Tully–Fisher relation for spiral and lenticular samples. If lenticular galaxies are an evolved stage of spiral galaxies then they should have a similar Tully–Fisher relation with spirals, but with an offset in the luminosity / absolute magnitude axis. This would result from brighter, redder stars dominating the stellar populations of lenticulars. An example of this effect can be seen in the adjacent plot.[5] One can clearly see that the best-fit lines for the spiral galaxy data and the lenticular galaxy have the same slope (and thus follow the same Tully–Fisher relation), but are offset by $\Delta I \approx 1.5$. This implies that lenticular galaxies were once spiral galaxies but are now dominated by old, red stars.

Formation theories

The morphology and kinematics of lenticular galaxies each, to a degree, suggest a mode of galaxy formation. Their disk-like, possibly dusty, appearance suggests they come from faded spiral galaxies, whose arm features disappeared. Alternatively, as lenticular galaxies are likely to be more luminous than spiral galaxies, which suggests that they are not merely the faded remnants of spiral galaxies. Rather, lenticular galaxies might result from galaxy merger, which increase the total stellar mass and give the newly merged galaxy its disk-like, arm-less appearance.[5] Recent research suggest that the evolution of luminous lenticular galaxies may be closely linked to that of elliptical galaxies, whereas fainter lenticulars might be more closely associated with ram-pressure stripped spiral galaxies.[12]

Faded spirals

The absence of gas, presence of dust, lack of recent star formation, and rotational support are all attributes one might expect of a spiral galaxy which had used up all of its gas in the formation of stars.[5] This possibility is further enhanced by the existence of gas poor, or "anemic," spiral galaxies. If the spiral pattern then dissipated the resulting galaxy would be similar to many lenticulars.[13] Moore et al. also document that tidal harassment - the gravitational effects from other, near-by galaxies - could aid this process in dense regions.[14] The clearest support for this theory, however, is their adherence to slightly shifted version of Tully–Fisher relation, discussed above.



This plot illustrates the Tully–Fisher relation for a spiral galaxy sample (black) as well as a lenticular galaxy sample (blue).[10] One can see how the best-fit line for spiral galaxies differs from the best-fit line for lenticular galaxies.[11]

A 2012 paper that suggests a new classification system, first proposed by the Canadian astronomer Sidney van den Bergh, for lenticular and dwarf spheroidal galaxies (S0a-S0b-S0c-dSph) that parallels the Hubble sequence for spirals and irregulars (Sa-Sb-Sc-Im) reinforces this idea showing how the spiral–irregular sequence is very similar to this new one for lenticulars and dwarf ellipticals.[15]

Mergers

The analyses of Burstein[16] and Sandage[17] showed that lenticular galaxies typically have surface brightness much greater than other spiral classes. It is also thought that lenticular galaxies exhibit a larger bulge-to-disk ratio than spiral galaxies and this may be inconsistent with simple fading from a spiral.[18][19] If S0s were formed by mergers of other spirals these observations would be fitting and it would also account for the increased frequency of globular clusters. It should be mentioned, however, that advanced models of the central bulge which include both a general Sersic profile and bar indicate a smaller bulge,[20] and thus a lessened inconsistency. Mergers are also unable to account for the offset from the Tully–Fisher relation without assuming that the merged galaxies were quite different from those we see today.

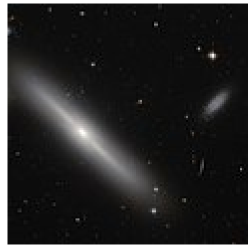
Examples

- Cartwheel Galaxy, lenticular galaxy about 500 million light-years away in the constellation Sculptor
- NGC 2787, a barred lenticular galaxy

Gallery

NGC 1222 contains three compact regions.[21]

PGC 83677 image obtained as part of the Coma Cluster Survey.[22]



Lenticular galaxy NGC 5308 is located just under 100 million light-years away in the constellation of Ursa Major.[23]

NGC 4111 is a lenticular galaxy, lying about 50 million light-years away in the constellation of Canes Venatici.[24]

Mrk 820 is a lenticular galaxy classified as type S0 on the Hubble Tuning Fork.[25]

Messier 84 is a lenticular galaxy also known for its supernovae.[26]

NGC 6861 is a lenticular galaxy discovered in 1826 by the Scottish astronomer James Dunlop.[27]

Cartwheel Galaxy

See also

- Spindle galaxy

Notes

1. Galaxies to the left side of the Hubble classification scheme are sometimes referred to as "early-type", while those to the right are "late-type".

References

1. R. J. Buta; H. G. Corwin, Jr.; S. C. Odewahn (2007s). *The de Vaucouleurs Atlas of Galaxies*. Cambridge: Cambridge University. ISBN 978-0521820486.
2. DeGraaff, Regina Barber; Blakeslee, John P.; Meurer, Gerhardt R.; Putman, Mary E. (December 2007). "A Galaxy in Transition: Structure, Globular Clusters, and Distance of the Star-Forming S0 Galaxy NGC 1533 in Dorado". *The Astrophysical Journal*. **671** (2): 1624–1639. Bibcode:2007ApJ...671.1624D (http://adsabs.harvard.edu/abs/2007ApJ...671.1624D). doi:10.1086/523640 (https://doi.org/10.1086%2F523640).
3. Binney & Merrifield (1998). *Galactic Astronomy*. ISBN 0-691-02565-7.
4. Lambas, D.G.; S.J.Maddox and J. Loveday (1992). "On the true shapes of galaxies". *MNRAS*. **258** (2): 404–414. Bibcode:1992MNRAS.258..404L (http://adsabs.harvard.edu/abs/1992MNRAS.258..404L). doi:10.1093/mnras/258.2.404 (https://doi.org/10.1093%2Fmnras%2F258.2.404).
5. Blanton, Michael; John Moustakas (2009). "Physical Properties and Environments of Nearby Galaxies". *Annual Review of Astronomy and Astrophysics*. **47** (1): 159–210. arXiv:0908.3017 (https://arxiv.org/abs/0908.3017). Bibcode:2009ARA&A..47..159B (http://adsabs.harvard.edu/abs/2009ARA&A..47..159B). doi:10.1146/annurev-astro-082708-101734 (https://doi.org/10.1146%2Fannurev-astro-082708-101734).
6. "A galaxy in bloom" (http://www.spacetelescope.org/news/heic1516/). Retrieved 13 July 2015.
7. "A stranger in the crowd" (http://www.spacetelescope.org/images/potw1328a/). *ESA/Hubble Picture of the Week*. Retrieved 21 July 2013.
8. Moran, Sean M.; Boon Liang Loh; Richard S. Ellis; Tommaso Treu; Kevin Bundy; Lauren MacArthur (20 August 2007). "The Dynamical Distinction Between Elliptical and Lenticular Galaxies in Distant Clusters: Further Evidence for the Recent Origin of S0 Galaxies". *The Astrophysical Journal*. **665** (2): 1067–1073. arXiv:astro-ph/0701114 (https://arxiv.org/abs/astro-ph/0701114). Bibcode:2007ApJ...665.1067M (http://adsabs.harvard.edu/abs/2007ApJ...665.1067M). doi:10.1086/519550 (https://doi.org/10.1086%2F519550).
9. Bedregal, A.G.; A. Aragon-Salamanca; M.R. Merrifield; B. Milvang-Jensen (October 2006). "S0 Galaxies in Fornax: data and kinematics". *Monthly Notices of the Royal Astronomical Society*. **371** (4): 1912–1924. arXiv:astro-ph/0607434 (https://arxiv.org/abs/astro-ph/0607434). Bibcode:2006MNRAS.371.1912B (http://adsabs.harvard.edu/abs/2006MNRAS.371.1912B). doi:10.1111/j.1365-2966.2006.10829.x (https://doi.org/10.1111%2Fj.1365-2966.2006.10829.x).
10. Bedregal, A. G.; A. Aragon-Salamanca; M. R. Merrifield (December 2006). "The Tully-Fisher relation for S0 galaxies". *Monthly Notices of the Royal Astronomical Society*. **373** (3): 1125–1140. arXiv:astro-ph/0609076 (https://arxiv.org/abs/astro-ph/0609076). Bibcode:2006MNRAS.373.1125B (http://adsabs.harvard.edu/abs/2006MNRAS.373.1125B). doi:10.1111/j.1365-2966.2006.11031.x (https://doi.org/10.1111%2Fj.1365-2966.2006.11031.x).
11. Courteau, Stephane; Aaron A. Dutton; Frank C. van den Bosch; Lauren A. MacArthur; Avishai Dekel; Daniel H. McIntosh; Daniel A. Dale (10 December 2007). "Scaling Relations of Spiral Galaxies". *The Astrophysical Journal*. **671** (1): 203–225. arXiv:0708.0422 (https://arxiv.org/abs/0708.0422). Bibcode:2007ApJ...671..203C (http://adsabs.harvard.edu/abs/2007ApJ...671..203C). doi:10.1086/522193 (https://doi.org/10.1086%2F522193).
12. Sidney van den Bergh. "Luminosities of Barred and Unbarred S0 Galaxies". *The Astrophysical Journal*. **754**: 68. arXiv:1205.6183 (https://arxiv.org/abs/1205.6183). Bibcode:2012ApJ...754...68V (http://adsabs.harvard.edu/abs/2012ApJ...754...68V). doi:10.1088/0004-637X/754/1/68 (https://doi.org/10.1088%2F0004-637X%2F754%2F1%2F68).
13. Elmegreen, Debra; Bruce G. Elmegreen; Jay A. Frogel; Paul B. Eskridge; Richard W. Pogge; Andrew Gallagher; Joel Iams (2002). "Arm Structure in Anemic Spiral Galaxies". *The Astronomical Journal*. **124** (2): 777–781. arXiv:astro-ph/0205105 (https://arxiv.org/abs/astro-ph/0205105). Bibcode:2002AJ....124..777E (http://adsabs.harvard.edu/abs/2002AJ....124..777E). doi:10.1086/341613 (https://doi.org/10.1086%2F341613).

14. Moore, Ben; George Lake; Neal Katz (1998). "Morphological Transformation from Galaxy Harassment". *The Astrophysical Journal*. **495** (1): 139–151. arXiv:astro-ph/9701211 (https://arxiv.org/abs/astro-ph/9701211). Bibcode:1998ApJ...495..139M (http://adsabs.harvard.edu/abs/1998ApJ...495..139M). doi:10.1086/305264 (https://doi.org/10.1086%2F305264).
15. Kormendy, John; Ralf Bender (2012). "A Revised Parallel-sequence Morphological Classification of Galaxies: Structure and Formation of S0 and Spheroidal Galaxies". *The Astrophysical Journal Supplement*. **198** (1): 2. arXiv:1110.4384 (https://arxiv.org/abs/1110.4384). Bibcode:2012ApJS..198....2K (http://adsabs.harvard.edu/abs/2012ApJS..198....2K). doi:10.1088/0067-0049/198/1/2 (https://doi.org/10.1088%2F0067-0049%2F198%2F1%2F2).
16. Burstein, D; Ho LC; Huchra JP; Macri LM (2005). "TheK-Band Luminosities of Galaxies: Do S0s Come from Spiral Galaxies?". *The Astrophysical Journal*. **621** (1): 246–55. Bibcode:2005ApJ...621..246B (http://adsabs.harvard.edu/abs/2005ApJ...621..246B). doi:10.1086/427408 (https://doi.org/10.1086%2F427408).
17. Sandage, A (2005). "THE CLASSIFICATION OF GALAXIES: Early History and Ongoing Developments". *Annual Review of Astronomy and Astrophysics*. **43** (1): 581–624. Bibcode:2005ARA&A..43..581S (http://adsabs.harvard.edu/abs/2005ARA&A..43..581S). doi:10.1146/annurev.astro.43.112904.104839 (https://doi.org/10.1146%2Fannurev.astro.43.112904.104839).
18. Dressler, A; Gilmore, Diane M. (1980). "On the interpretation of the morphology-density relation for galaxies in clusters". *The Astrophysical Journal*. **236**: 351–65. Bibcode:1991ApJ...367...64W (http://adsabs.harvard.edu/abs/1991ApJ...367...64W). doi:10.1086/169602 (https://doi.org/10.1086%2F169602).
19. Christlein, D; Zabludoff AI (2004). "Can Early-Type Galaxies Evolve from the Fading of the Disks of Late-Type Galaxies?". *The Astrophysical Journal*. **616** (1): 192–98. arXiv:astro-ph/0408036 (https://arxiv.org/abs/astro-ph/0408036). Bibcode:2004ApJ...616..192C (http://adsabs.harvard.edu/abs/2004ApJ...616..192C). doi:10.1086/424909 (https://doi.org/10.1086%2F424909).
20. Laurikainen, Eija; Heikki Salo; Ronald Buta (October 2005). "Multicomponent decompositions for a sample of S0 galaxies". *MNRAS*. **362** (4): 1319–1347. arXiv:astro-ph/0508097 (https://arxiv.org/abs/astro-ph/0508097). Bibcode:2005MNRAS.362.1319L (http://adsabs.harvard.edu/abs/2005MNRAS.362.1319L). doi:10.1111/j.1365-2966.2005.09404.x (https://doi.org/10.1111%2Fj.1365-2966.2005.09404.x).
21. "A greedy giant" (https://www.spacetelescope.org/images/potw1645a/). *www.spacetelescope.org*. Retrieved 7 December 2016.
22. "Standing out from the crowd" (http://www.spacetelescope.org/images/potw1637a/). *www.spacetelescope.org*. Retrieved 12 September 2016.
23. "Busy bees" (http://www.spacetelescope.org/images/potw1620a/). Retrieved 16 May 2016.
24. "Elegance conceals an eventful past" (http://www.spacetelescope.org/images/potw1616a/). Retrieved 18 April 2016.
25. "At the centre of the tuning fork" (http://www.spacetelescope.org/images/potw1544a/). Retrieved 2 November 2015.
26. "A fascinating core" (http://www.spacetelescope.org/images/potw1522a/). Retrieved 8 June 2015.
27. "The third way of galaxies" (http://www.spacetelescope.org/images/potw1502a/). *www.spacetelescope.org*. ESA/Hubble. Retrieved 12 January 2015.