Today's Topics

Monday, April 14, 2025 (Week 11, Lecture 28) – Chapter 25.

0. **Interlude 2: Curtis-Shapley debate**
1. The "Great Debate"
2. Rotation curve … dark matter
3. Formation of the galaxy

Problem Set #9 is due on ExpertTA on Friday, April 18, 2025, by 9:00 AM

PHYS 172: Stellar Astronomy & Cosmology
Due date: Monday, April 28, 2025 (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.

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.

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?

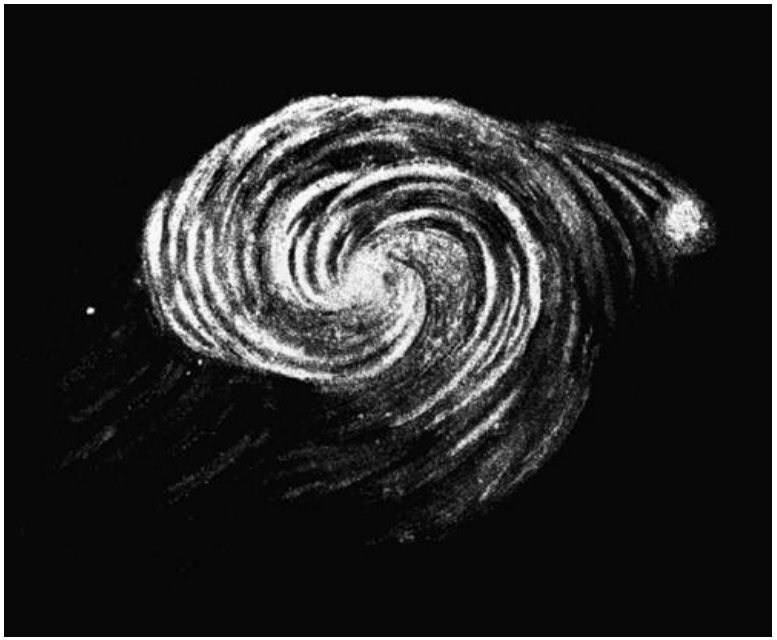
→ This was the crux of the debate.

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.

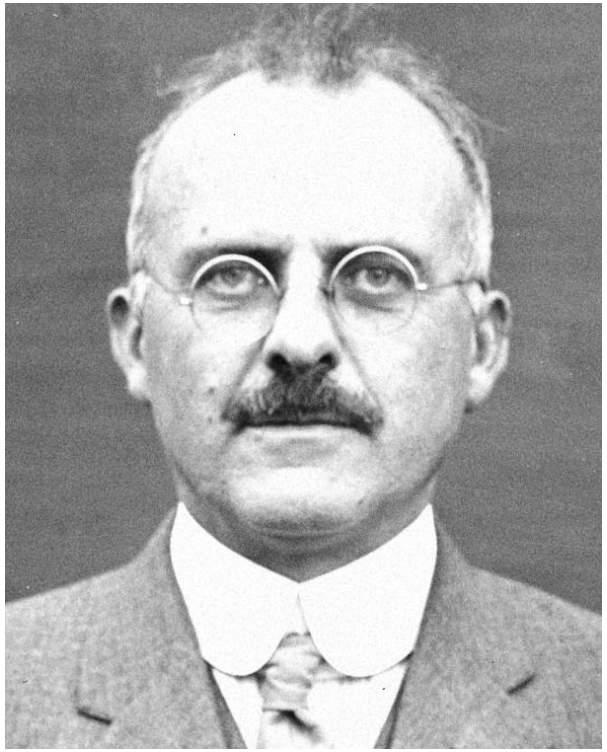
Shapley thought that the Milky Way was huge (almost 100,000 light years) and that we were NOT in the center.

→ 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.

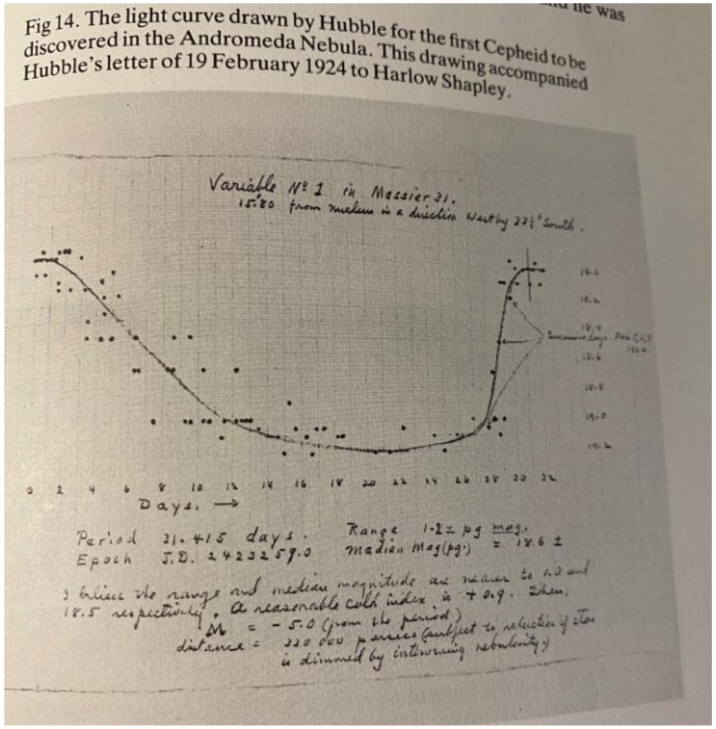
  - Curtis was a better debater and was thought by many to have "won".
  - Shapley focused more on the size of the galaxy and our location in it.
  - Curtis focused more on the existence of other galaxies.
  - **They were both right** (on the aspects which they focused on!).

- 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

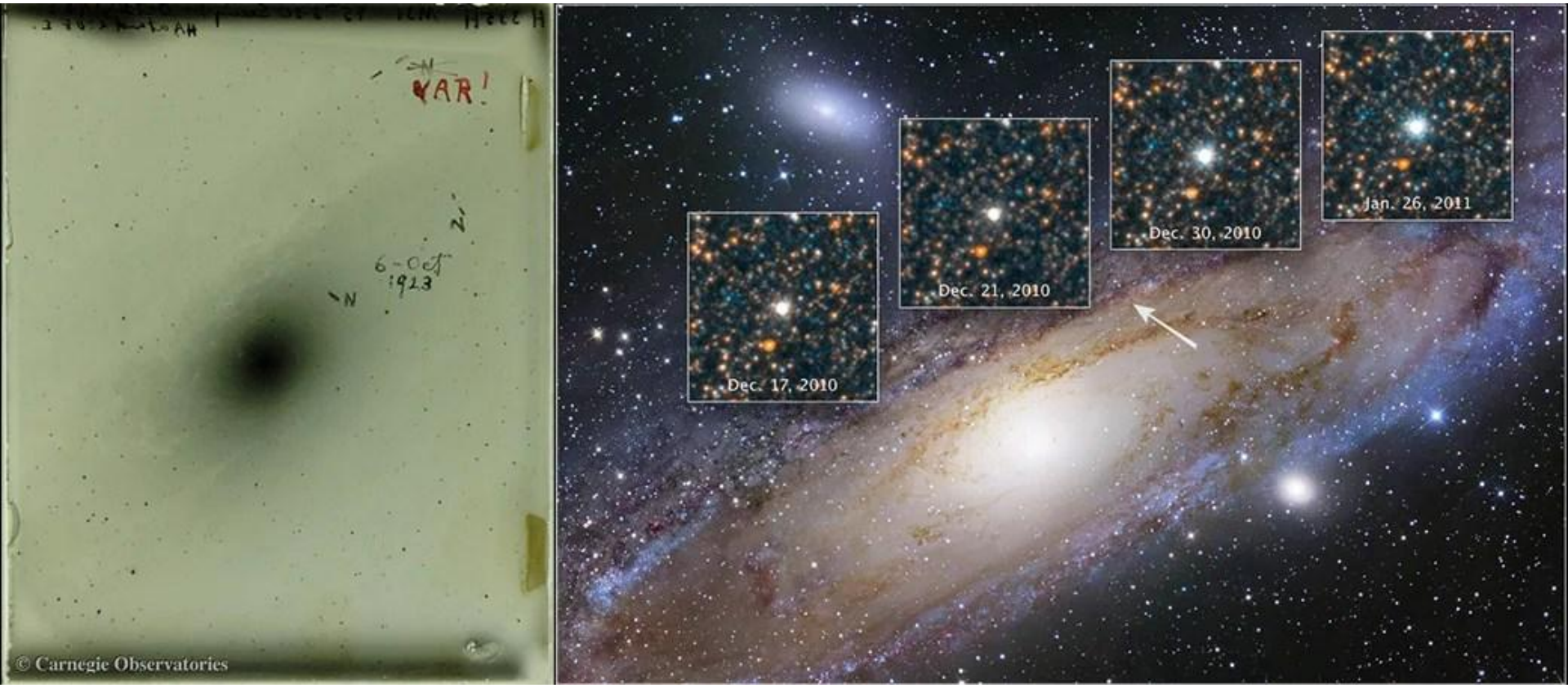
  → Obviously another galaxy.



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

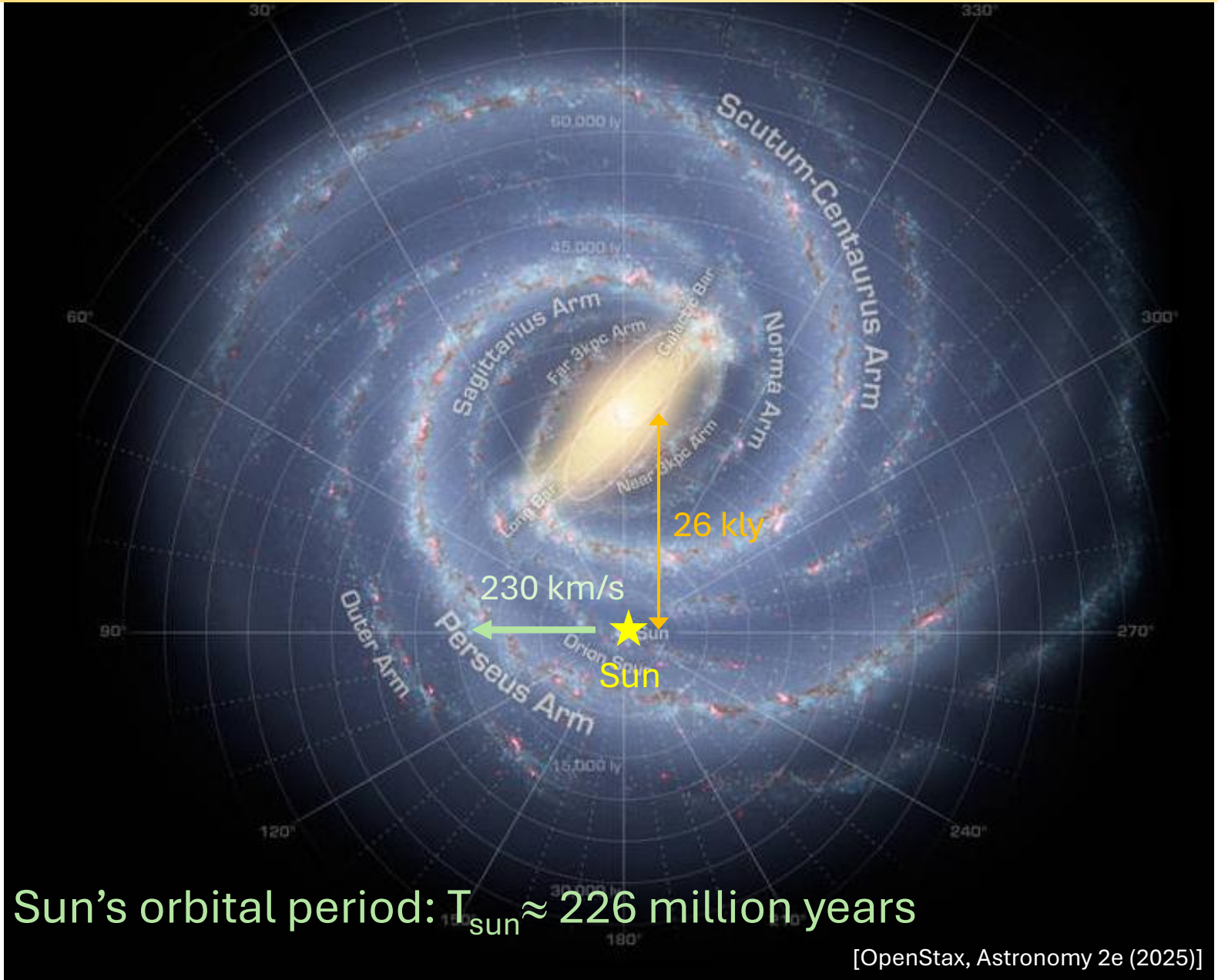


- Shapley gave in quickly.
- According to his PhD student, Cecelia Payne-Gaposchkin (who figured out that all stars are mostly H and He), when he got Hubble's letter he said

  "Here is the letter that destroyed my universe"

… back to the Milky Way Galaxy

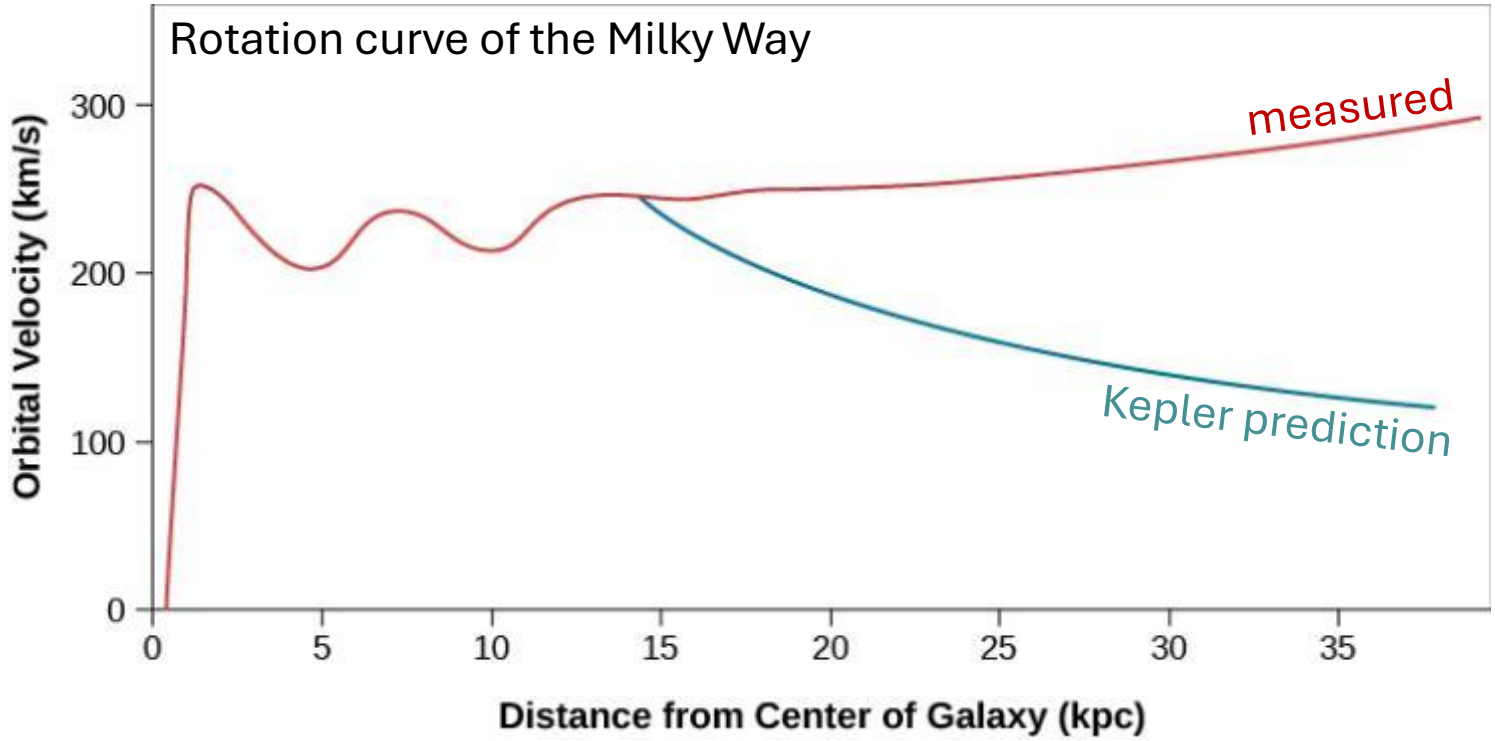
Sun's Orbital Speed



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

[OpenStax, Astronomy 2e (2025)]

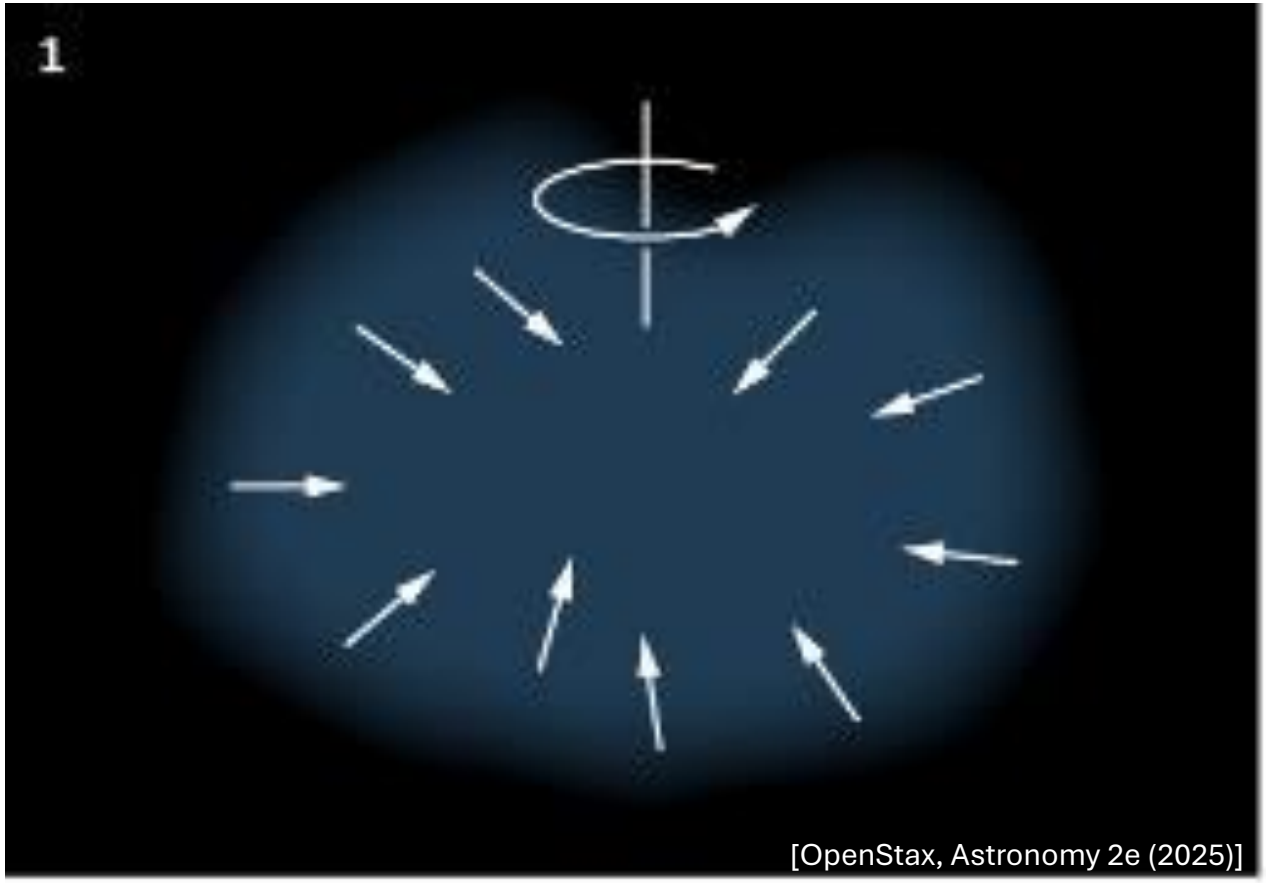
Orbital Velocities



- 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).

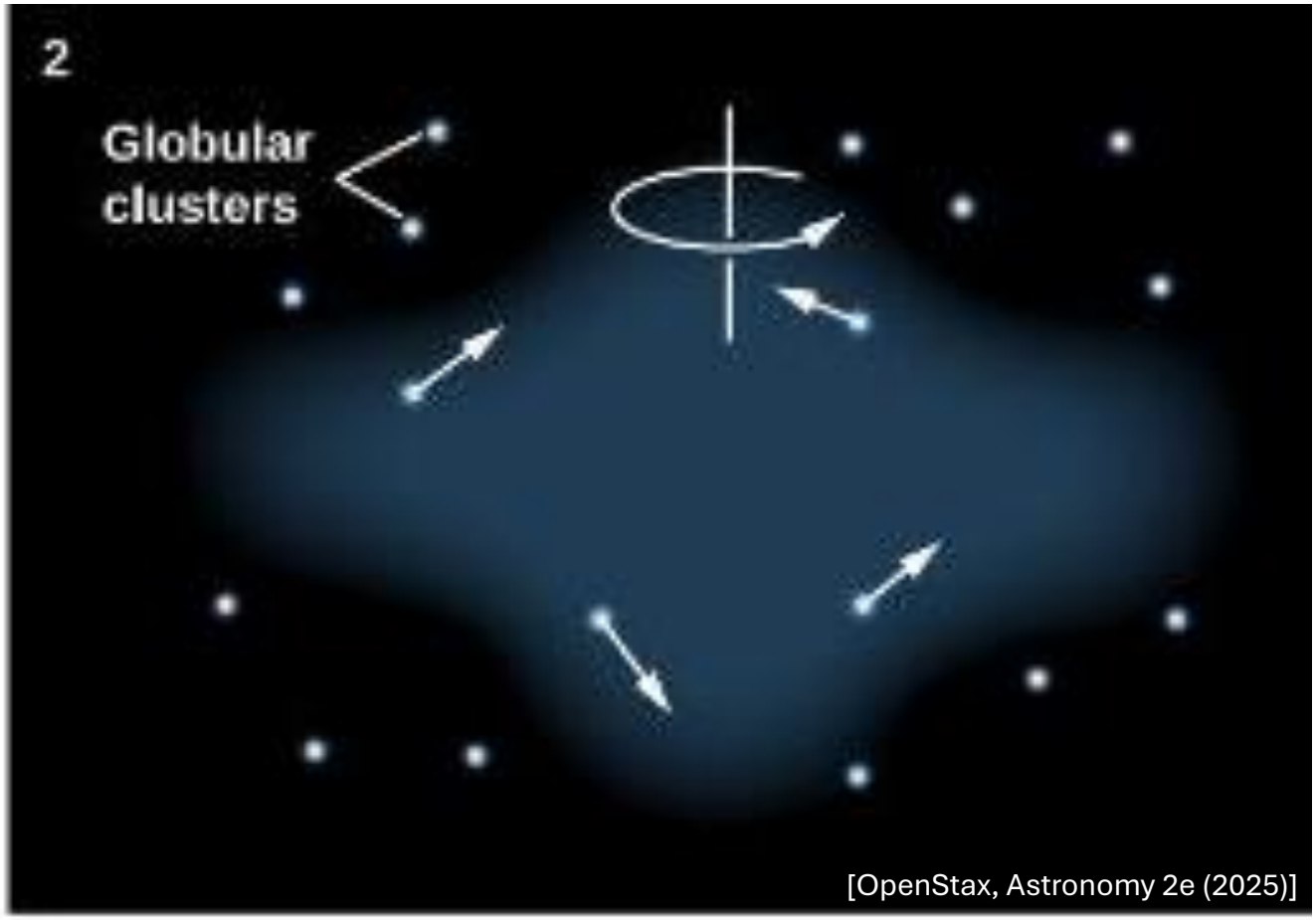
[OpenStax, Astronomy 2e (2025)]

Monolithic Collapse Model: Galaxy formation



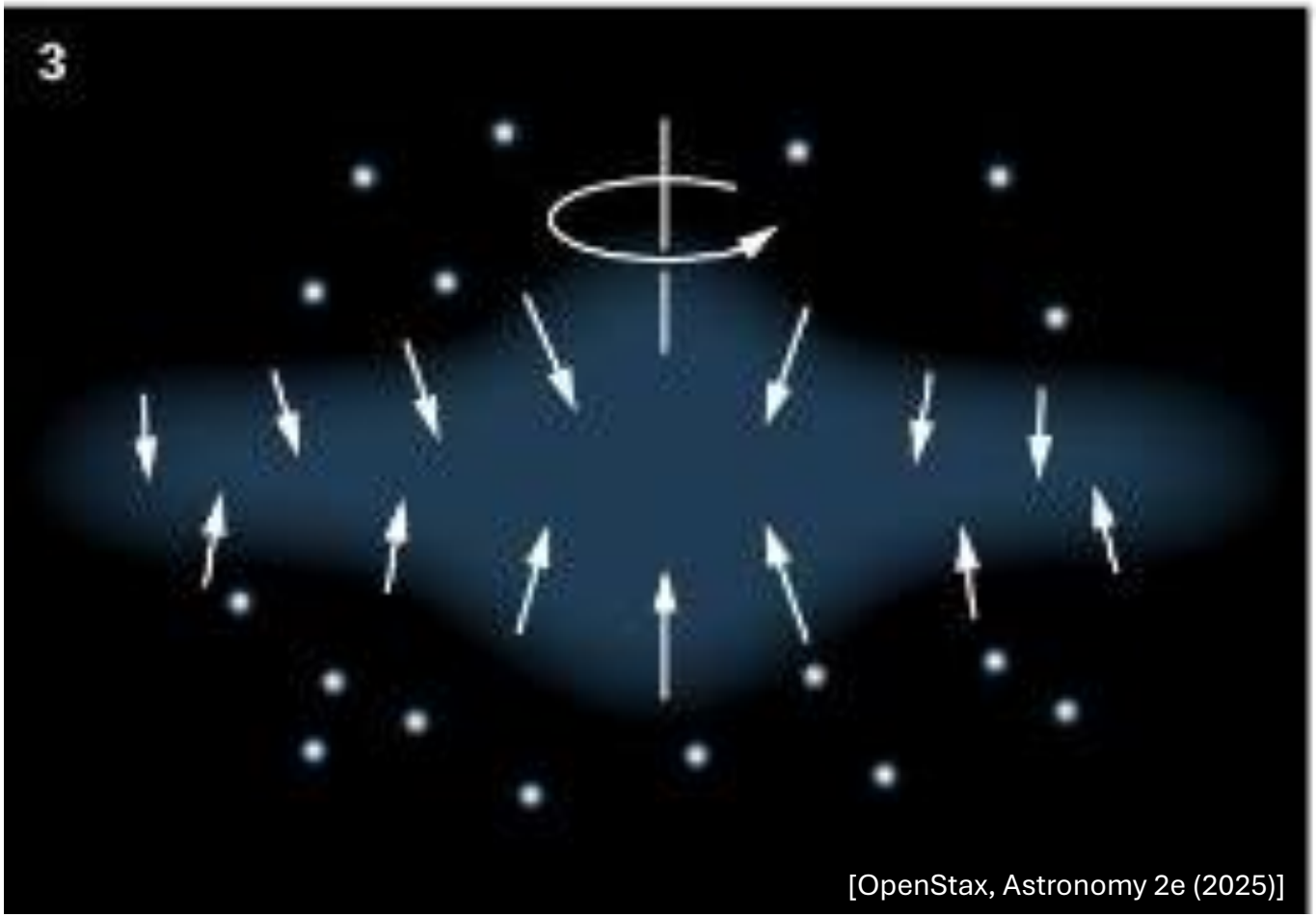
- An initial cloud of gas and dust collapses under its own gravity.
- As it collapses, its initial angular momentum is conserved, and the cloud rotates faster.

Monolithic Collapse Model: Galaxy formation



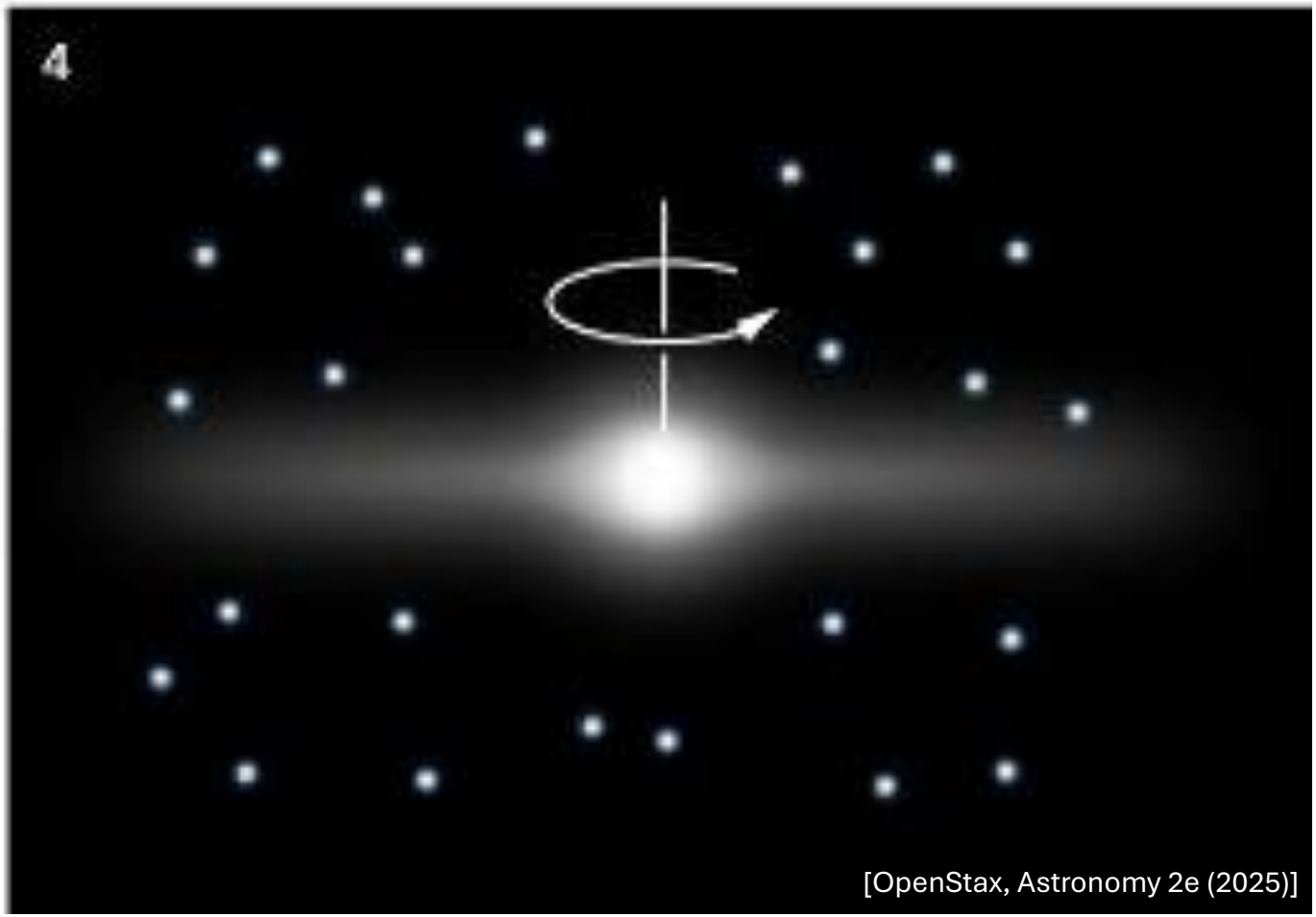
- The globular clusters were formed prior to collapse or were formed elsewhere.
- As it collapses, stars begin to form in regions of higher density.

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).