Today's Topics

Monday, April 13, 2026 (Week 11, Lecture 29) – Chapter 25.

1. The "Great Debate"
2. Formation of the galaxy
3. Rotation curve … dark matter

Problem Set #9 is due on ExpertTA on Friday, April 17, 2026, by 9:00 AM

The “Great Debate”: One Galaxy or Many?

- This little-remembered debate was at the crux of humanity's view of our place in the universe.
- Ultimately, the events of 1910-1930 were much more than a debate.
- The story of the "Great Debate" is really the story of humanity's discovery of the vastness of our universe.
- A seemingly small academic disagreement whose resolution staggered the world.

The "Great Spiral Nebula" in the constellation Andromeda (1902 photograph). The ***Debate*** was essentially over whether this was a cloud of gas and dust or a distant galaxy.

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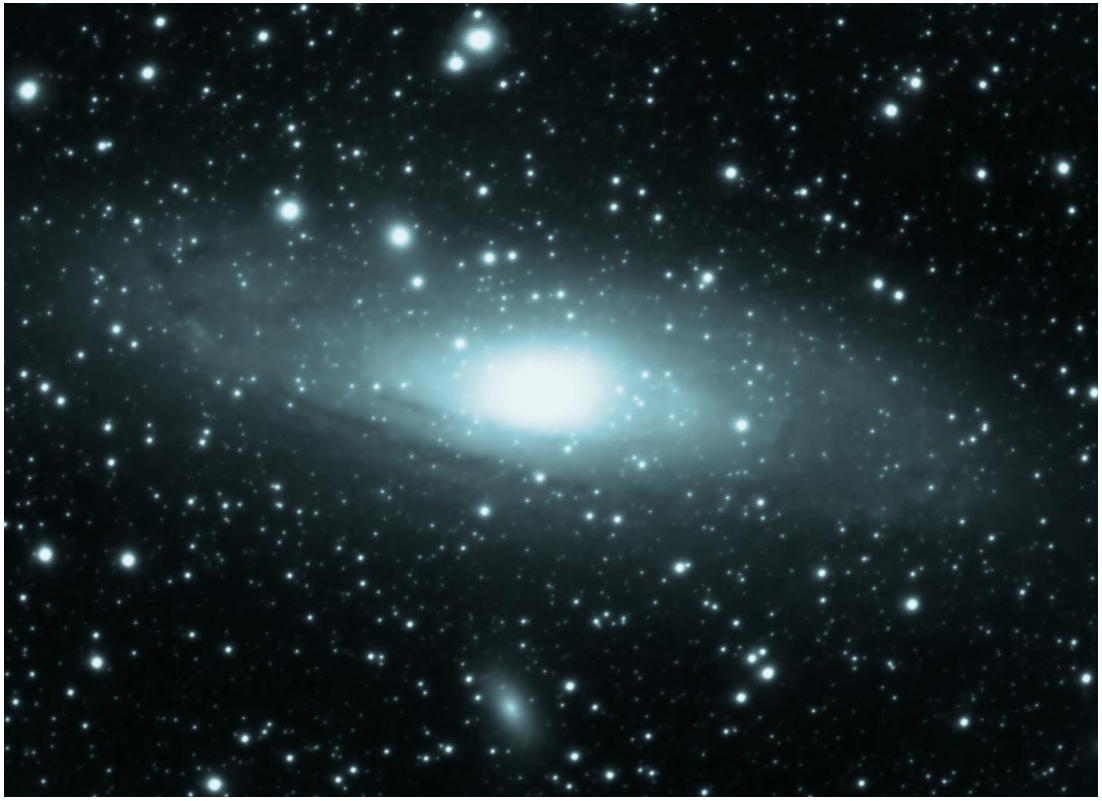


Andromeda galaxy (M31) – photo by W&M student and amateur astronomer Kathryn Day using an image intensifier (2025).

The "Great Debate": Setting the Stage

- Spiral nebulae were seen by many astronomers.
  → See drawing by W. Parsons (Lord Rosse) using the "Leviathan" telescope.

- Were they just spiral shaped clouds in the galaxy (possibly nascent solar systems) or were they distant galaxies?

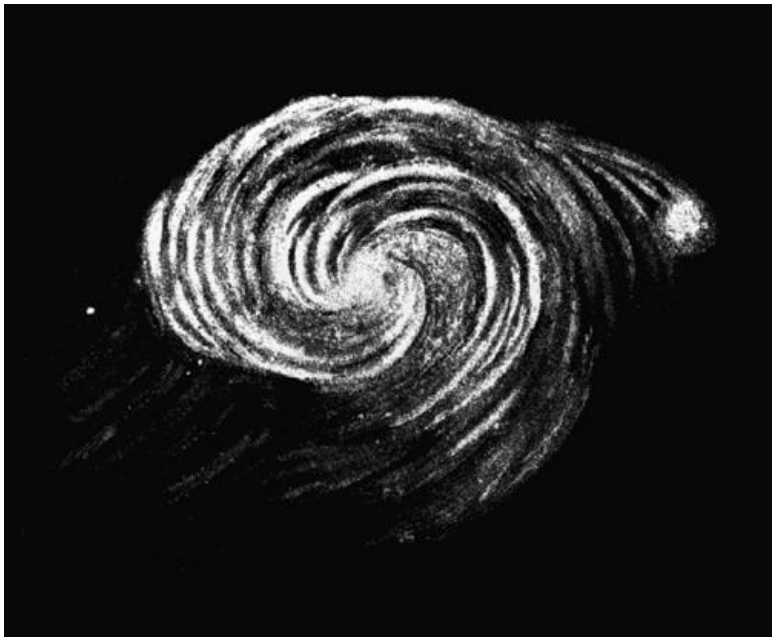
→ This was the crux of the debate.

M51 nebula (the "whirlpool galaxy") drawn William Parsons (1845).

"Starry Night" by Vincent Van Gogh (1889), possibly inspired by the Parsons drawing

The “Great Debate”: Setting the Stage

M51 the Whirlpool Galaxy as photographed by NASA/ESA with the Hubble Space Telescope (2005).



M51 nebula (the “whirlpool galaxy”) drawn William Parsons (1845).

The "Great Debate": Harlow Shapley

Shapley: Milky Way is the entire universe.

→ The spiral nebulae are in the Milky Way.

- If not, then Andromeda (M31) would have to be millions of light years away (and others much farther) and that was considered to be unacceptable.

- An astronomer had claimed a measurement of the rotation of a spiral nebula (the Pinwheel Galaxy) and found it to have a rotational period of decades. If the Pinwheel was a distant galaxy, then that rotation period meant stars at its edges would be moving unphysically fast (faster than c).

- A nova was seen in M31. If it was that, then it would have had to outshine the entire galaxy (this seemed impossible).

[Wikipedia (2025)]

Harlow Shapley 1885-1972.

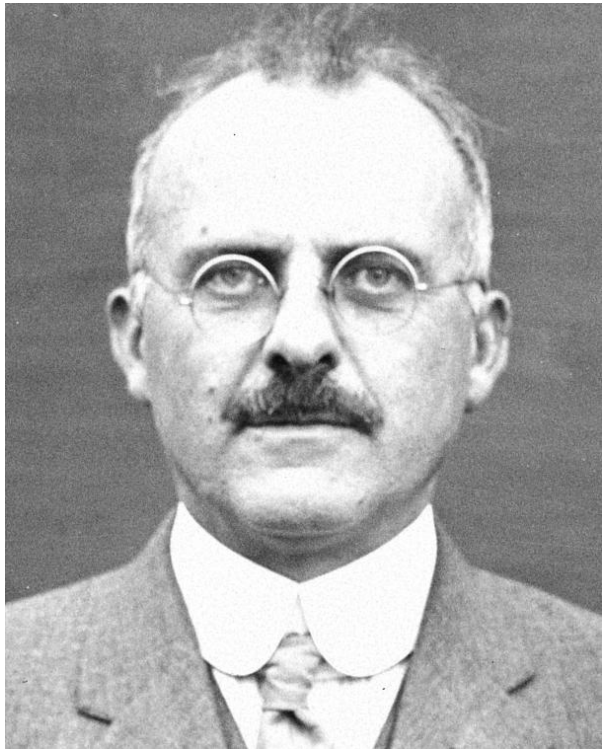
Shapley thought that the Milky Way was huge (almost 100,000 light years) and that we were NOT in the center.

→ He based the latter on an asymmetry in the distribution of globular clusters (as seen from Earth), which he had measured.

The “Great Debate”: Heber Curtis

Curtis: The spiral nebulae are "island universes", or separate galaxies.

- More novae in Andromeda than the rest of the Milky Way.
- Velocities of spiral nebulae showed that they were not gravitationally bound to the Milky Way.
- "dark lanes" in nebulae are similar to the dust cloud regions in Milky Way.



[Wikipedia (2025) and NIST]

Heber Curtis 1872-1942.

Curtis thought that our Sun was ***near the center*** of the Milky Way, which was only 10,000 light years in size.

The "Great Debate"

- The Shapley-Curtis debate was held as a public event during the 1920 meeting of the National Academies of Sciences.
  → It was held in the main auditorium of the Natural History Museum (originally the U.S. National Museum) in Washington, D.C. on April 26, 1920.

- The debate was well attended.

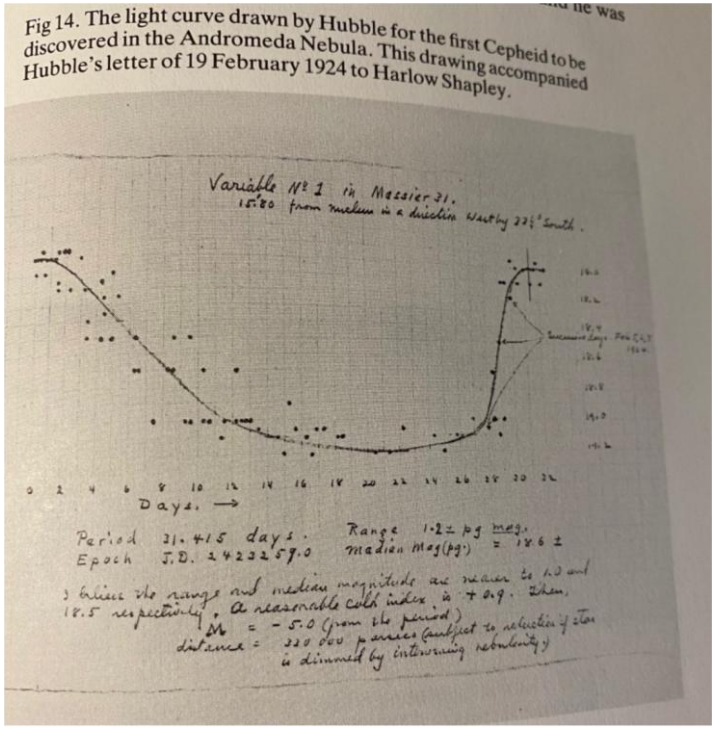
  - Curtis was a better debater and was thought by many to have "won".
  - Shapley focused more on the size of the galaxy and our location in it.
  - Curtis focused more on the existence of other galaxies.
  - **They were both right** (on the aspects which they focused on!).

- Resolution of the existence of other galaxies came in 1923 from Edwin Hubble.

The "Great Debate": Resolution

- Hubble discovered a Cepheid variable star in Andromeda (M31) and deduced its distance to be over 700,000 light years

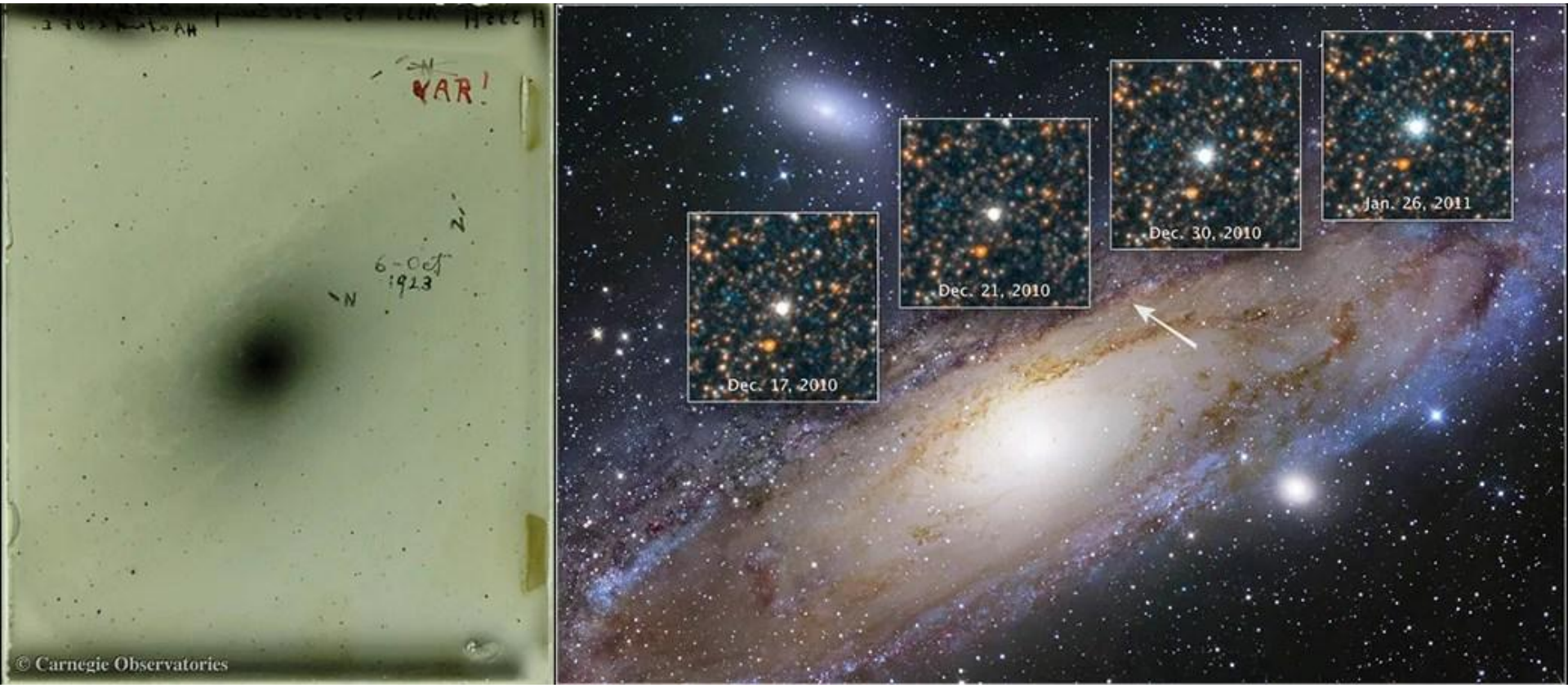
  → Obviously another galaxy.



February 1924 -- Hubble letter to Shapley:
"You will be interested to hear that I have found a Cepheid variable in the Andromeda nebula. I have followed the nebula this season as closely as the weather permitted and found two variables this week"

- Hubble found a dozen more in the next few months.
- Data from each Cepheid agreed on the distance.

The “Great Debate”: Resolution

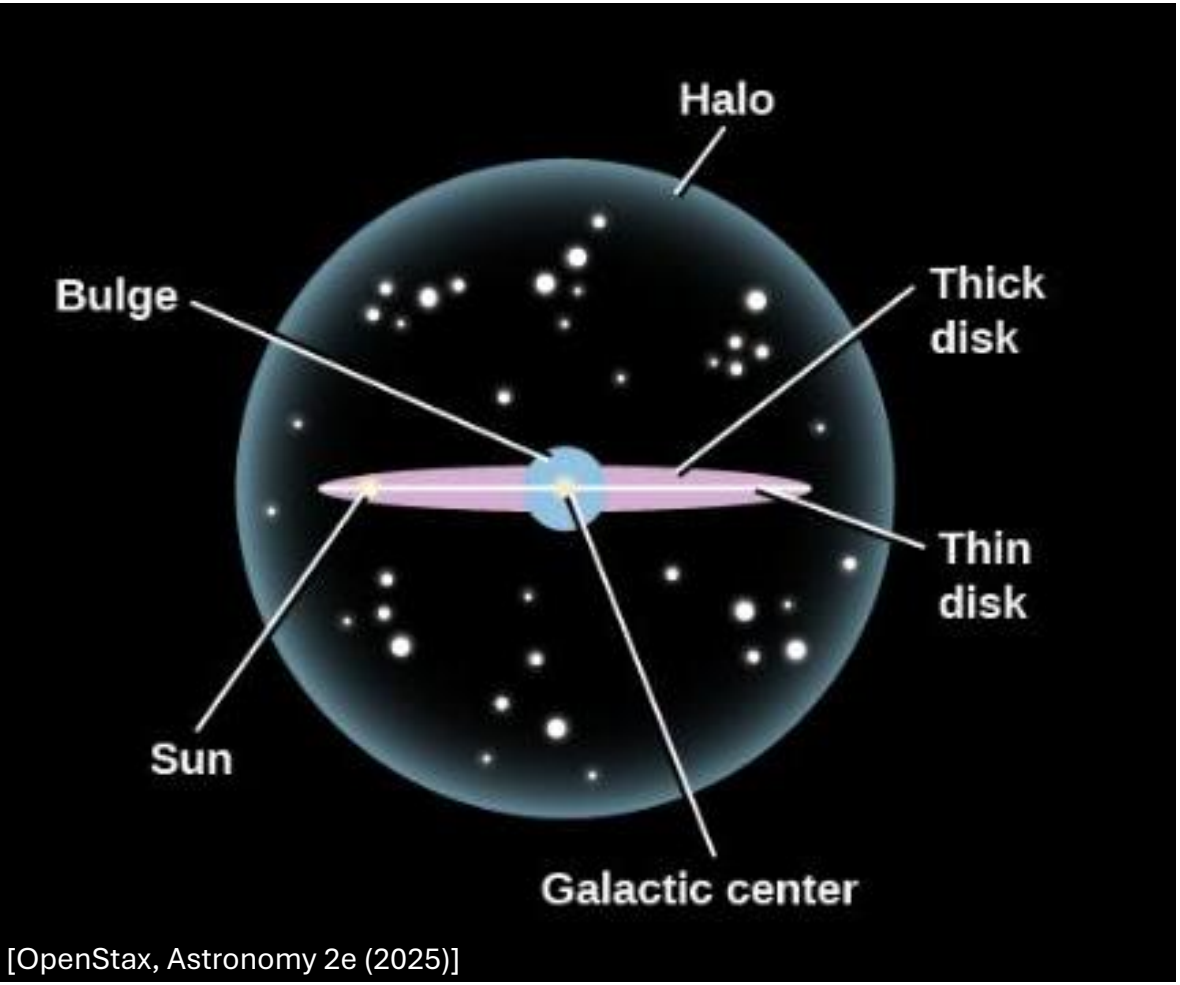


- Shapley gave in quickly.
- According to his PhD student, Cecelia Payne-Gaposchkin (who figured out that all stars are mostly H and He), when he got Hubble's letter he said

  "Here is the letter that destroyed my universe"

… back to the Milky Way Galaxy

Broad Structure



[OpenStax, Astronomy 2e (2025)]

Bulge region
- Stars have more random and out-of-plane orbits.
- Includes central bar.

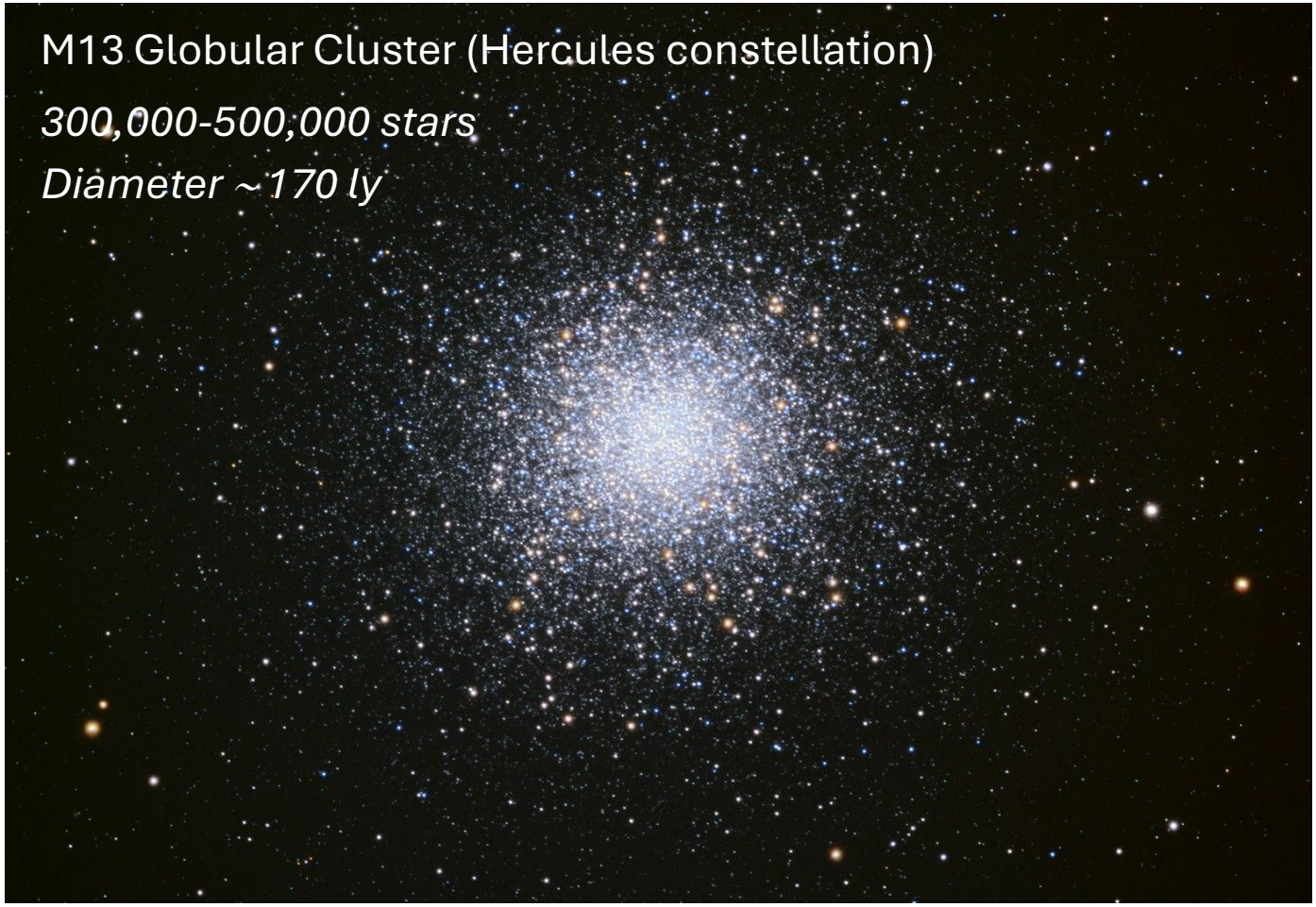
Thin & Thick Disk region
- Star orbits are more circular and in-plane.
- Includes the spiral arms.

Halo region
- Very old stars with out-of-plane and random orbits.
- Low density of matter.
- Includes dwarf galaxies.
- Includes globular clusters.
- Includes ***dark matter***.
- Stellar/visible part extends out to ~ 150-200 kly.

Globular Clusters

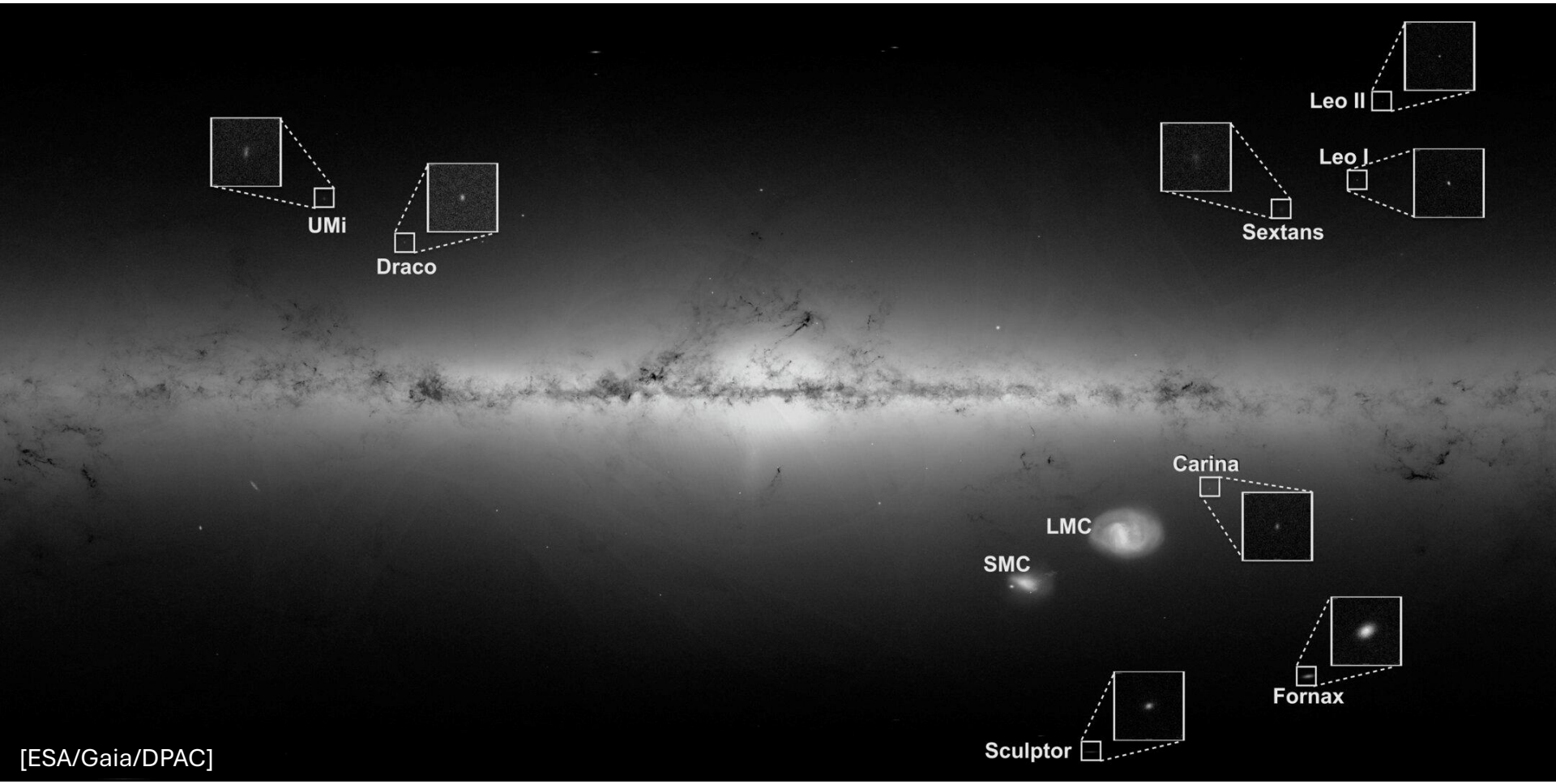
Globular clusters are essentially “micro” galaxies.

- Many old stars.
- Not much gas or dust.
- Spheroidal shape.
- Stars have relatively random orbits (no spiral arms).
- 150-ish globular clusters orbit the Milky Way in the halo region.



[By Sid Leach/Adam Block/Mount Lemmon SkyCenter]

Satellite Dwarf Galaxies

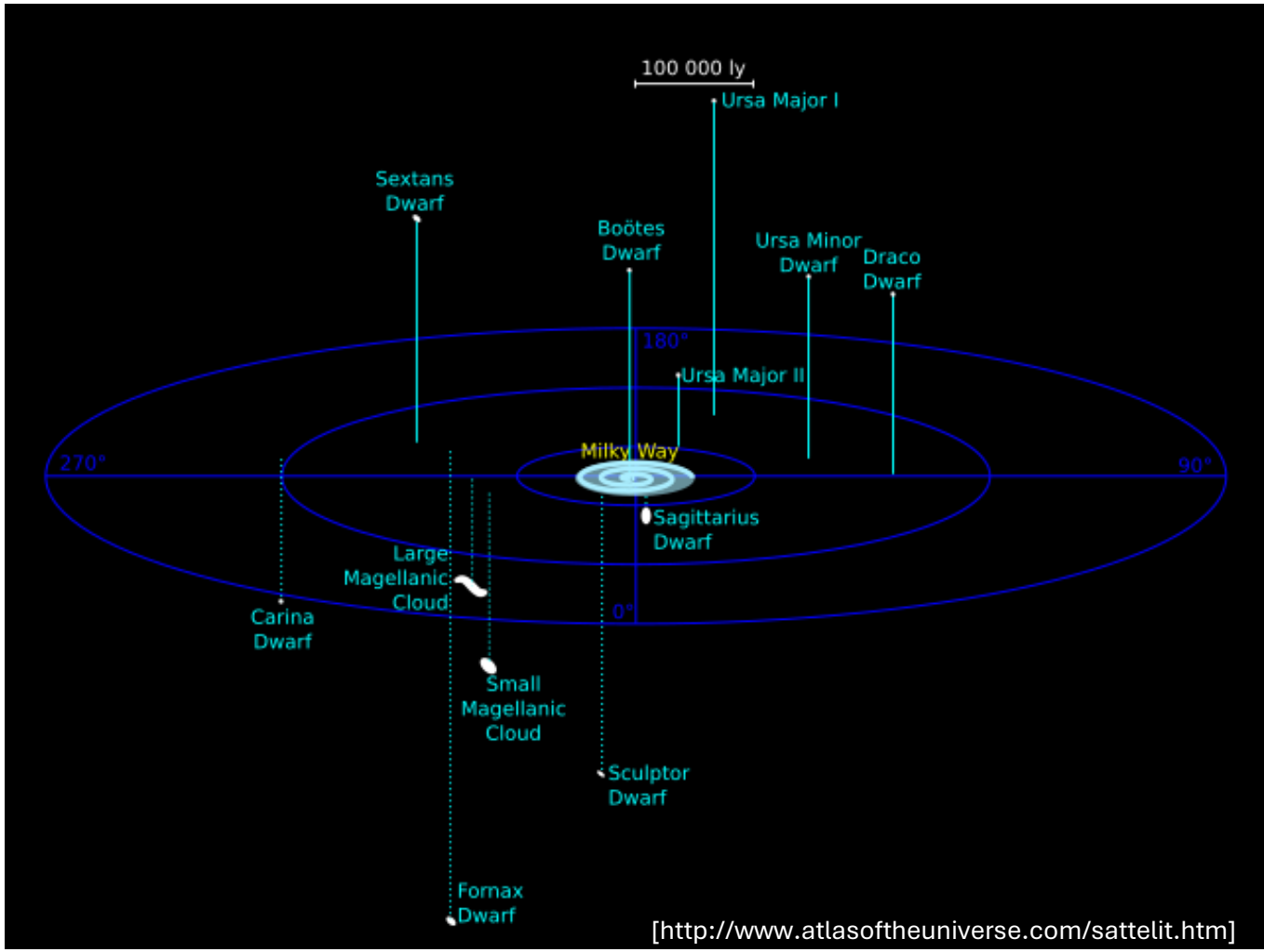


20-60 dwarf galaxies in vicinity of Milky Way

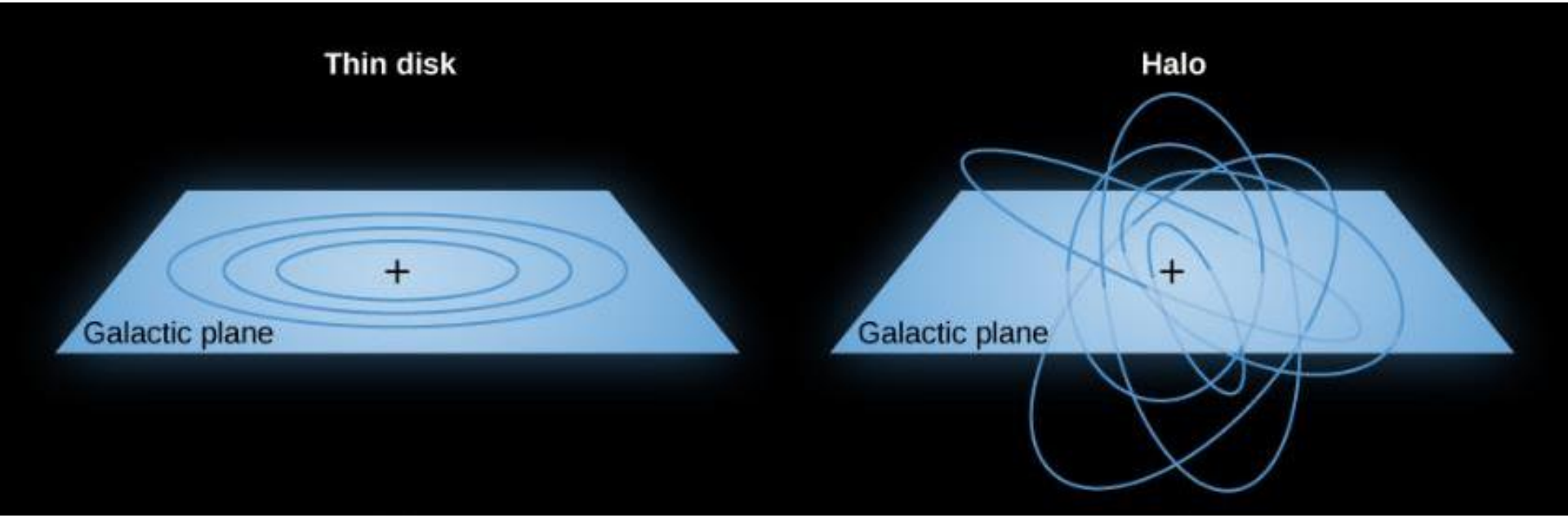
LMC = Large Magellanic Cloud
SMC = Small Magellanic Cloud

Satellite Dwarf Galaxies

- Not all dwarf galaxies are in orbit around the Milky Way.
- The **Sagittarius Dwarf** is being actively absorbed by the Milky Way.
- The LMC and SMC **may or may not** be in orbit around Milky Way.



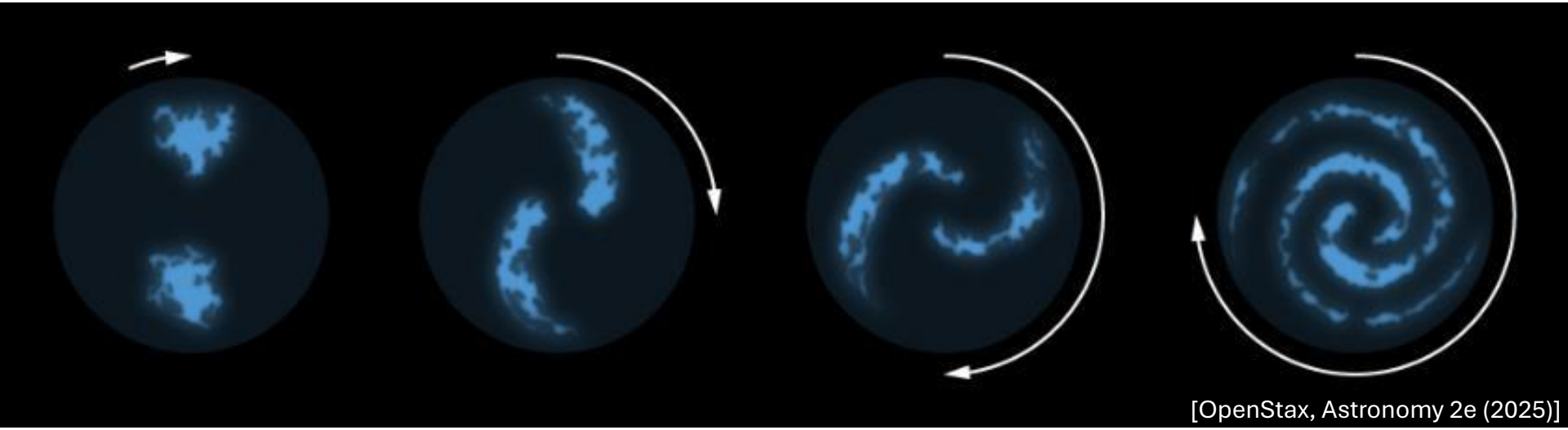
Orbits: Disk vs Halo



Stars (e.g., our Sun)
Gas & dust (nebulae)
White dwarfs, neutron stars, etc

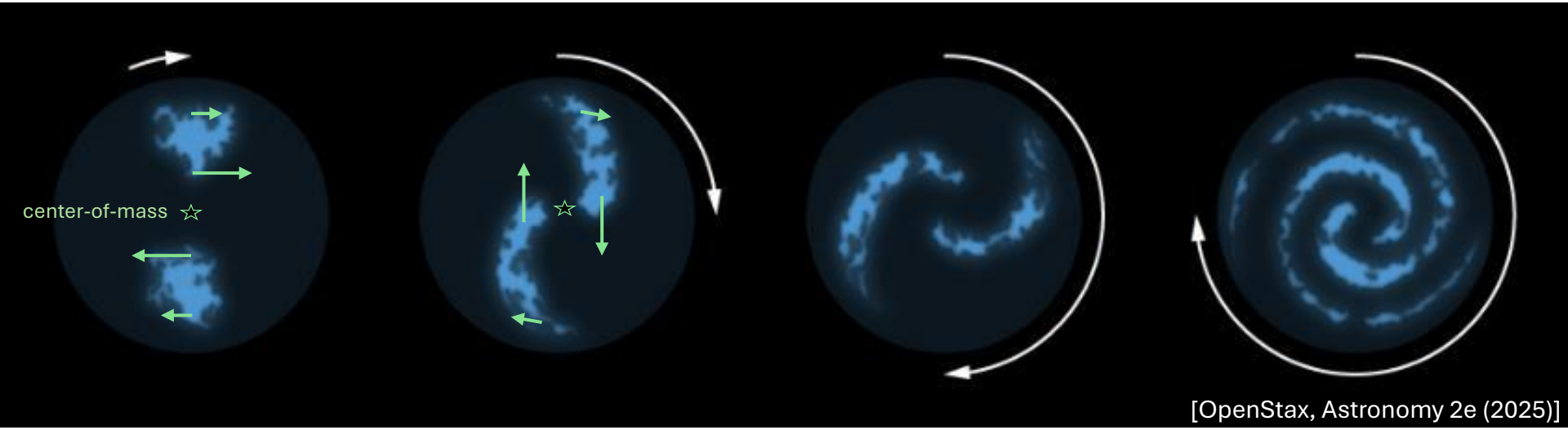
Stray stars
Globular clusters
Dwarf galaxies

Spiral Arms



- The matter in the spiral arms orbit around the center-of-mass of the galaxy.
  → *Kepler's laws determine the orbits (or Newton's version).*

Spiral Arms



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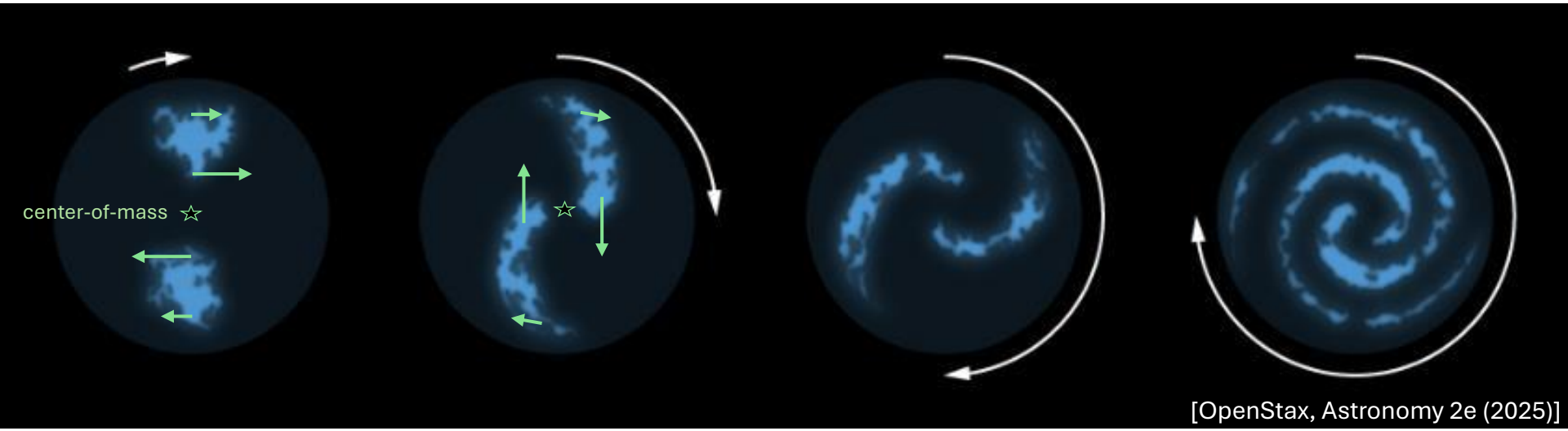
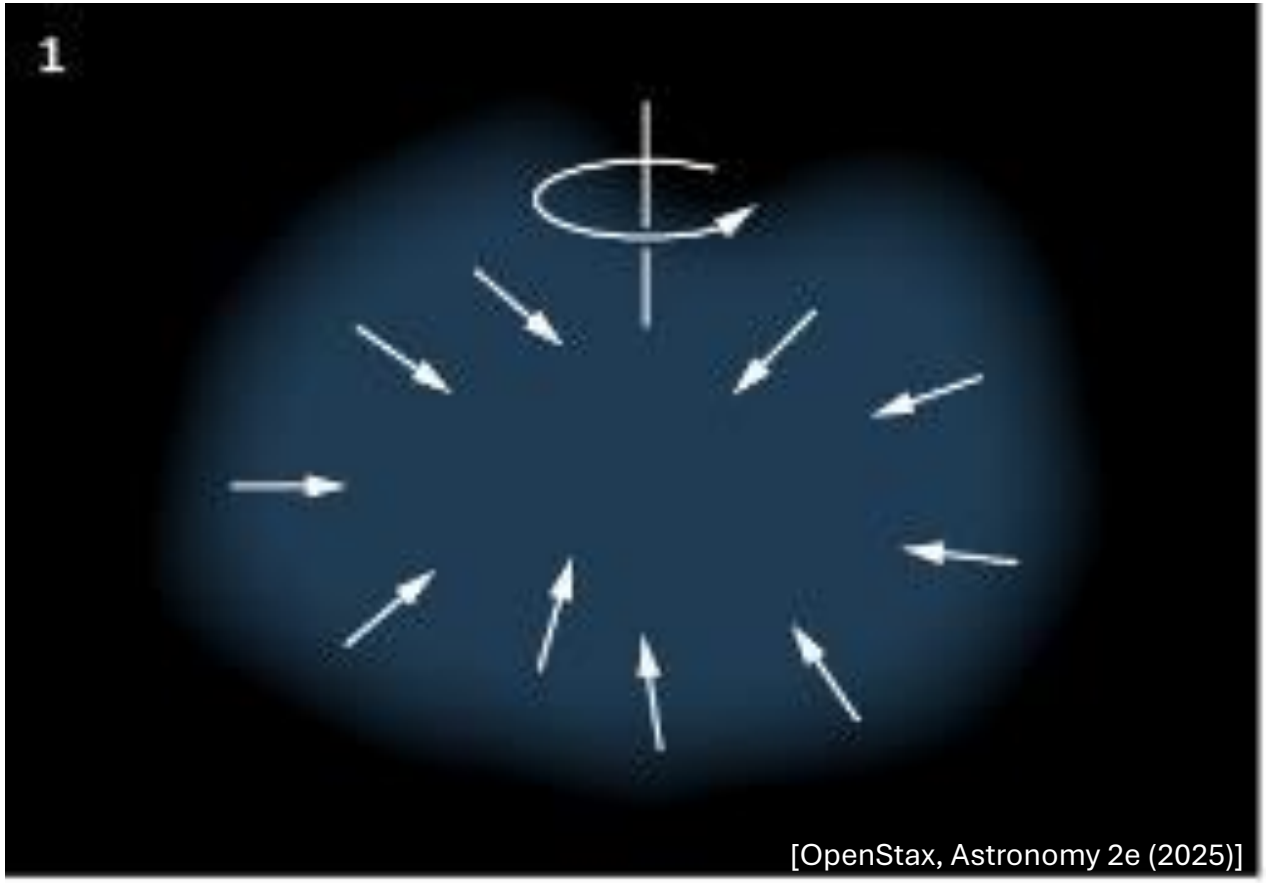
Spiral Arms



- The matter in the spiral arms orbit around the center-of-mass of the galaxy.
  → *Kepler's laws determine the orbits (or Newton's version).*
- The spiral arms of the galaxy do NOT rotate rigidly (i.e., not like a frisbee).
- The spiral arm shape evolves in time.
- The spirals do not continuous "wind up" forever.
  → *Gravitational interaction between the arms partially stabilizes them.*

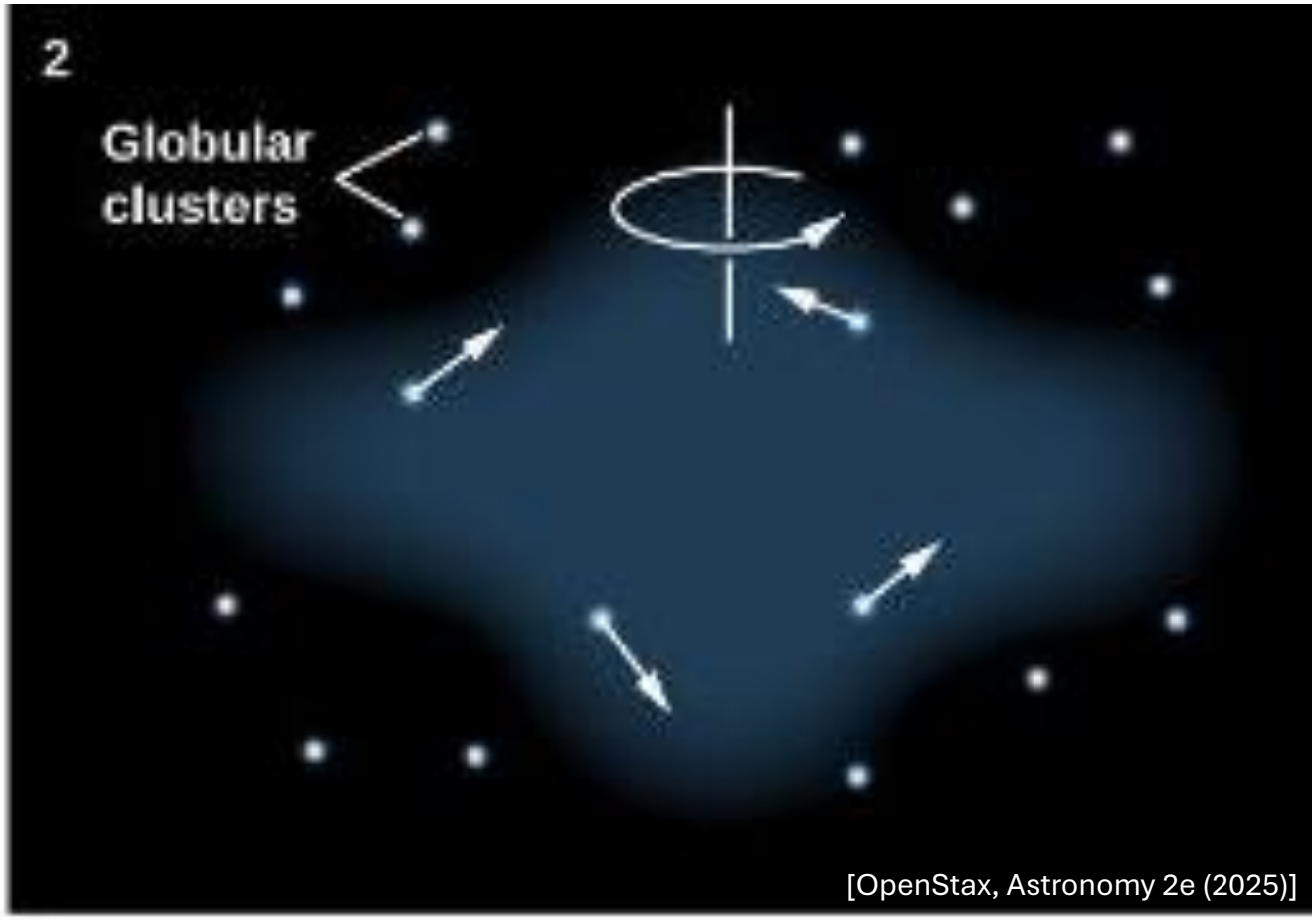
PollEv Quiz: PollEv.com/sethaubin

Monolithic Collapse Model: Galaxy formation



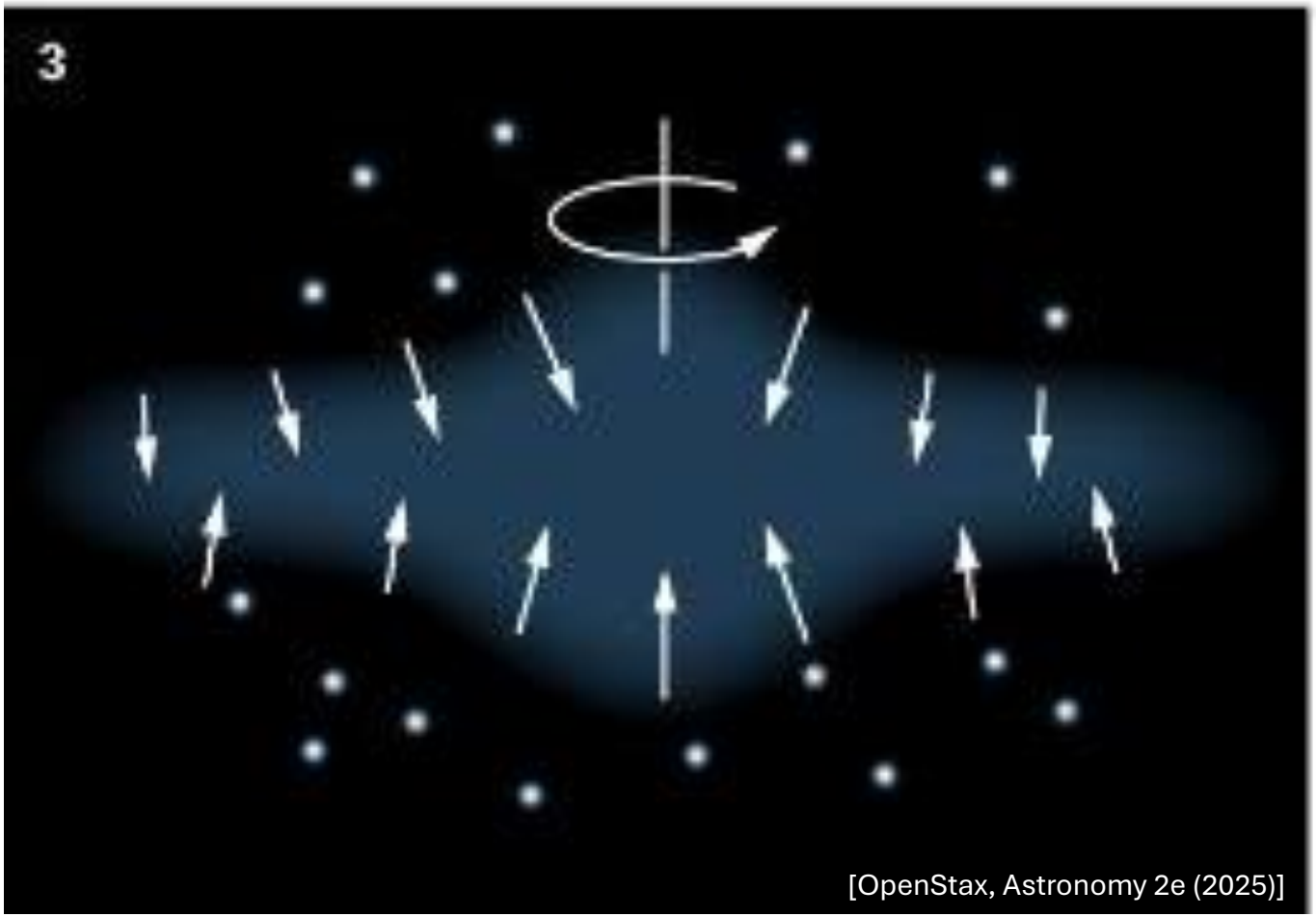
- An initial cloud of gas and dust collapses under its own gravity.
- As it collapses, its initial angular momentum is conserved, and the cloud rotates faster.

Monolithic Collapse Model: Galaxy formation



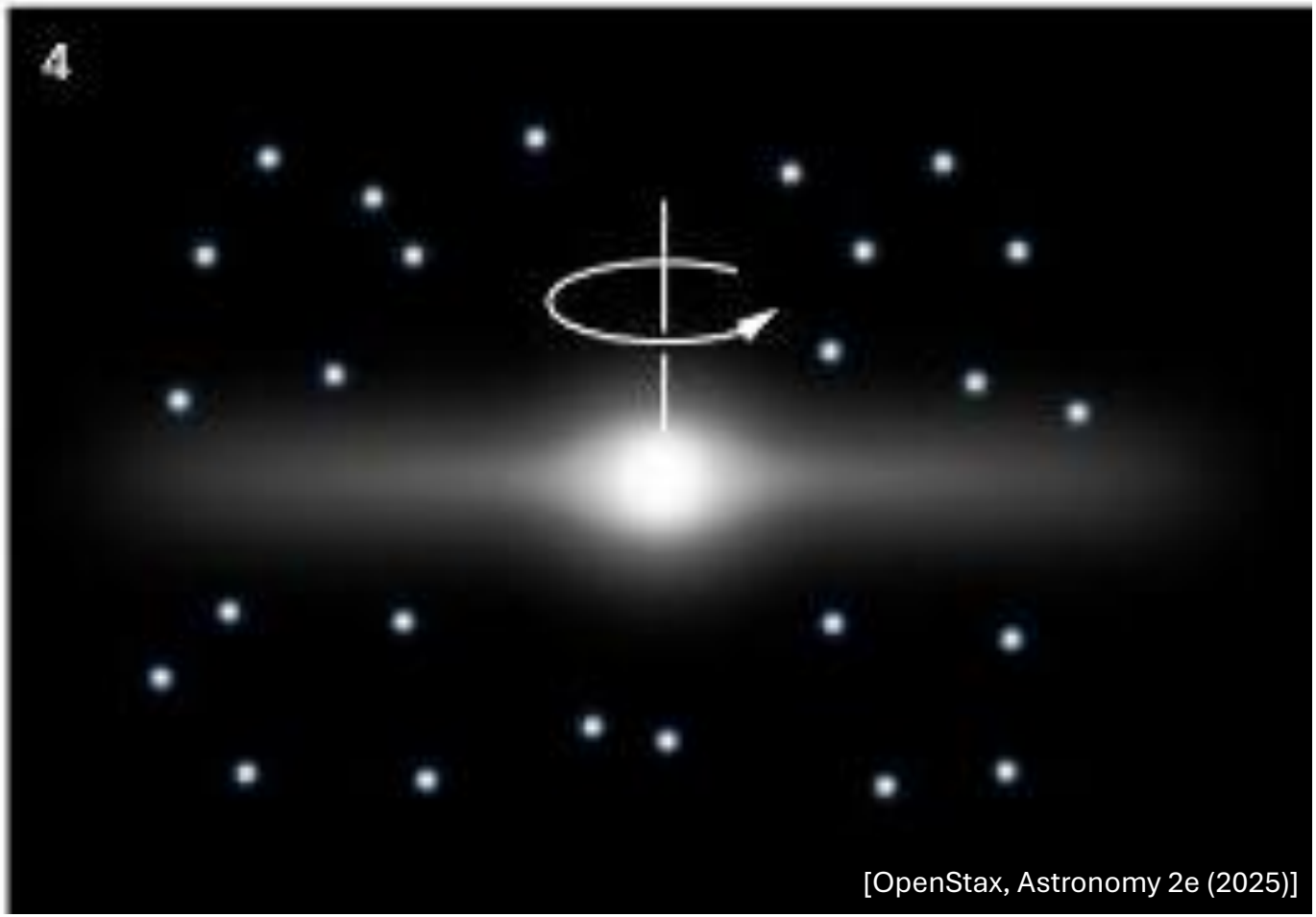
- The globular clusters were formed prior to collapse or were formed elsewhere.
- As it collapses, stars begin to form in regions of higher density.

Monolithic Collapse Model: Galaxy formation



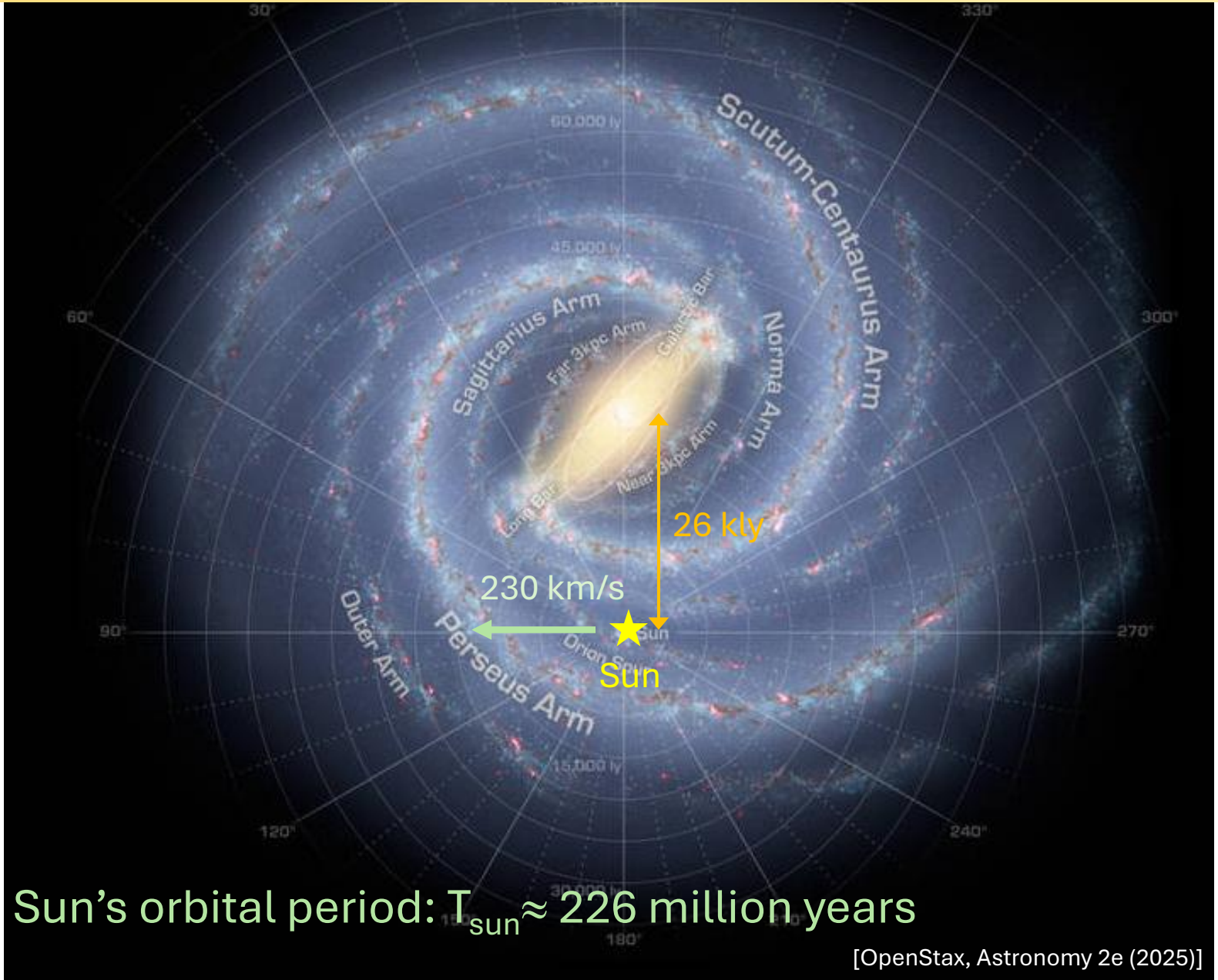
- Interactions between the gas/dust and stars pulls the cloud into a disk (angular momentum is conserved).

Monolithic Collapse Model: Galaxy formation



- The densest region centered on the center of mass has the most stars, and bulge emerges with somewhat random orbits (out-of-plane).

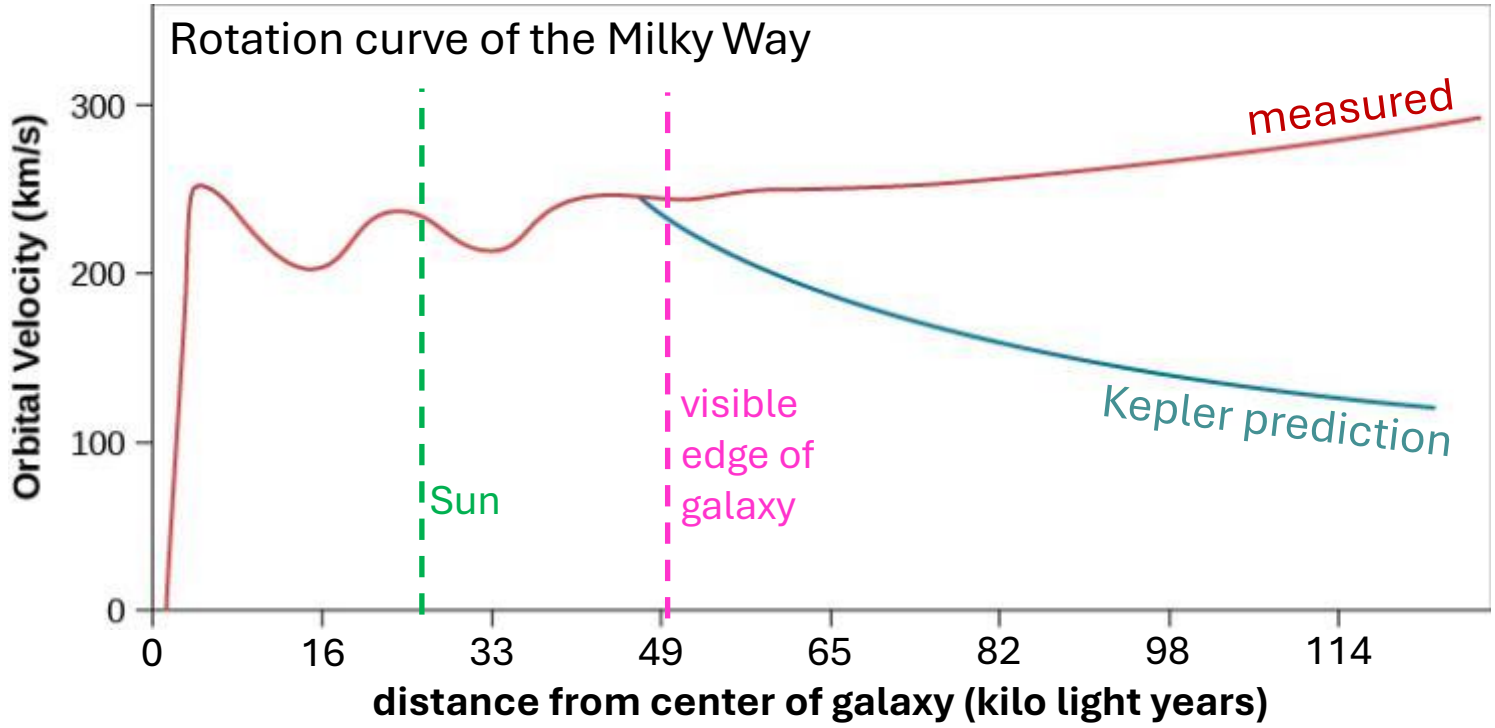
Sun's Orbital Speed



Sun's orbital period: $T_{sun} \approx 226$ million years

[OpenStax, Astronomy 2e (2025)]

Rotation Curve for Milky Way



- The orbital speed of carbon monoxide (CO) and hydrogen (H) gas at different distances from the center of the Milky Way Galaxy (red).
- The blue curve shows what the rotation curve would look like if all the matter in the Galaxy were located inside a radius of 30,000 light-years.

→ *Instead of going down, the speed of gas clouds farther out remains high, indicating a great deal of mass beyond the Sun's orbit*... Indicator of **dark matter**.

[OpenStax, Astronomy 2e (2025)]