Today's Topics

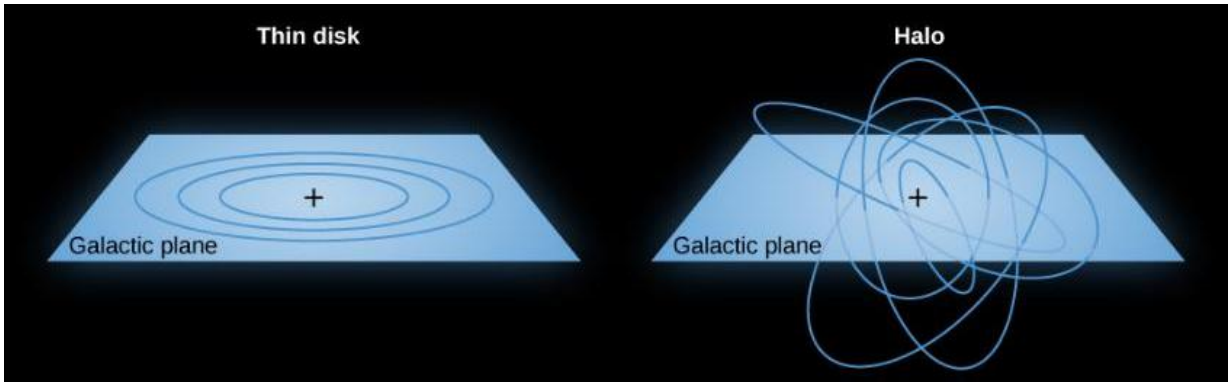
Friday, April 18, 2025 (Week 11, Lecture 31) – Chapter 25, 26.

1. Stellar population types
2. Formation of the galaxy
3. Barred galaxies
4. Distance Ladder

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

Stellar Population Types

Studies of Milky Way & Andromeda reveal **two** stellar population types.



Stellar population types provide clues to galactic formation process

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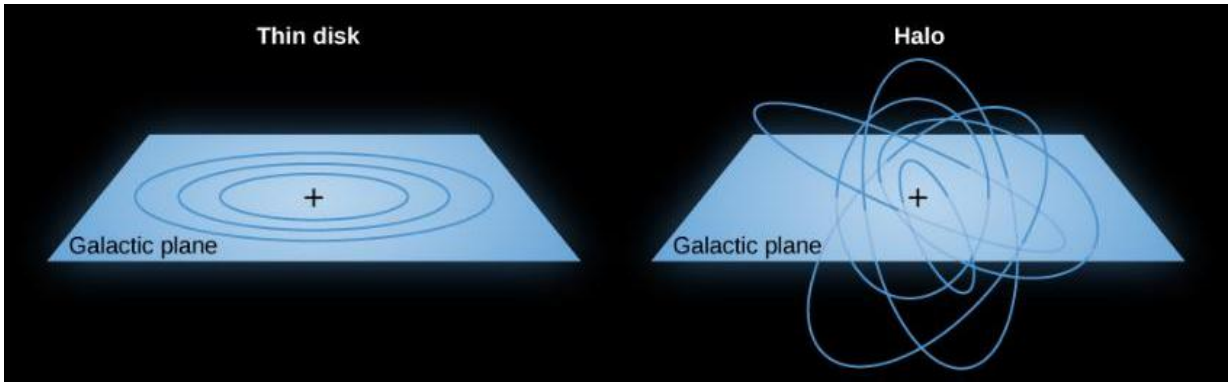

Population I stars

- **In the disk**, orbiting the galactic center. Bright supergiants and O and B spectral class.
- Typically members of young, open (100-1000 stars) clusters. Wide range of ages.
- They are composed of relatively large fractions of heavy elements
  → 1-4% of the mass is neither H nor He = High **metallicity**
- Accompanied by molecular clouds near these stars.

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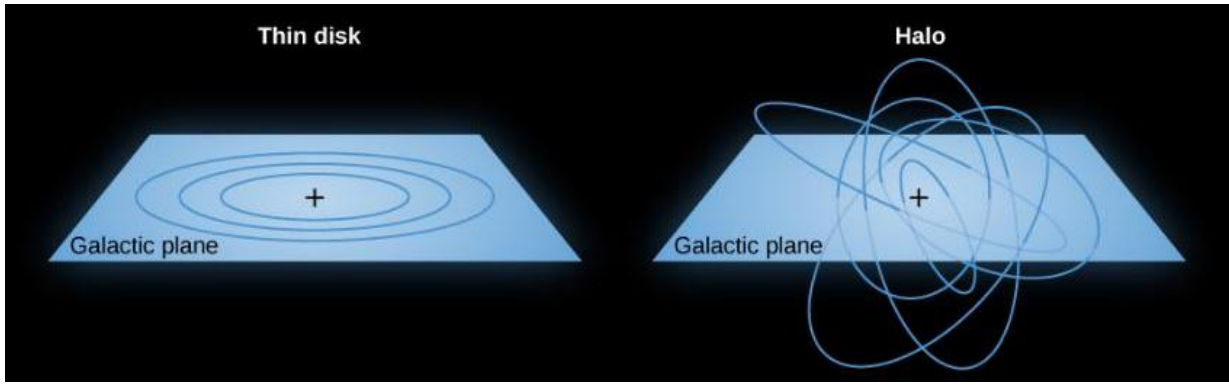

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Population II stars

- **Mainly in the halo,** follow elliptical orbits.
- Typically, they are very old (11-13 billion years).
- Almost entirely H or He. Not surprising – heavy elements are produced in stars.
  → When these stars were formed long ago, there was only H and He in the interstellar gas.

Stellar population types provide clues to galactic formation process

Milky Way Formation-Evolution

Rough timeline of the formation of the Milky Way

1. **Proto-galaxy**: Initial clump of material (possibly two clumps), no spiral structure.
   → *Roughly 12-13 billion years ago.*

2. 0-2 billion years: **central bulge** develops, fuzzy spiral arms develop.

3. 3-4 billion years: Two well-defined **spiral arms form**

4. 8+ billion years: **multiple spiral arms**

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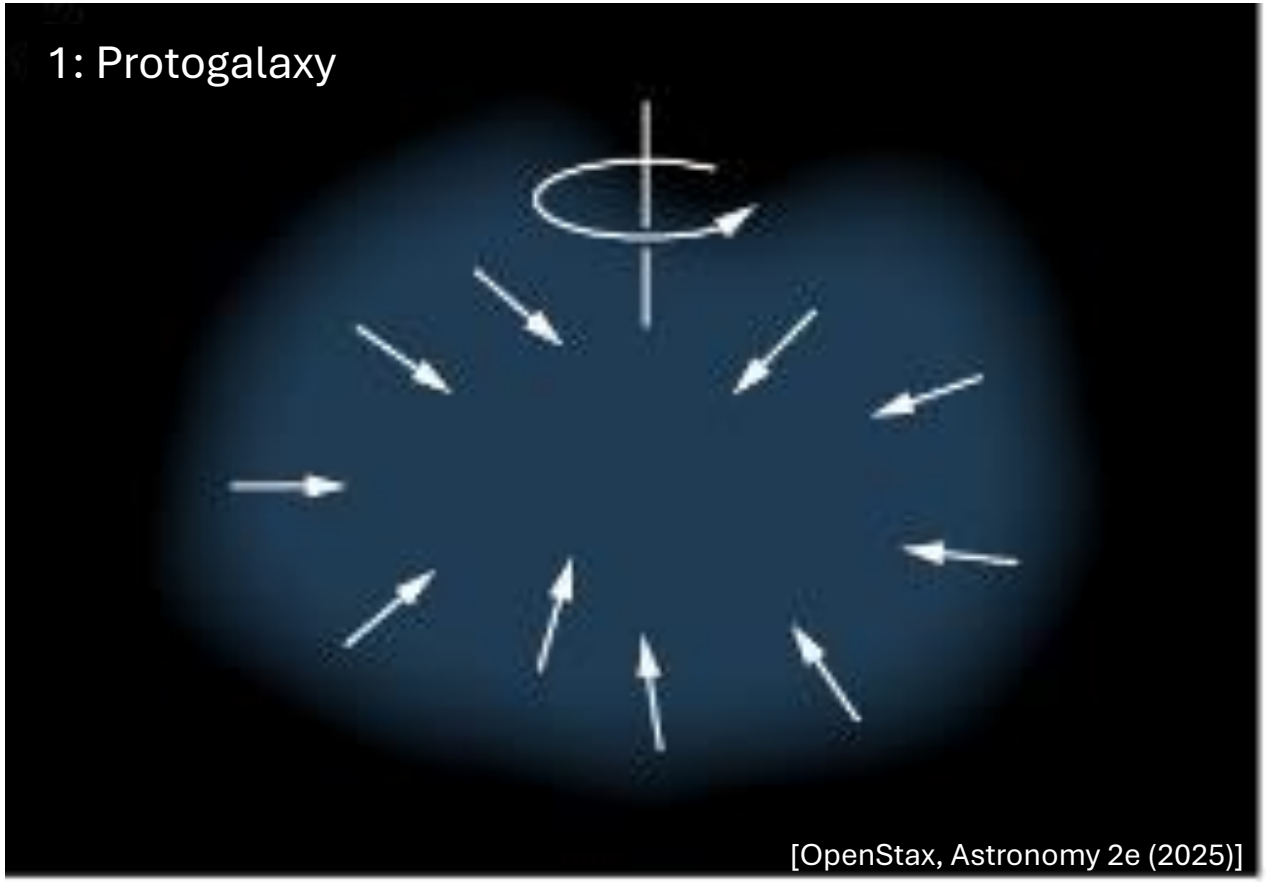
Additional facts:

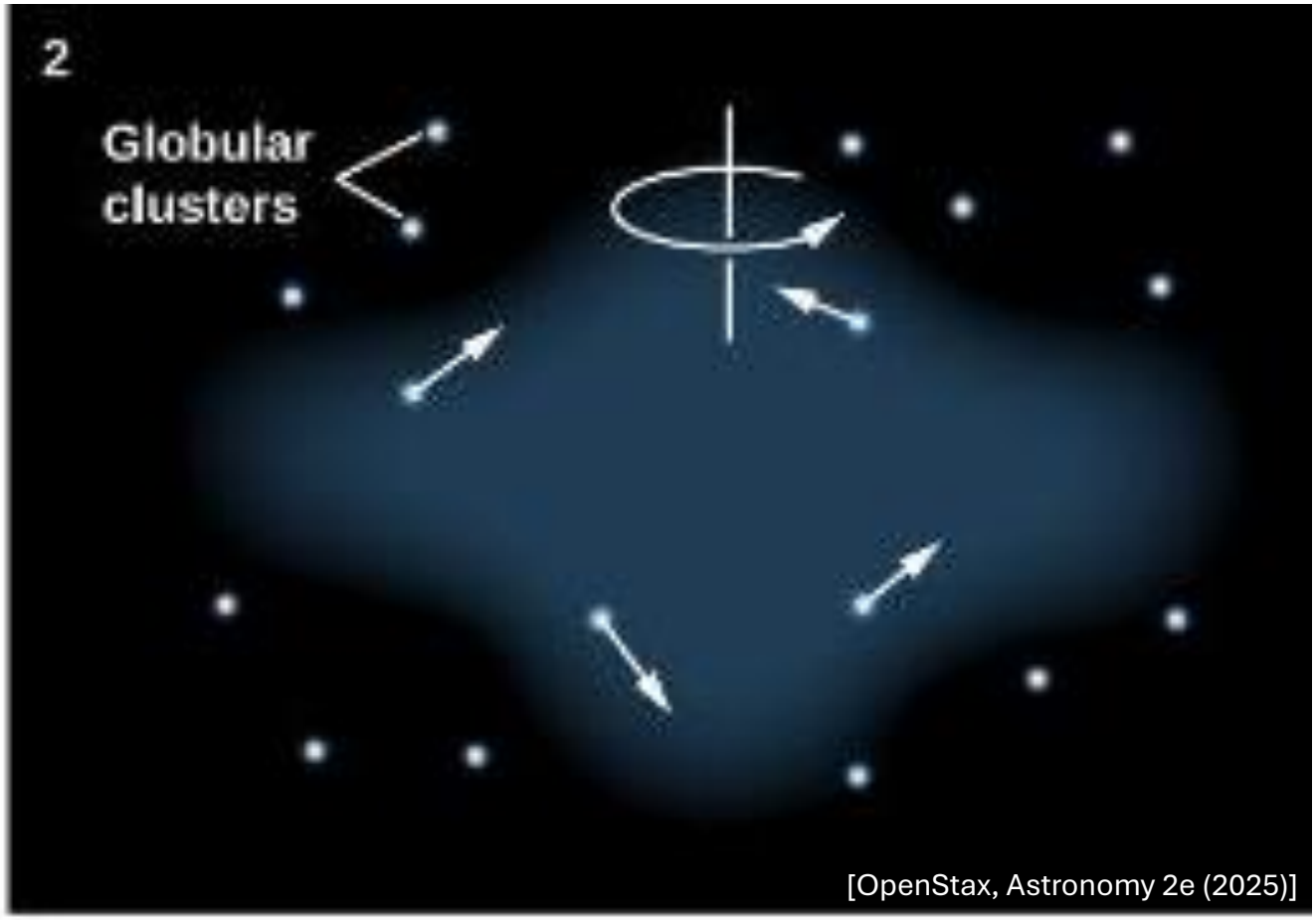
- It is likely that in the early stages the Milky Way **merged** with other large galaxies.
- At present, the Milky Way is **accreting** material from nearby **dwarf galaxies**.
  → e.g. Large and Small Magellanic Clouds, Sagittarius Dwarf.
- The Milky Way is expected to **merge** with Andromeda (M31) in about 4 billion years.

Monolithic Collapse Model: Galaxy formation



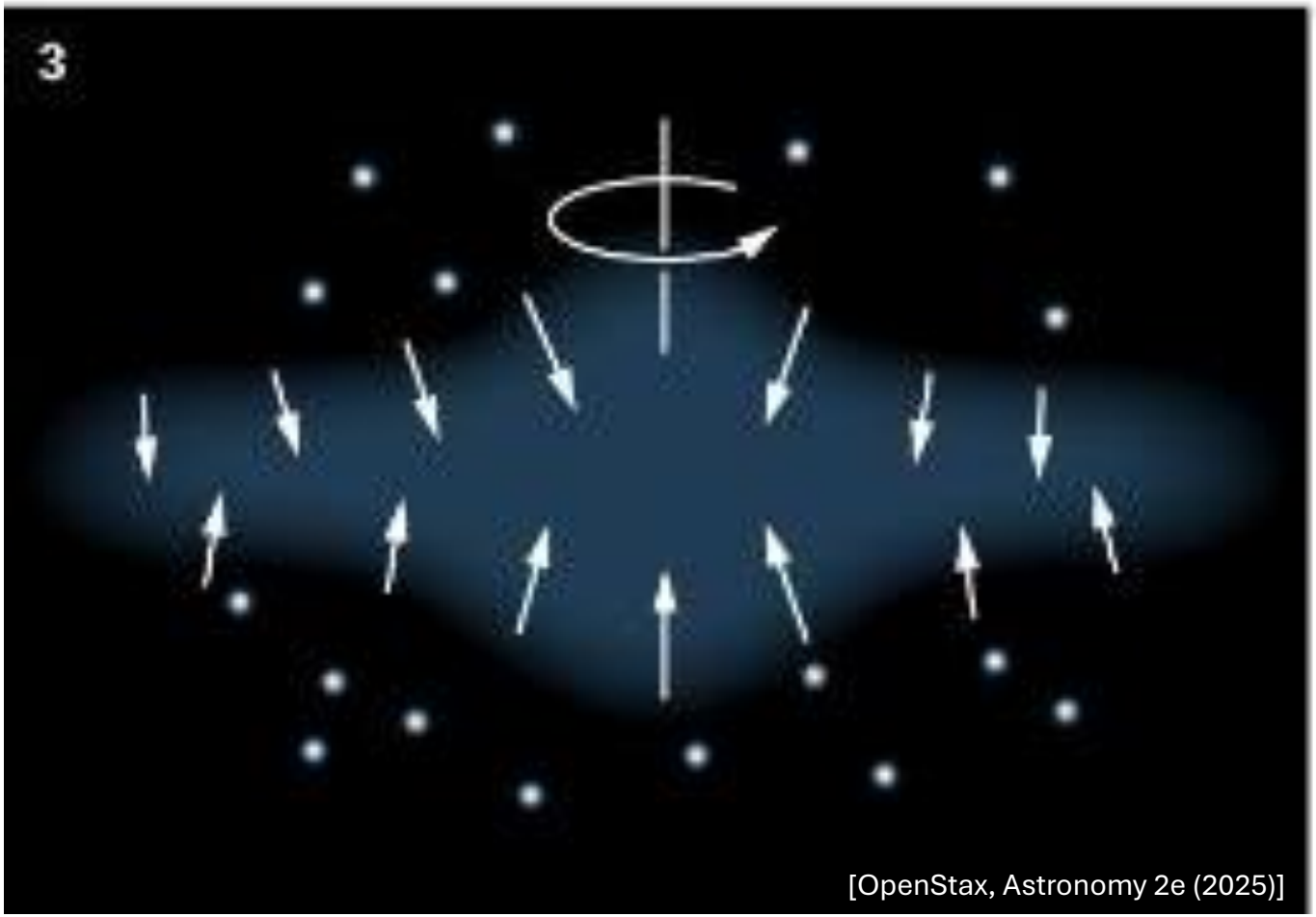
- An initial cloud of gas and dust collapses under its own gravity.
- As it collapses, its initial angular momentum is conserved, and the cloud rotates faster.

Monolithic Collapse Model: Galaxy formation



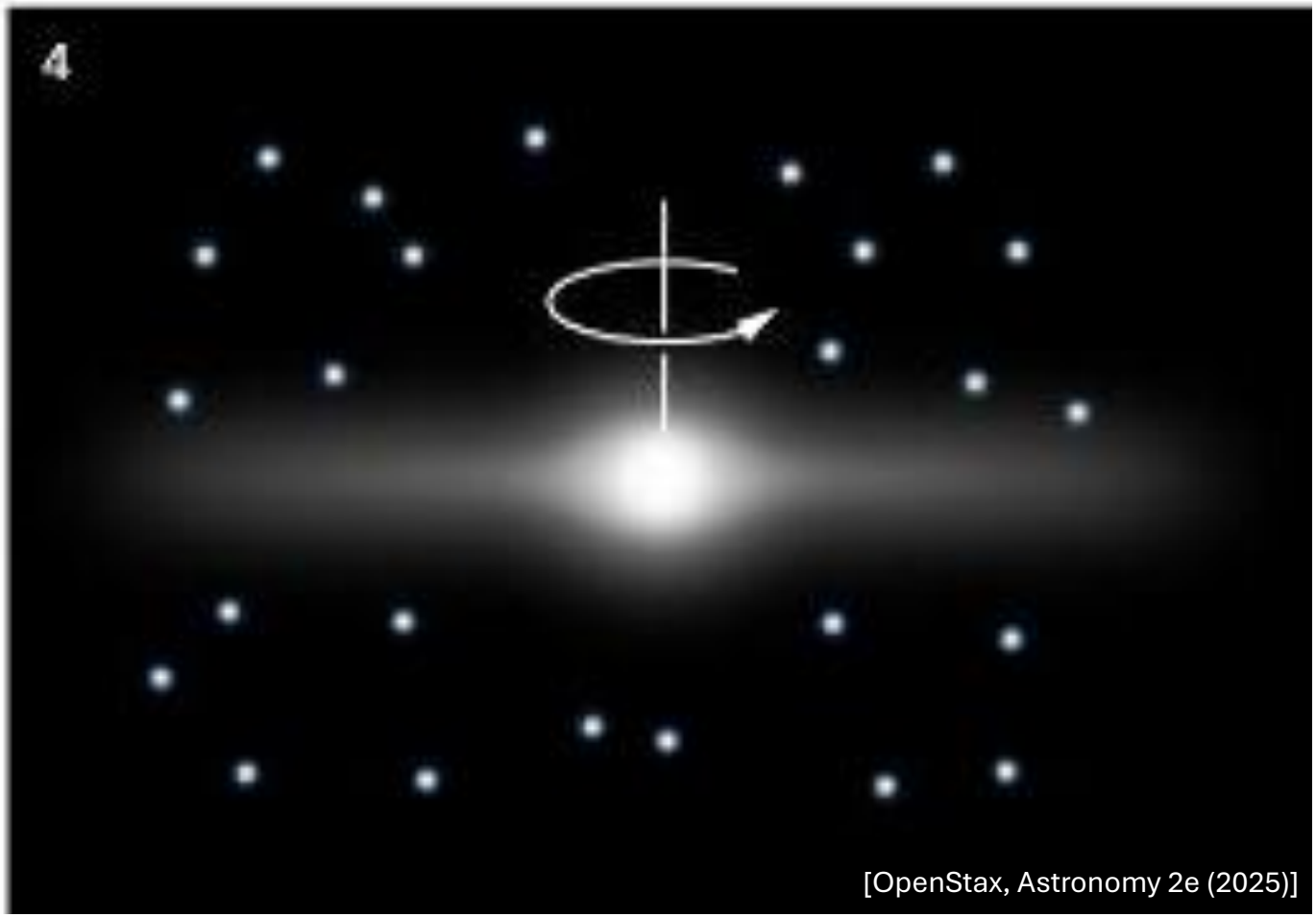
- The globular clusters were formed prior to collapse or were formed elsewhere.
- As it collapses, stars begin to form in regions of higher density.

Monolithic Collapse Model: Galaxy formation



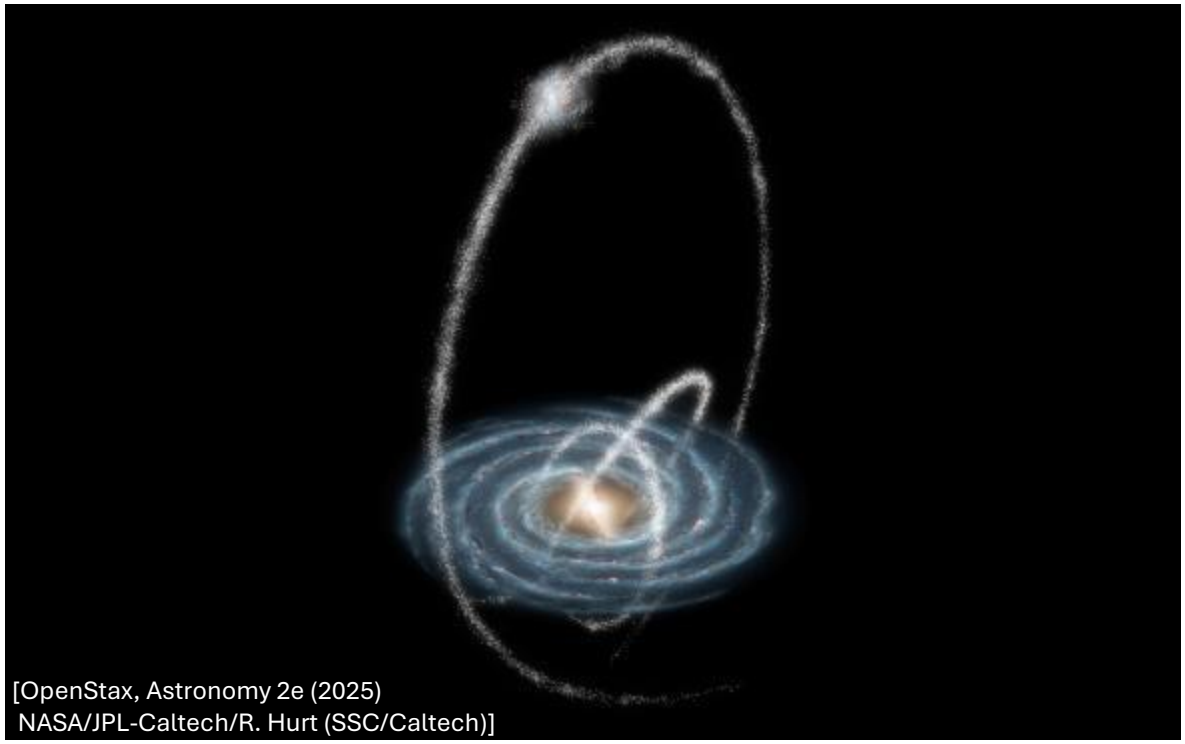
- Interactions between the gas/dust and stars pulls the cloud into a disk (angular momentum is conserved).

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).

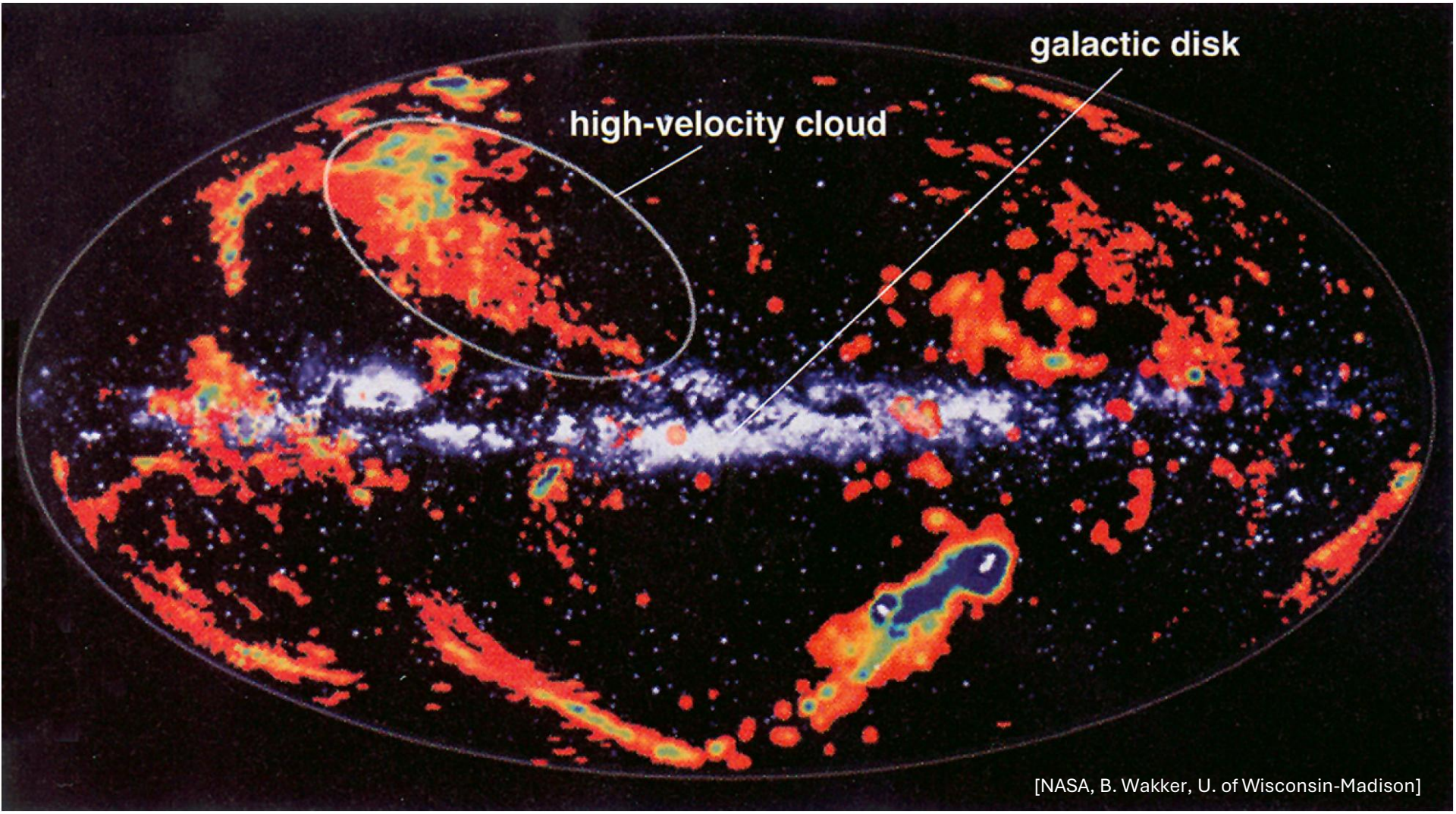
Dwarf Galaxy Merger-Accretion



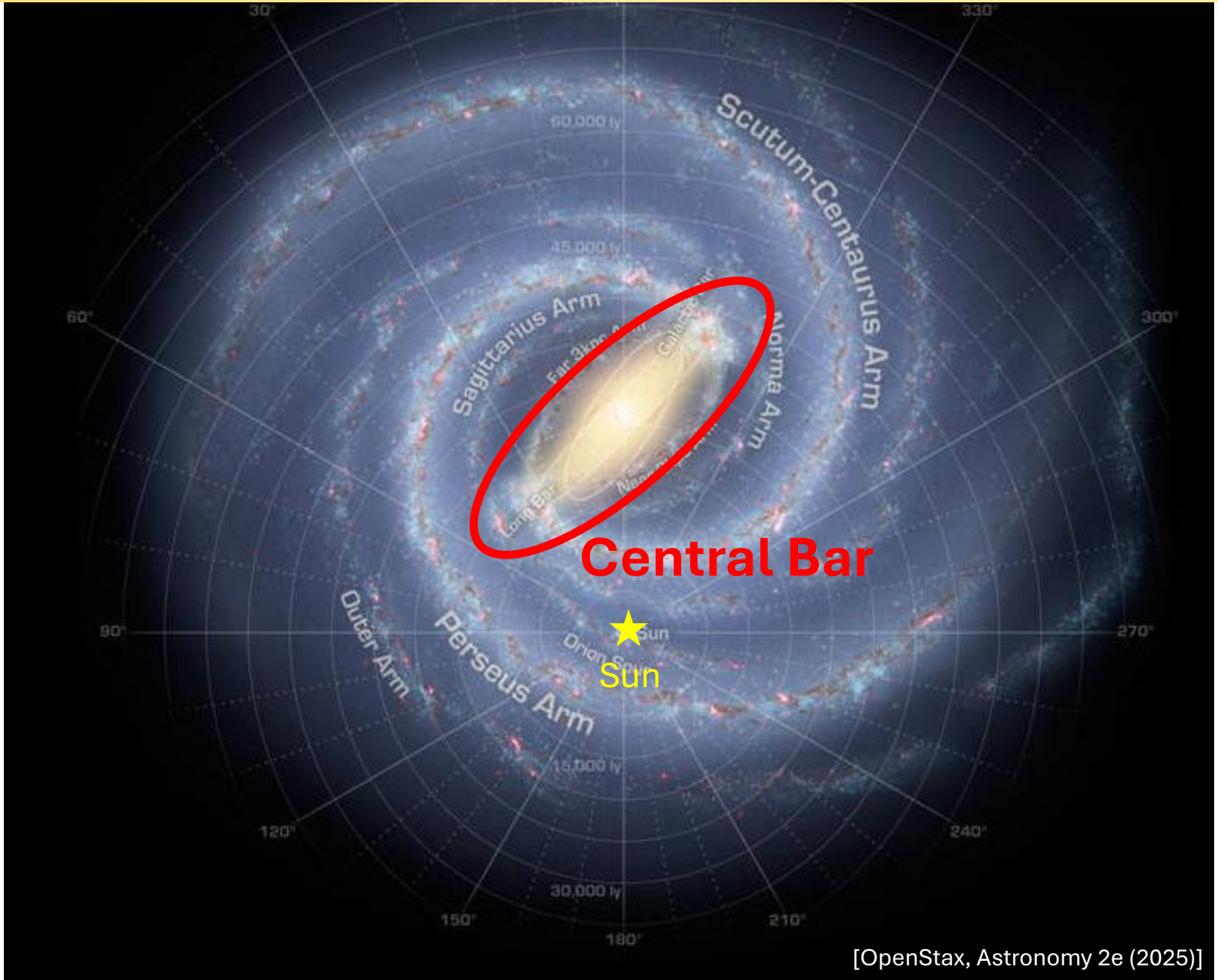
[OpenStax, Astronomy 2e (2025)
NASA/JPL-Caltech/R. Hurt (SSC/Caltech)]

- **Streams in the Galactic Halo:** When a small galaxy is swallowed by the Milky Way, its member stars are stripped away and form streams of stars in the galactic halo.
- This image is based on calculations of what some of these tidal streams might look like if the Milky Way swallowed 50 dwarf galaxies over the past 10 billion years.

Dwarf Galaxy Merger-Accretion



Barred Spiral Galaxies



[OpenStax, Astronomy 2e (2025)]

Barred Spiral Galaxies

NGC 1365 (74 million light years away)
Fornax Propeller Galaxy
[Dark Energy Survey/DOE/FNAL/DECam/CTIO/NOIRLab/NSF/AURAImage]

Barred Spiral Galaxies

NGC 925 (30 million light years away)

[KPNO/NOIRLab/NSF/AURA]

Barred Spiral Galaxies

NGC 2903 (30 million light years away)

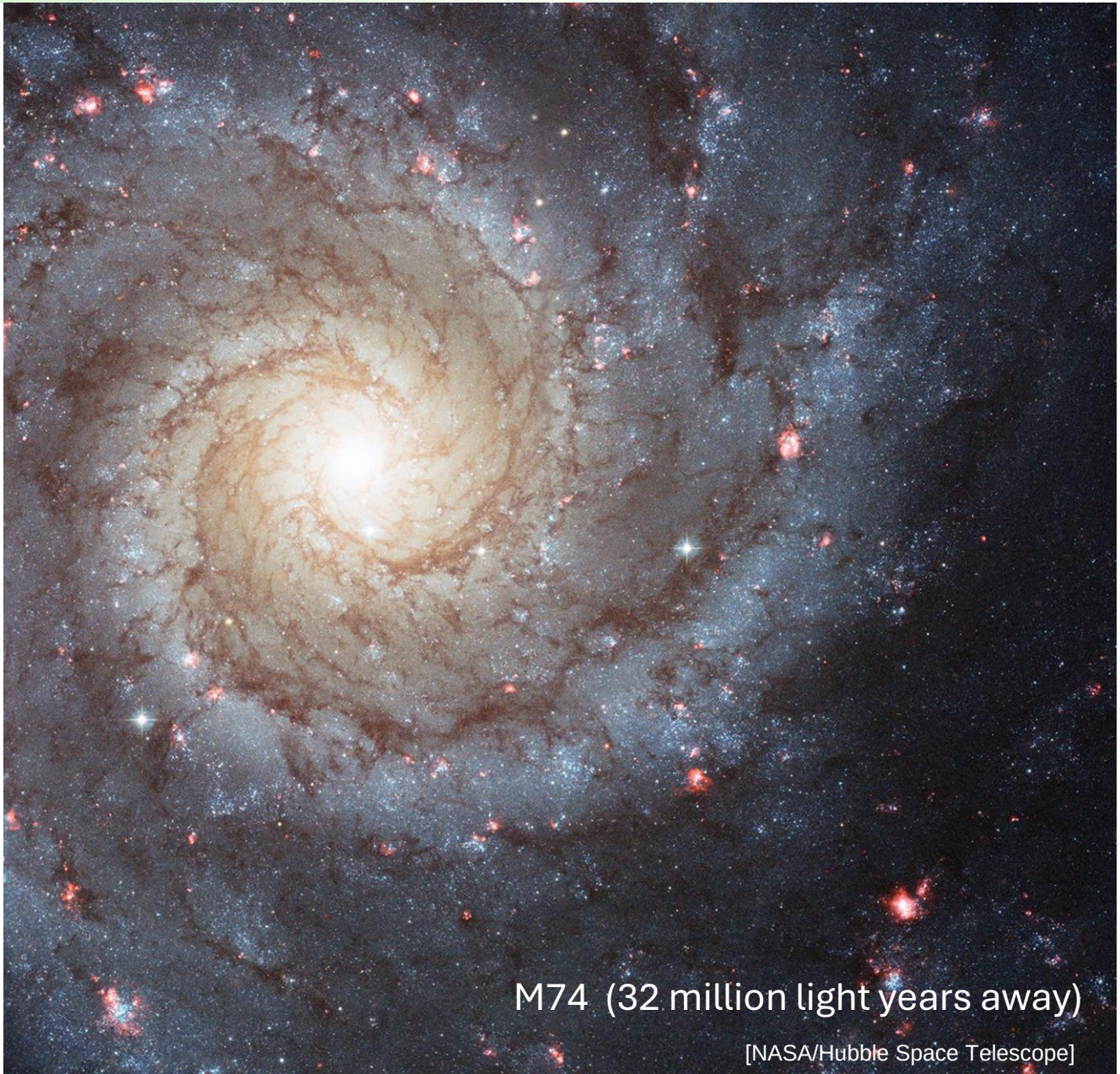
[Jschulman555 – Wikipedia (2025)]

Barred Spiral Galaxies

NGC 7479 (120 million light years away)

[Ichi Tanaka / National Astronomical Observatory of Japan]

Unbarred Spiral Galaxies (tend to be younger)



M74 (32 million light years away)

[NASA/Hubble Space Telescope]

The Distance Ladder

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

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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

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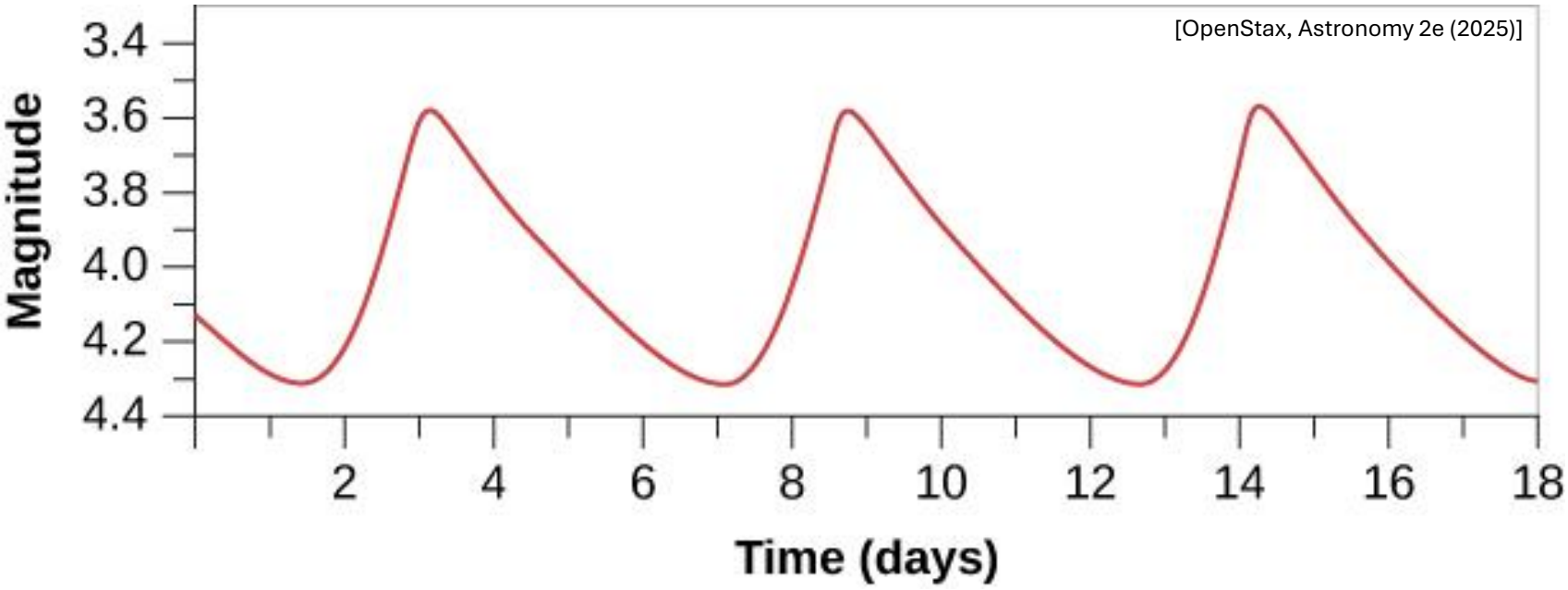
Main idea: if we can find some sort of "standard candle", *i.e.,* a star where we know (from some other property) what its Luminosity is, then its Apparent Brightness tells us its Distance.

PollEv Quiz: PollEv.com/sethaubin

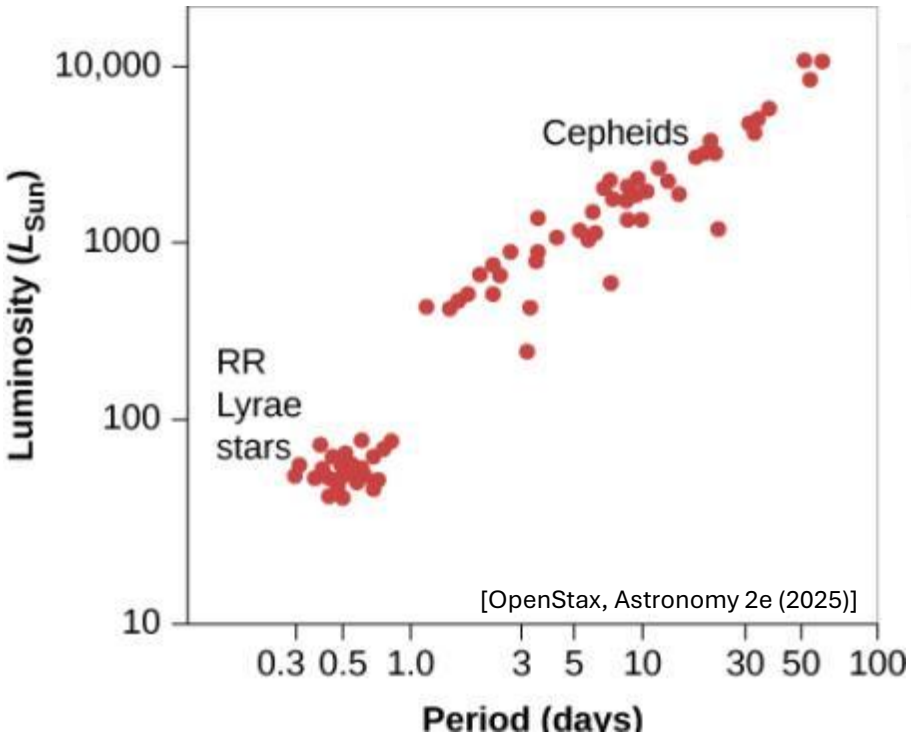
Cepheid Variable Stars – a standard candle



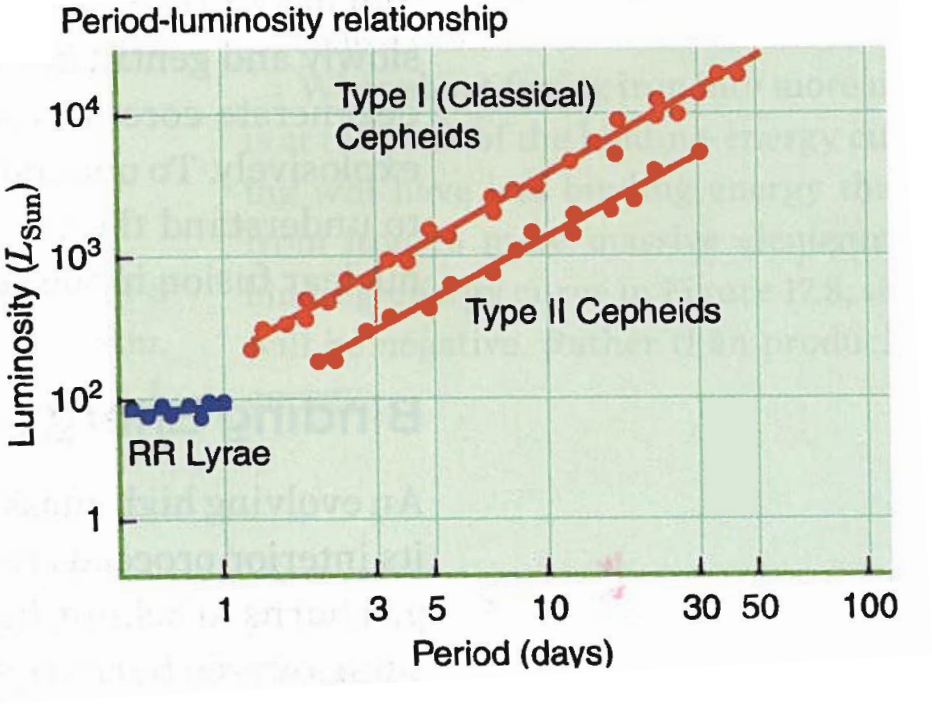
Cepheid Light Curve

Here the brightness of the star changes periodically with a period of about 6 days.

Cepheid Variable Stars – a standard candle



[OpenStax, Astronomy 2e (2025)]

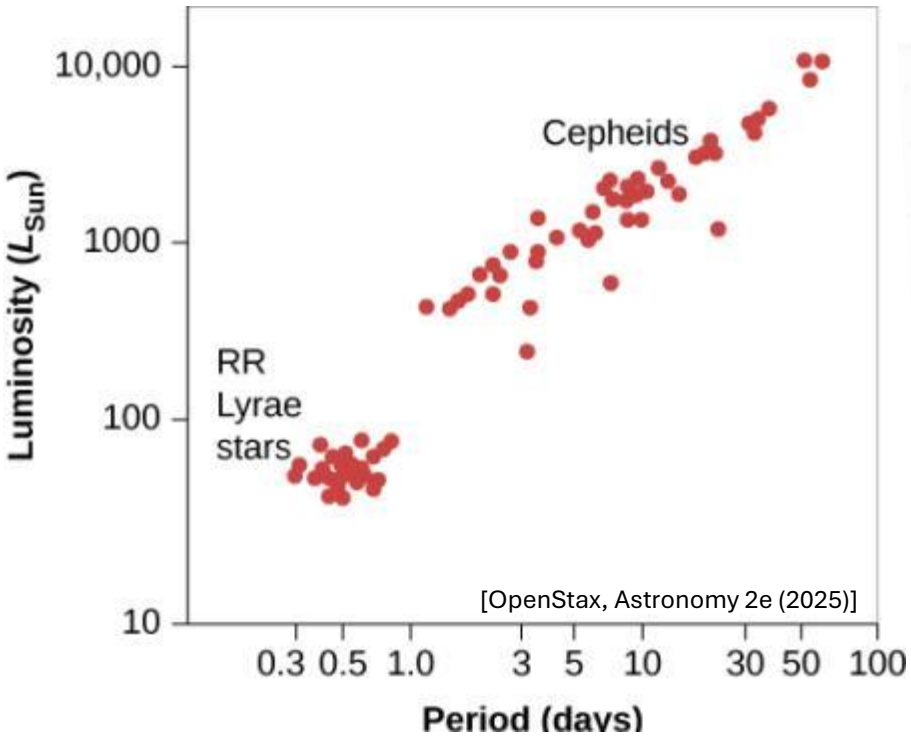


[*21st century Astronomy*, 5th ed.,
by L. Kay, S. Palen, and G. Blumenthal (Norton, 2016)]

Period-Luminosity Relation for Cepheid Variables

- The time the star takes to go through a cycle of luminosity changes is related to the average luminosity of the star.
- RR Lyrae stars have a comparable behavior.

Cepheid Variable Stars – a standard candle



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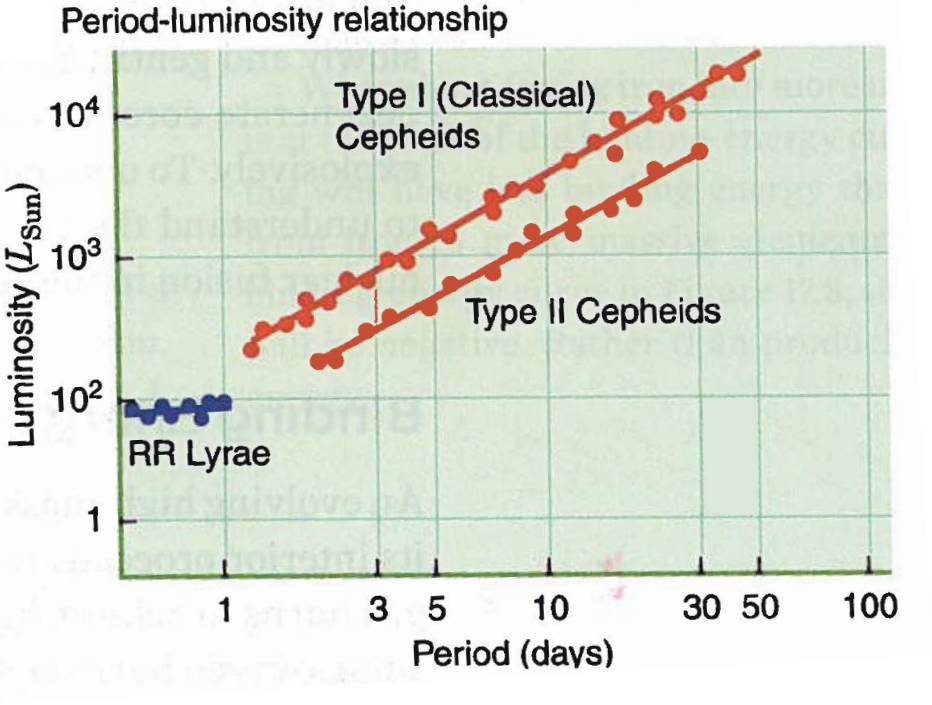

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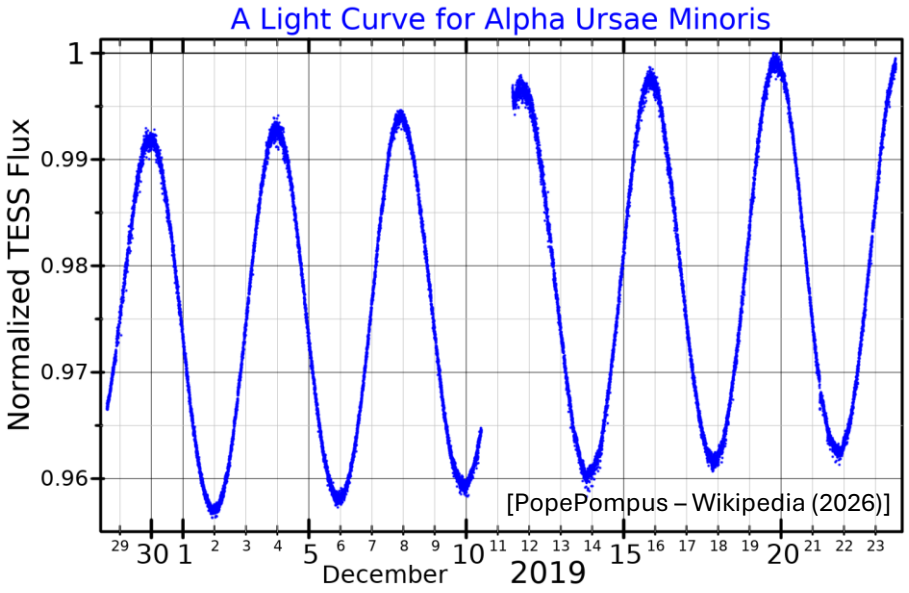
History: Period-luminosity relationship discovered by Henrietta Swan Leavitt (1912) by looking at Cepheids in the LMC and SMC.

Cepheid Variable Stars – a standard candle

Polaris Aa (cepheid) and Polaris Ab

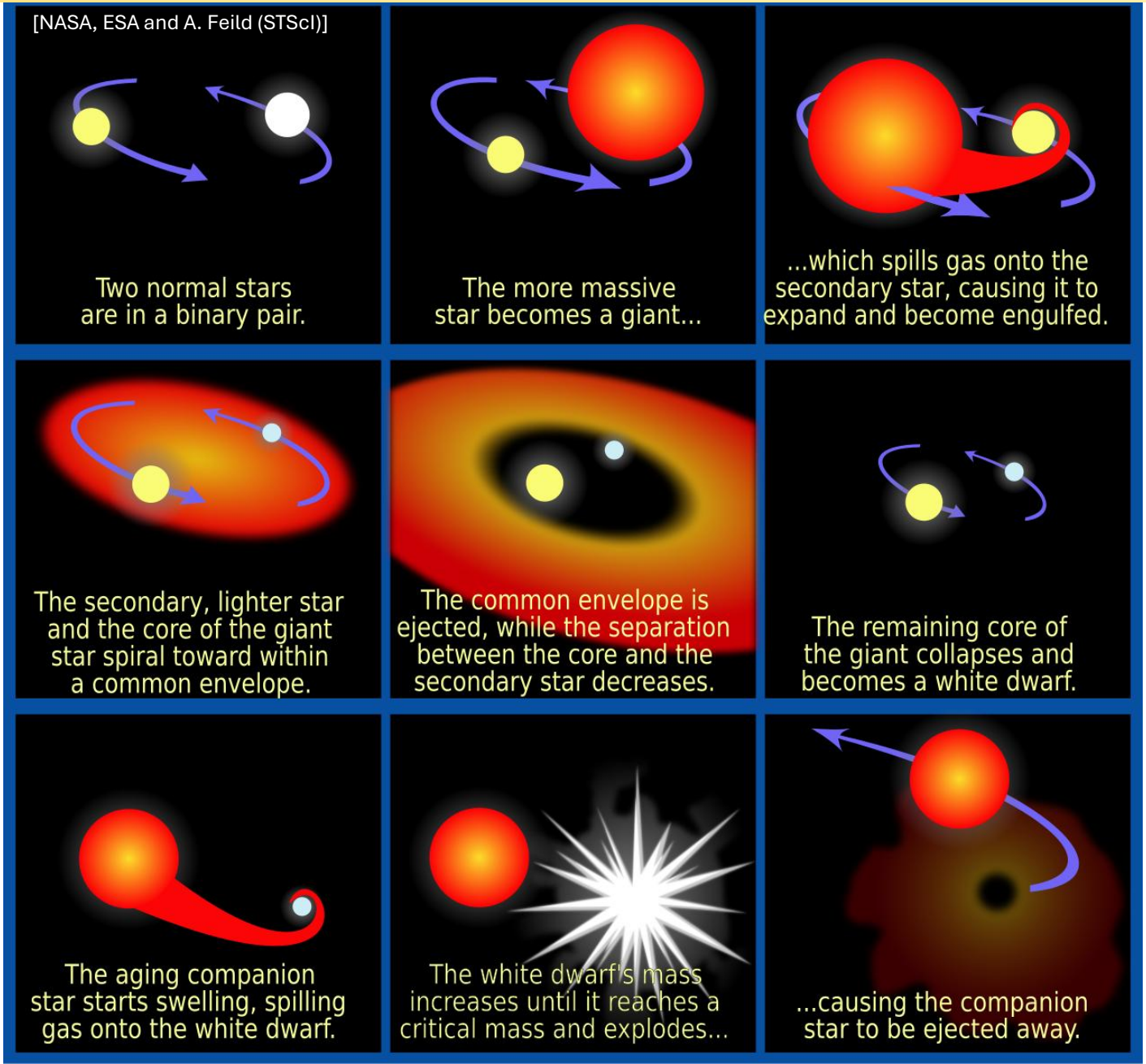
(time lapse sequence)



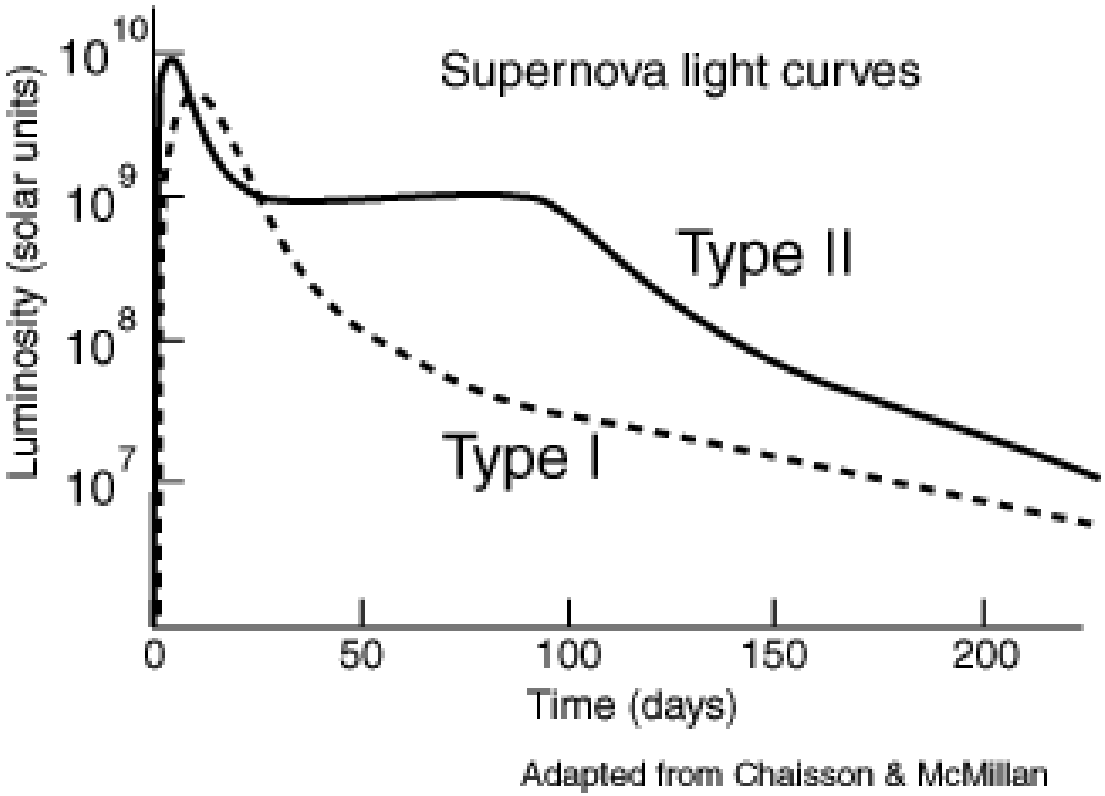
Light curve for Polaris Aa

(cepheid type 1: 4 day period)

Type 1a Supernovae



Type 1a Supernovae – a standard candle



Adapted from Chaisson & McMillan

Type 1a Supernovae – a standard candle