Today's Topics

Friday, April 11, 2025 (Week 10, Lecture 27) – Chapter 25.

A. Our Milky Way Galaxy

B. Overall structure

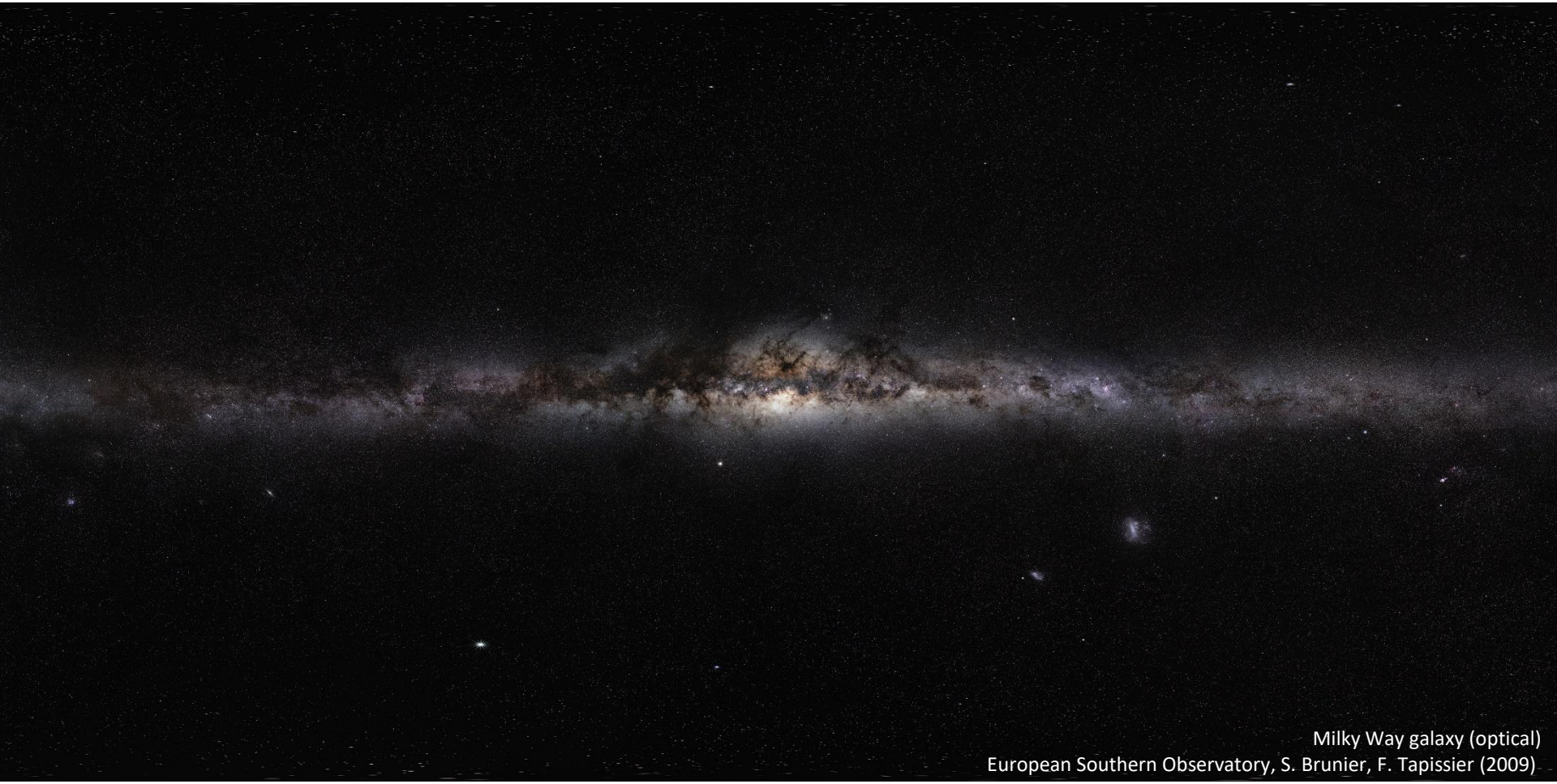
C. Formation of the galaxy

Our Milky Way Galaxy – by eye

[Peter Komka, MTI, AP]

Our Milky Way Galaxy – by telescope

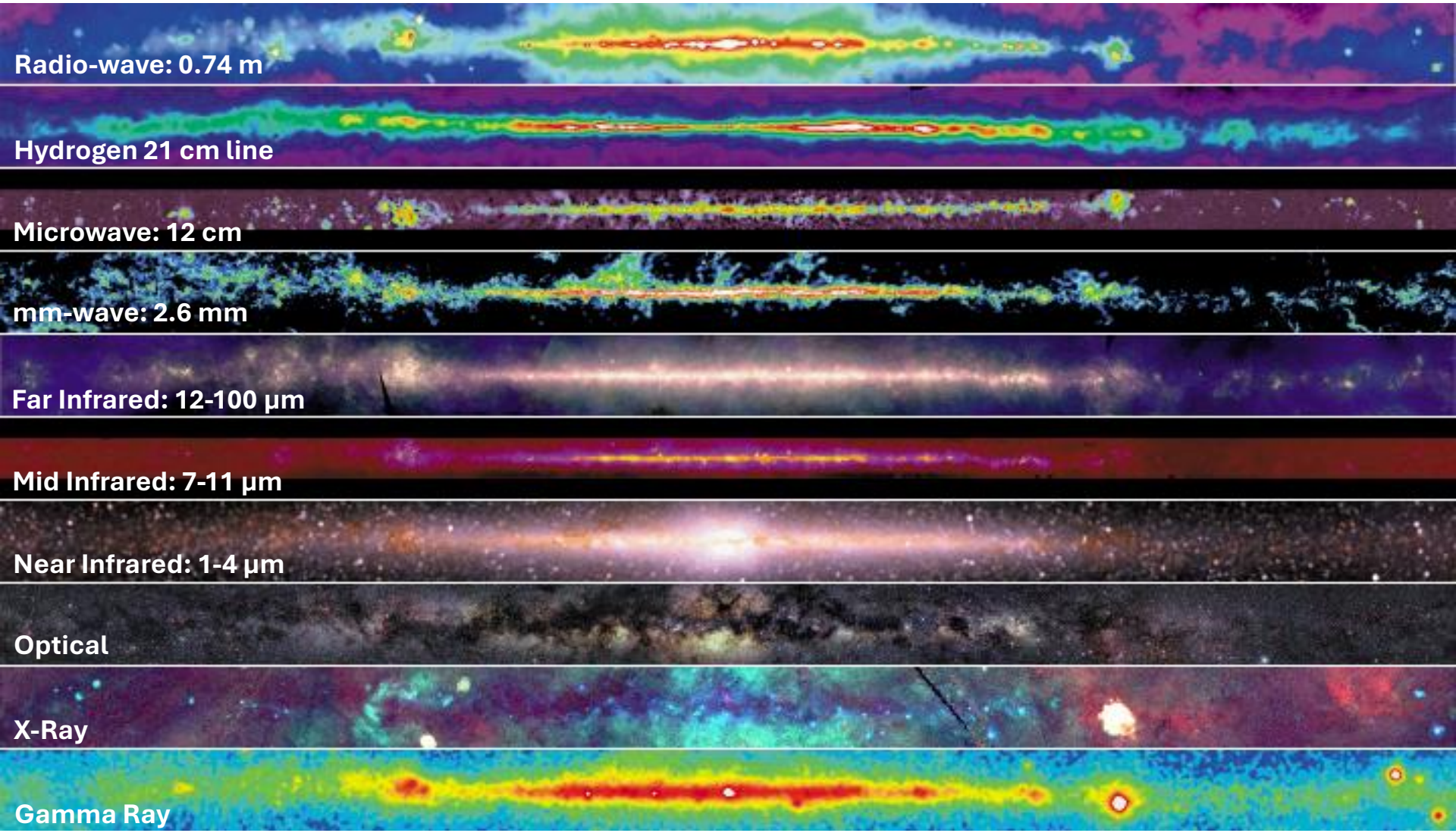
Our Milky Way galaxy has 100-400 billion stars



Milky Way galaxy (optical)
European Southern Observatory, S. Brunier, F. Tapissier (2009)

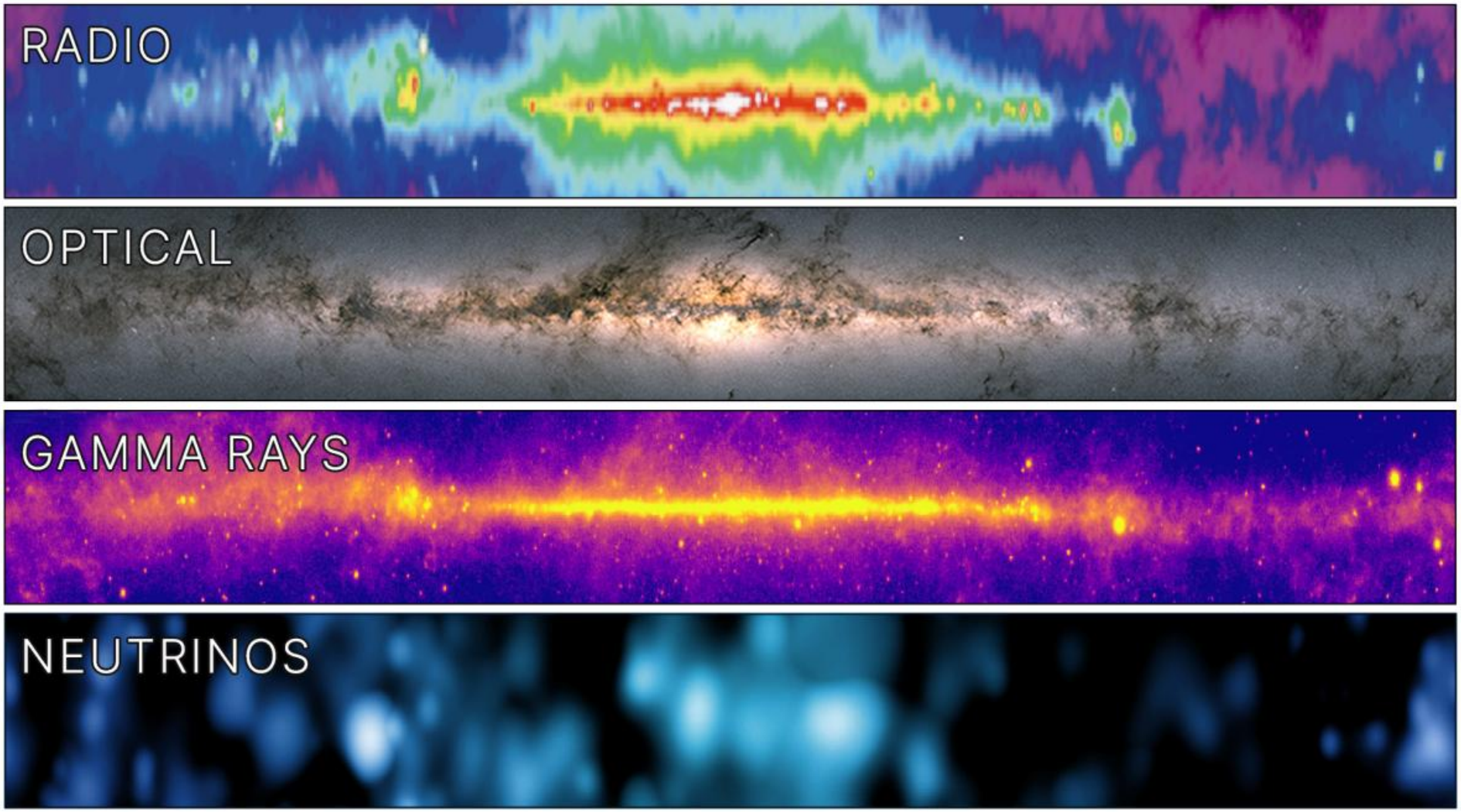
Milky Way galaxy: 360° view.

Milky Way: Full EM spectrum



[NASA, Goddard Space Flight Center (2018)]

Milky Way: Photons vs Neutrinos



[IceCube collaboration, 2023]

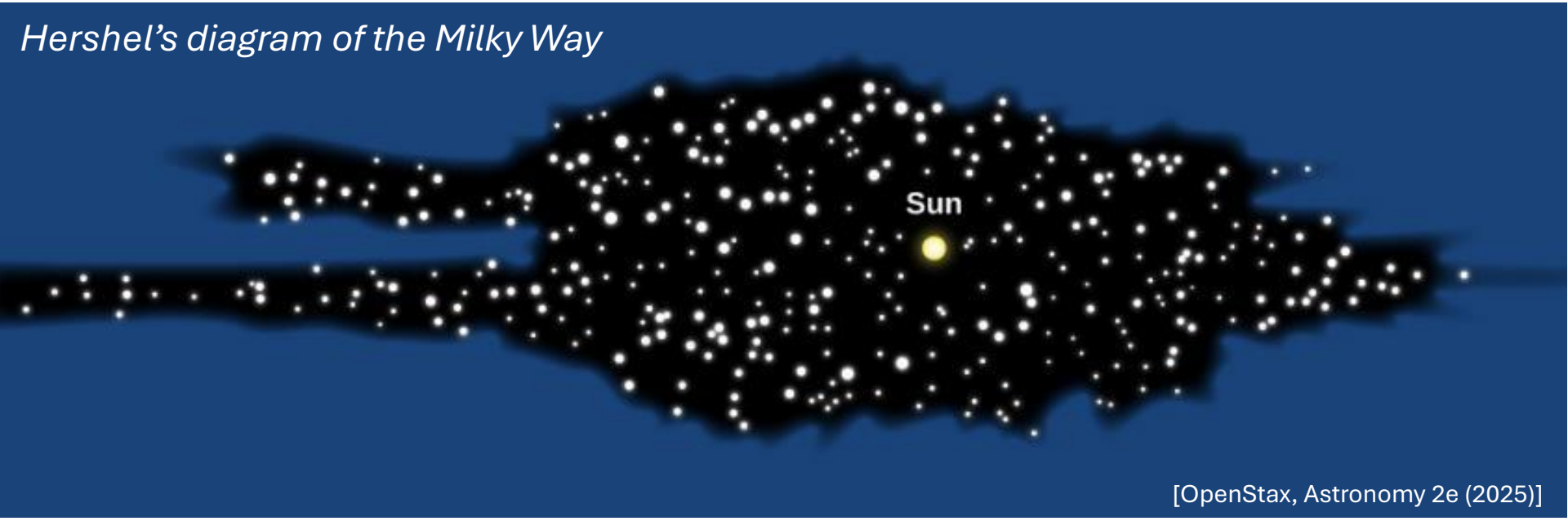
Mapping the Milky Way

By measuring the distance to many, many stars and interstellar gas/dust clouds, one can construct a map of our galaxy:

- William **Herschel's** map (18th century).
- Harlow **Shapley's** map (20th century).
- Current maps show a **spiral galaxy** structure.

Herschel's Milky Way (18th Century)

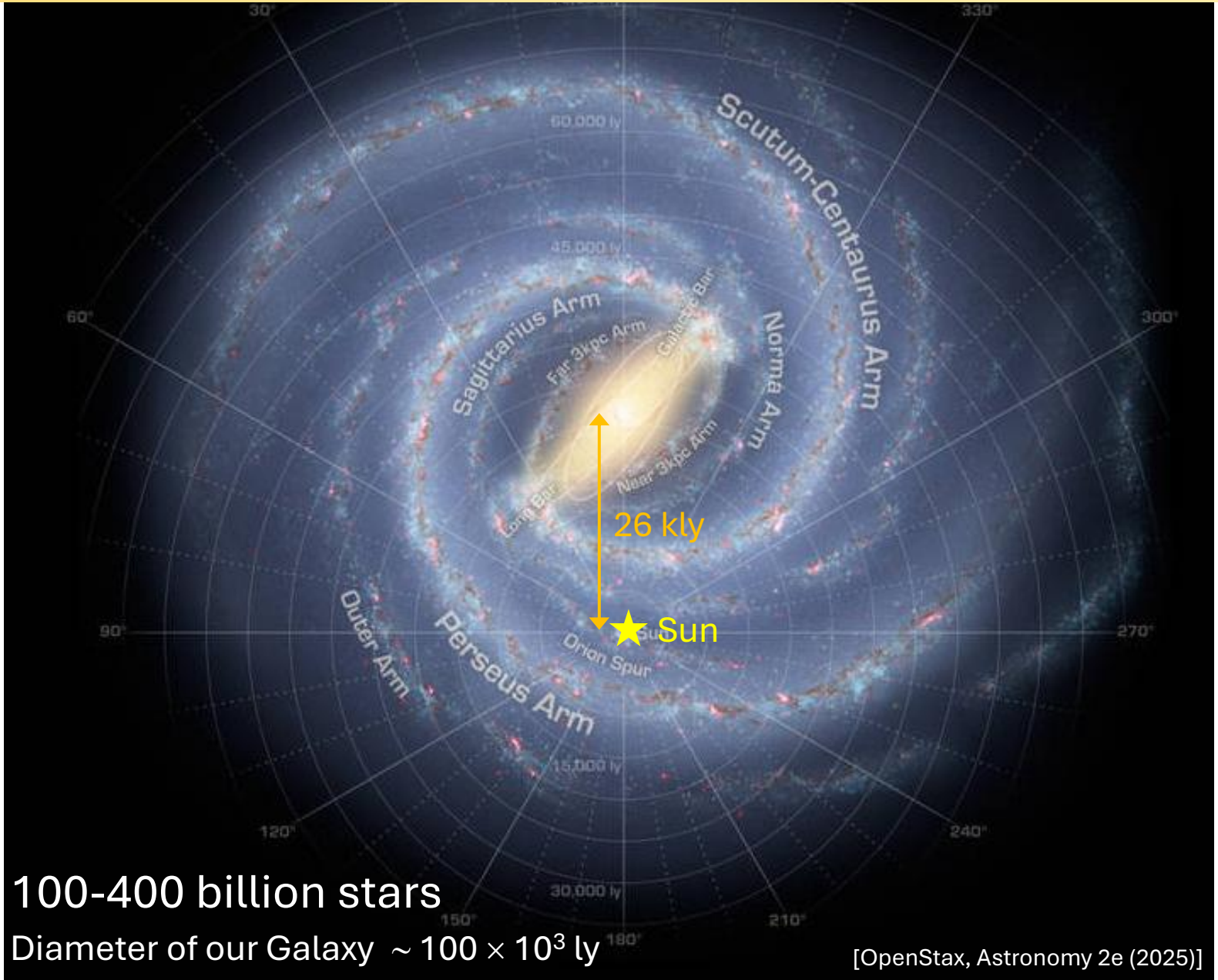
Hershel's diagram of the Milky Way



[OpenStax, Astronomy 2e (2025)]

William Herschel (1738-1822) and **Caroline Herschel** (1750-1848) measured the distribution of stars in various directions of the sky to determine the shape of the Milky Way galaxy (i.e., "universe").

Milky Way Structure (present day)



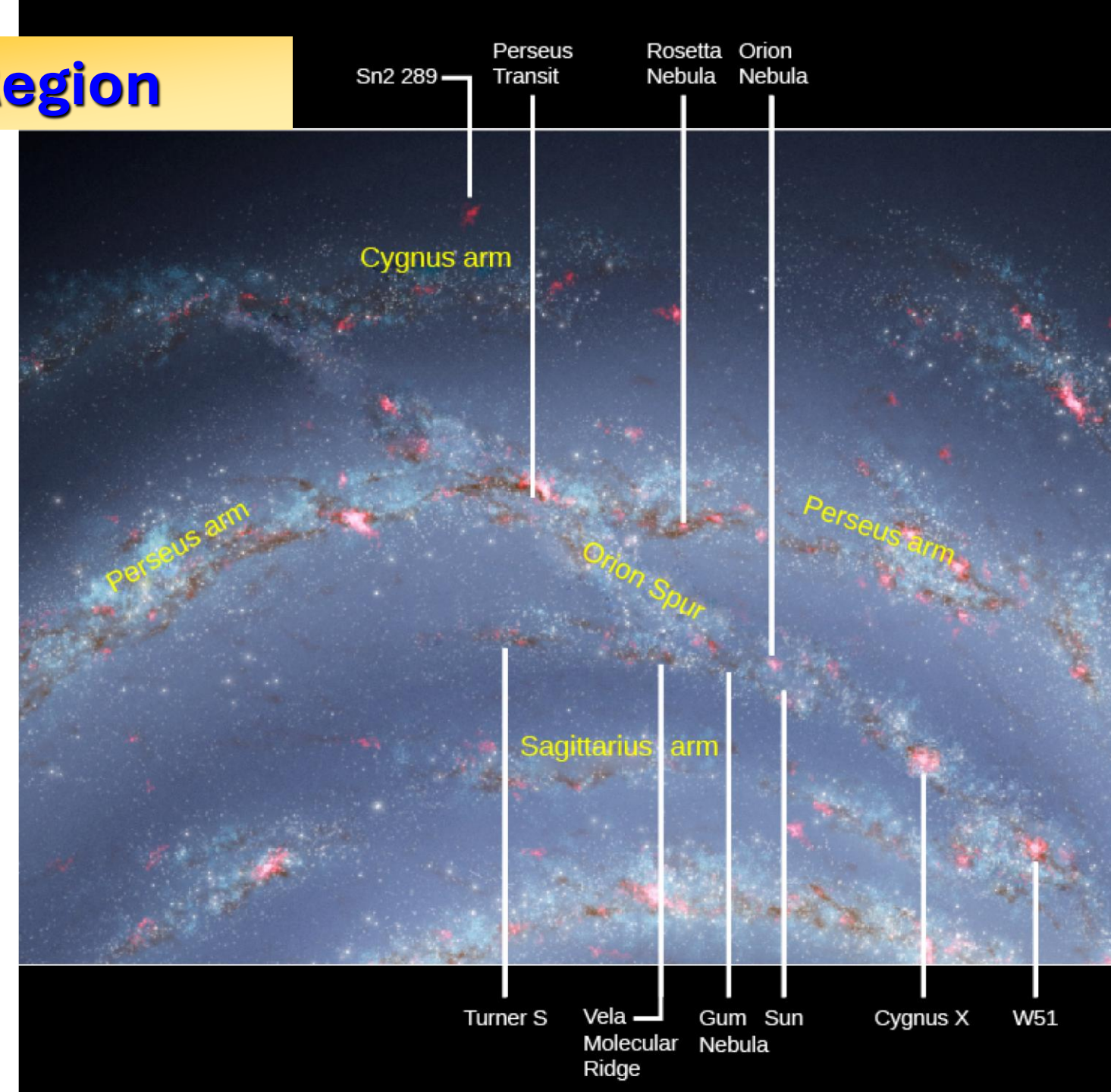
100-400 billion stars

Diameter of our Galaxy $\sim 100 \times 10^3$ ly

[OpenStax, Astronomy 2e (2025)]

Local Region

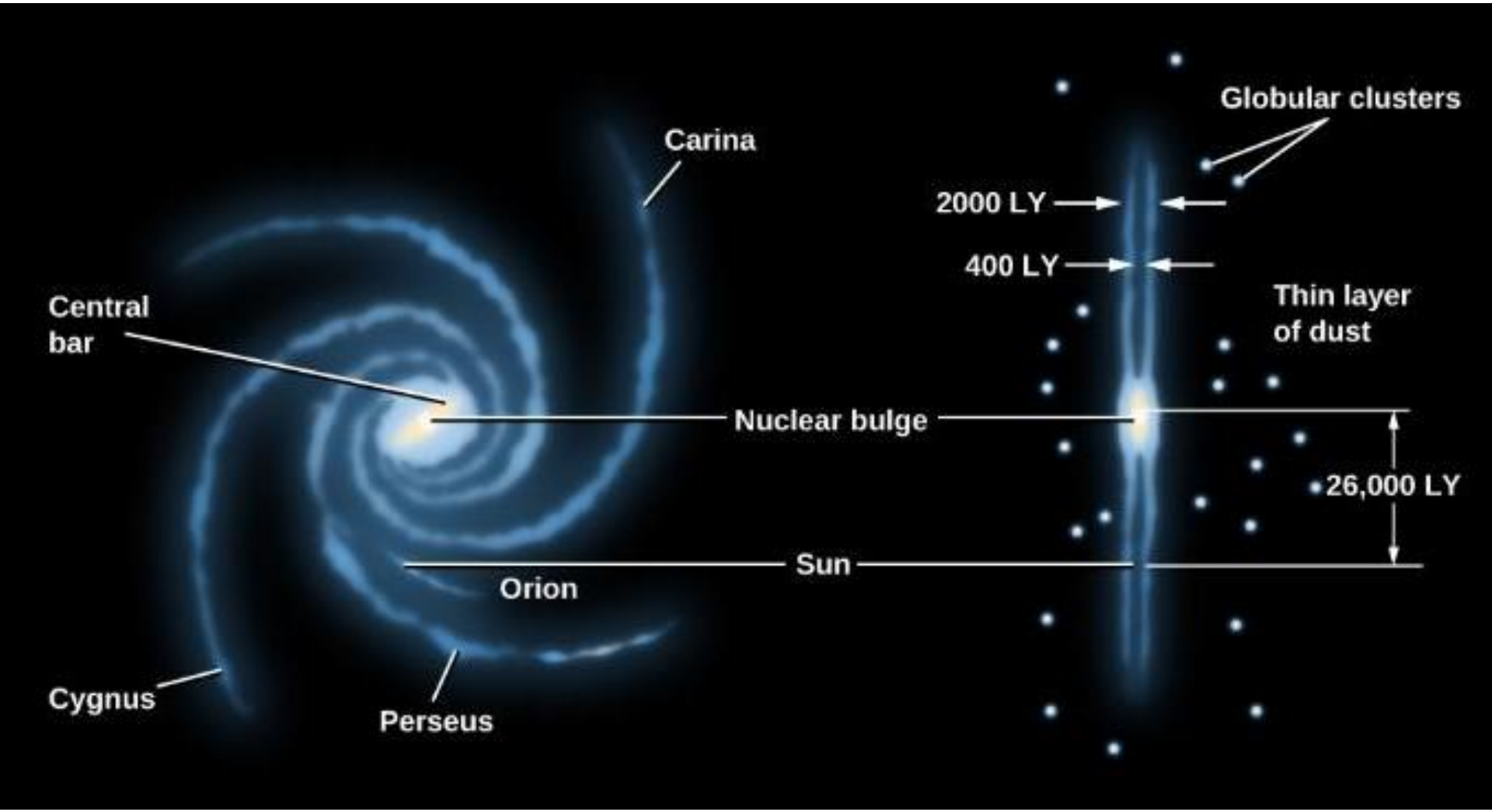
- Our solar system is in the Orion spur.
- Between the Perseus arm and the Sagittarius arm.



Cygnus X: Star forming region.

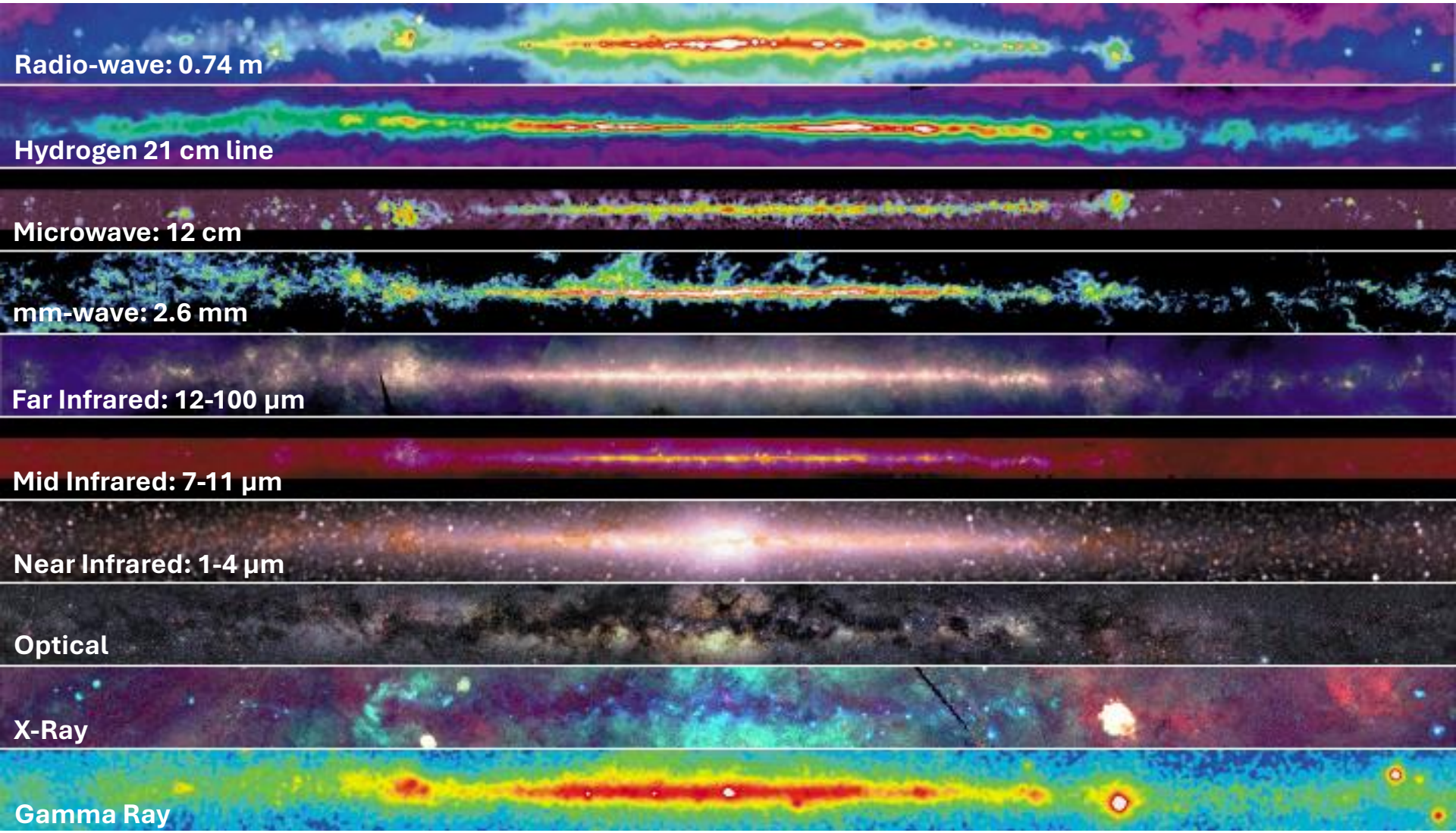
W51: large star "factory".

Basic Structure



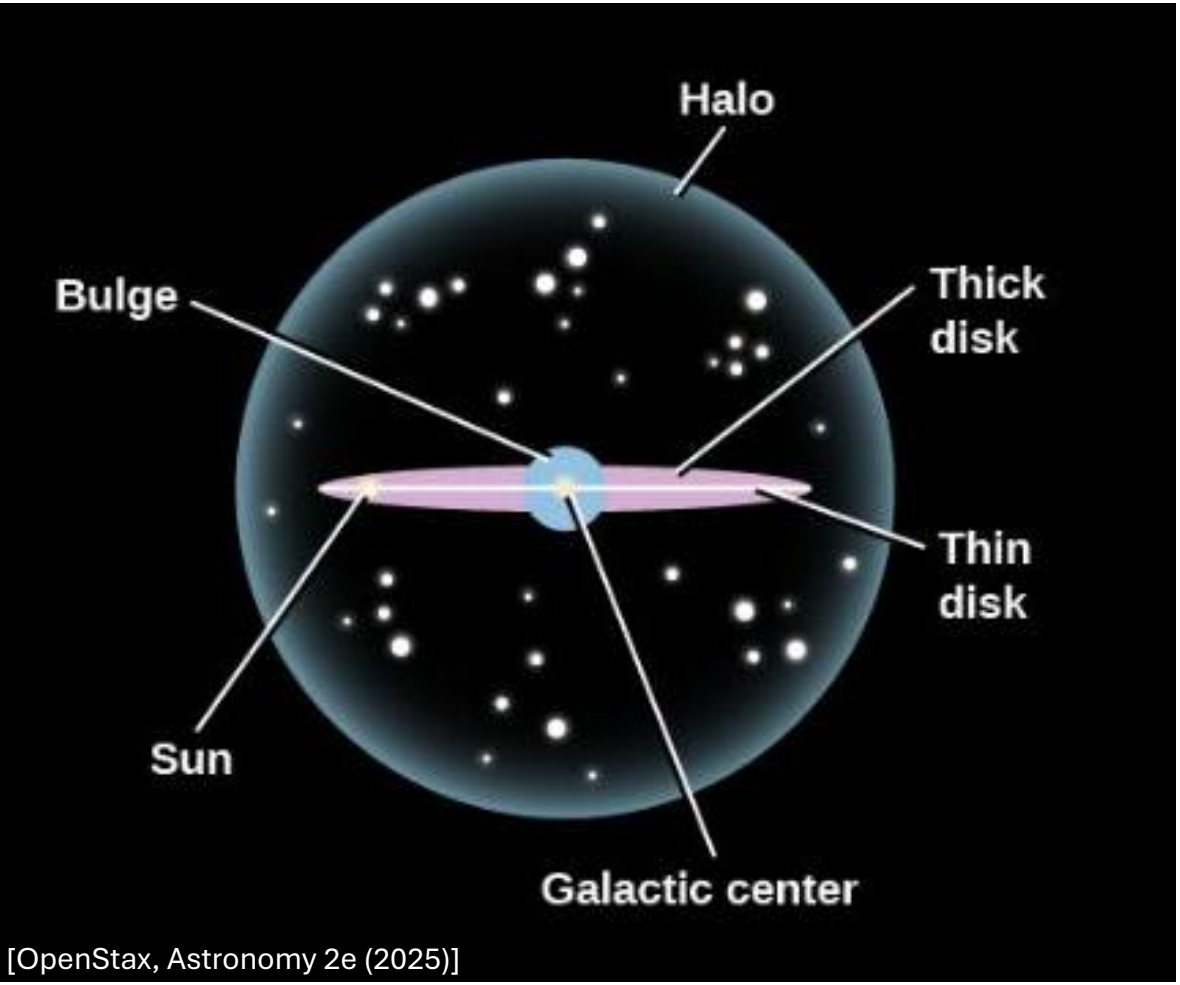
[OpenStax, Astronomy 2e (2025)]

Milky Way: Full EM spectrum



[NASA, Goddard Space Flight Center (2018)]

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***.
- Extends out to ~ 150-200 kly.

Broad Structure

Characteristics of the Milky Way Galaxy

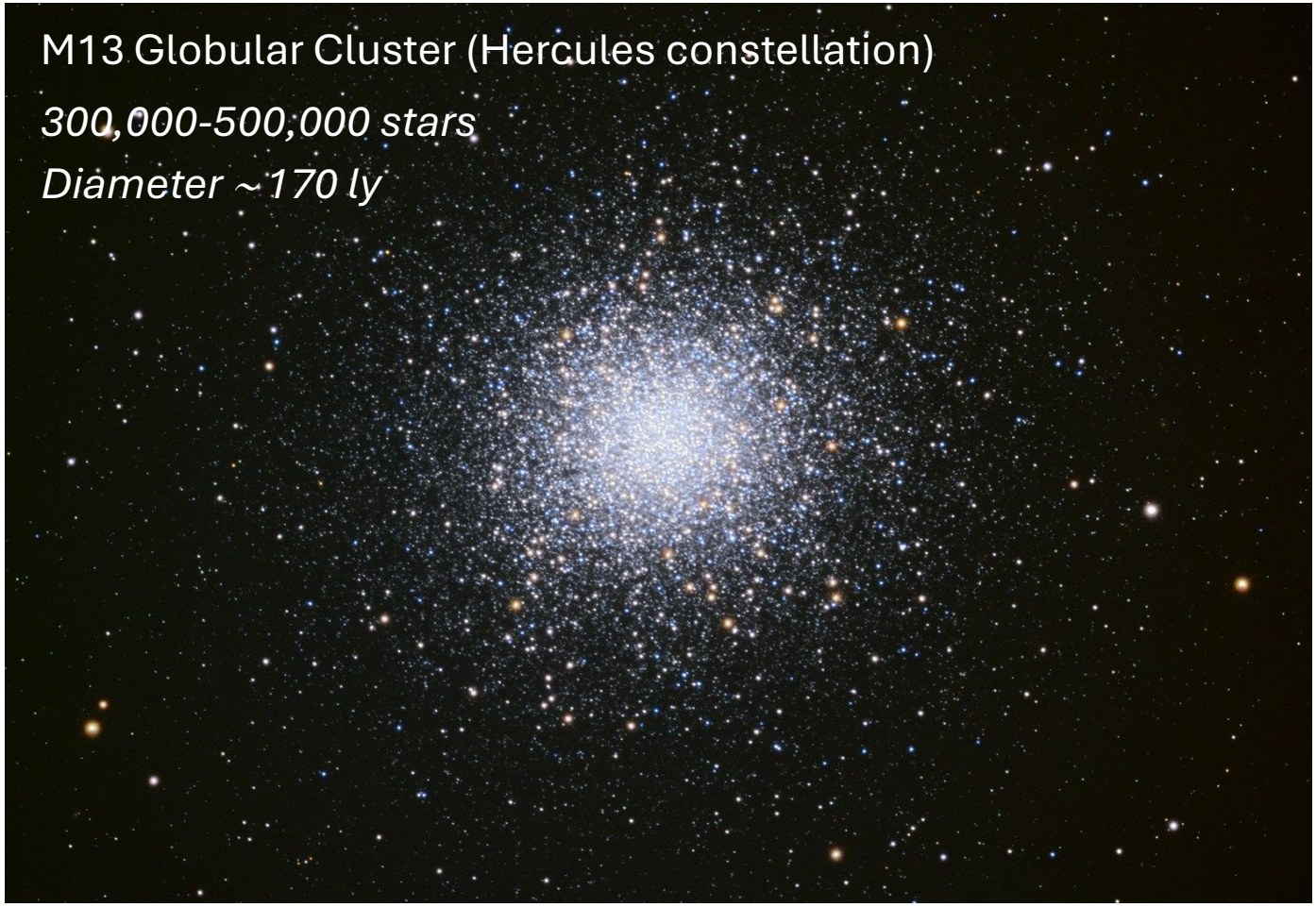
Property	Thin Disk	Thick Disk	Stellar Halo (Excludes Dark Matter)
Stellar mass	$4 \times 10^{10}\ M_{\text{Sun}}$	A few percent of the thin disk mass	$10^{10}\ M_{\text{Sun}}$
Luminosity	$3 \times 10^{10}\ L_{\text{Sun}}$	A few percent of the thin disk luminosity	$8 \times 10^{8}\ L_{\text{Sun}}$
Typical age of stars	1 million to 10 billion years	11 billion years	13 billion years
Heavier-element abundance	High	Intermediate	Very low
Rotation	High	Intermediate	Very low

[OpenStax, Astronomy 2e (2025)]

Globular Clusters

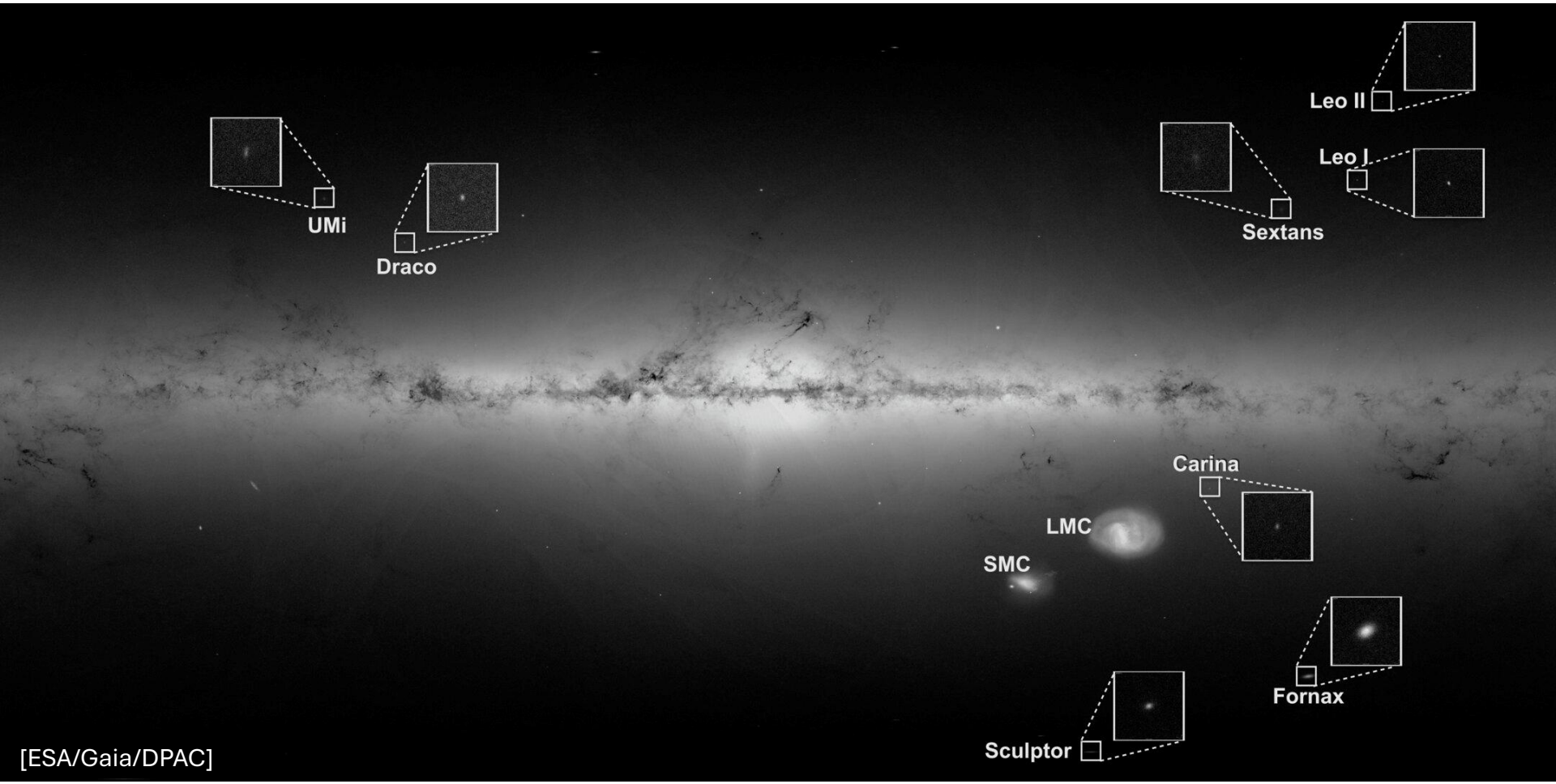
Globular clusters are essentially “micro” galaxies.

- 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

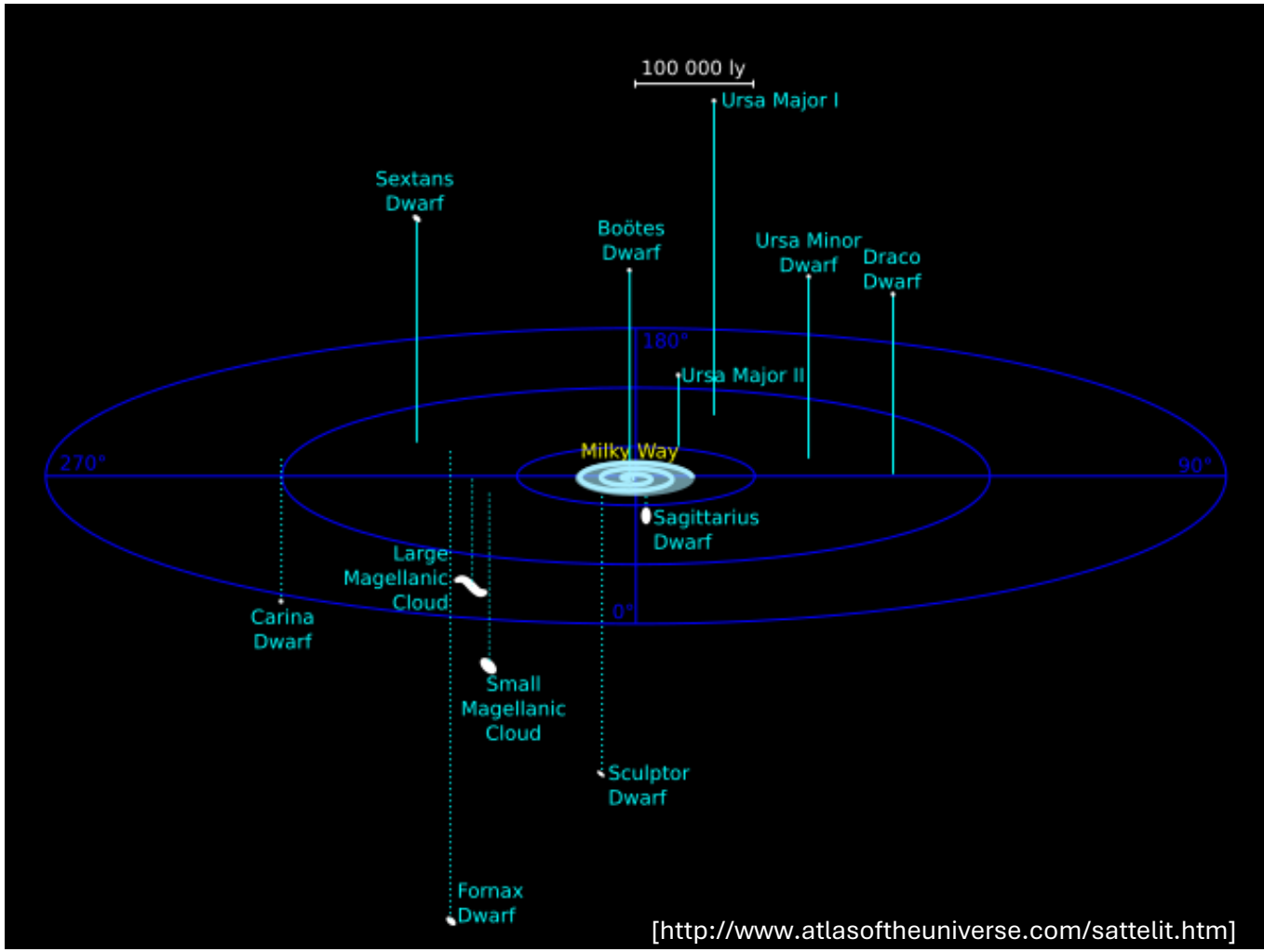


20-60 dwarf galaxies in vicinity of Milky Way

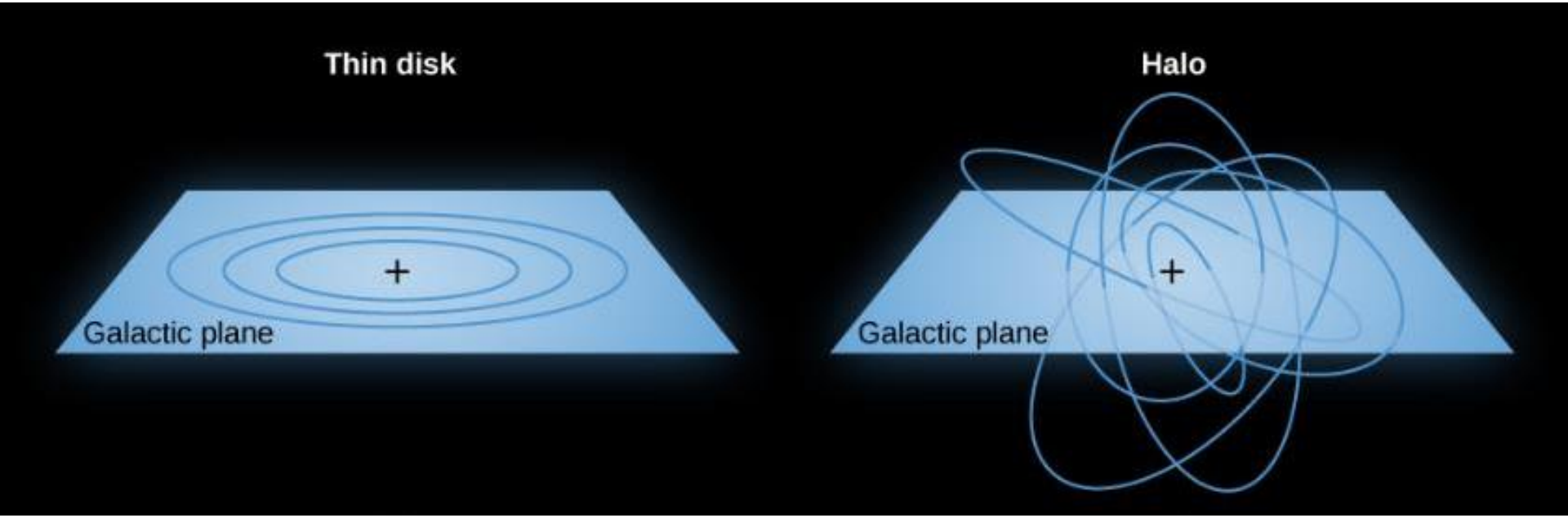
LMC = Large Magellanic Cloud
SMC = Small Magellanic Cloud

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.



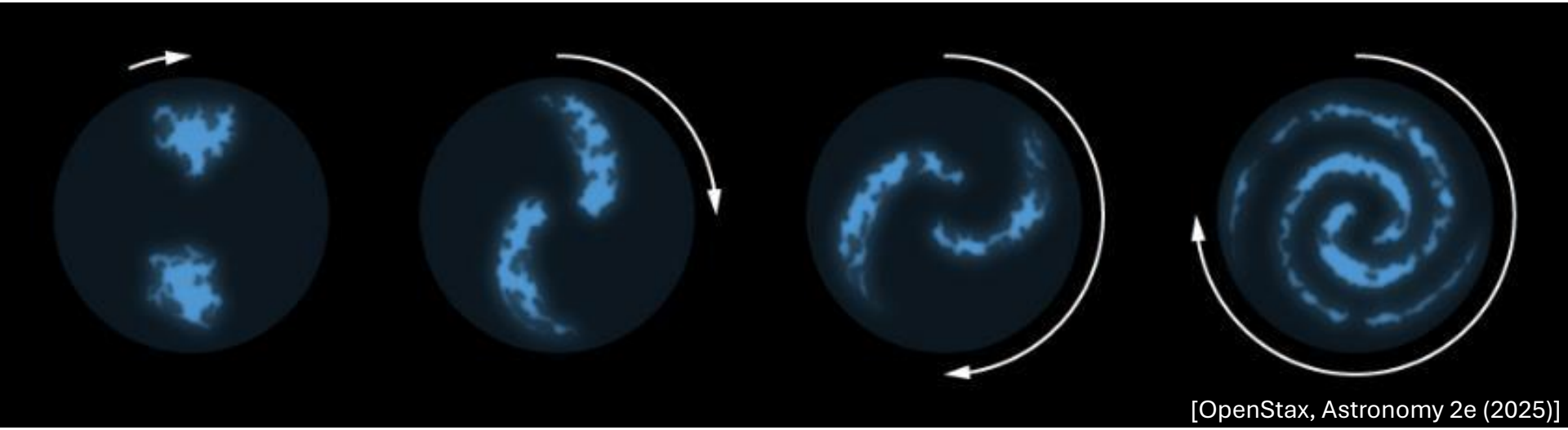
Orbits: Disk vs Halo



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

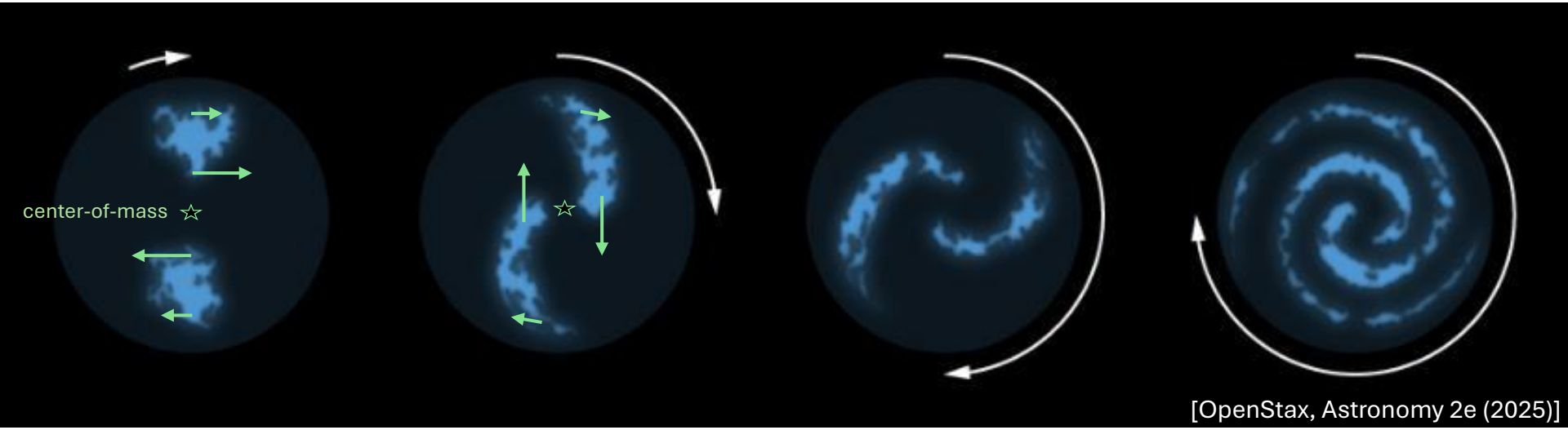
Stray stars
Globular clusters
Dwarf galaxies

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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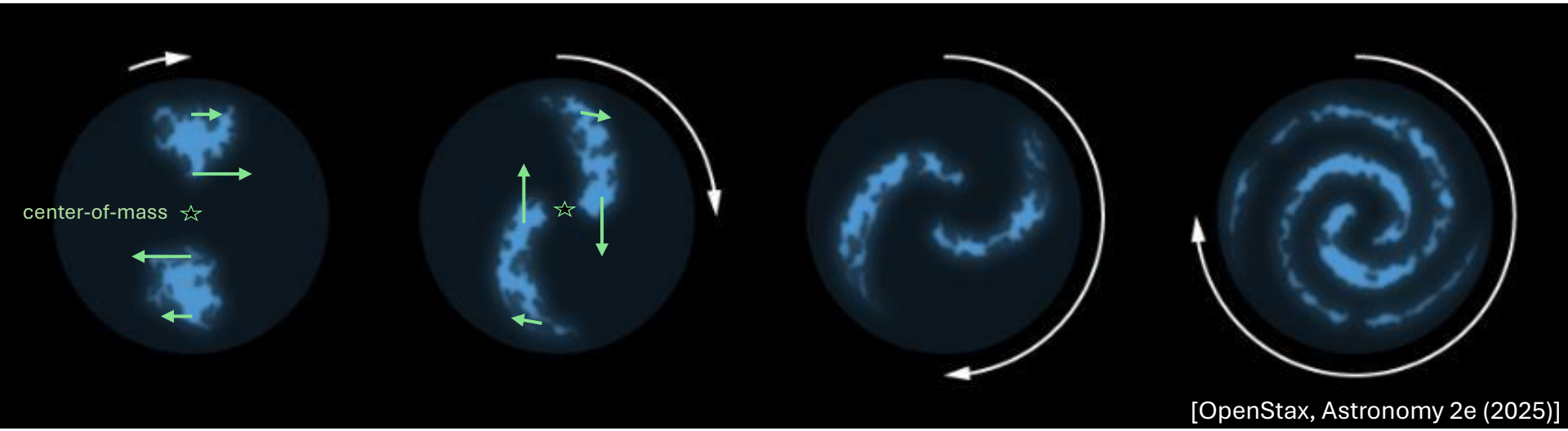
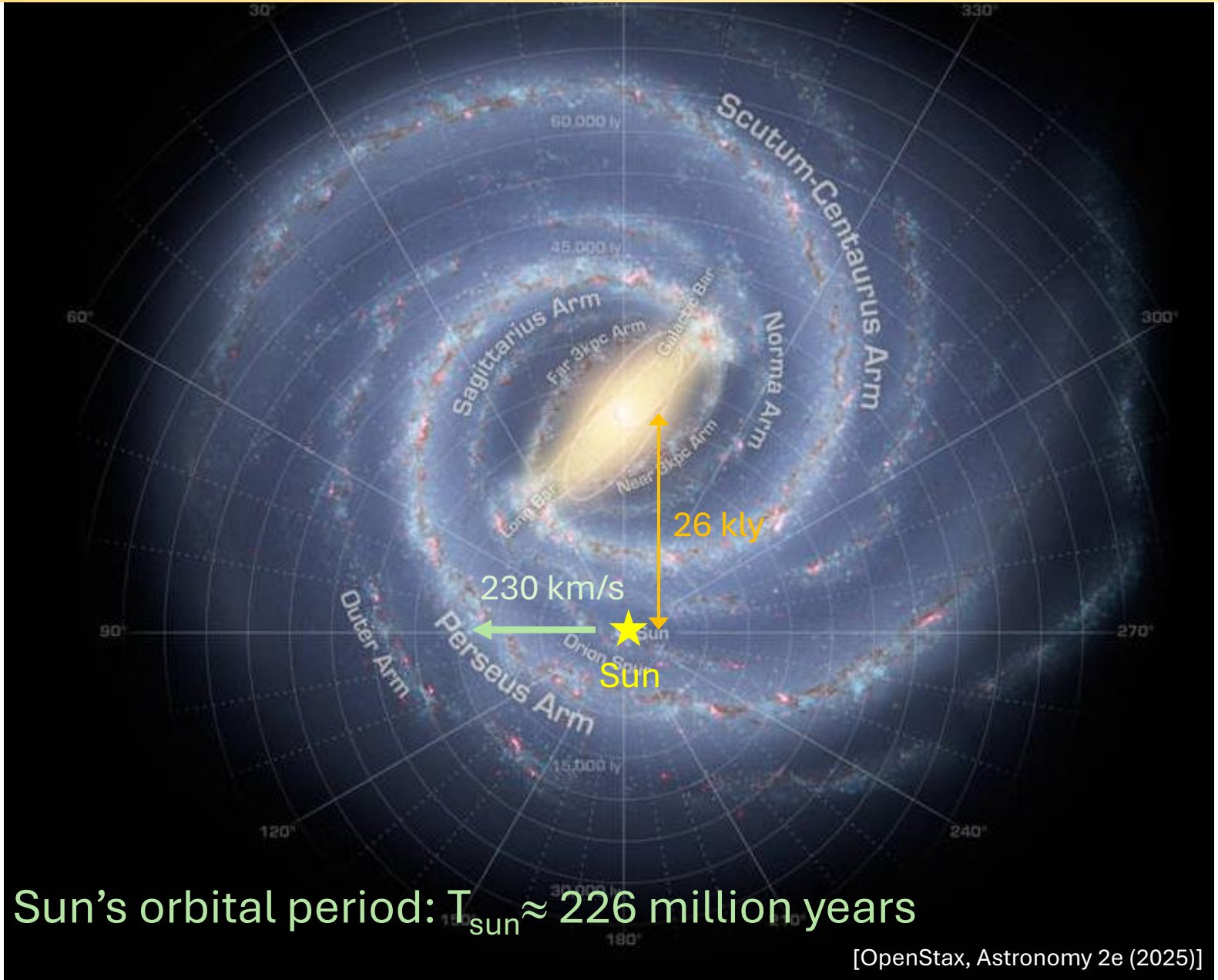
Spiral Arms



- 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.*

Sun's Orbital Speed

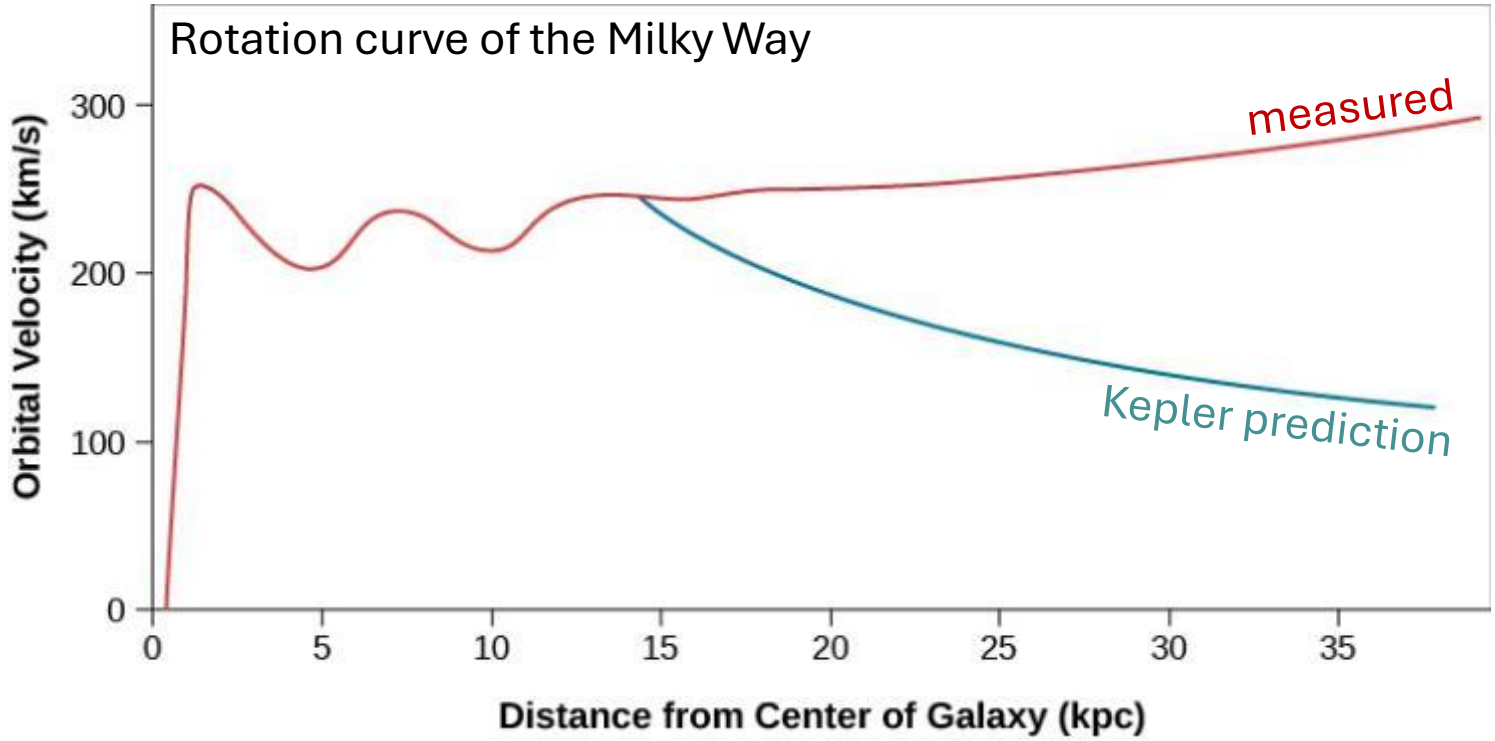


Sun's orbital period: $T_{sun} \approx 226$ million years

[OpenStax, Astronomy 2e (2025)]

PollEv Quiz: PollEv.com/sethaubin

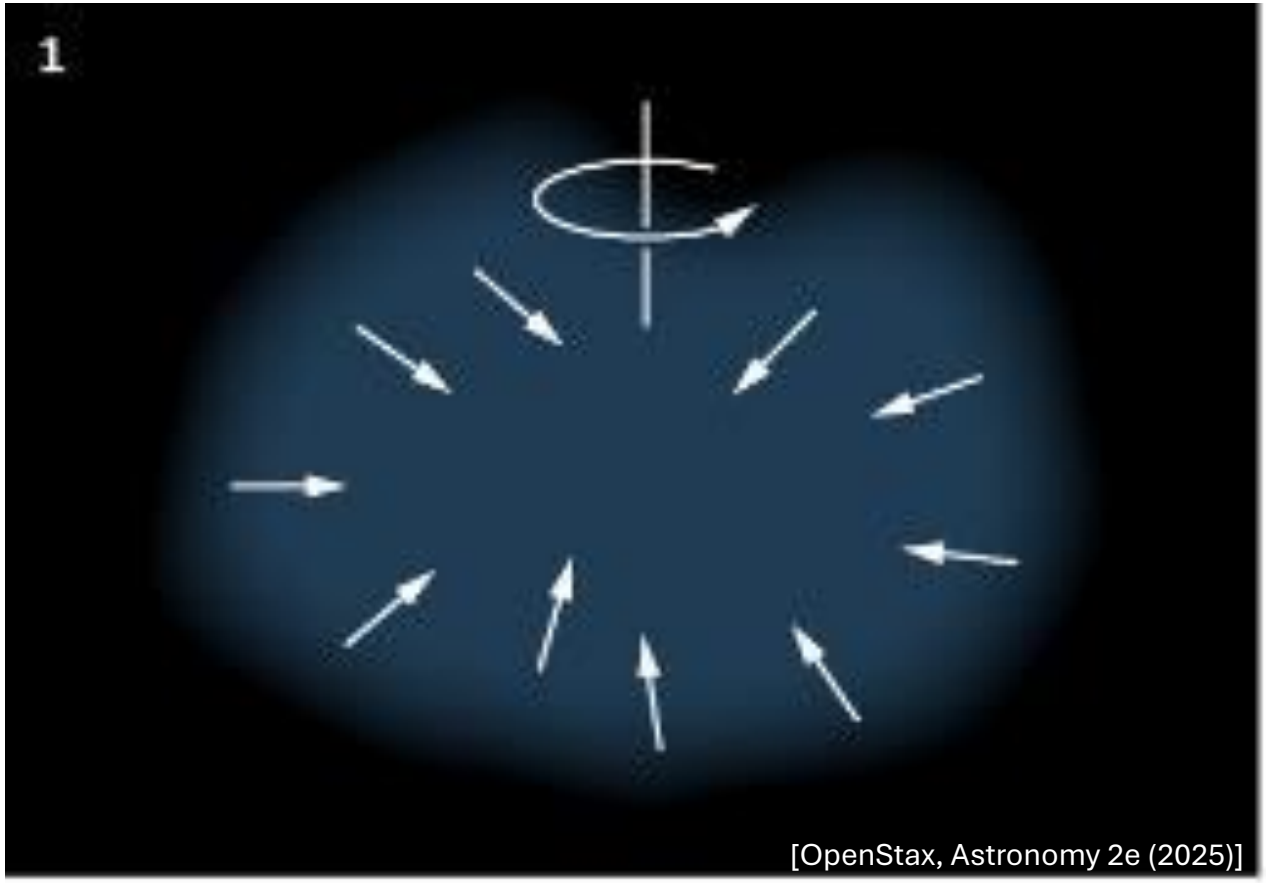
Orbital Velocities



- 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**.
- The horizontal axis shows the distance from the galactic center in kiloparsecs (where a kiloparsec equals 3,260 light-years).

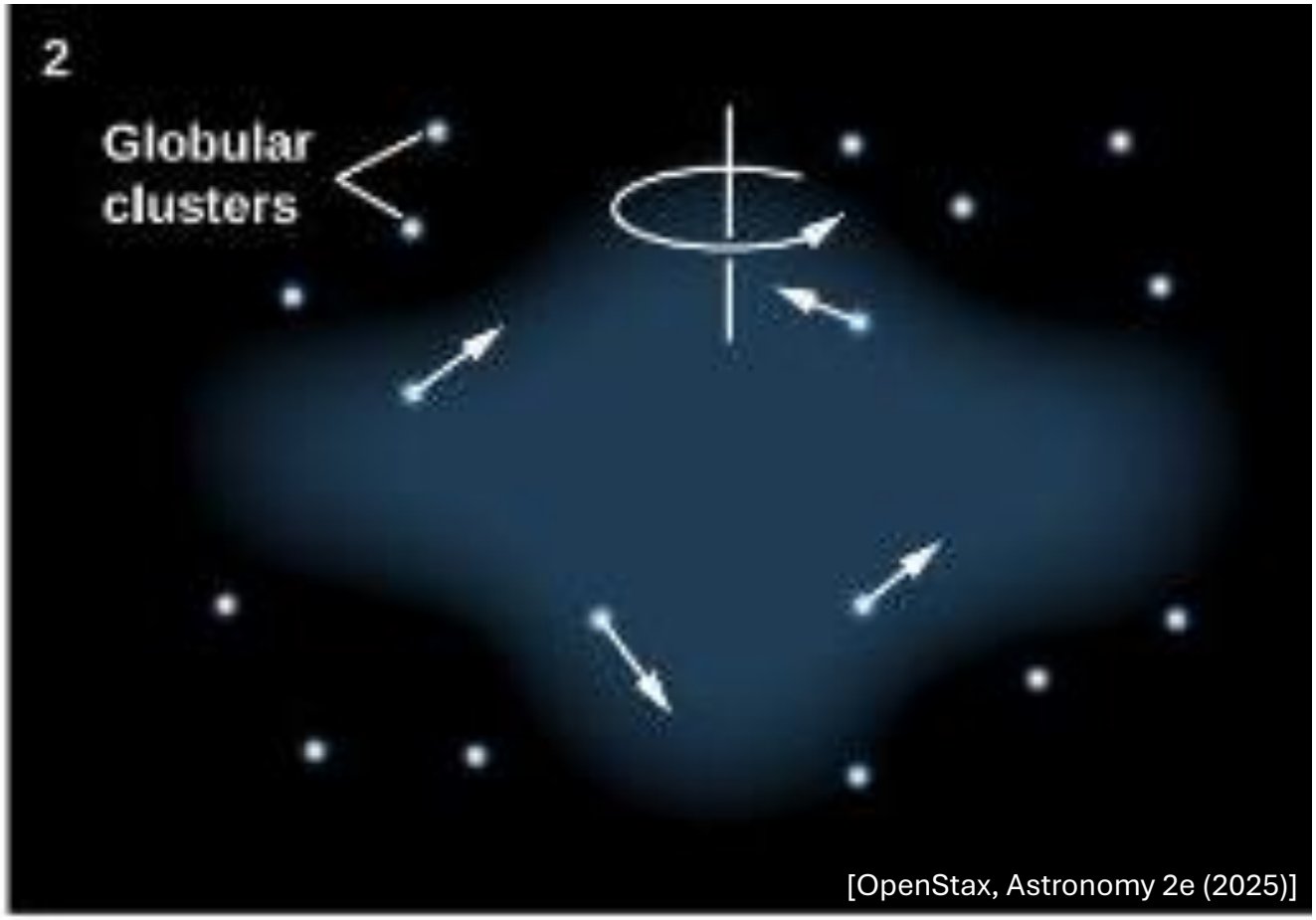
[OpenStax, Astronomy 2e (2025)]

Monolithic Collapse Model: Galaxy formation



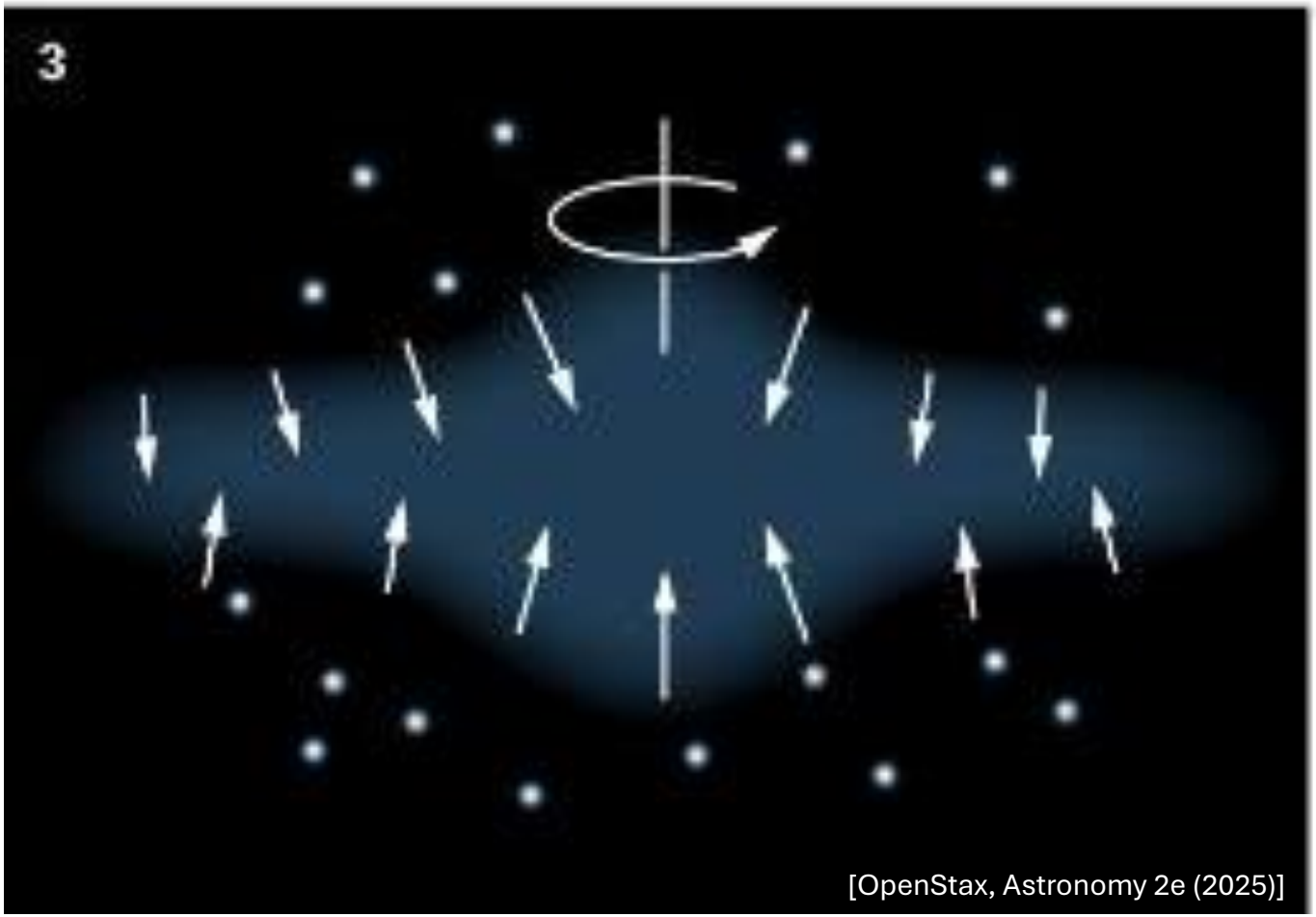
- An initial cloud of gas and dust collapses under its own gravity.
- As it collapses, its initial angular momentum is conserved, and the cloud rotates faster.

Monolithic Collapse Model: Galaxy formation



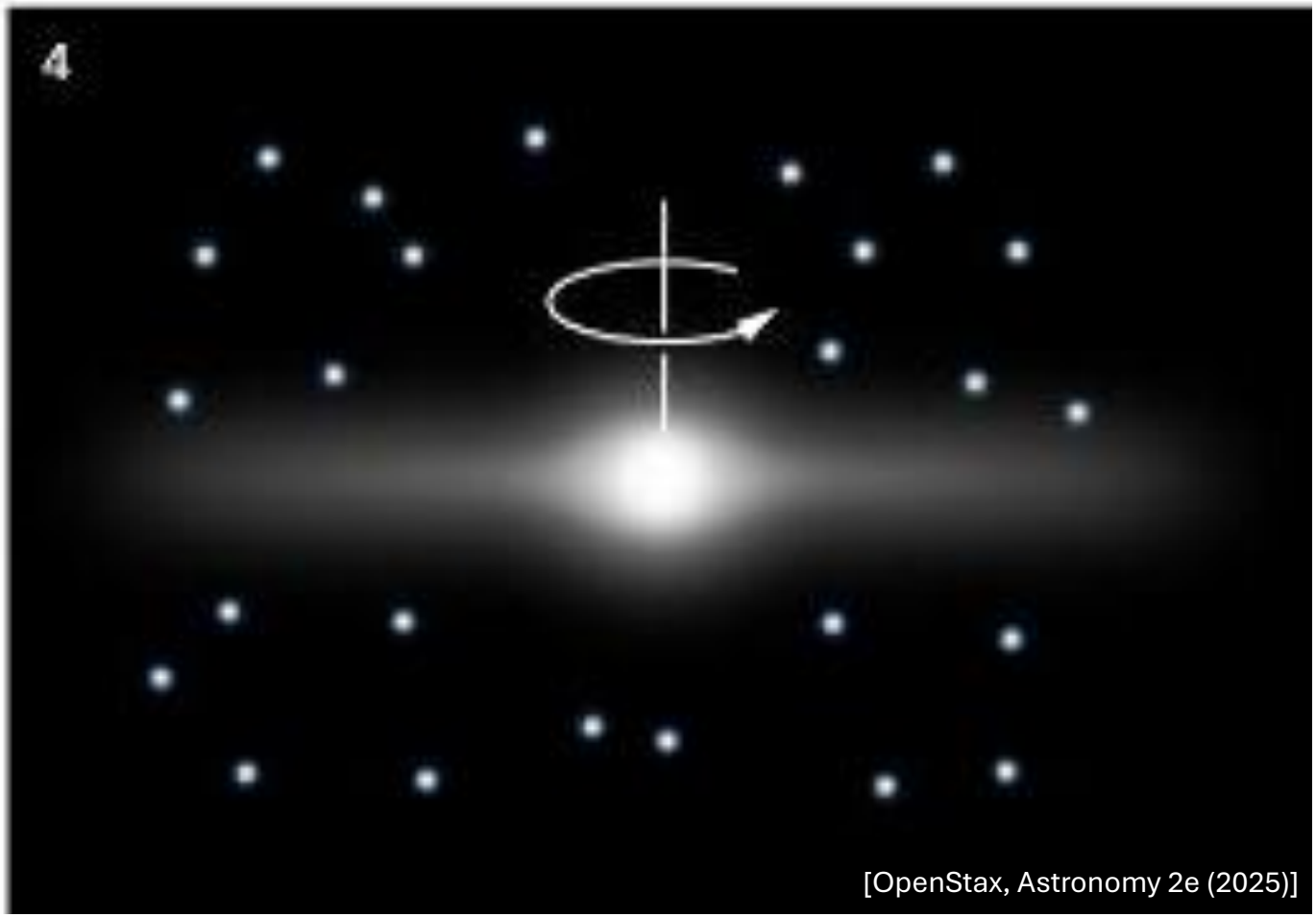
- The globular clusters were formed prior to collapse or were formed elsewhere.
- As it collapses, stars begin to form in regions of higher density.

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).