

Today's Topics

Friday, April 10, 2026 (Week 10, Lecture 28) – Chapter 25.

0. Interlude 2: Curtis-Shapley debate

1. Our Milky Way Galaxy

2. Overall structure

3. Formation of the galaxy

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

PHYS 172: Stellar Astronomy & Cosmology

Due date: Monday, April 27, 2026 (on Gradescope)

Interlude II: The “Great Debate” of 1920 (Curtis-Shapley)

Instructions

In this second interlude, you will explore the “Great Debate” of 1920, between Harlow Shapley and Heber Curtis, regarding whether the Milky Way galaxy is the entire universe or whether it is one of many galaxies (or “island universes”).

Readings

On the Blackboard course site, you will read “The Introduction to the ‘Great Debate’” and “Summary of the ‘Great Debate’” (both by R. J. Nemiroff and J. T. Bonnell). You should supplement these texts with **at least** one the subsequent additional documents on the Blackboard course site (e.g., those by R. Smith, V. Trimble, and M. Hoskin).

Paper requirements

You will write a reaction paper based on these readings. The paper should be 3-5 pages long (double spaced). A paper longer than 5 pages is fine. The paper should include references (within the text), and the associated bibliography does not count towards the official length of the paper.

Your paper should have at least one quotation from at least one of the three supplementary readings to support your arguments. You may use other references that you find, and those references should be cited as well. When you cite a reference it should be done with a consistent format, which will allow the reader to locate the source. If you are concerned about the citation format, then you can use the MLA citation format:

https://owl.purdue.edu/owl/research_and_citation/mla_style/mla_formatting_and_style_guide/mla_formatting_and_style_guide.html

The paper should be your own writing. The use of artificial intelligence (e.g., ChatGPT) to create or modify your text is NOT acceptable and will be considered an honor code violation. The use of a grammar-checking tool, such as provided within Microsoft Word is acceptable.

Format: 12 point, Times New Roman, 1" margins, 8" × 11" paper.

N.B. The paper should have a title.

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Grading Rubric

Explanation of the “Great Debate”: 30/30

Is the paper’s topic and/or the prompt clear?: 10/10

Quotation/citation: 15/15 (i.e., at least one relevant direct quote from the provided readings)

Use of science facts/observations: 20/20

Do your points support your argument: 10/10

Writing style: 15/15 (this category is intended to separate an “A-“ paper, where everything is fine, but which has unclear or weak writing, from an “A” paper in which the writing is unambiguous, clear, and compelling. These points are analogous to the “style” points in figure skating.)

Note: Your introduction should state the thesis of your essay.

Late papers: Late papers will be accepted with a 5% per day penalty.

Prompts (1)

1. Take Shapley's "side" in the debate: what are the best arguments/evidence, and how would you counter the other side's arguments/evidence? Use only evidence available at the time of the debate.
2. Take Curtis's "side" in the debate: what are the best arguments/evidence, and how would you counter the other side's arguments/evidence? Use only evidence available at the time of the debate.
3. Which side would an educated layperson at the time (not a present-day layperson) be more likely to side with, and why?
4. Did the much larger size of the universe implied in the Curtis picture prevent this view of the universe from being easily accepted? Why?
5. Should the ability of a scientist as a public speaker/debater be allowed to sway a scientific argument such as this? Was it important who was a more persuasive speaker, and why?
6. Is an actual public debate (such as the Shapley-Curtis debate) a useful way to air scientific disagreements? Why or why not?
7. What astronomical observations (made more recently than the 1930's, and not including the Cepheid variable stars seen in M31) would have resolved the debate immediately, if they were available at the time of the debate?

Prompts (2)

8. Draw analogies between the Great Debate and any present-day scientific controversy. What kind of evidence might be needed to resolve the present-day controversy? Compare or draw analogies with how the Great Debate was resolved.

9. In the Shapley-Curtis debate, both sides were wrong about at least one important point. Choose one of those points and argue whether or not it provided a fatal flaw to either Shapley's view of the universe or Curtis's view.

10. The title of the debate was "The Scale of the Universe". Did Shapley and Curtis even agree on what the actual topic of the debate really was? Explain.

11. Make an argument that one or the other of Shapley or Curtis made the most important contributions to astronomy.

12. Argue that neither Shapley nor Curtis was entirely right or wrong, and both presented ideas that represented major advances. What does this imply for current scientific controversies?

13. Provide arguments, based on the debate, that even very good scientists, when working at the forefront of science, are challenged when coming to a valid conclusion based on evidence that is fragmentary or faulty.

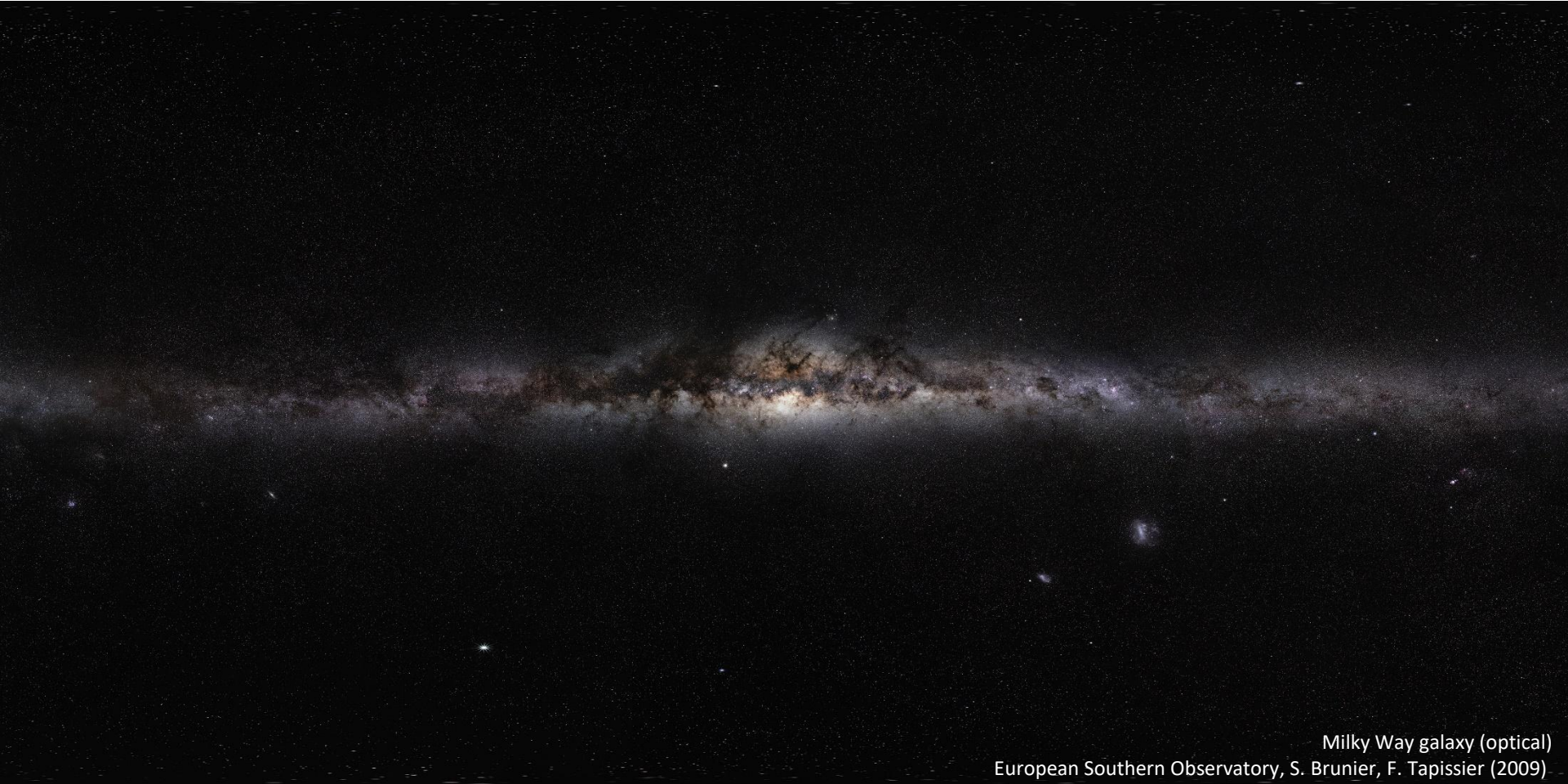
14. Argue that the history of this debate/controversy supports the power of the scientific method to make progress towards a better understanding of the universe, or argue that it exposes flaws in the scientific method.

Our Milky Way Galaxy – by eye



Our Milky Way Galaxy – by telescope

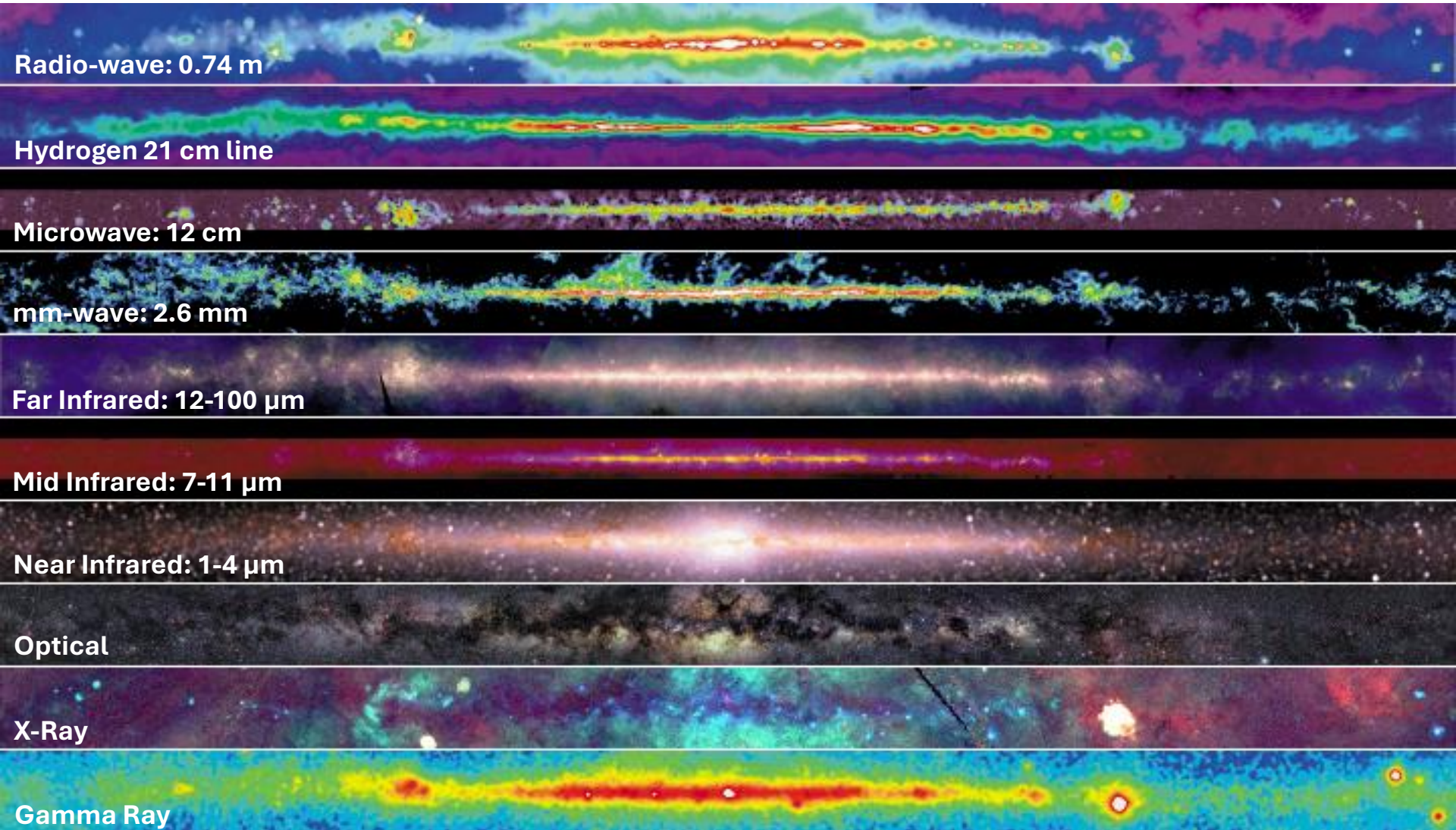
Our Milky Way galaxy has 100-400 billion stars



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

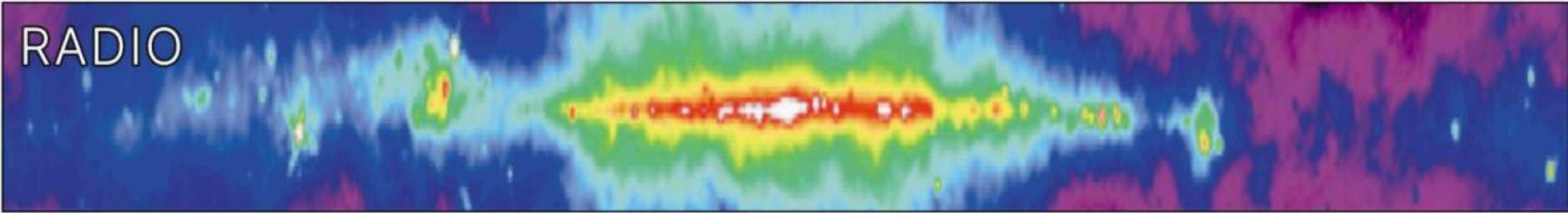
Milky Way galaxy: 360° view.

Milky Way: Full EM spectrum

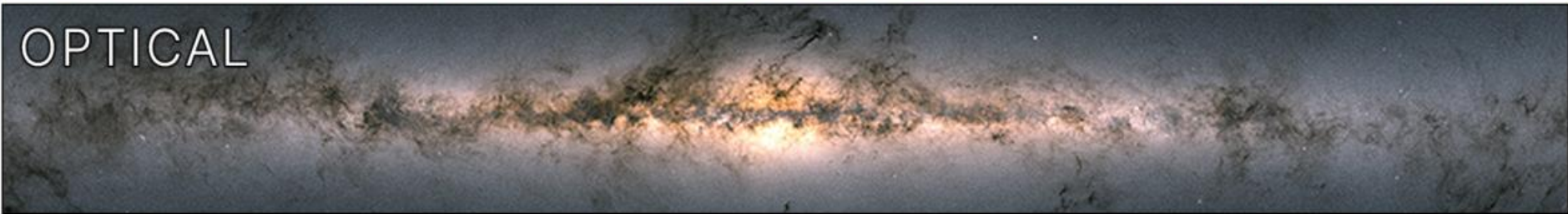


Milky Way: Photons vs Neutrinos

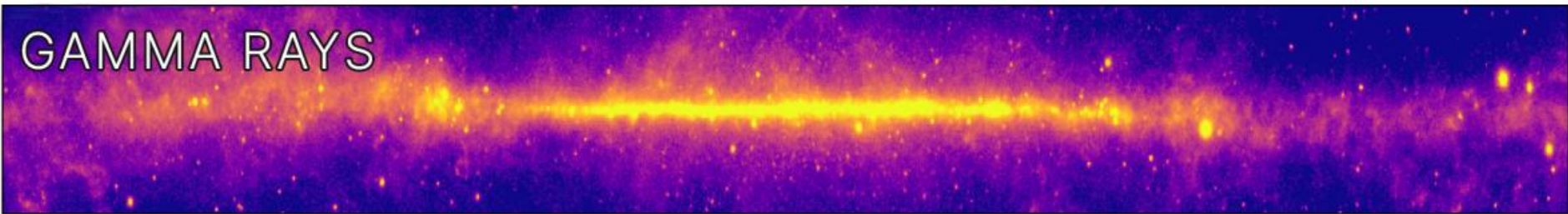
RADIO



OPTICAL



GAMMA RAYS



NEUTRINOS



Mapping the Milky Way

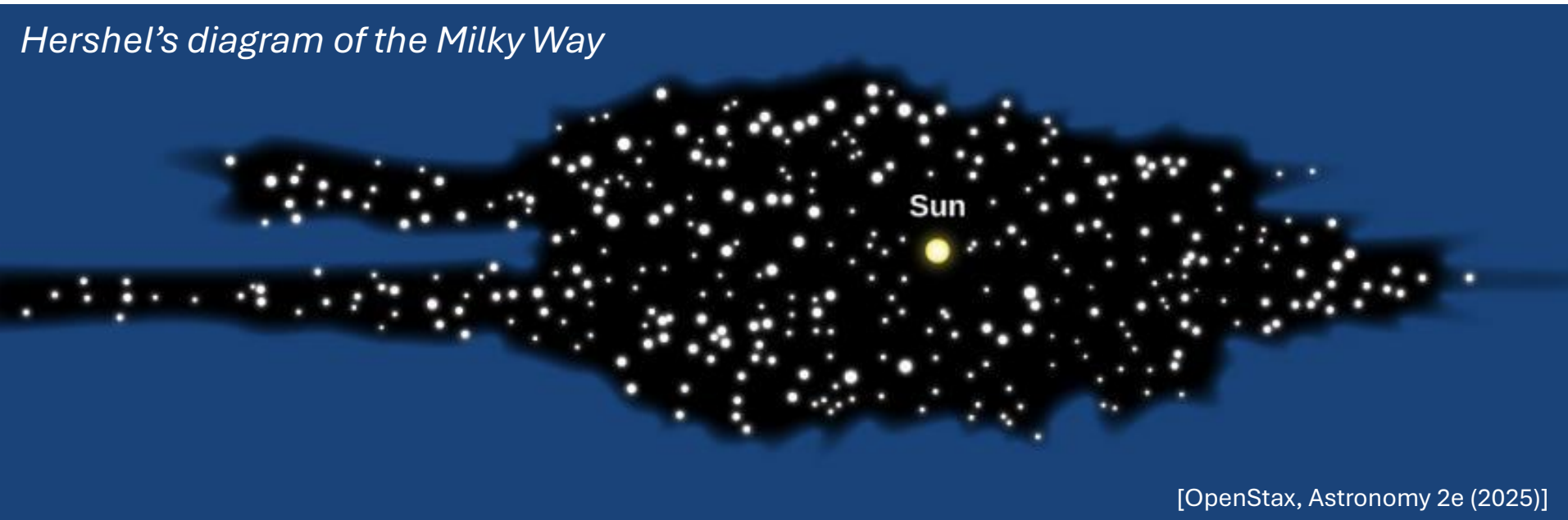


By measuring the distance to many, many stars and interstellar gas/dust clouds, one can construct a map of our galaxy:

- 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)

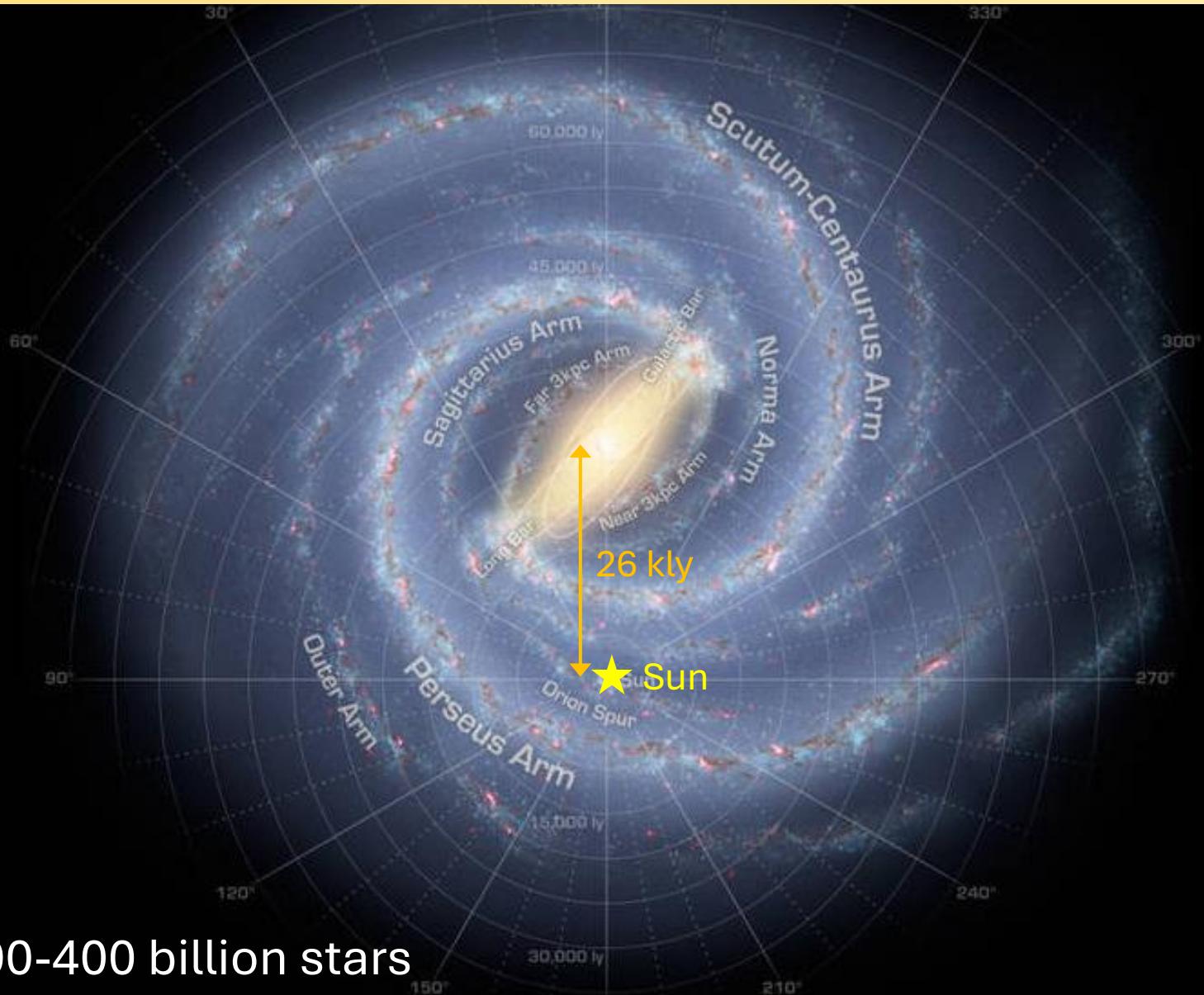
Herschel's diagram of the Milky Way



[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

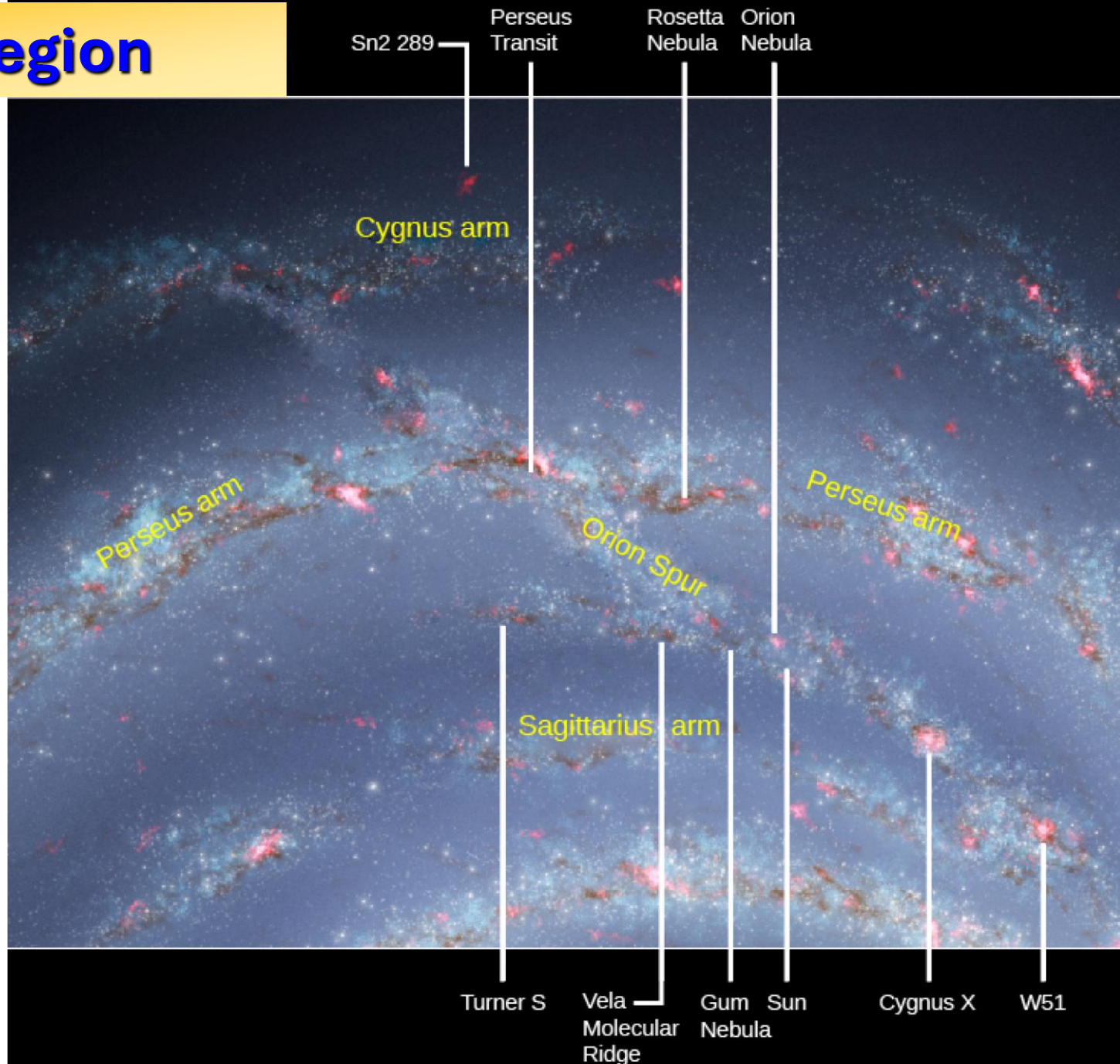
Diameter of our Galaxy $\sim 100 \times 10^3$ ly

Local Region

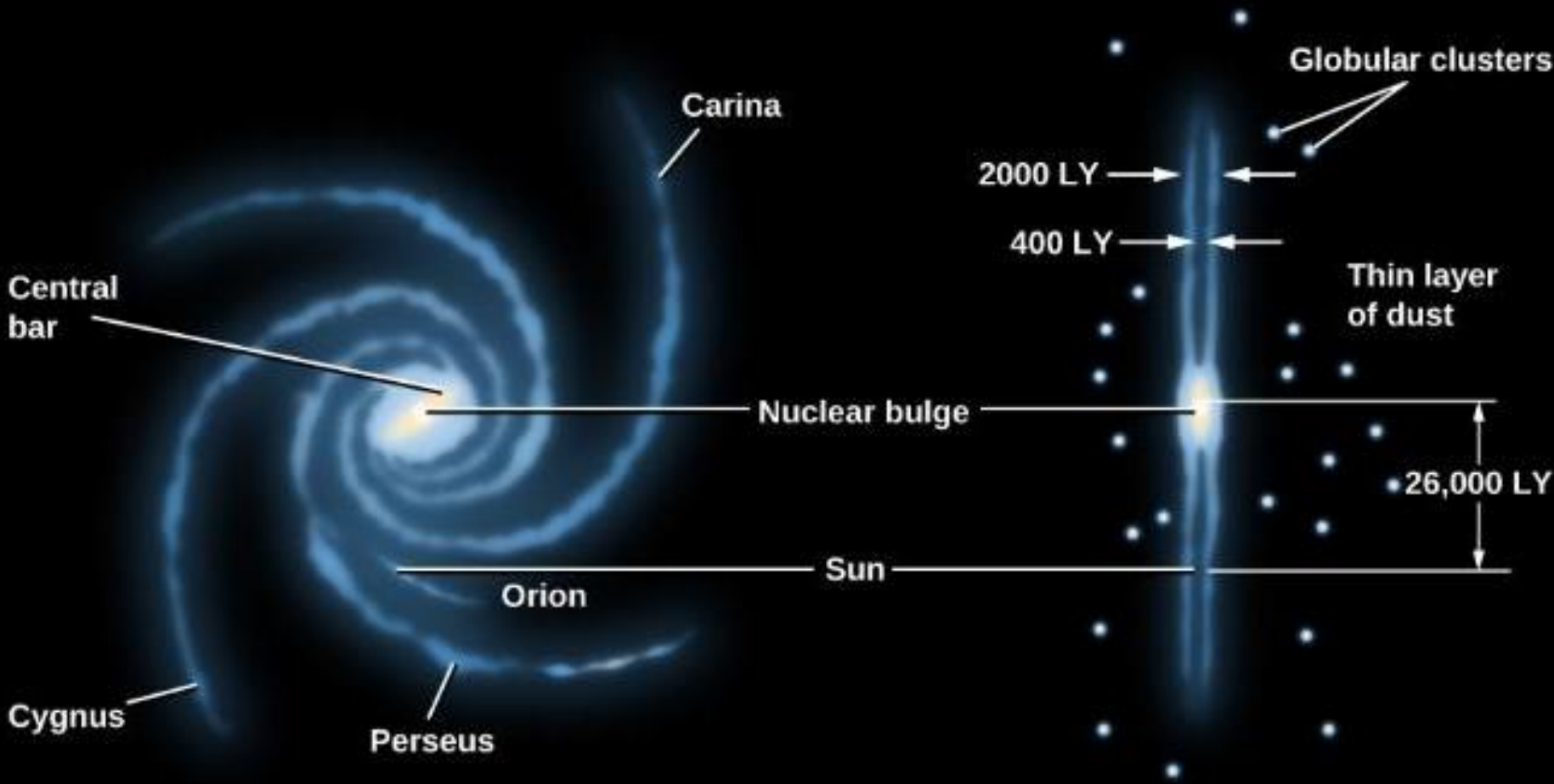
- Our solar system is in the Orion spur.
- Between the Perseus arm and the Sagittarius arm.

Cygnus X: Star forming region.

W51: large star "factory".

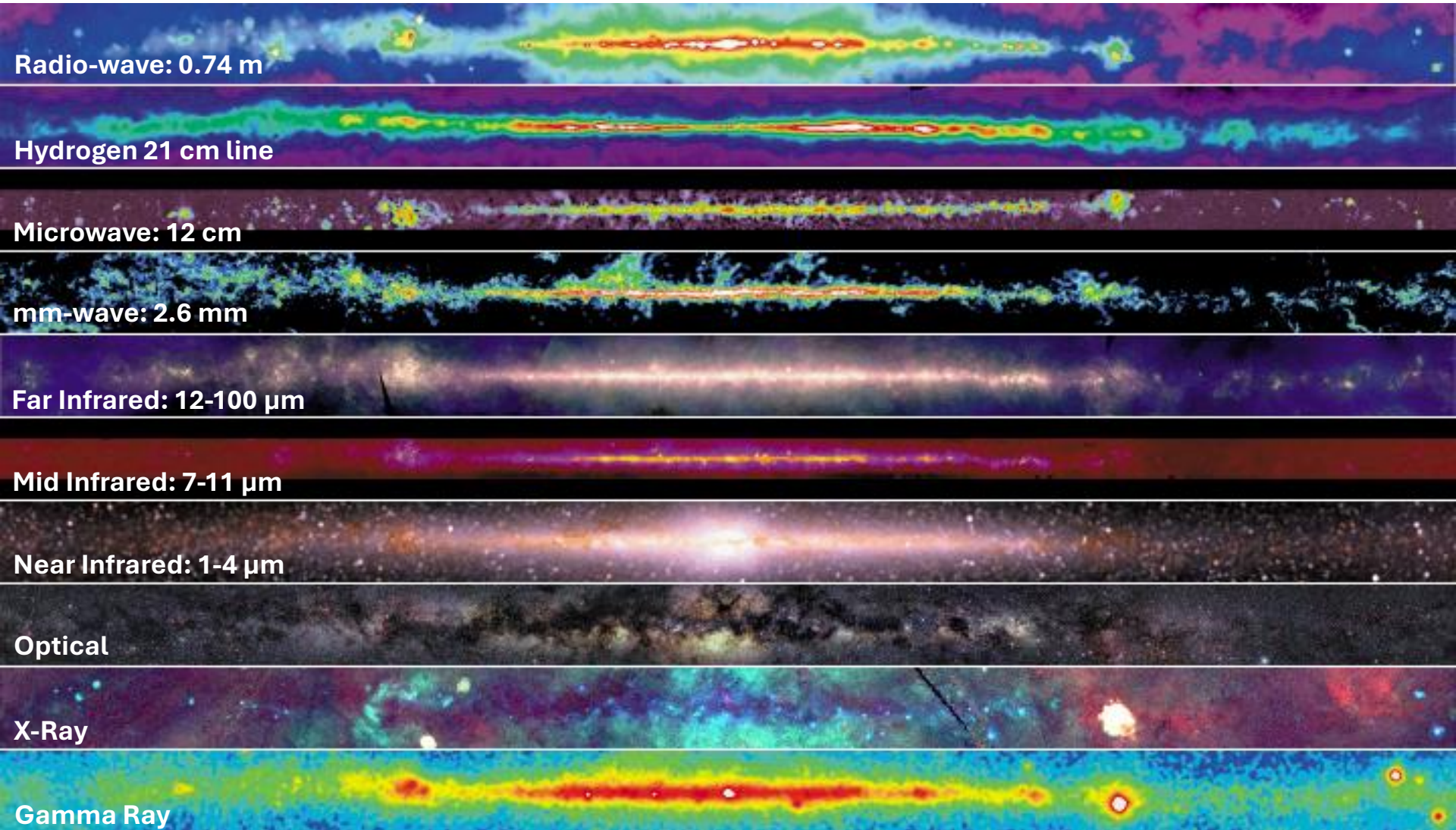


Basic Structure

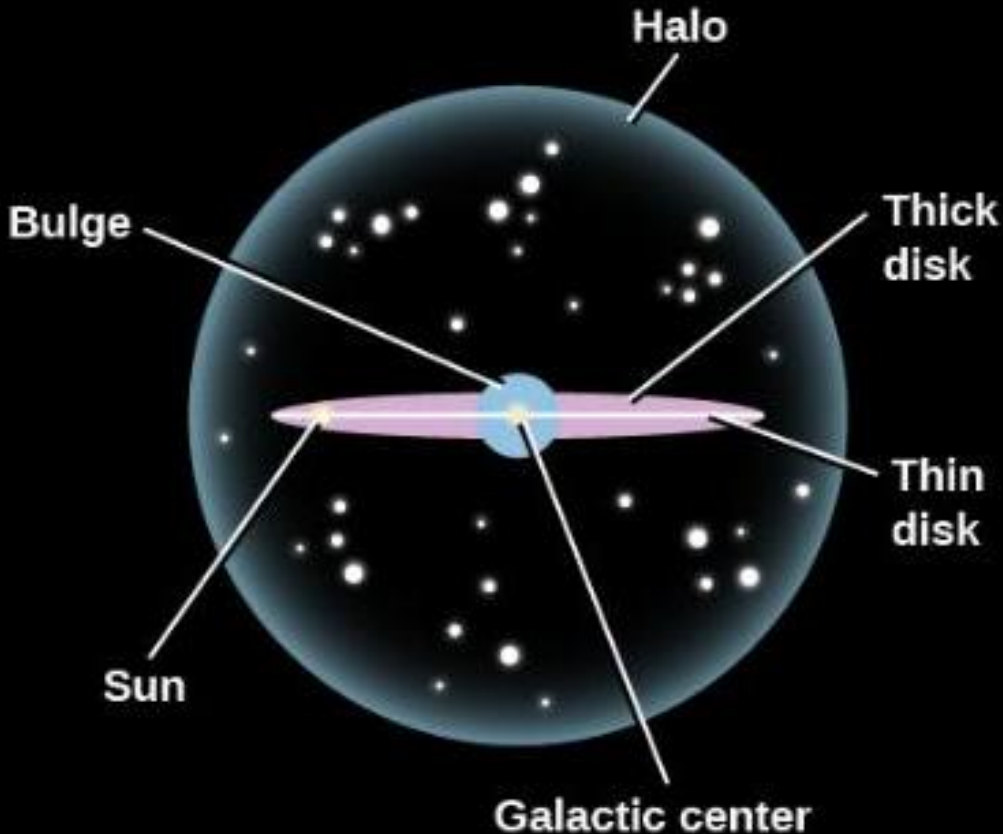


[OpenStax, Astronomy 2e (2025)]

Milky Way: Full EM spectrum



Broad Structure



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.

Broad Structure

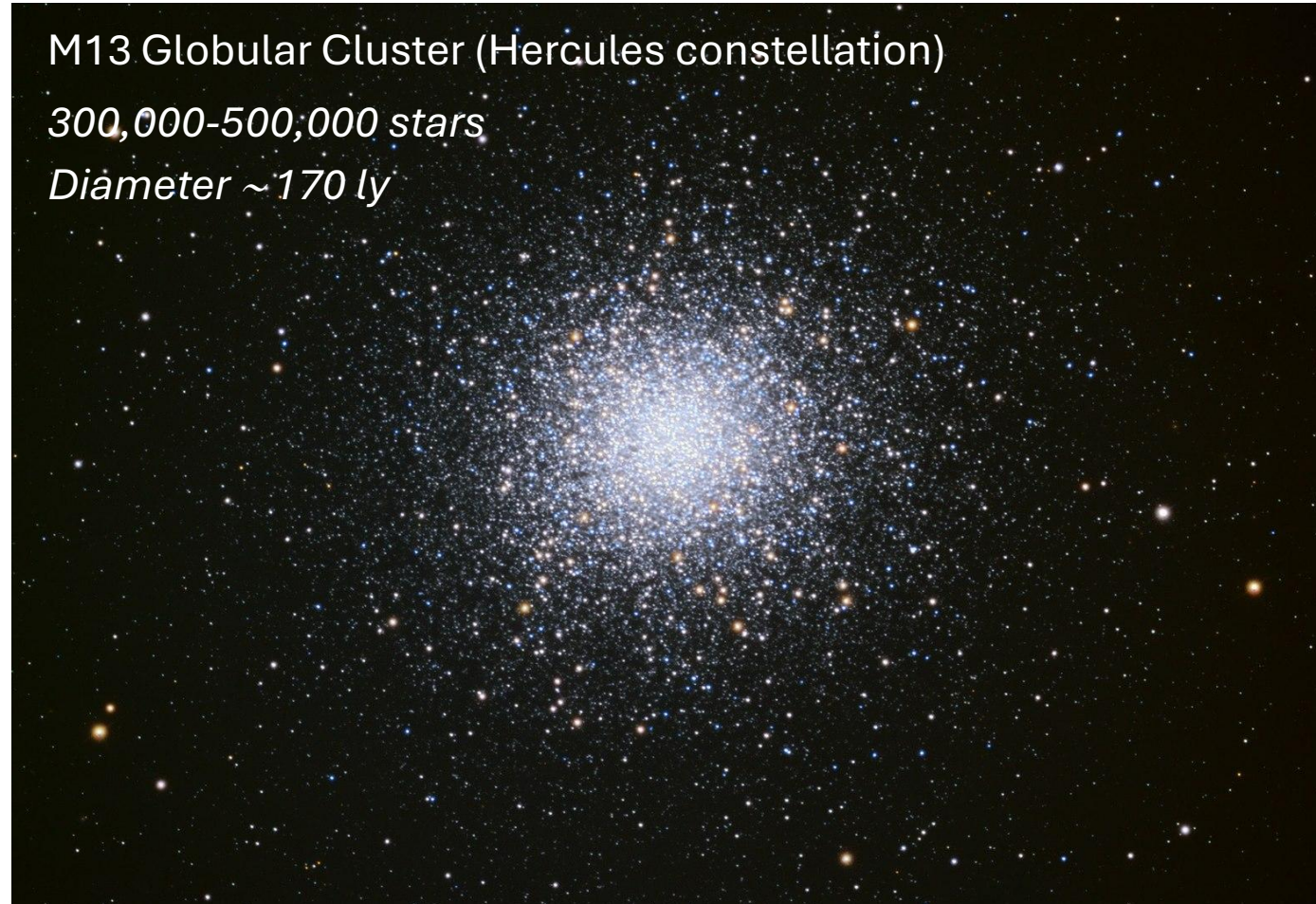
Characteristics of the Milky Way Galaxy

| 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 |

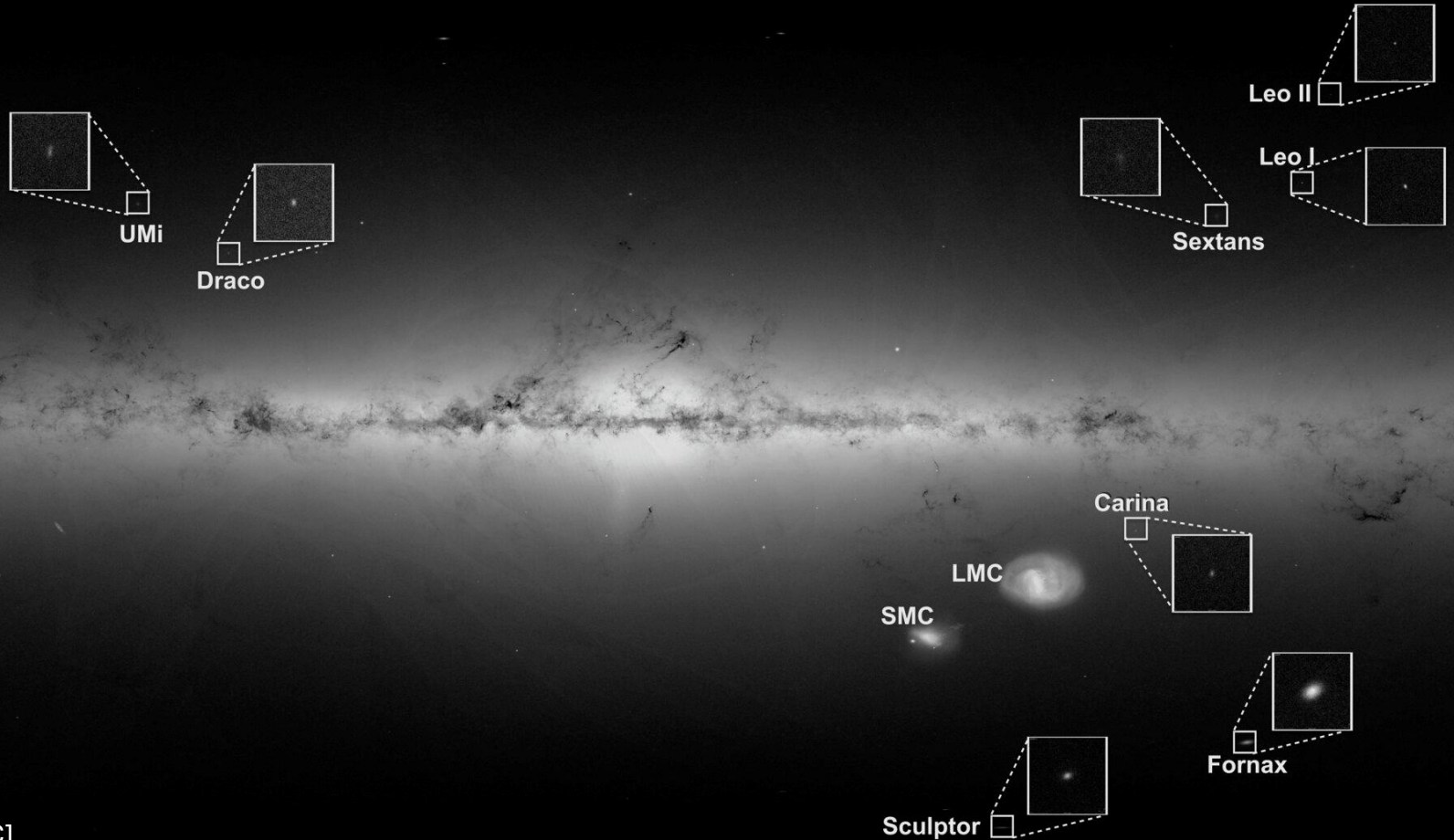
Globular Clusters

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.



Satellite Dwarf Galaxies



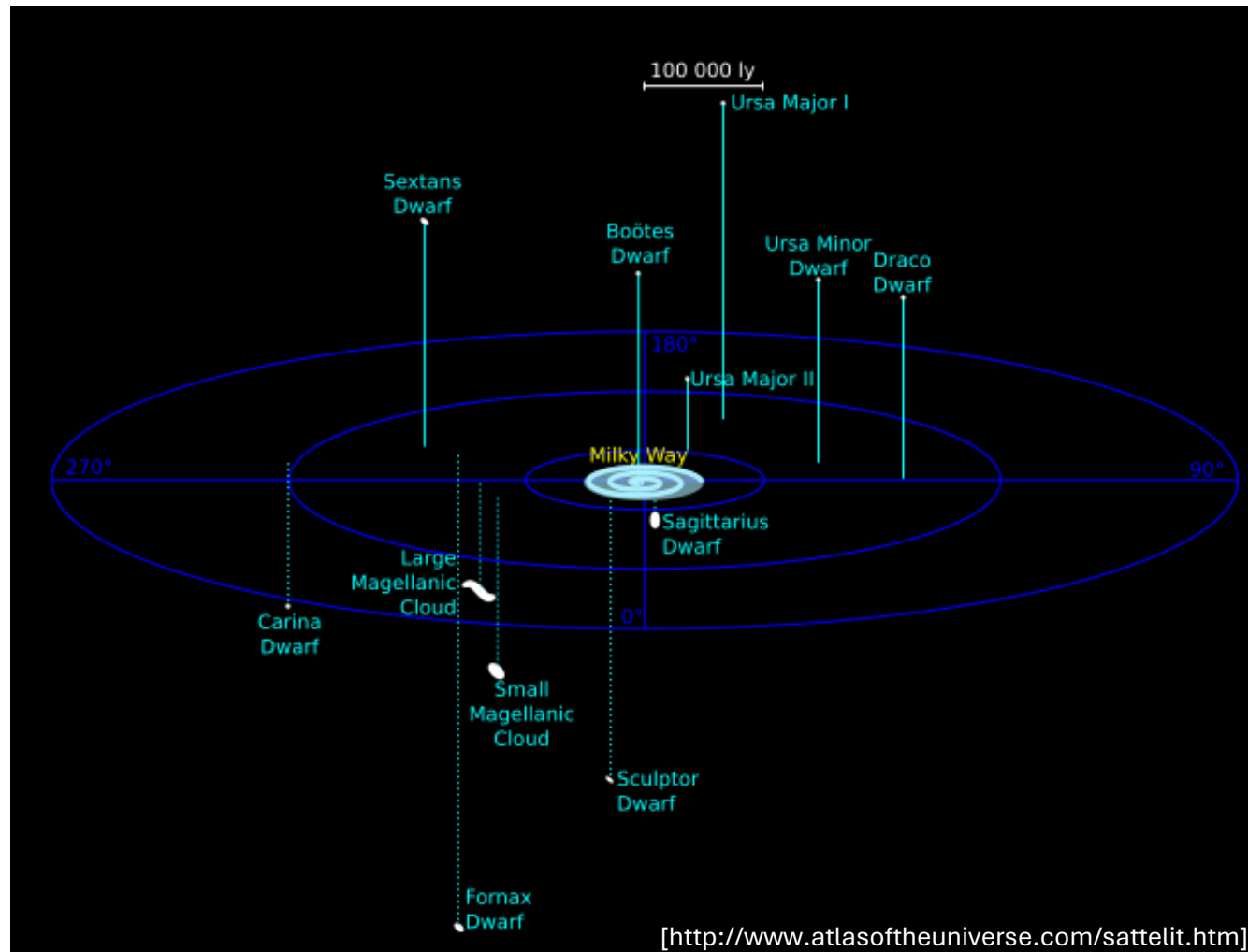
[ESA/Gaia/DPAC]

LMC = Large Magellanic Cloud
SMC = Small Magellanic Cloud

20-60 dwarf galaxies in vicinity of Milky Way

Satellite Dwarf Galaxies

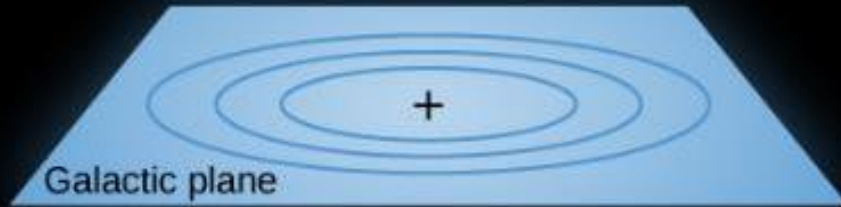
- Not all dwarf galaxies are in orbit around the Milky Way.
- The **Sagittarius Dwarf** is being actively absorbed by the Milky Way.
- The LMC and SMC may or may not be in orbit around Milky Way.



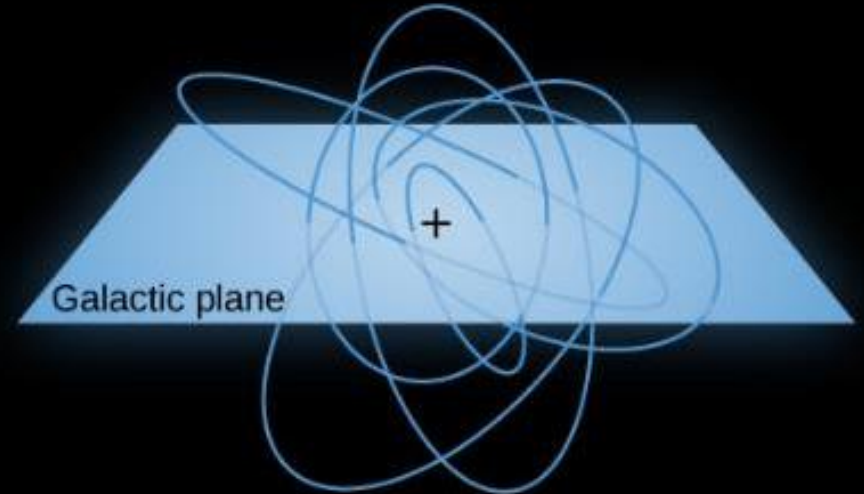
[<http://www.atlasoftheuniverse.com/sattelit.htm>]

Orbits: Disk vs Halo

Thin disk



Halo

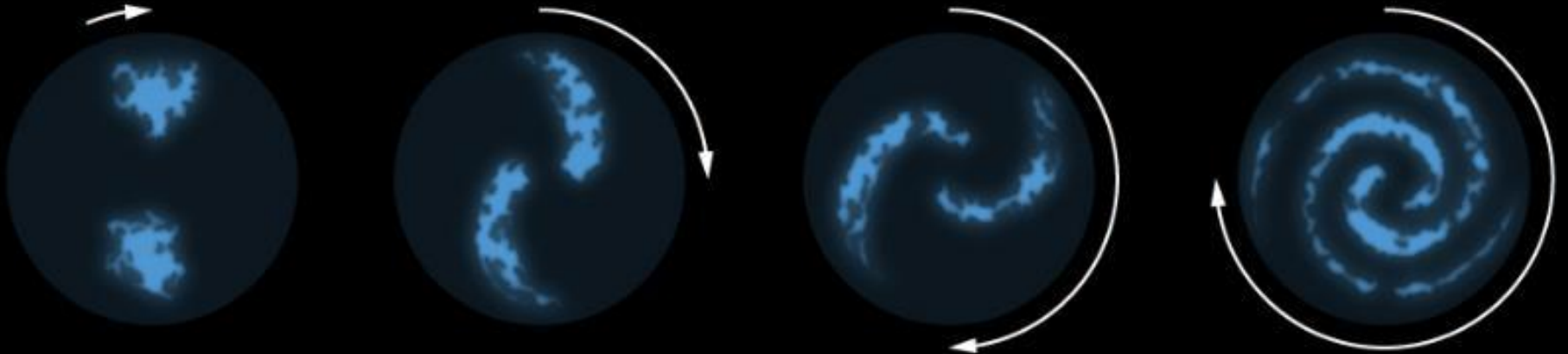


Stars (e.g., our Sun)
Gas & dust (nebulae)
White dwarfs, neutron stars, etc



Stray stars
Globular clusters
Dwarf galaxies

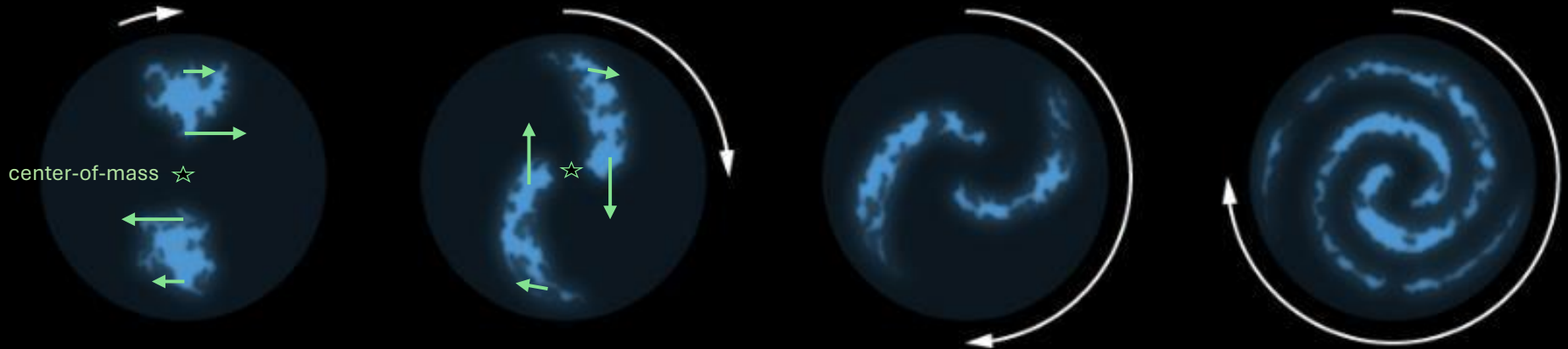
Spiral Arms



[OpenStax, Astronomy 2e (2025)]

- 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).*

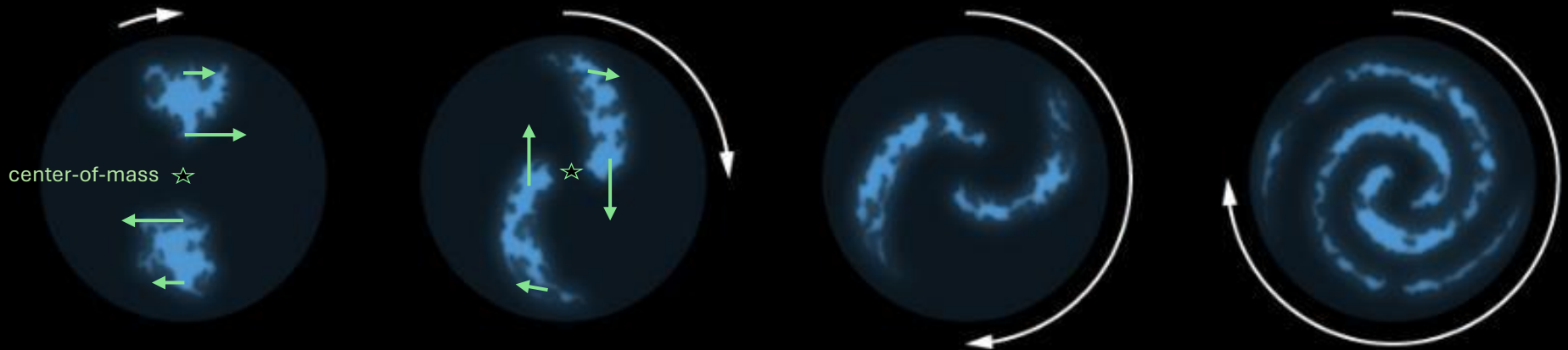
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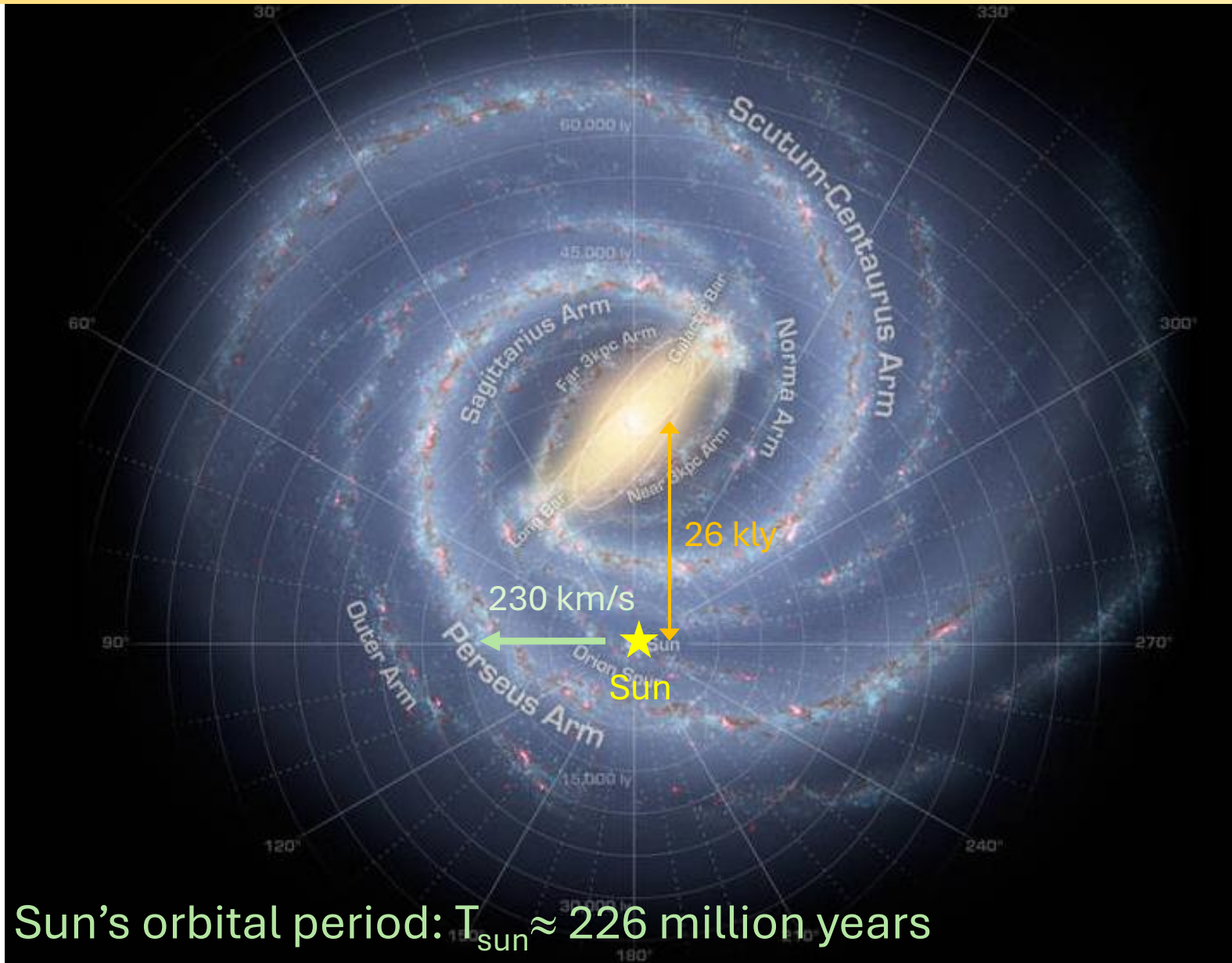
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- The spiral arms of the galaxy do NOT rotate rigidly (i.e., not like a frisbee).
- The spiral arm shape evolves in time.
- The spirals do not continuous “wind up” forever.
→ *Gravitational interaction between the arms partially stabilizes them.*

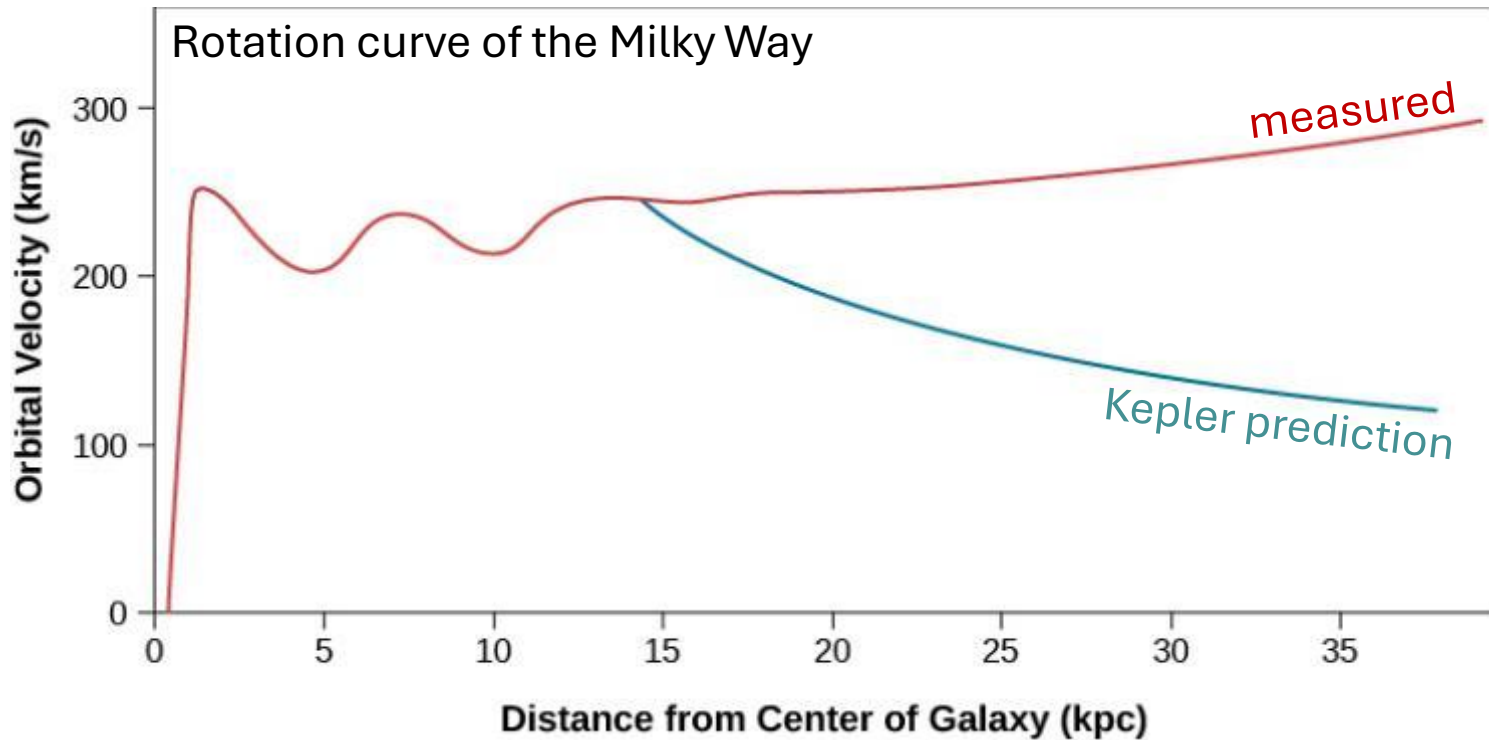
Sun's Orbital Speed



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

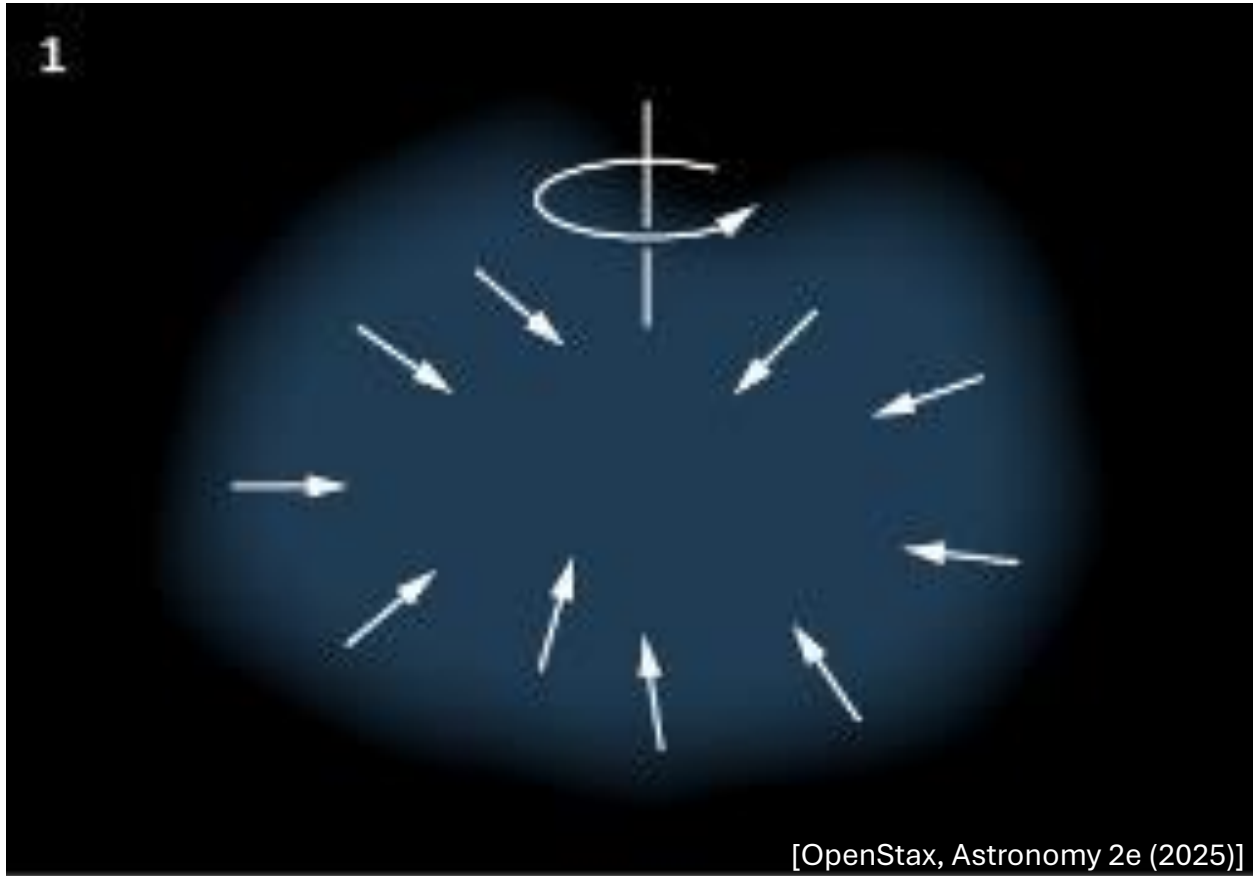
PolEv Quiz: PolEv.com/sethaubin

Orbital Velocities



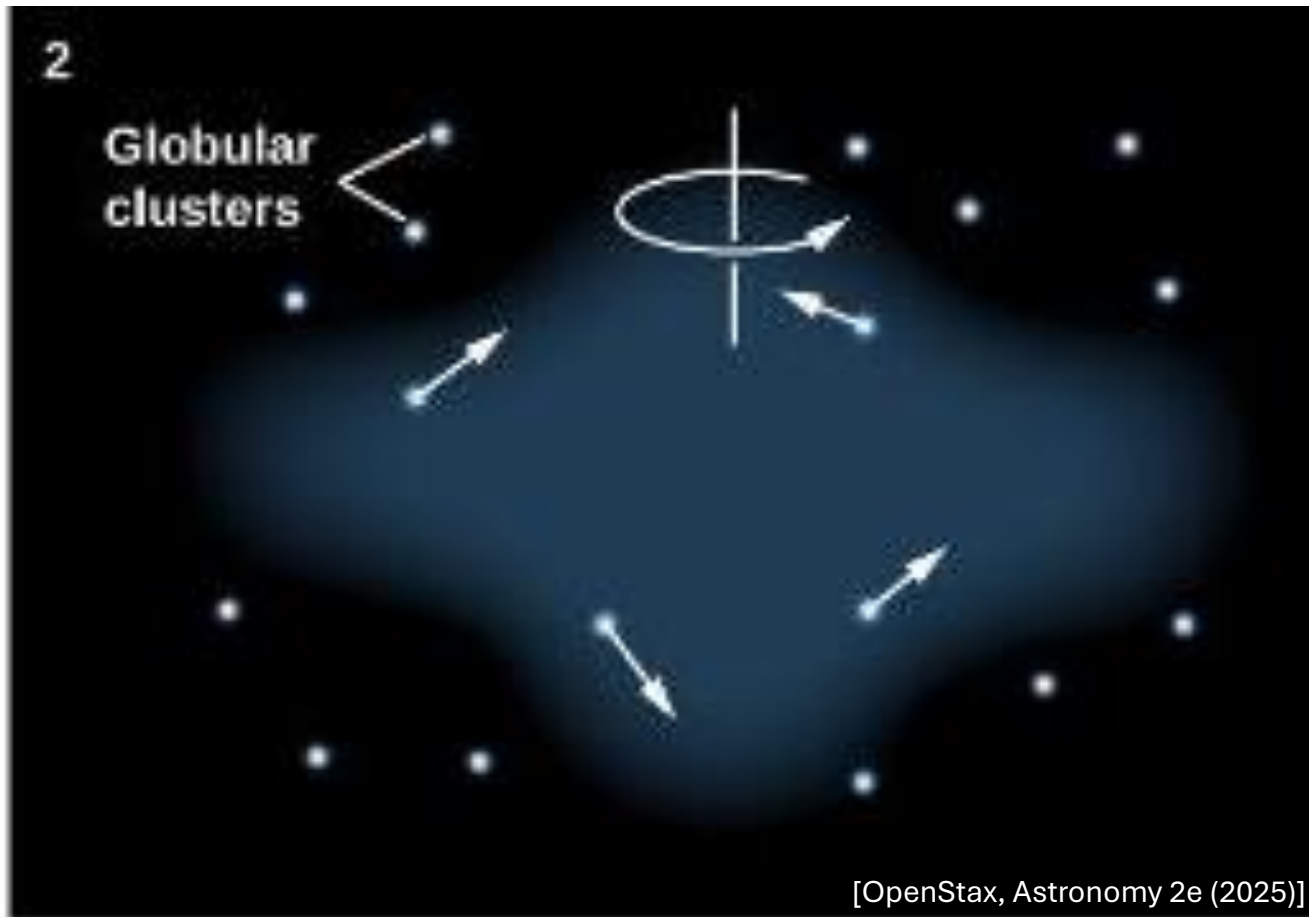
- The orbital speed of carbon monoxide (CO) and hydrogen (H) gas at different distances from the center of the Milky Way Galaxy (red).
- The blue curve shows what the rotation curve would look like if all the matter in the Galaxy were located inside a radius of 30,000 light-years. *Instead of going down,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

Monolithic Collapse Model: Galaxy formation



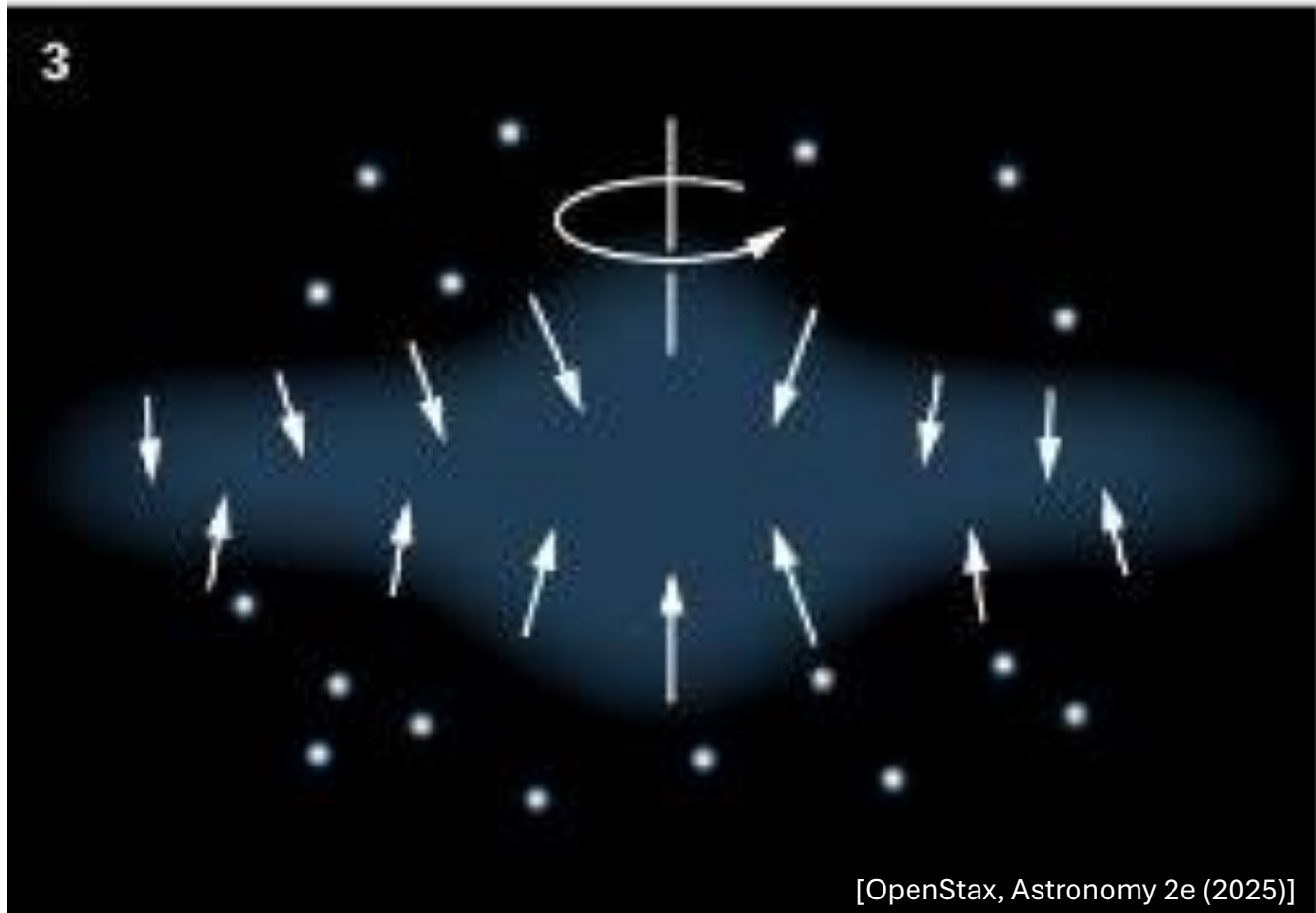
- An initial cloud of gas and dust collapses under its own gravity.
- As it collapses, its initial angular momentum is conserved, and the cloud rotates faster.

Monolithic Collapse Model: Galaxy formation



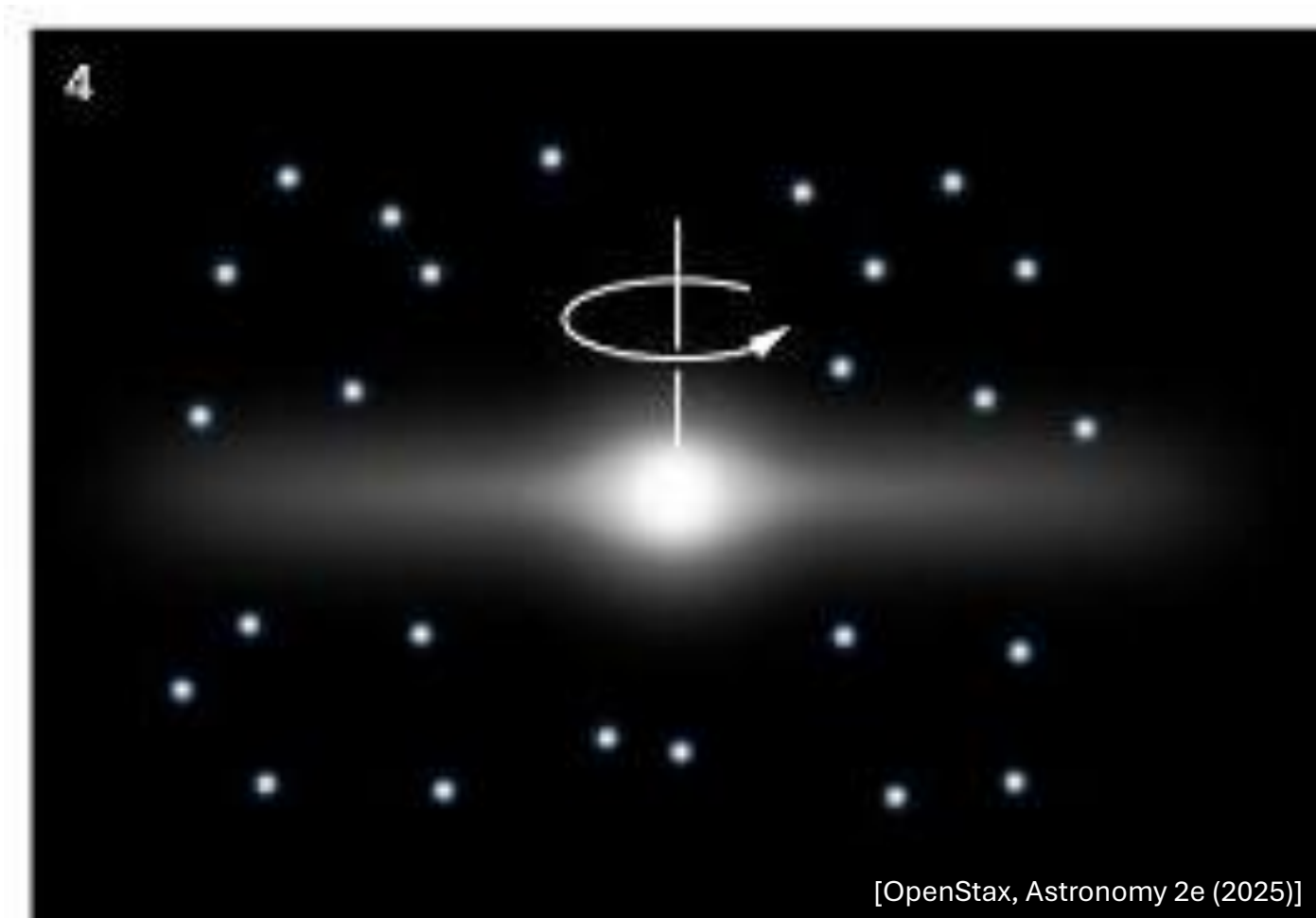
- The globular clusters were formed prior to collapse or were formed elsewhere.
- As it collapses, stars begin to form in regions of higher density.

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).