Astronomy 401/Physics 903
Lecture 5
Types of Galaxies and the Hubble Sequence

1 Are there other galaxies outside the Milky Way?

A bit of historical perspective: fuzzy things in the sky (called "nebulae") had been catalogued, but it wasn't known whether or not they were part of the Milky Way. If the Milky Way was a finite disk of stars, perhaps there were other, similar disks farther away. The philosopher Immanuel Kant suggested this in the 18th century, and called these systems "island universes." The debate continued into the 20th century, and was formalized in what's called the "Great Debate." In 1920, Harlow Shapley (the one who determined that we aren't at the center of the Milky Way by looking at the distribution of globular clusters) and William Curtis debated this question. Shapley argued that the nebulae were part of the Milky Way, and Curtis argued the reverse. The debate highlighted the issues rather than settled the question; it wasn't answered definitively until 1923 when Edwin Hubble measured the distance to Andromeda with a Cepheid variable star (using the 100-inch Hooker Telescope at Mount Wilson Observatory, in the San Gabriel Mountains above Pasadena, CA), and realized that it was so far away that it could not be part of the Milky Way.

1.1 Aside: Cepheid variable stars

- Pulsating variable stars whose period is proportional to their luminosity
- **Period-luminosity relation** discovered by Henrietta Swan Leavitt in early 20th century
- If we measure the pulsation period, we then know the luminosity of the star and therefore can determine how far away it is (but the method must be calibrated with another distance indicator!)
- One of the most important astronomical distance indicators
- Closest Cepheid is Polaris
- Pulsating stars lie on the **instability strip** in the H-R diagram, in some phases of post-main-sequence evolution
- In addition to Cepheid variables, **RR Lyrae** stars are also pulsating stars which can be used as a distance indicator. They are not as bright as Cepheids, so they are less useful for measuring large distances
- See Schneider section 2.2.7 for an order of magnitude derivation of the period-luminosity relationship

2 The Hubble sequence

Once it was known that there were other galaxies out there, we needed to classify them. Goals of a galaxy classification scheme:

- Impose order
- Reveal correlations between properties or evolution
- Classification should be complete—include every galaxy

- Classification should be economical—don't include irrelevant details (how do we know which details are irrelevant?)

In 1926, Edwin Hubble suggested a classification scheme which is still used today. This is a morphological classification scheme which divides galaxies into categories based on their overall appearance. Three general categories, with subdivisions:

- Ellipticals (E)
- Spiral, divided into normal spirals (S) and barred spirals (SB)
- Irregular

Galaxies intermediate between spirals and ellipticals are called lenticular (S0 or SB0).

The types of galaxies were arranged in a diagram shaped like a tuning fork. A galaxy's classification according to this scheme is called its Hubble type.

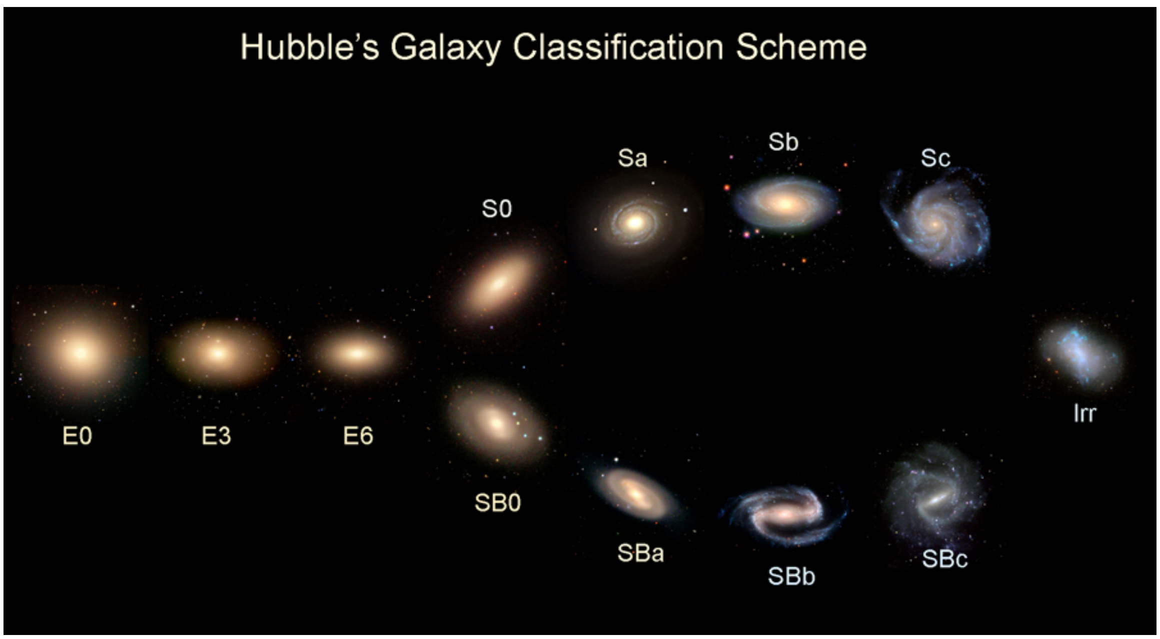


Figure 1: The Hubble galaxy classification scheme.

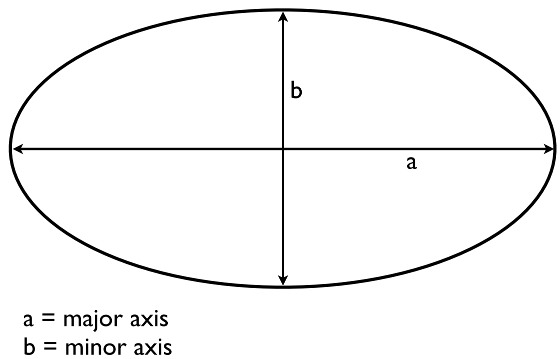
Hubble originally thought that this might be an evolutionary sequence, and therefore called elliptical galaxies *early types* and spiral galaxies *late types* (with Sc later than Sa). This isn't true, but astronomers still use the early and late terms to describe these types of galaxies.

2.1 Elliptical galaxies

Elliptical galaxies are classified according to their observed **ellipticity**. We measure the major axis a and minor axis b, and define the ellipticity

$$\epsilon \equiv 1 - b/a \tag{1}$$

with $0 \leq \epsilon \lesssim 0.7$. We classify the galaxy using the notation En, where $n = 10\epsilon = 10(1 - b/a)$, rounded to the nearest integer.



There are no ellipticals seen with shapes flatter than E7.

Obvious problem: classification depends on our viewing angle, and the observed ellipticity may not be the actual ellipticity of the galaxy. Note though that the true flattening is always greater than or equal to what we observe.

Elliptical galaxies are **triaxial**: spheroids with axes a, b and c. For a sphere, $a = b = c$. Galaxies may be **oblate** or **prolate**. A perfectly oblate galaxy has $a = b$ and $c < a$: flattened sphere. A perfectly prolate galaxy has $b = c$ and $a > b$: one axis extended, like a football. These two galaxies can look the same, depending on the viewing angle.

There is a wide variety of elliptical galaxies: giant ellipticals are the biggest galaxies in the universe, and the smallest dwarfs are comparable in size to globular clusters. Mass range $\sim 10^7$ to $\sim 10^{13}$ $\mathrm{M}_\odot$.

2.2 Spiral galaxies

Spiral galaxies have a disk with spiral arm structure and a central bulge. They are divided into subclasses: normal spirals (S), and barred spirals (SB). Features used to classify spiral galaxies:

- Bulge-to-disk ratio, B/D, the ratio of the luminosities of the bulge and the disk. Largest $L_{\rm bulge}/L_{\rm disk} \sim 0.3$.
- Smoothness of the distribution of stars. Reflects current star formation, since bright spots are regions where hot, bright young stars have just formed.
- Pitch angle of spiral arms: how tightly wound the spiral arms are

Galaxies with the largest bulge-to-disk ratios, smoothest stellar distributions, and most tightly wound spiral arms are Sa (or SBa). Sc (and SBc) galaxies have smaller B/D ($L_{\rm bulge}/L_{\rm disk} \sim 0.05$), loosely wound spiral arms, and the spiral arms are clumpy, can be resolved into stars and HII regions (HII, ionized hydrogen—compare HI. Hot young stars ionize the gas around them, and these are called HII regions.)

Spiral galaxies are large, with masses $\sim 10^9$ to $\sim 10^{12}$ $\mathrm{M}_\odot$, and don't vary as much as elliptical galaxies. M31 (Andromeda) is Sb. Milky Way is probably SBbc.

2.3 Irregular galaxies

Remaining galaxies were called irregular, placed off to the side of the diagram. These are usually not very large, but can vary widely.

3 General trends

- Spiral galaxies are generally blue, ellipticals red
- Spirals have more dust and gas than ellipticals
- Most current star formation occurs in spirals
- These things are related, since young stars are blue and form out of gas

4 Surface brightness

Our goal is to understand the 3-d structure of galaxies. How do we get to this from what we can observe?

Easiest to observe: the 2-d surface brightness of a galaxy.

Surface brightness Σ: luminosity per unit area (e.g. $\mathrm{L}_\odot\ \mathrm{pc}^{-2}$). Also used, μ, magnitudes per square arcsecond. This is what we actually measure.

The surface brightness of the night sky isn't zero (depends on wavelength, and rises strongly in the IR), so it's hard to observe faint galaxies. Background subtraction is usually necessary, and sometimes the sky is brighter than the galaxies of interest.

For nearby galaxies (when we can neglect cosmological effects) surface brightness does not depend on distance d:

$$\Sigma = \frac{\text{flux}}{\Omega} \approx \frac{L/d^2}{\text{area}/d^2} \approx \frac{L}{\text{area}} \approx \text{ constant} \tag{2}$$

Ω is the angular area of the source. Flux from a patch of sky decreases as $1/d^2$, but the angular area of the patch also decreases as $1/d^2$, so the surface brightness is constant. (This is no longer true for galaxies with a significant redshift; as we'll see later in the cosmology section of the course, surface brightness decreases with redshift as $(1+z)^{-4}$, which means that the observed surface brightness is 68% of its intrinsic value at $z \sim 0.1$, corresponding to a distance of ~ 400 Mpc.)

Measurement of light from astronomical sources is called **photometry**. Measuring the spatial distribution of light from an object is called **surface photometry**. One way to do this is to look at an image of a galaxy and map lines of constant surface brightness—these are called **isophotes**.