Today's Topics

Wednesday, April 22, 2026 (Week 12, Lecture 33) – Chapter 26.

0. Type 1a supernova example
1. Hubble's Law
2. Red Shift
3. Galaxy types

Problem Set #10 is due on ExpertTA on Friday, April 24, 2026, by 9:00 AM

Interlude 2 essay is due on Gradescope on Monday, April 27, 2026 by 9:00 AM

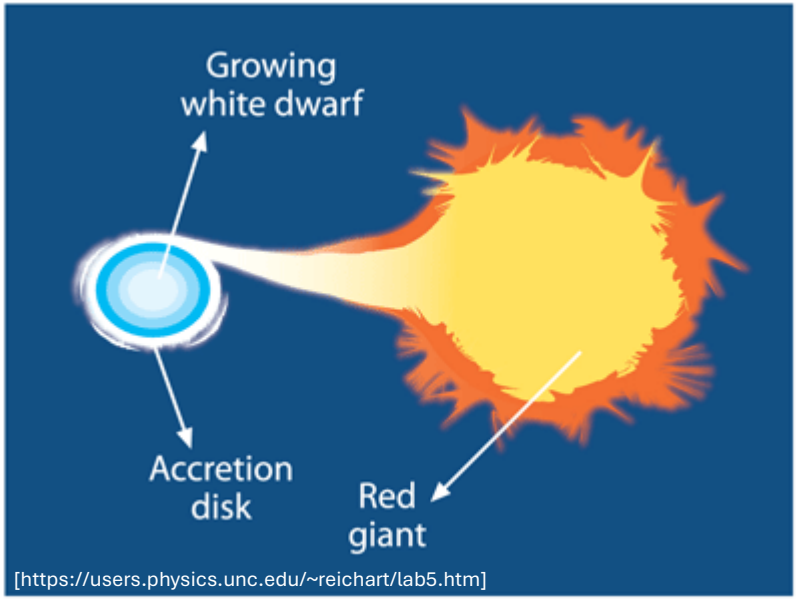
The Distance Ladder

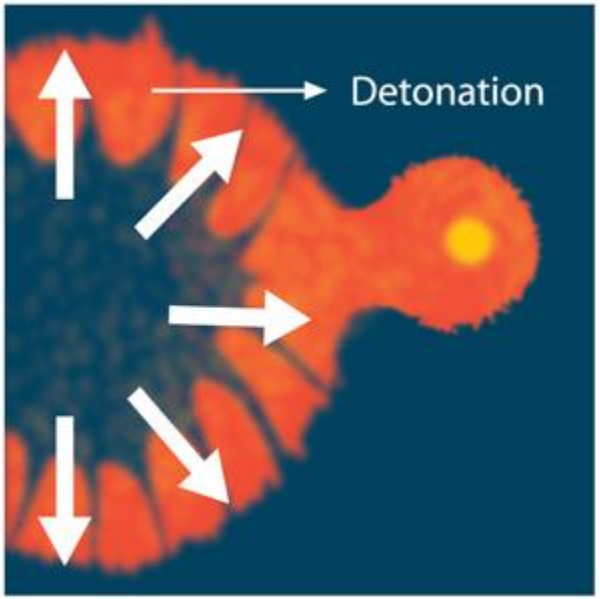
How do we measure **distance** to stars and galaxies?

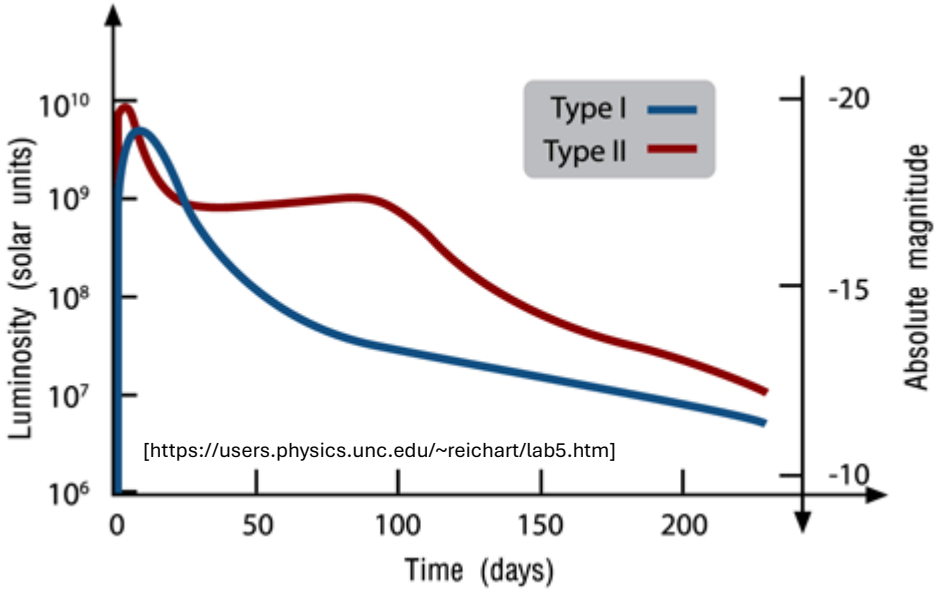
0. **Solar system distances:** Radar
1. **4 to 1000 light years:** Parallax
2. **to 300,000 light years:** RR Lyrae variable stars
3. **to 1 million light years:** H-R diagram - comparing same types of stars
4. **to 60 million light years:** Cepheid variable stars
5. **to 300 million light years: Tully-Fisher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

Type 1a Supernovae – a standard candle



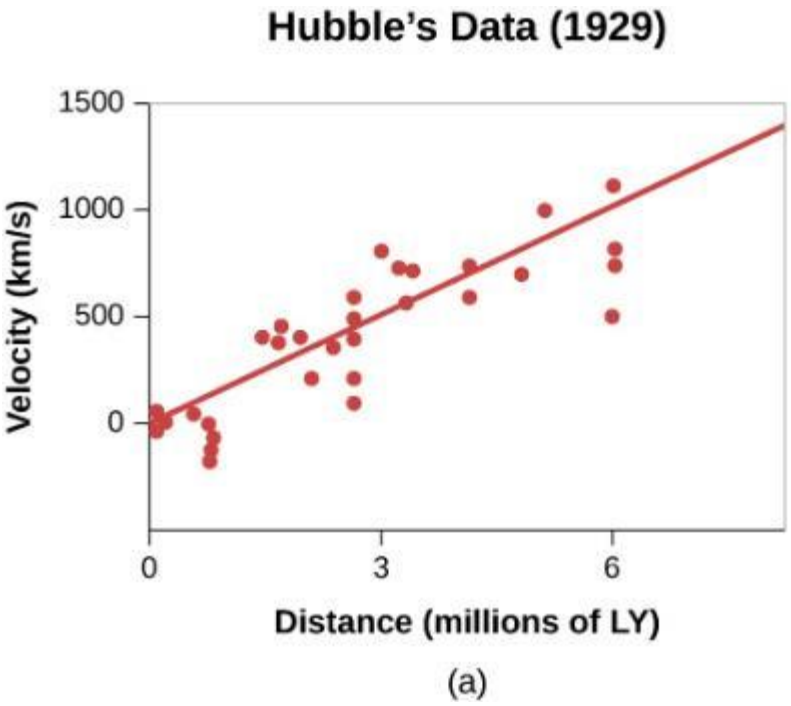


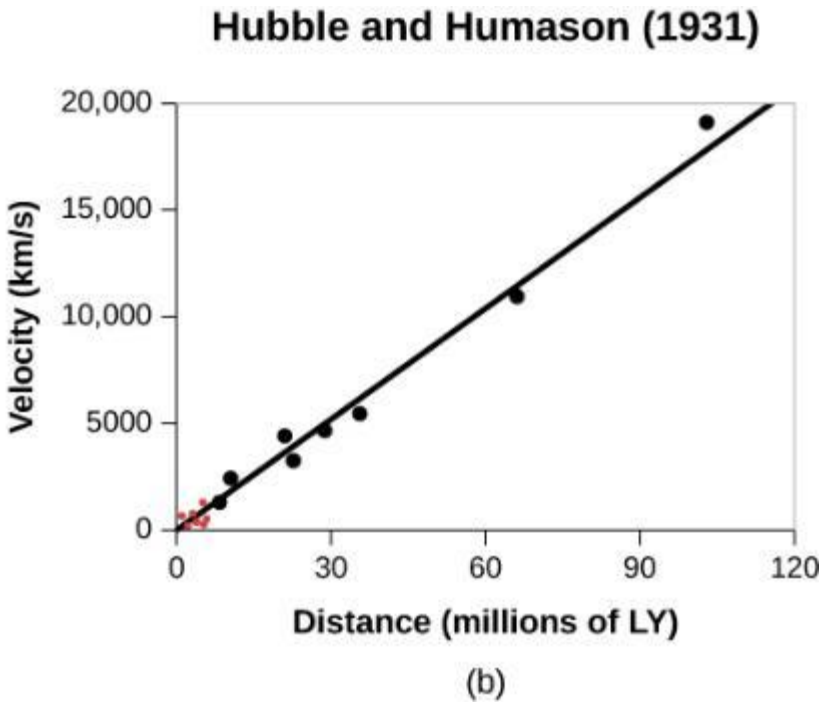


All type 1a supernovae have an effective maximum luminosity of about $5 \times 10^9 \, L_{Sun}$.

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

Hubble's Law: The Expansion of the Universe

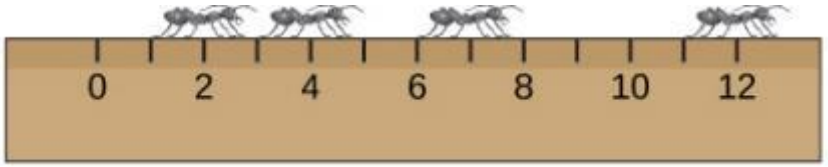
- The fact that we (on Earth) see all the galaxies moving away from us, and the farther away they are, the faster they are receding, does ***not*** mean that we are in some special location (an anthropocentric view).

- On the contrary – someone located in a distant galaxy would see ***exactly the same thing***! Everything (including us) is rushing away from them.

  → The farther away, the faster the recession.

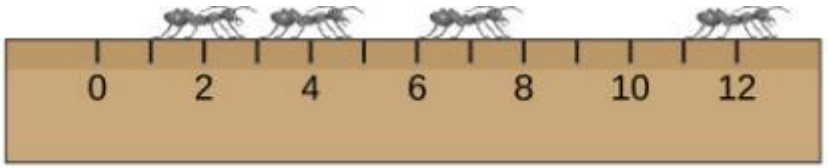
- ***Huh?***

1D model of Expanding of the Universe



Ants at rest on stretchable ruler.

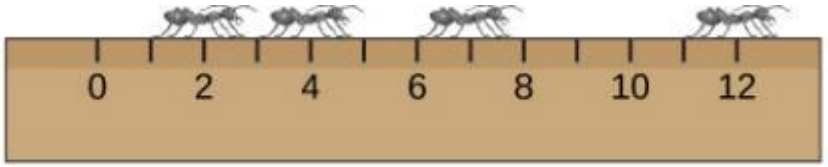
1D model of Expanding of the Universe



Ants at rest on stretchable ruler.

- Ruler is stretched.
- Each ant sees each other ant having moved farther away.

1D model of Expanding of the Universe



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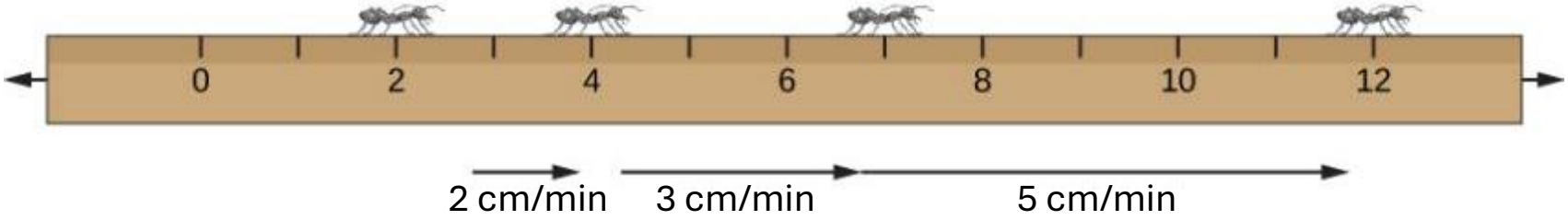

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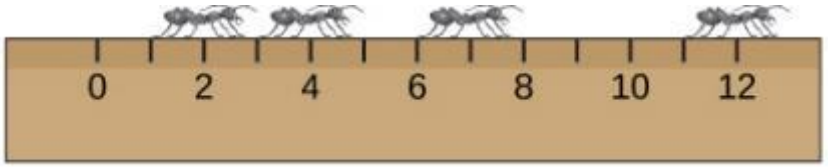

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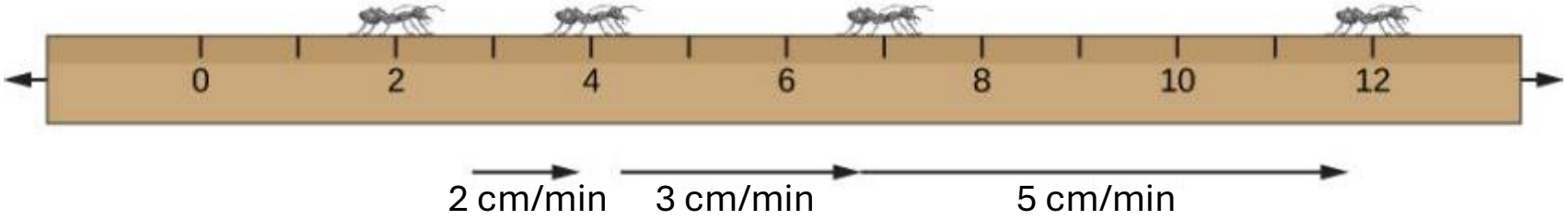
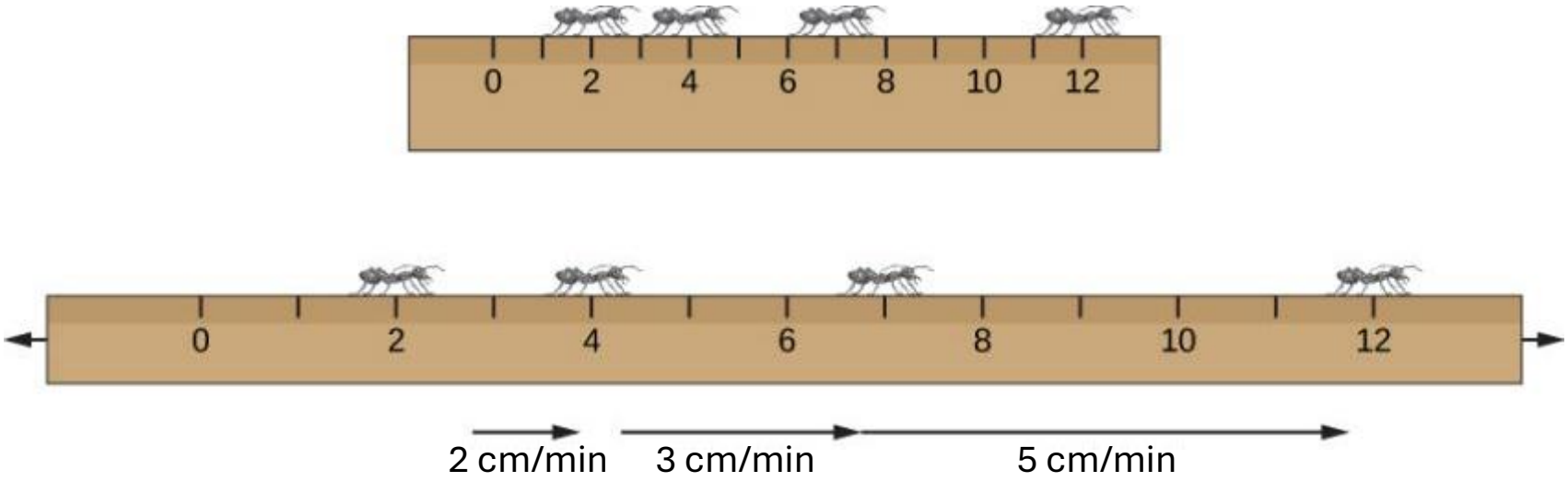


- The farther away ant B was from ant A originally, the farther it has moved from ant A.
- The larger the initial separation, the larger the stretched separation (proportionally).

  → *Larger the separation = higher recession velocity (i.e., higher redshift).*

1D model of Expanding of the Universe



Note: everything stays the same if the ruler is infinitely long (no boundaries or edges to this 1D universe).

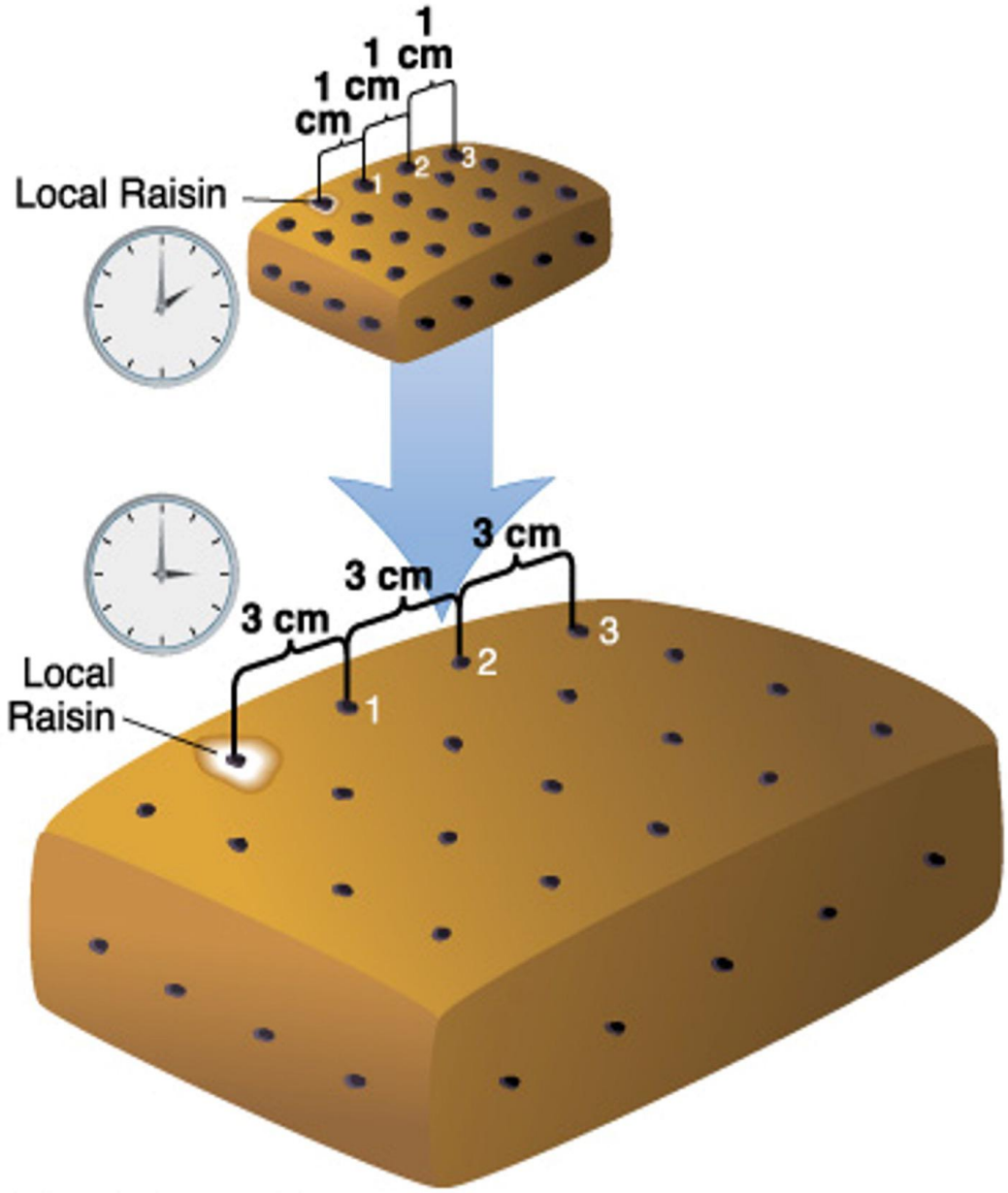
→ An expanding universe doesn't have to expand ***into*** anything!

→ It also has **no center**.

Think of the ruler as like the number line in math, which, of course, is infinite…

Expanding of the Universe: 3D Analogy

- Insert raisin bread loaf in oven.
- Loaf expands.
- Every raisin gets farther away from every other raisin.



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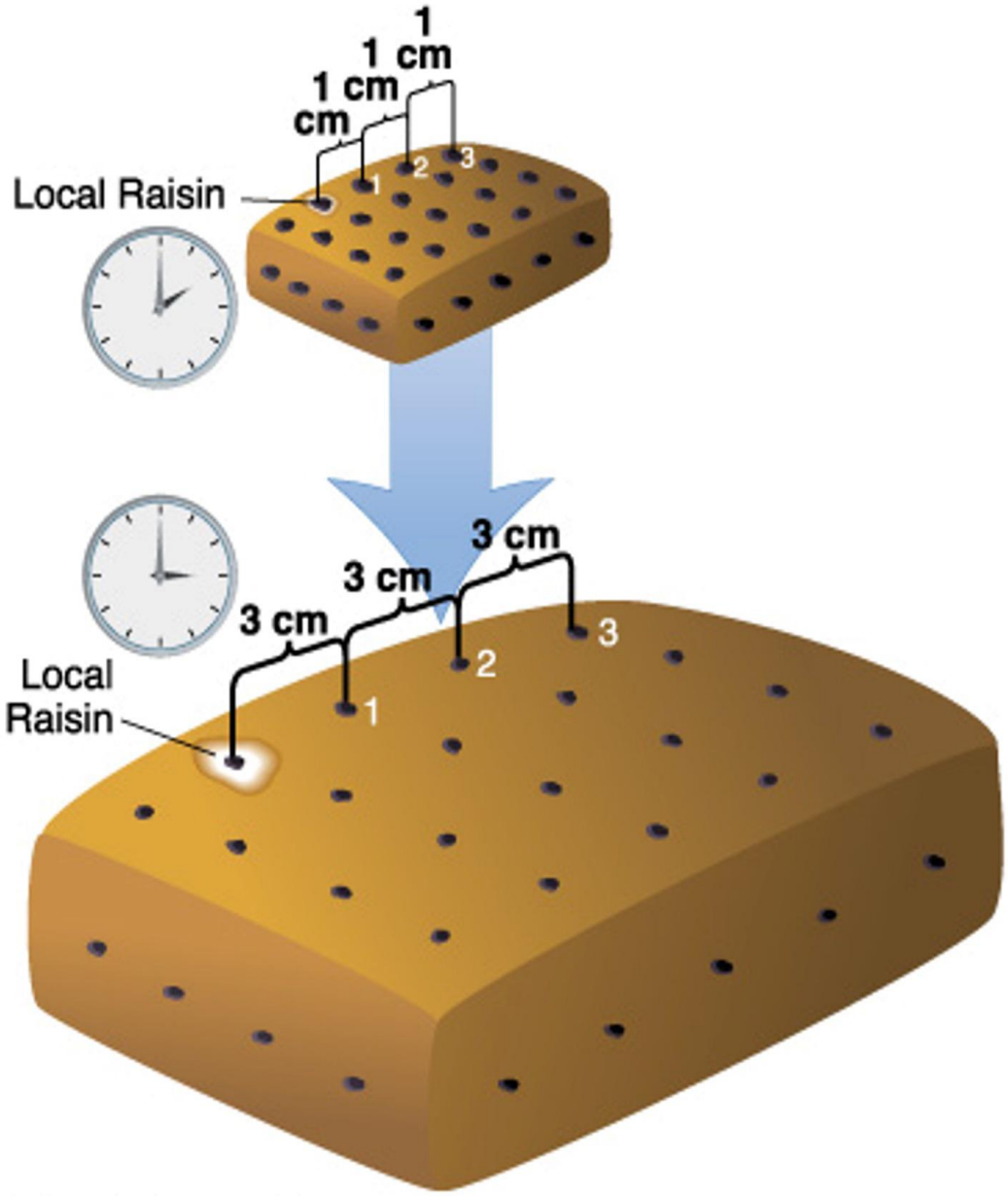
- The **relative velocity** of raisins <u>increases with distance</u>.
- Now imagine an infinite loaf …
  … The same thing happens.



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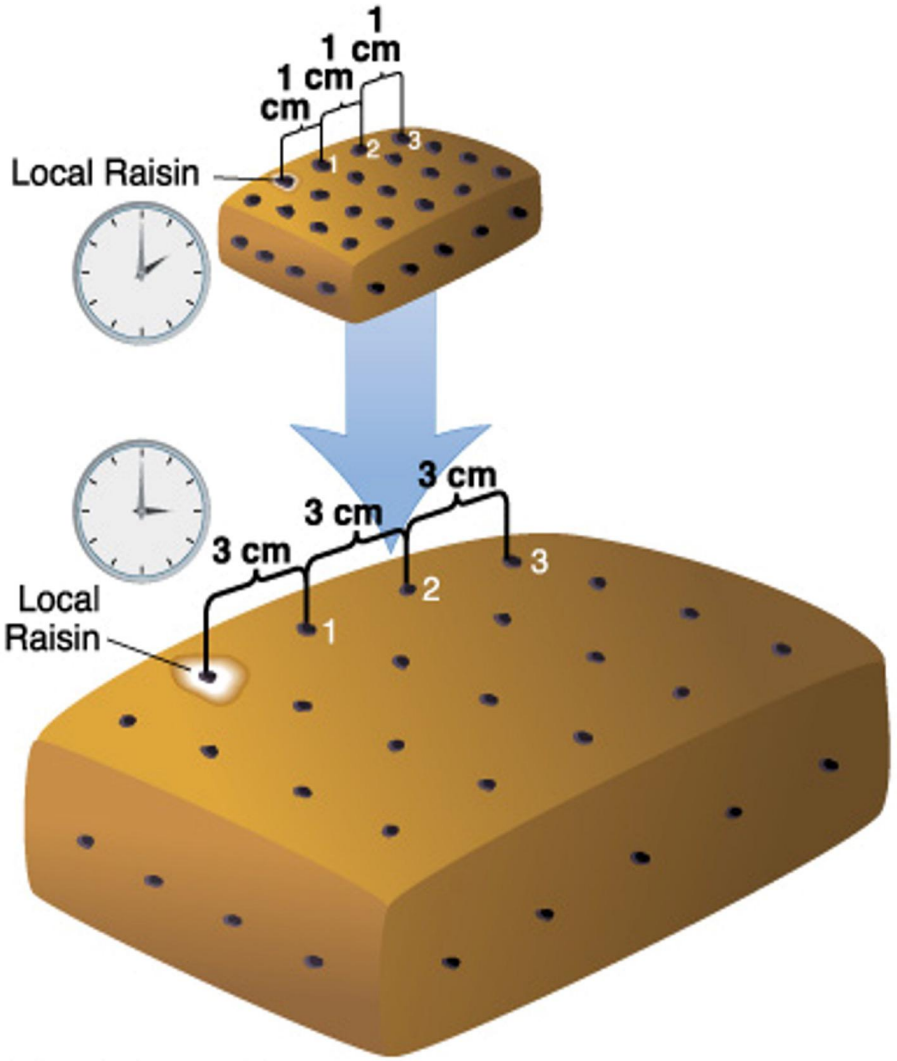
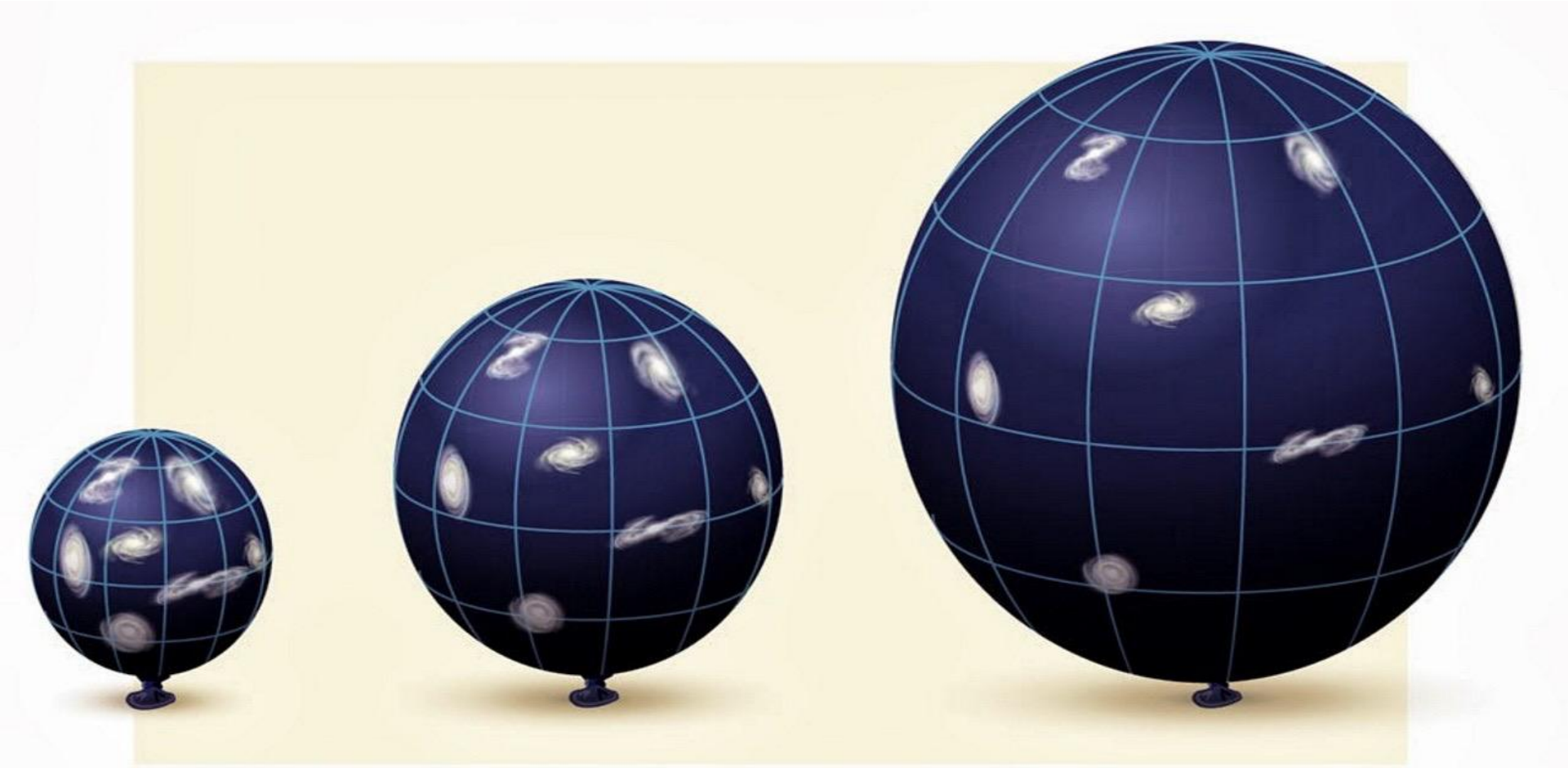
Note: a raisin itself does not expand. Think of the raisins as galaxies.



Gravity holds galaxies and clusters of galaxies together, and they get farther away from each other—without themselves changing in size—as the universe expands.

Expanding of the Universe: Another Visualization



Hubble's Law: The Expansion of the Universe

Hubble's law is interpreted to mean that the **universe is expanding.**

What does this mean?

- It does NOT mean the universe is expanding from a point.
- It does NOT mean the universe is expanding into something else.
- It does NOT mean that the universe started as a single point-like "cosmic atom".

→ It just means that <u>the distance between all points is getting larger</u>.

→ That's all.

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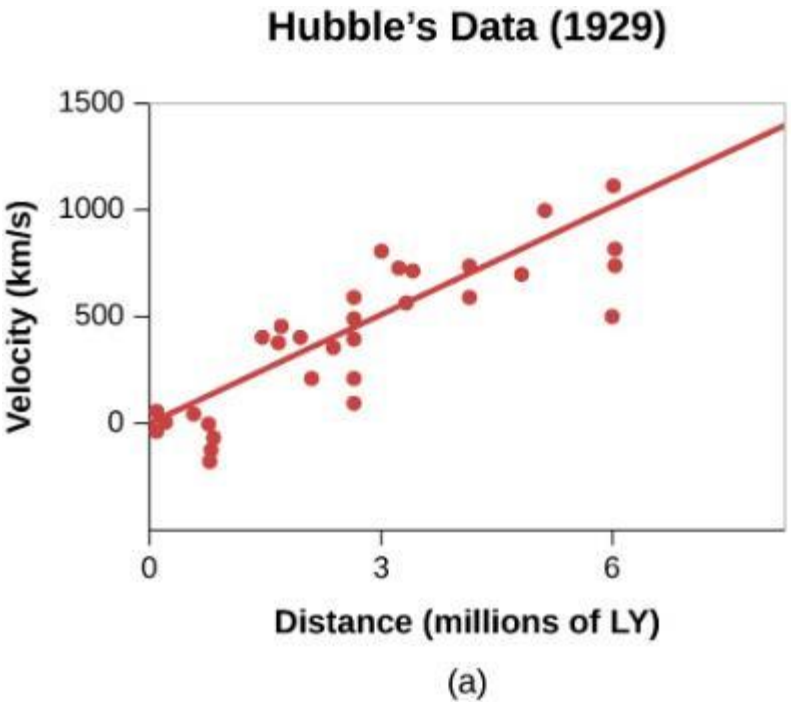
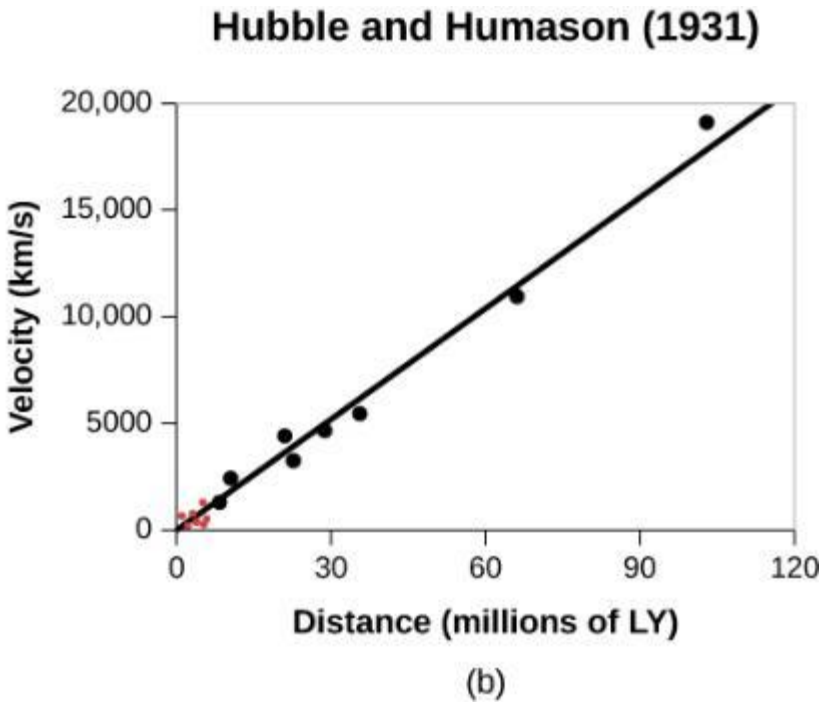
(* caveat)

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.

Red Shifts & Hubble's Law





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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 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 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

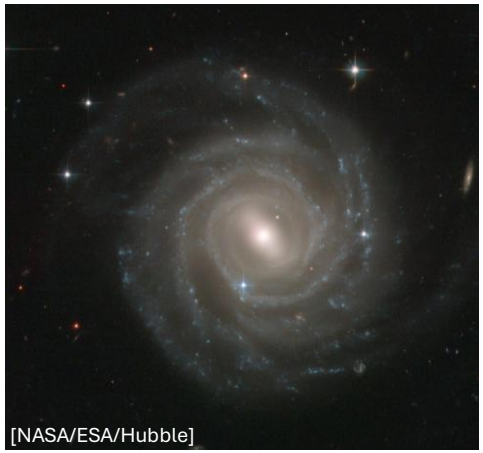
- Proved that the Milky Way is one of many galaxies.
  → Showed that Andromeda (M31)is outside of Milky Way.
- Studied many galaxies and classified them.
  → Spirals, ellipticals, and irregulars.
- Expansion of the universe.
  → Hubble's law (or Hubble-Lemaitre law).
  → Hubble did not fully believe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

Edwin Hubble, 1889-1953

Hubble's Galaxy Classification

Three broad classes of galaxies:

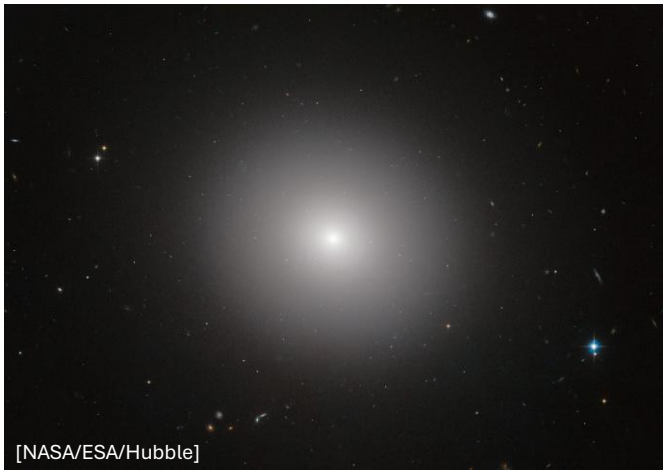
- Spiral galaxies
- Elliptical galaxies
- Irregular galaxies



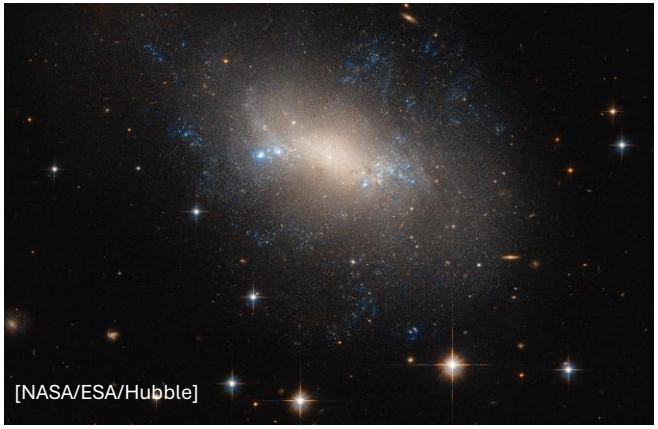
UGC 12158 Spiral Galaxy

Size (mass and width)

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



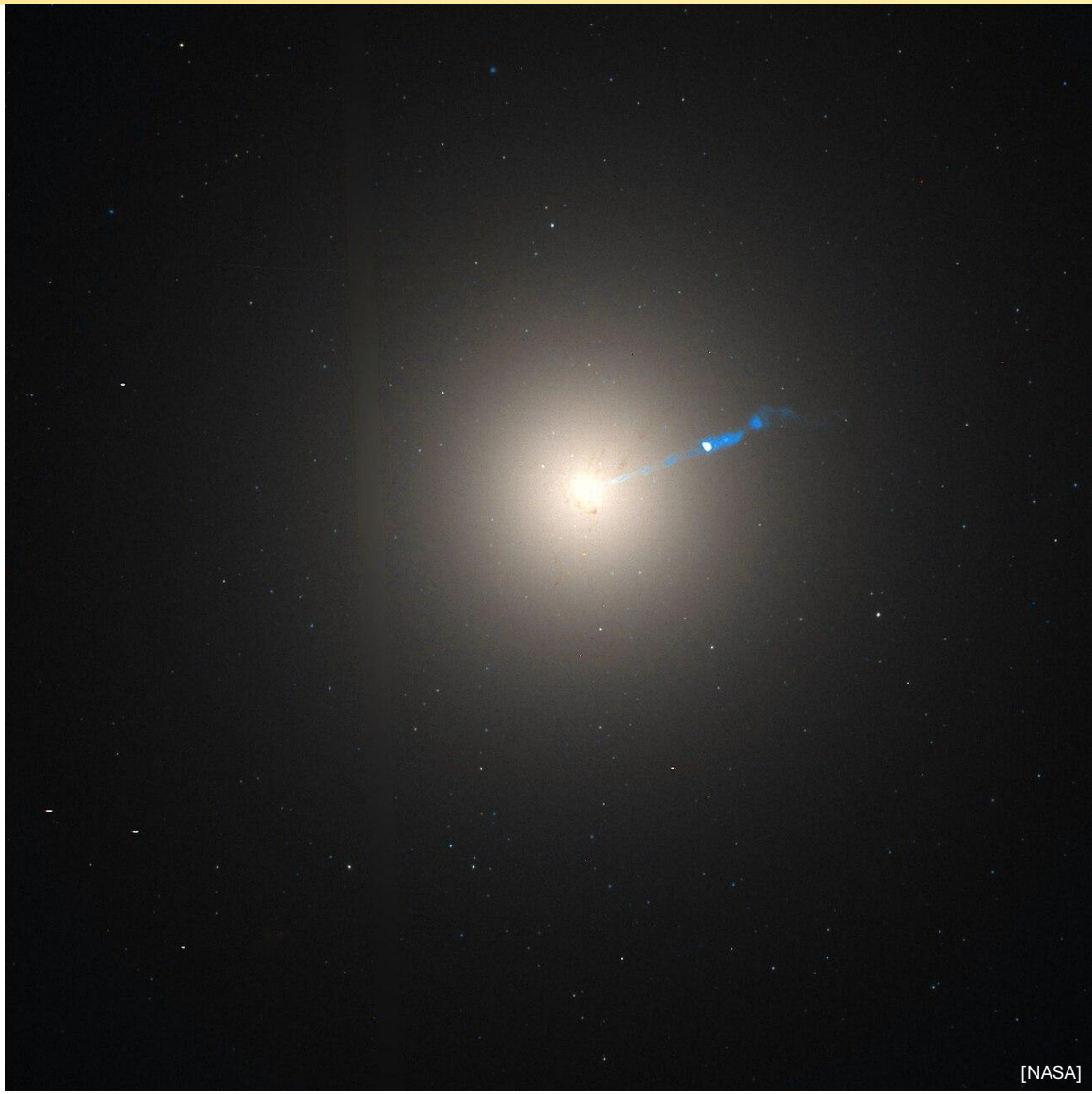
IC 2006 Elliptical Galaxy



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)

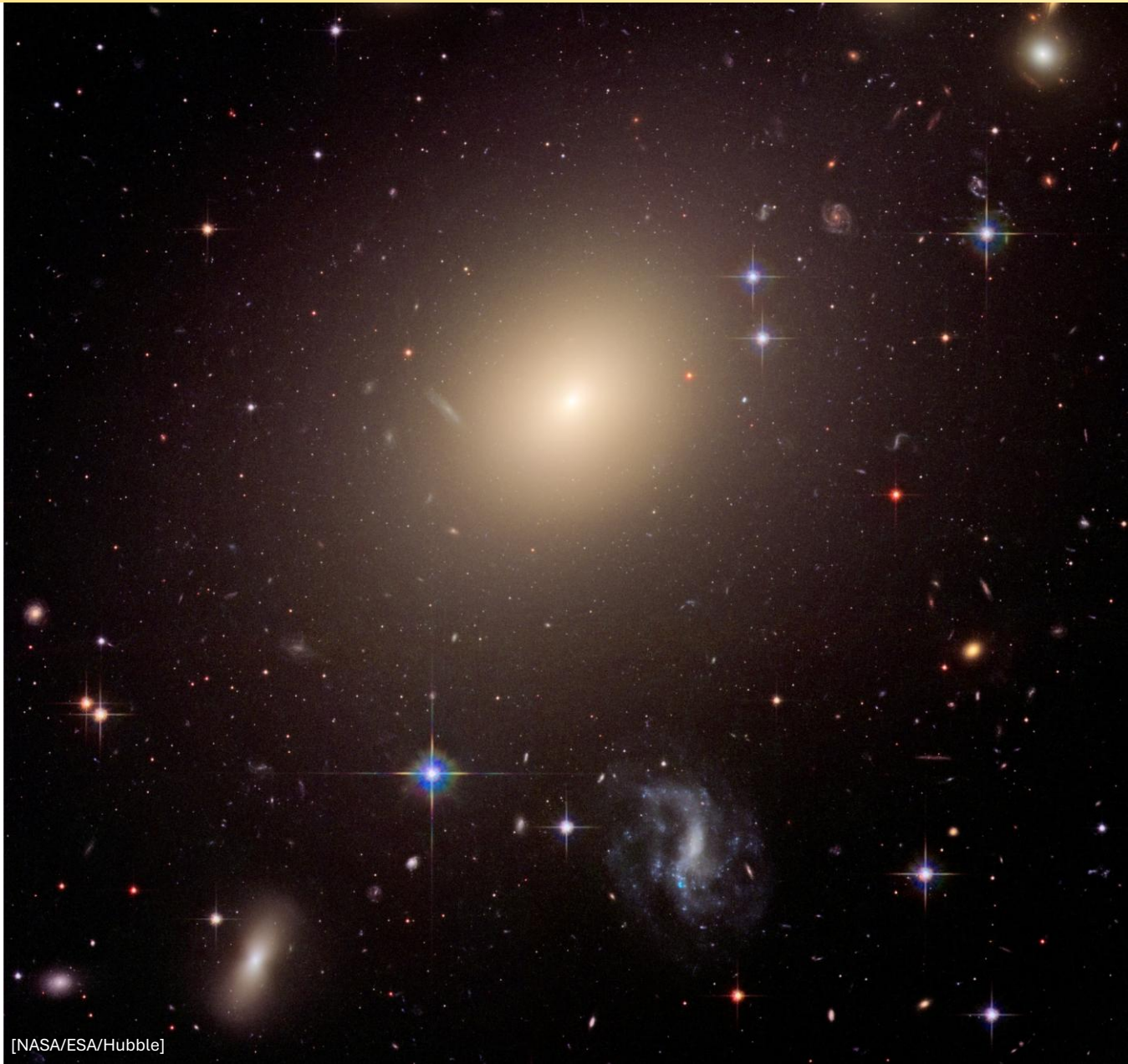
Elliptical Galaxies

Giant elliptical galaxy ESO 325-G004.

Distance
430-650 million light years

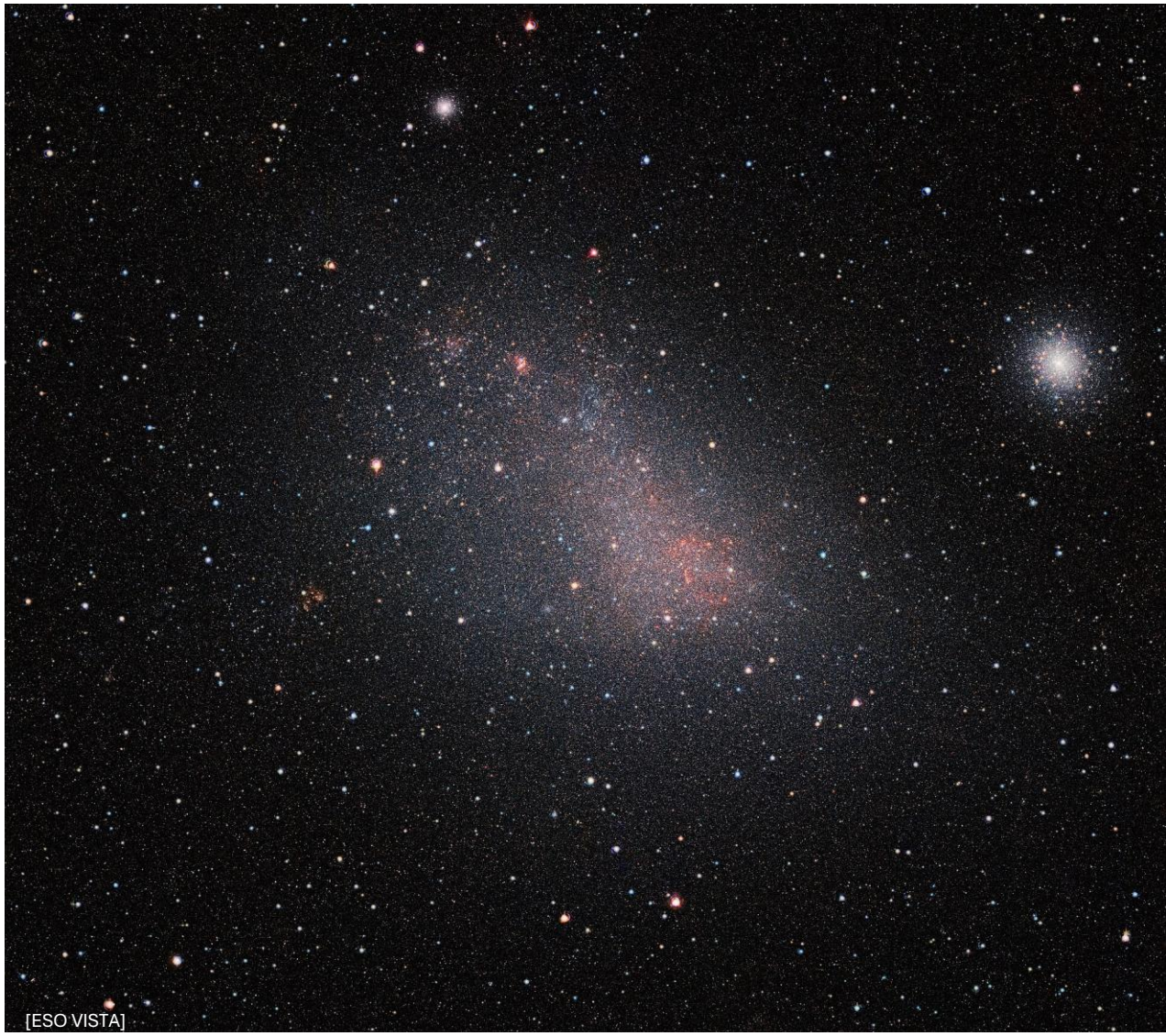
Diameter
400,000-500,000 light years

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}

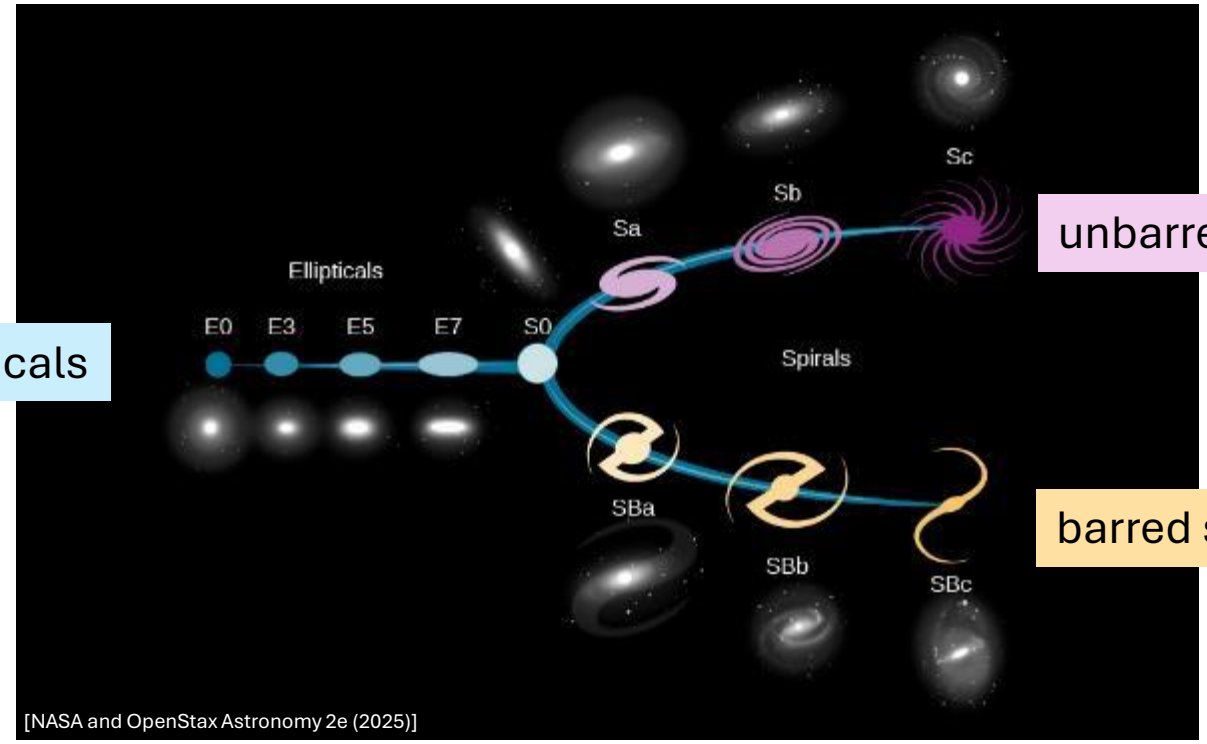
$$\text{Mass-to-Light ratio} = \frac{Mass}{Luminosity}$$

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



ellipticals

unbarred spirals

barred spirals

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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