Today's Topics

Wednesday, April 23, 2025 (Week 12, Lecture 32) – Chapter 26.

1. Red Shift
2. Galaxy types

Problem Set #10 is due on ExpertTA on Friday, April 25, 2025, by 9:00 AM

Interlude 2 essay is due on Gradescope on Monday, April 28, 2025 by 9:00 AM

The Distance Ladder

How do we measure **distance** to stars and galaxies?

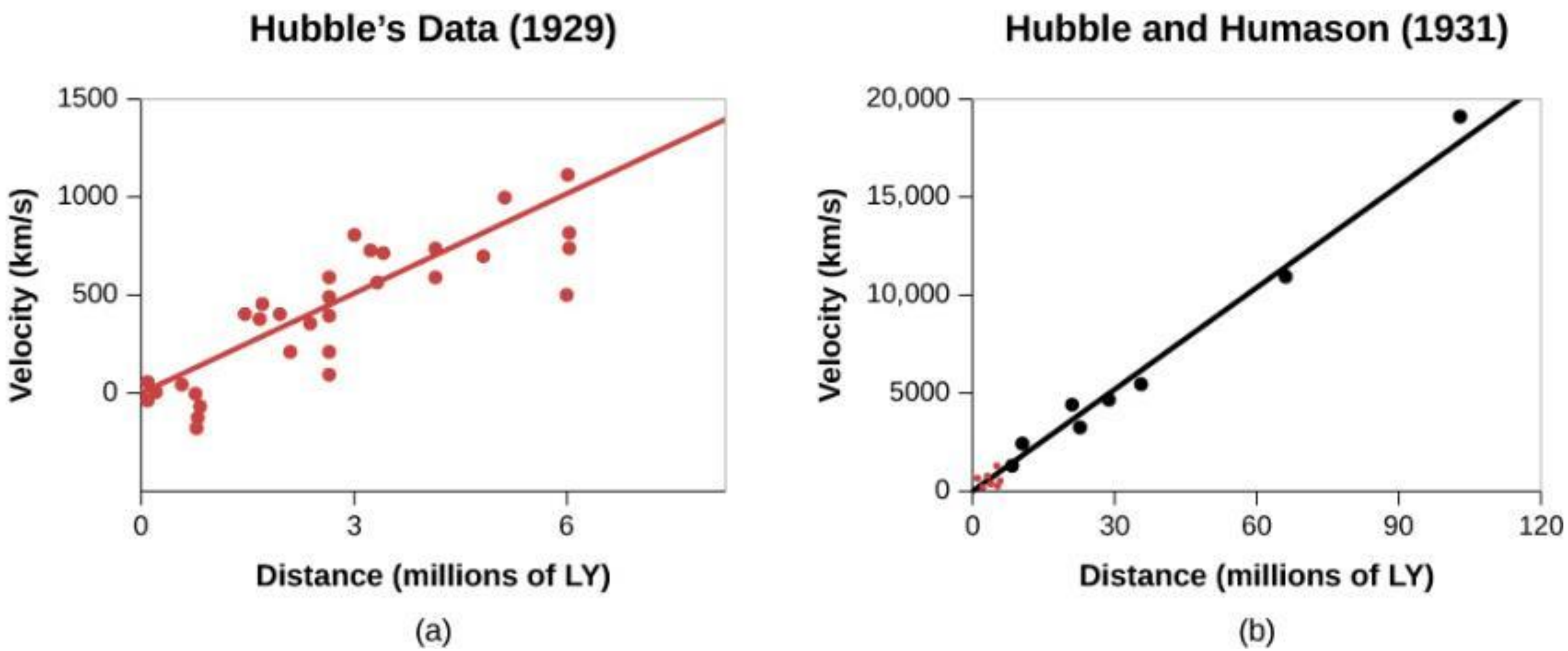
0. **Solar system distances:** Radar
1. **4 to 1000 light years:** Parallax
2. **to 300,000 light years:** RR Lyrae variable stars
3. **to 1 million light years:** H-R diagram - comparing same types of stars
4. **to 60 million light years:** Cepheid variable stars
5. **to 300 million light years:** **Tully-Fisher law** (for spiral galaxies)
6. **to 11,000 million light years:** Type 1A Supernovae
7. **30 to 13,000 million light years:** **Red shift** and **Hubble's Law***

(* caveat)

Main idea: if we can find some sort of "standard candle", *i.e.,* a star where we know (from some other property) what its Luminosity is, then its Apparent Brightness tells us its Distance.

PollEv Quiz: PollEv.com/sethaubin

Red Shifts & Hubble's Law



Hubble's Law: $V = H \times d$

V = recession velocity

D = distance from Earth

H = Hubble constant [modern value]

= 22 *(km/s)/million-light-years*

= slope of the above lines

Red Shift

When celestial objects are moving rapidly, astronomers often quantify their **speed** $\boldsymbol{v}$ in terms of their **redshift** "z" that they measure **spectroscopically**:

$$z = \frac{\Delta\lambda}{\lambda}$$ = *redshift*

with: $\lambda = wavelength$

$\Delta\lambda = shift\ in\ wavelength$

Red Shift

When celestial objects are moving rapidly, astronomers often quantify their **speed** $\boldsymbol{v}$ in terms of their **redshift** "z" that they measure **spectroscopically**:

$$z = \frac{\Delta\lambda}{\lambda}$$

= *redshift*

with: $\lambda = wavelength$

$\Delta\lambda = shift\ in\ wavelength$

If the velocity v is non-relativistic ($v << c$), then

$$z \approx \frac{v}{c}$$

If the velocity v is relativistic ($v \lesssim c$), then

$$\frac{v}{c} = \frac{(z+1)^2 - 1}{(z+1)^2 + 1}$$

Due to Hubble's law, astronomers often use the **redshift** $\boldsymbol{z}$ as a proxy for **distance**.

Edwin Hubble

Education background

- B. Sc. at U. of Chicago (math, astronomy, philosophy).
  → Gifted athlete: Basketball and track teams.
- Rhodes Scholar (Oxford U., studied law).
- Taught high school (Spanish, Physics, and Math).
- PhD in Astronomy (U. of Chicago).

... served in WW1.

Discoveries

- Proved that the Milky Way is one of many galaxies.
  → Showed that Andromeda (M31)is outside of Milky Way.
- Studied many galaxies and classified them.
  → Spirals, ellipticals, and irregulars.
- Expansion of the universe.
  → Hubble's law (or Hubble-Lemaitre law).
  → Hubble did not fully believe that the universe is expanding.

Edwin Hubble, 1889-1953

Hubble's Galaxy Classification

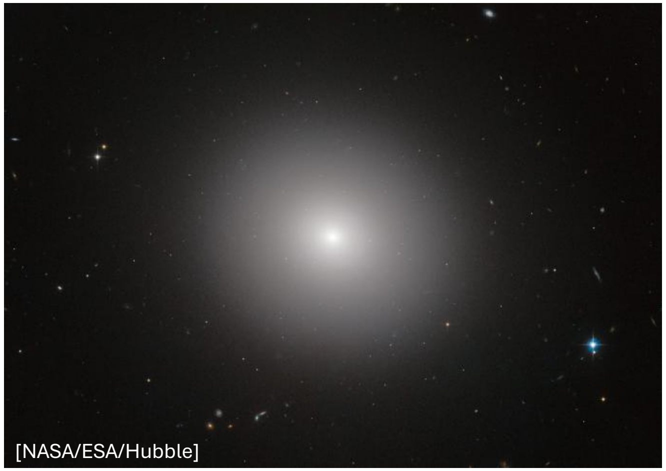
<u>Three broad classes</u> of galaxies:

- Spiral galaxies
- Elliptical galaxies
- Irregular galaxies

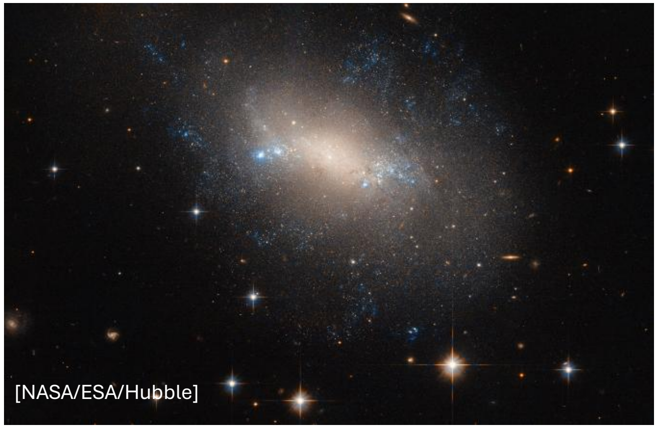
UGC 12158 Spiral Galaxy

<u>Size (mass and width)</u>

- Spirals are medium size to large.
- Ellipticals can be very large.
- Irregulars tend to be smaller.



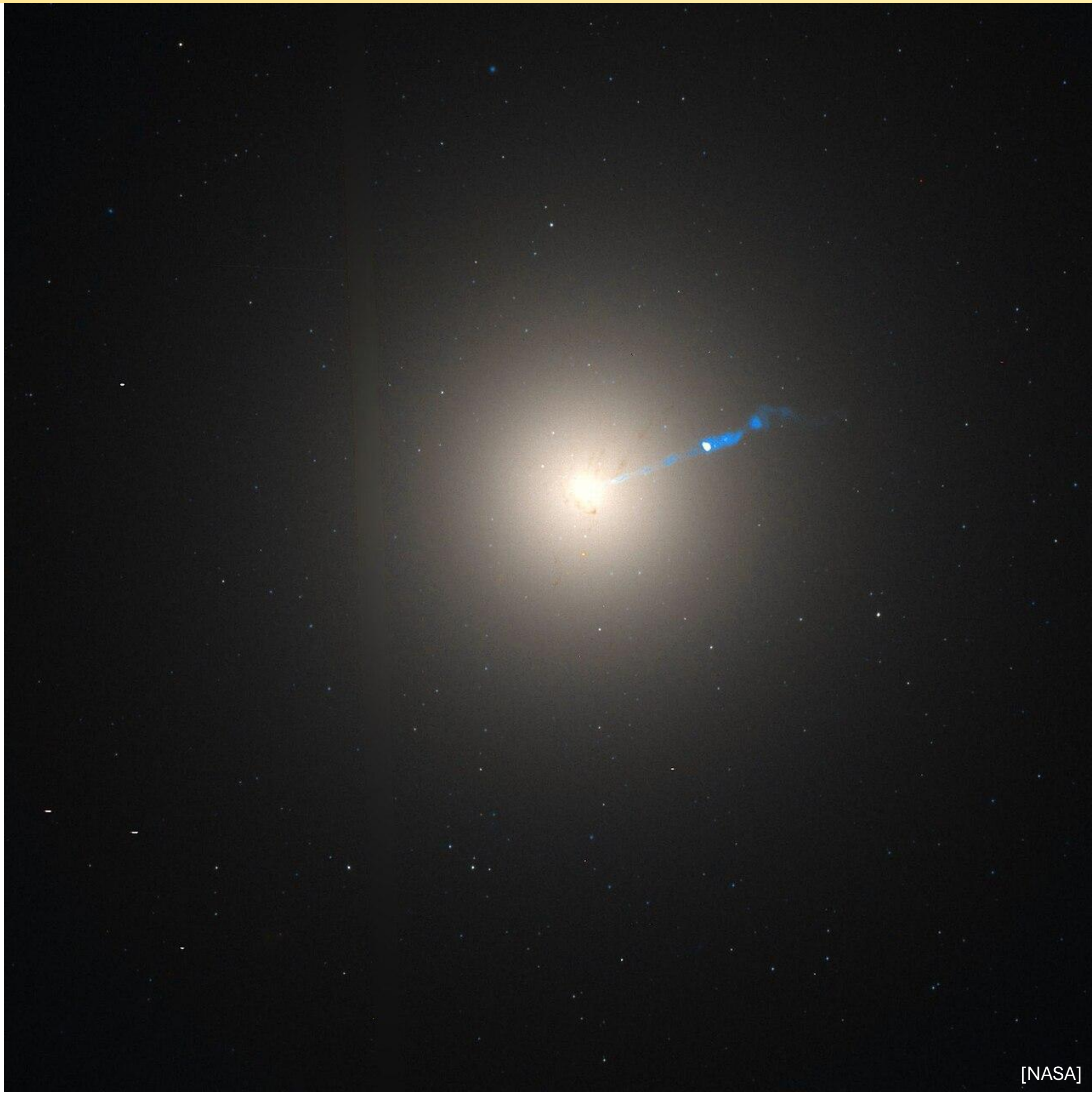
IC 2006 Elliptical Galaxy



NGC 2337 Irregular Galaxy

Elliptical Galaxies

- Roughly as common as spiral galaxies.
- Very little internal structure.
- Ellipsoidal shape.
- Size range: small to very large.
  → largest galaxies are elliptical.
- Most stars are very old.
- Very little gas and dust.
- Star orbits are disorganized and random.
  → Ellipticals are similar to the central bulge of a spiral galaxy.
- Mass often determined from gravitational lensing.



M87 *Elliptical Galaxy (53 million light years away)*
(diameter=130,000 light years)

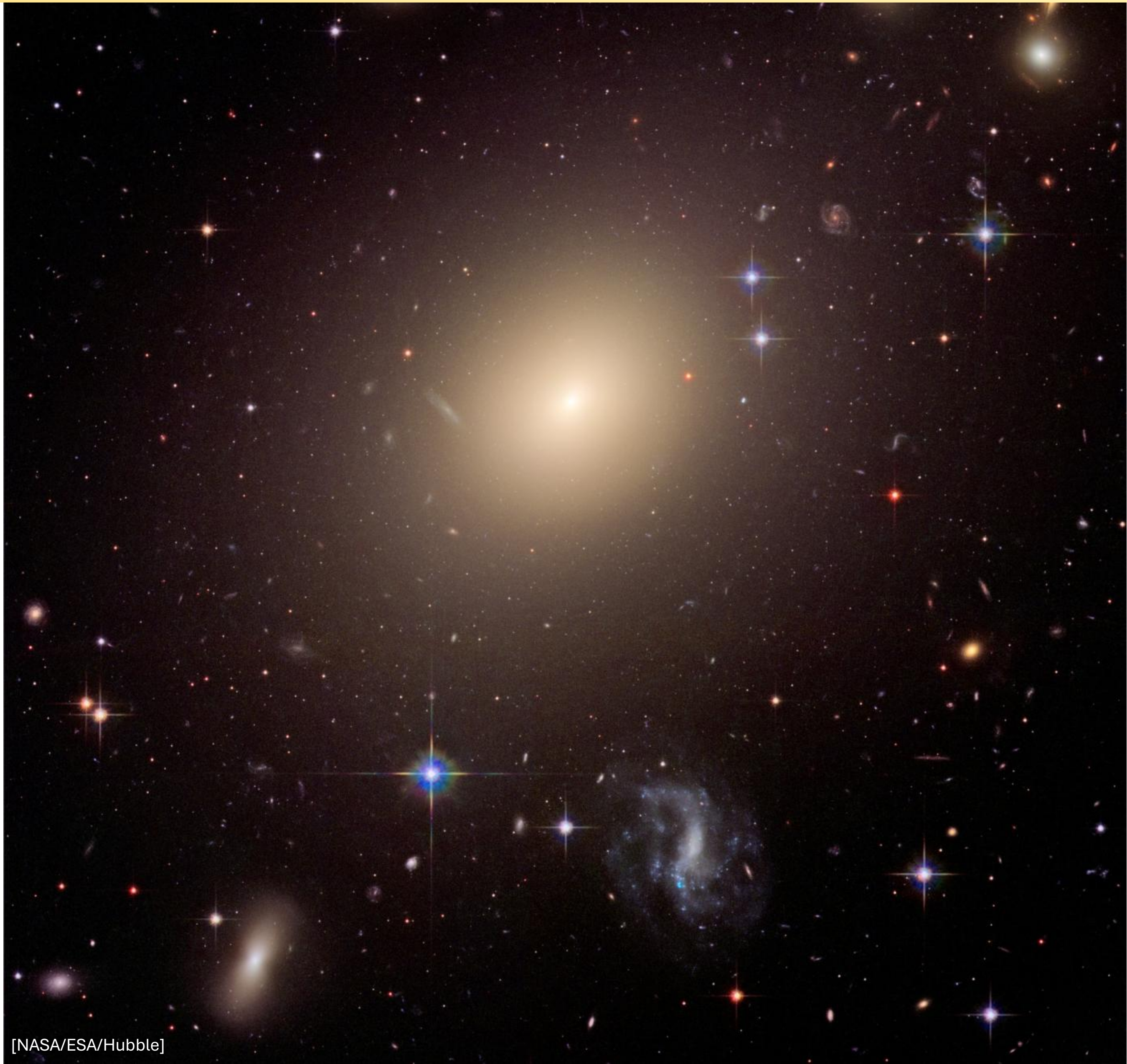
Elliptical Galaxies

Giant elliptical galaxy ESO 325-G004.

Distance
430-650 million light years

Diameter
400,000-500,000 light years

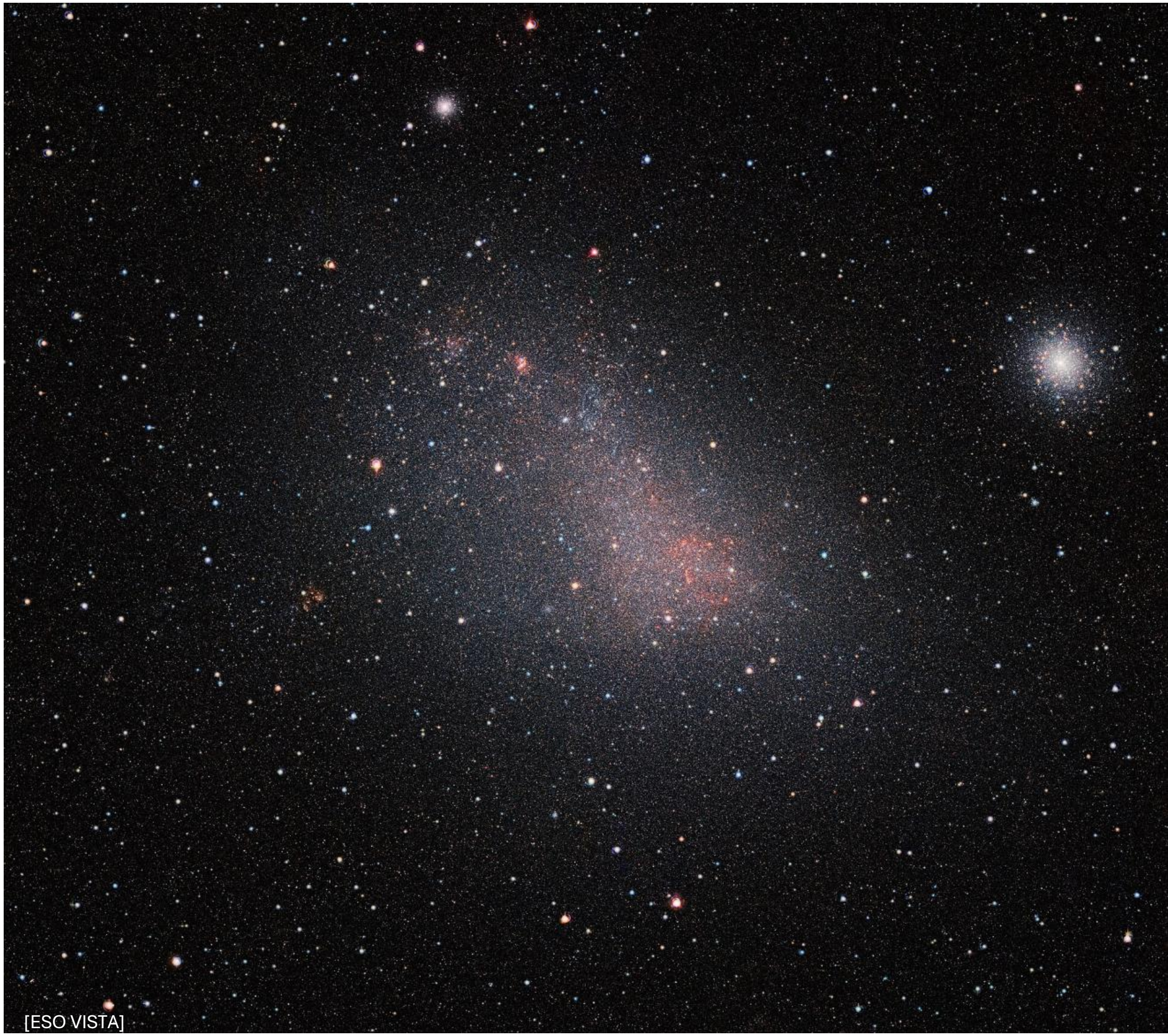
Mass
140 billion solar masses



[NASA/ESA/Hubble]

Irregular Galaxies

- No defined shape.
- Tend to be smaller.
- Lots of gas; dust varies.
- Both old and young stars.



Small Magellanic Cloud (diameter=19,000 light years)

Properties of Galaxy Classes

Characteristics of the Different Types of Galaxies

Characteristic	Spirals	Ellipticals	Irregulars
Mass (M_{Sun})	10^9 to 10^{12}	10^5 to 10^{13}	10^8 to 10^{11}
Diameter (thousands of light-years)	15 to 150	3 to >700	3 to 30
Luminosity (L_{Sun})	10^8 to 10^{11}	10^6 to 10^{11}	10^7 to 2×10^9
Populations of stars	Old and young	Old	Old and young
Interstellar matter	Gas and dust	Almost no dust; little gas	Much gas; some have little dust, some much dust

[OpenStax, Astronomy 2e (2025), Table 26.1]

Mass-to-Light Ratio

Mass in units of M_{sun} Luminosity in units of L_{sun}

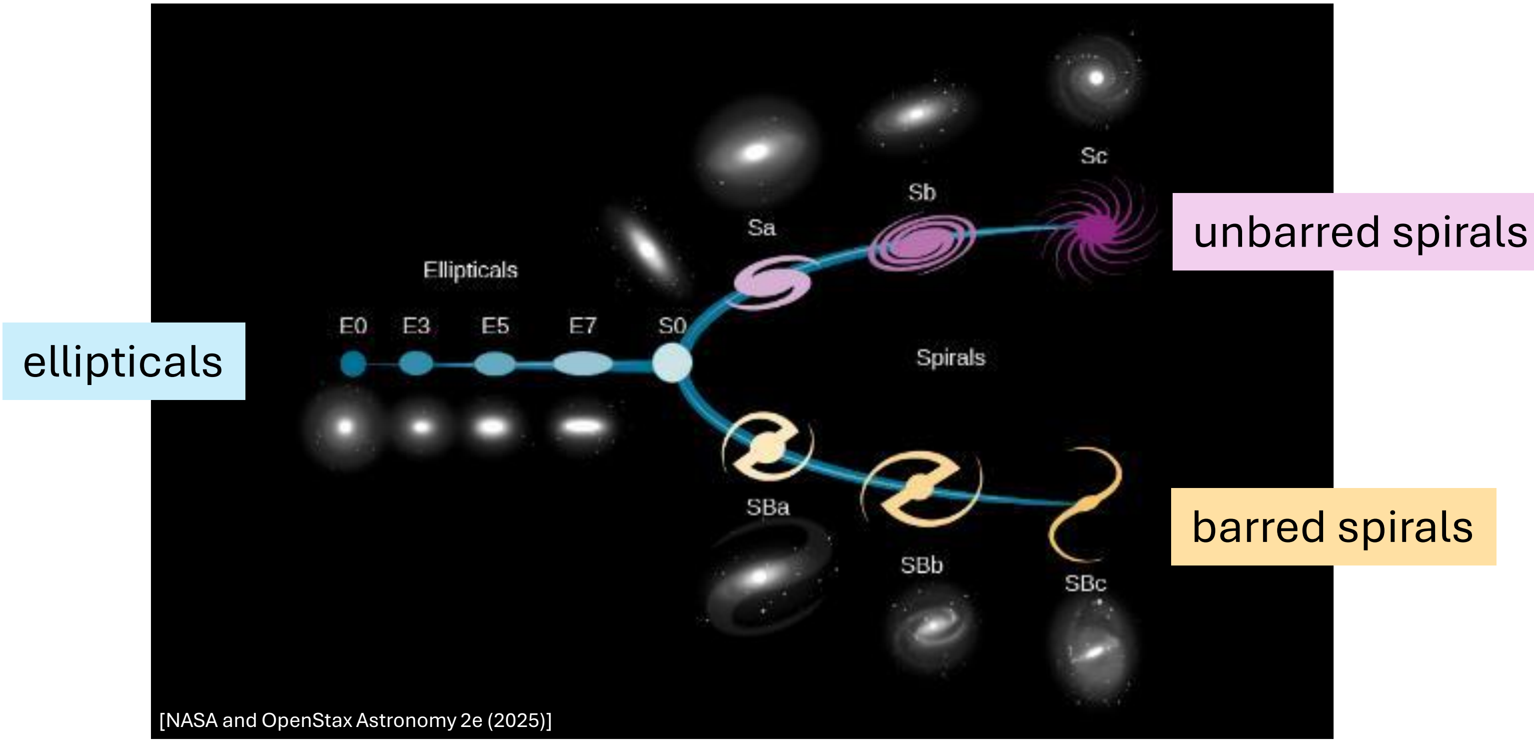
$$\text{Mass-to-Light ratio} = \frac{Mass}{Luminosity}$$

Characteristic	Spirals	Ellipticals	Irregulars
Mass-to-light ratio in the visible part	2 to 10	10 to 20	1 to 10
Mass-to-light ratio for total galaxy	100	100	?

Includes dark matter

[OpenStax, Astronomy 2e (2025), Table 26.1]

Hubble's Classification Scheme



Edwin Hubble's original classification of galaxies.

IMPORTANT: This "tuning fork" diagram does NOT represent galaxy evolution.

(though astronomers did try … sort of like the H-R diagram)

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