

Use all available information to determine answers relating to **quasars, AGNs, galaxy clusters, and groups of galaxies**, including star formation, massive and **supermassive** black holes, galactic structure, globular clusters, Type Ia and Type II supernovae, eclipsing binaries and X-ray binaries.

# 1 Properties of Galaxies

## 1.1 History

derived from the Greek *galaxias*, meaning milky.

## 1.2 Galaxy Morphological Classification

astronomers divide galaxies into groups based on their visual appearance. the most often used is the **Hubble sequence**, invented by Edwin Hubble in 1926.

### 1.2.1 Elliptical Galaxies

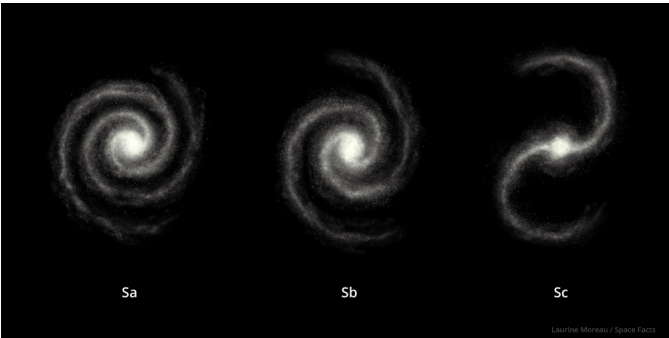

General Characteristics	<ul style="list-style-type: none"> <li>• smooth, featureless image comprised of ovoid masses of stars attached by the gravitational attraction b/w them</li> <li>• no rotational axis — stars show wide range of orbital paths around center, primarily radial motion; slight uniformity is what determines overall shape of the galaxy</li> </ul>
Stars	<ul style="list-style-type: none"> <li>• ellipticals contain mostly <b>old stars</b> <ul style="list-style-type: none"> <li>– more red in color</li> <li>– very little gas and dust hampers formation of new stars</li> </ul> </li> </ul>
Shapes and Sizes	<ul style="list-style-type: none"> <li>• highest variability of all galaxy types: <ul style="list-style-type: none"> <li>– wide range of masses — <math>10^5</math> to <math>10^{13}</math> solar masses</li> <li>– wide range of sizes — observations showing that objects can have diameters of between 1 and 100 kiloparsecs (or 3260 to 326,000 light years)</li> <li>– wide range of brightnesses — some can be up to 10 times brighter than the brightest spirals. At the other end of the scale, the faintest ellipticals can be 1000 times less luminous than the faintest spirals</li> </ul> </li> <li>• The Hubble classification of elliptical galaxies contains an integer, <math>n</math> that describes how elongated the galaxy image is. The classification is determined by the ratio of the major (a) to the minor (b) axes of the galaxy's isophotes*: <math>10 \times (1 - \frac{b}{a})</math></li> <li>• thus, a given elliptical galaxy can be classified as <math>E_n</math>, where an <math>E_0</math> galaxy is spherical, and an <math>E_7</math> galaxy is flat. this classification is dependent on the angle from which the galaxy is viewed and thus does not affect its physical properties, but is useful for describing how a galaxy appears through a telescope.</li> </ul>

Evolution	<ul style="list-style-type: none"> <li>• astronomers believe that elliptical galaxies form earlier than spiral galaxies, but they can still have quantities of gas and dust, and can still be very noisy in the radio spectrum. evidence has shown that a reasonable proportion (25%) of early-type (E, ES and S0) galaxies have residual gas reservoirs and low level star-formation.</li> <li>• evolve from the fusion of smaller, gravitationally bound galaxies which are of similar size</li> <li>• more commonly found around clusters and groups of galaxies due to forming from fusion. They are less frequently spotted in the early universe, which supports the idea that they evolved from the collisions that came later in the life of a galaxy.</li> <li>• A supermassive black hole is thought to lie at the center of these ancient galaxies. These gluttonous giants consume gas and dust, and may play a role in the slower growth of elliptical galaxies.</li> </ul>
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### 1.2.2 Dwarf Elliptical Galaxy

General Characteristics	elliptical galaxies that are smaller than ordinary elliptical galaxies. They are quite common in galaxy groups and clusters, and are usually companions to other galaxies. Low-luminosity elliptical galaxies are distinguished from late-type galaxies (spirals and irregulars) by their smooth surface-brightness profiles. Despite their name, dwarf ellipticals are not really fainter versions of true elliptical galaxies, but are structurally distinct.
Shapes and Sizes	<p>Dwarf elliptical galaxies have blue absolute magnitudes* within the range <math>-18\text{mag} &lt; M &lt; -14\text{ mag}</math>, fainter than ordinary elliptical galaxies. Below luminosities of MB approx -18 the smooth-profile galaxies divide into two classes: compact galaxies with high central surface brightnesses (exemplified by M32), and diffuse galaxies with low central surface brightnesses (exemplified by the Local Group dwarf spheroidals).</p> <p>Typical dE's have masses of about one billion solar masses, or about 1/1000th that of a typical giant galaxy. They contain very little or no gas, which makes them different from dwarf irregular galaxies. Three relatively bright dE's are known in the Local Group: NGC 147, 185, and NGC 205, all companions of the Andromeda Galaxy. Hundreds of similar galaxies exist in the relatively nearby Virgo Cluster.</p>
Evolution	<ul style="list-style-type: none"> <li>• thought to be primordial objects built from the coalescing of dark matter and gas objects to form the building blocks of ordinary galaxies</li> <li>• alternately, they could be the remains of low-mass spiral galaxies that were transfigured into a rounder shape through repeated galaxy harassment* from ordinary galaxies within a cluster. <ul style="list-style-type: none"> <li>– evidence for the hypothesis had been claimed by studying early-type dwarf galaxies in the Virgo Cluster and finding structures, such as disks and spiral arms, which suggest they are former disk systems transformed by the above-mentioned interactions.</li> <li>– however, the existence of similar structures in isolated early-type dwarf galaxies, such as LEDA 2108986, has undermined this hypothesis.</li> </ul> </li> </ul>

### 1.2.3 Spiral Galaxies

General Characteristics	<p>Most spiral galaxies consist of a flat, rotating disk containing stars, gas and dust, and a central concentration of stars known as the bulge. These are often surrounded by a much fainter halo of stars, many of which reside in globular clusters*. Together with irregular galaxies, spiral galaxies make up approximately 60% of galaxies in today's universe. They are mostly found in low-density regions and are rare in the centers of galaxy clusters.</p>
Shapes and Sizes	<ul style="list-style-type: none"> <li>Each spiral galaxy is classified with a label which gives some indication of its appearance: <ul style="list-style-type: none"> <li><math>S_a</math> — tightly wound spiral arms w/ large central nuclei.</li> <li><math>S_b</math> — looser bound spiral arms w/ smaller central nuclei. the majority of spiral galaxies are of type <math>S_b</math>.</li> <li><math>S_c</math> — very open, “untidy” spiral arms and relatively small nuclei. often referred to as the “grand design.”</li> </ul> </li> </ul>  <p style="text-align: right; font-size: small;">Laurence Moreau / Space Facts</p> <ul style="list-style-type: none"> <li><math>\frac{2}{3}</math> spirals have an additional bar-like elongation of stars extending from the central bulge at the ends of which the spiral arms begin <ul style="list-style-type: none"> <li>the proportion of barred galaxies has changed over the history of the universe from 10% to the current amt</li> <li>these are denoted by the additional label <math>SB</math></li> </ul> </li> </ul>  <p style="text-align: center; font-size: small;">© Anglo-Australian Observatory</p> <ul style="list-style-type: none"> <li><b>bulge</b> — a huge, tightly packed central group of stars, often defined as the excess of stellar light above the inward extrapolation of the outer (exponential) disk light. Many bulges are thought to host a supermassive black hole at their centers.</li> </ul>

## Glossary

**absolute magnitude** a measure of the luminosity of a celestial object, on a logarithmic astronomical magnitude scale. An object's absolute magnitude is defined to be equal to the apparent magnitude that the object would have if it were viewed from a distance of exactly 10 parsecs (32.6 light-years), with no extinction (or dimming) of its light due to absorption by interstellar dust particles. By hypothetically placing all objects at a standard reference distance from the observer, their luminosities can be directly compared on a magnitude scale. 2, 5

**galaxy harassment** a type of interaction between a low-luminosity galaxy and a brighter one that takes place within rich galaxy clusters, such as Virgo and Coma, where galaxies are moving at high relative speeds and suffering frequent encounters with other systems of the cluster by the high galactic density of the latter. According to computer simulations, the interactions convert the affected galaxy disks into disturbed barred spiral galaxies and produces starbursts followed by, if more encounters occur, loss of angular momentum and heating of their gas. The result would be the conversion of (late type) low-luminosity spiral galaxies into dwarf spheroidals and dwarf ellipticals. 2, 5

**globular cluster** a spherical collection of stars that orbits a galactic core as a satellite. Globular clusters are very tightly bound by gravity, which gives them their spherical shapes and relatively high stellar densities toward their centers. they are found in the halo of the galaxy. Every galaxy of sufficient mass in the Local Group has an associated group of globular clusters, and almost every large galaxy surveyed has been found to possess a system of globular clusters. Although it appears that globular clusters contain some of the first stars to be produced in the galaxy, their origins and their role in galactic evolution are still unclear. It does appear clear that globular clusters are significantly different from dwarf elliptical galaxies and were formed as part of the star formation of the parent galaxy rather than as a separate galaxy. 2, 5

**isophote** a curve on an illuminated surface that connects points of equal brightness. In astronomy, the isophote is commonly used to define two things: the shape of an object, and the amount of light it gives off. The most common use of isophotes in astronomy is in the imaging and classification of galaxies, particularly of elliptical galaxies. The isophotes of elliptical galaxies provide information on a galaxy's shape, and hence upon its structure and dynamical behavior. Isophotes can be used on spiral galaxies, too, particularly to measure their radii, or to map the structures within their spiral arms. Isophotes are also used to measure the size, structure, and brightness of many gaseous or tenuous objects, such as X-ray galaxy clusters, radio jets from quasars, and the distribution of dust in our Galaxy. They have even been used to map the light reflected from the Moon and other planets to understand the properties of their surfaces. 1, 5

**open cluster** a group of up to a few thousand stars that were formed from the same giant molecular cloud and have roughly the same age, found in the disk of a galaxy. They are loosely bound by mutual gravitational attraction and become disrupted by close encounters with other clusters and clouds of gas as they orbit the galactic center. This can result in a migration to the main body of the galaxy and a loss of cluster members through internal close encounters. Open clusters generally survive for a few hundred million years, with the most massive ones surviving for a few billion years. In contrast, the more massive globular clusters of stars exert a stronger gravitational attraction on their members, and can survive for longer. Open clusters have been found only in spiral and irregular galaxies, in which active star formation is occurring. 5