Today's Topics

Monday, April 27, 2026 (Week 13, Lecture 35) – Chapter 27, 28.

0. Quasars (continued)
1. Accretion disks & jets
2. Supermassive black holes & galaxies
3. Galaxy mergers
4. Clusters & Superclusters

Interlude 2 essay is due on Gradescope on Monday, April 27, 2026 by 9:00 AM

Problem Set #11 (optional/ungraded) is posted on ExpertTA

What Are Quasars?

- ✓ 1000 times luminosity of Milky Way
- ✓ Size of the solar system

→ **Supermassive black hole** feeding on 10 – 1000 M_{sun} per year

→ Gravitational potential energy is converted to radiation.
(efficiency: 6% – 32%)

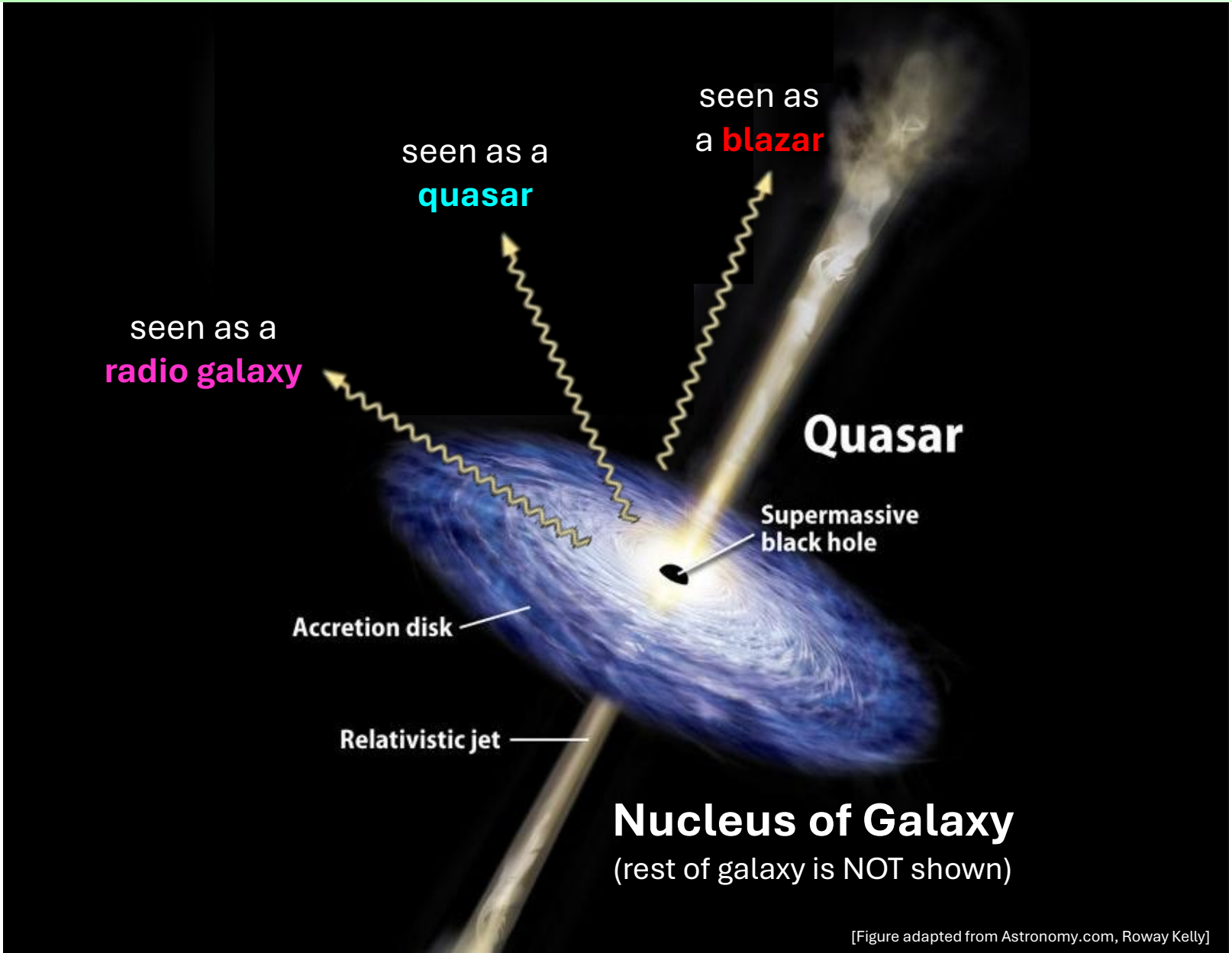
→ Supermassive black hole with mass of 10^9 M_{sun} or larger needed.

Milky Way "supermassive" black hole (Sagittarius A*) is much smaller.

→ Mass of only 4×10^6 M_{sun}.

→ About 1 M_{Sun} falls in every 1000 years.

Quasar = Active Galactic Nucleus (AGN)

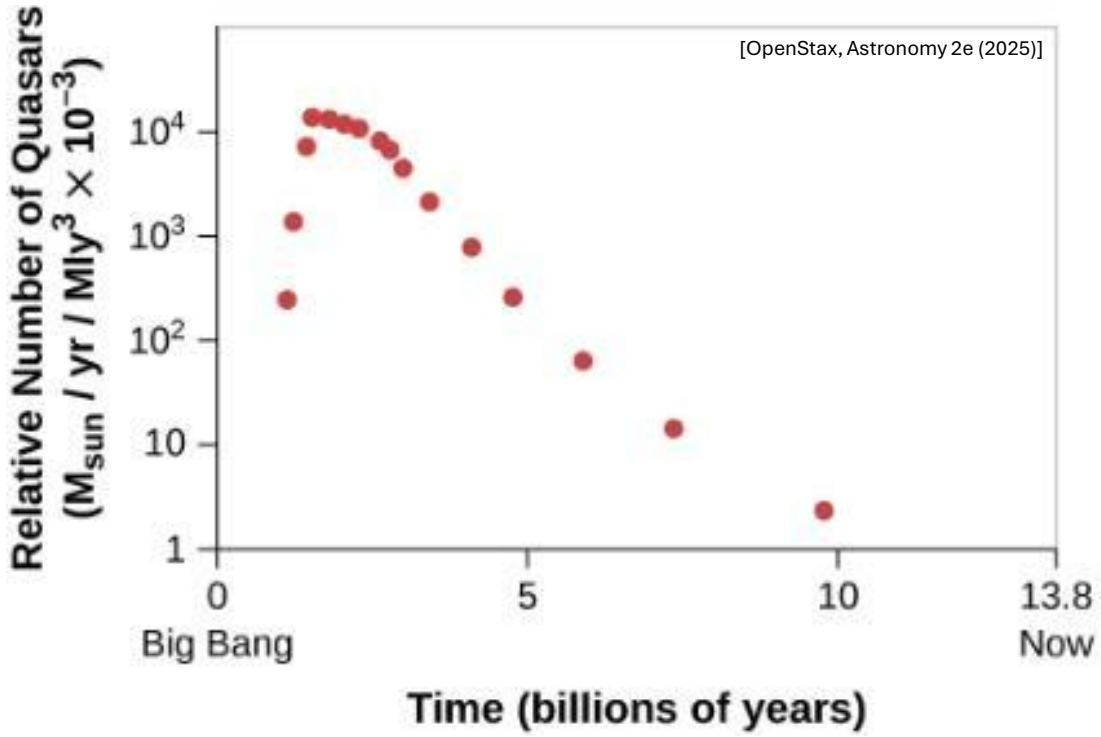


[Figure adapted from Astronomy.com, Roway Kelly]

The Quasar Era

- Quasars existed primarily in the **early universe** (peaks at 2 billion years after Big Bang).
  → Galaxies are forming.
  → There is a lot of material (gas) for an accretion disk to feed supermassive black hole.

- The early universe had more **galaxy-galaxy collisions**.
  → More collisions because galaxies are closer together.
  → Collisions can put more material closer to supermassive black hole.



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  - → These conditions also favor star formation (peaks at 2 billion years after Big Bang).

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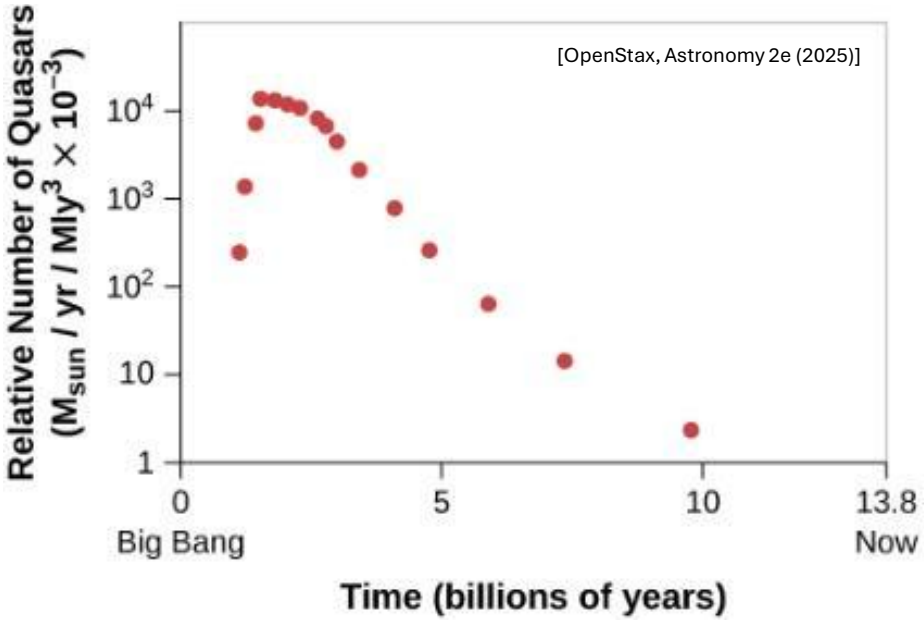

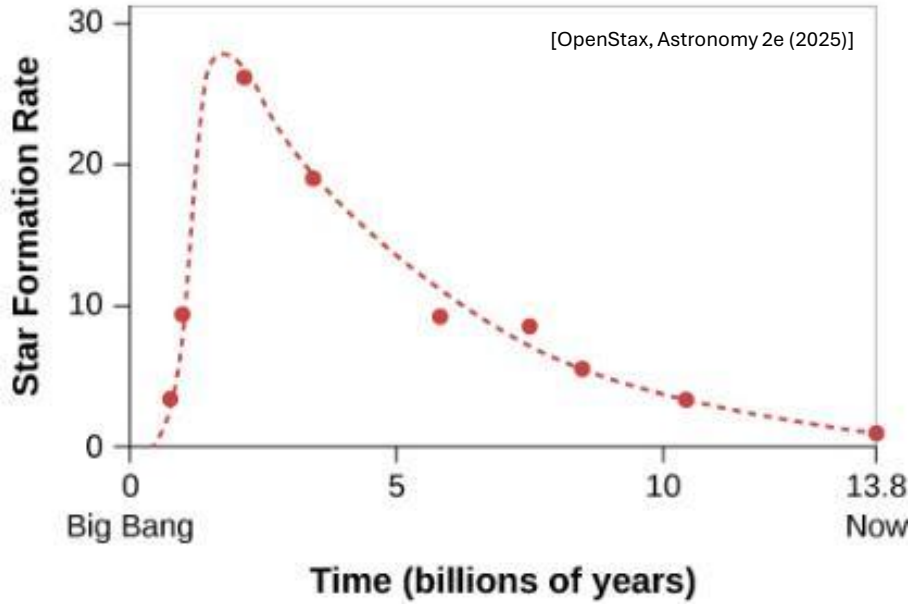

Active Galactic Nucleus (AGN)

An AGN is a supermassive black hole that is emitting lots of radiation (radio, visible, x-ray), because it is feeding on its accretion disk.

→ All quasars are AGNs.

→ Not all AGNs are quasars.

→ Quasars are very active AGNs.

→ AGNs typically have jets of material emitted along the spin axis of the black hole.

→ The Milky Way supermassive black hole (Sagittarius A*) is NOT an AGN at present.

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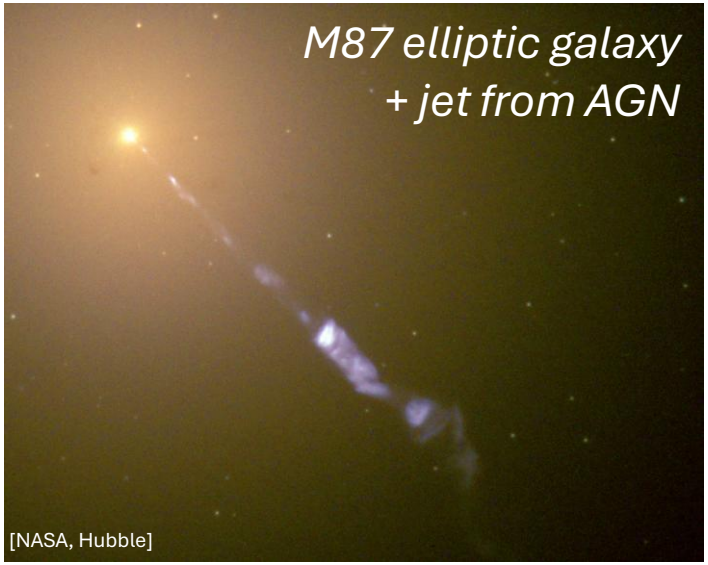
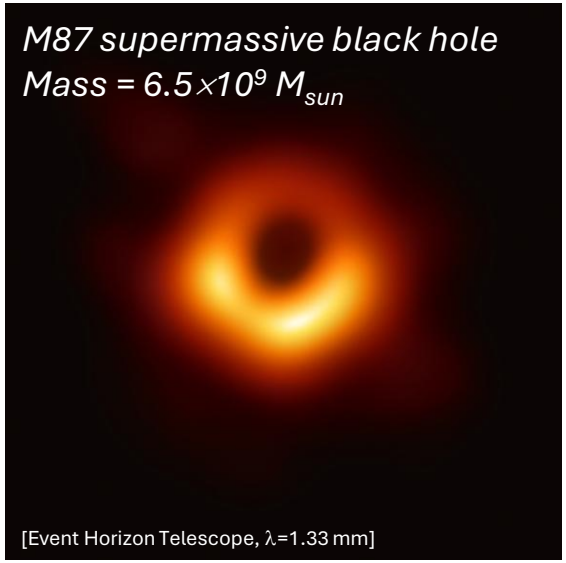
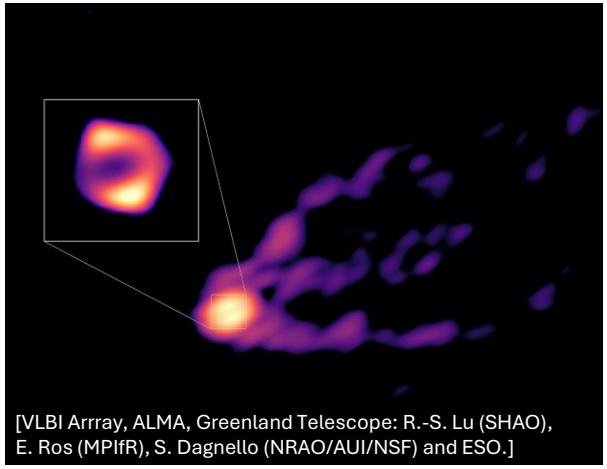




M87 supermassive black hole with radio jets emanating from it.



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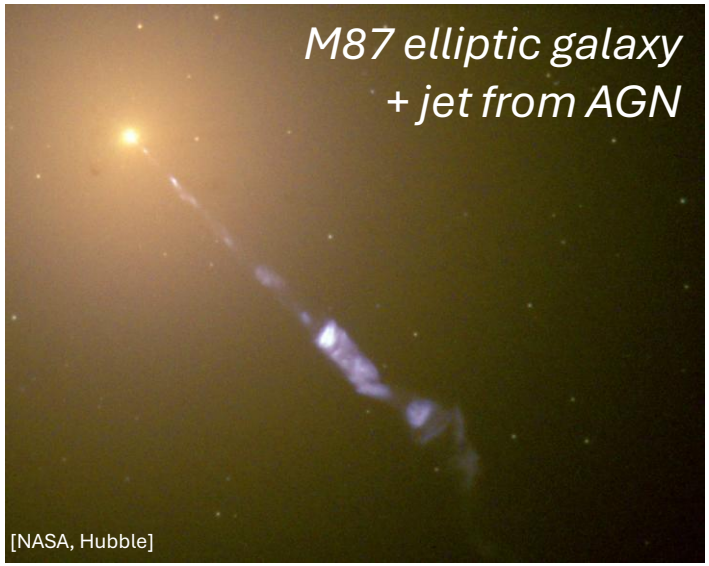
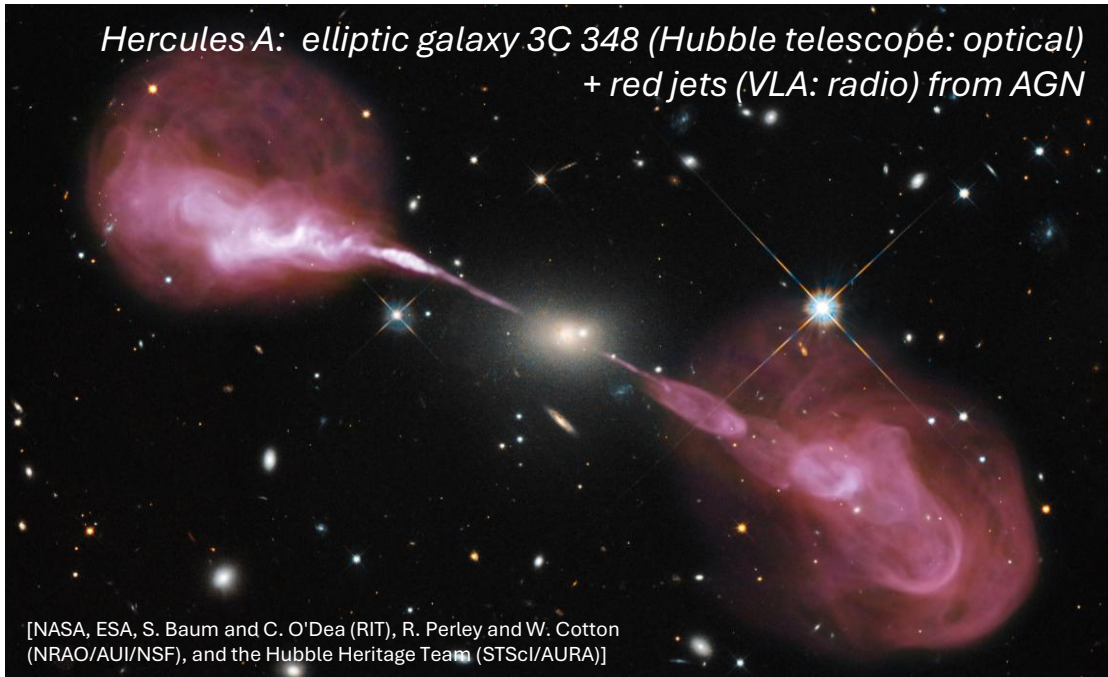
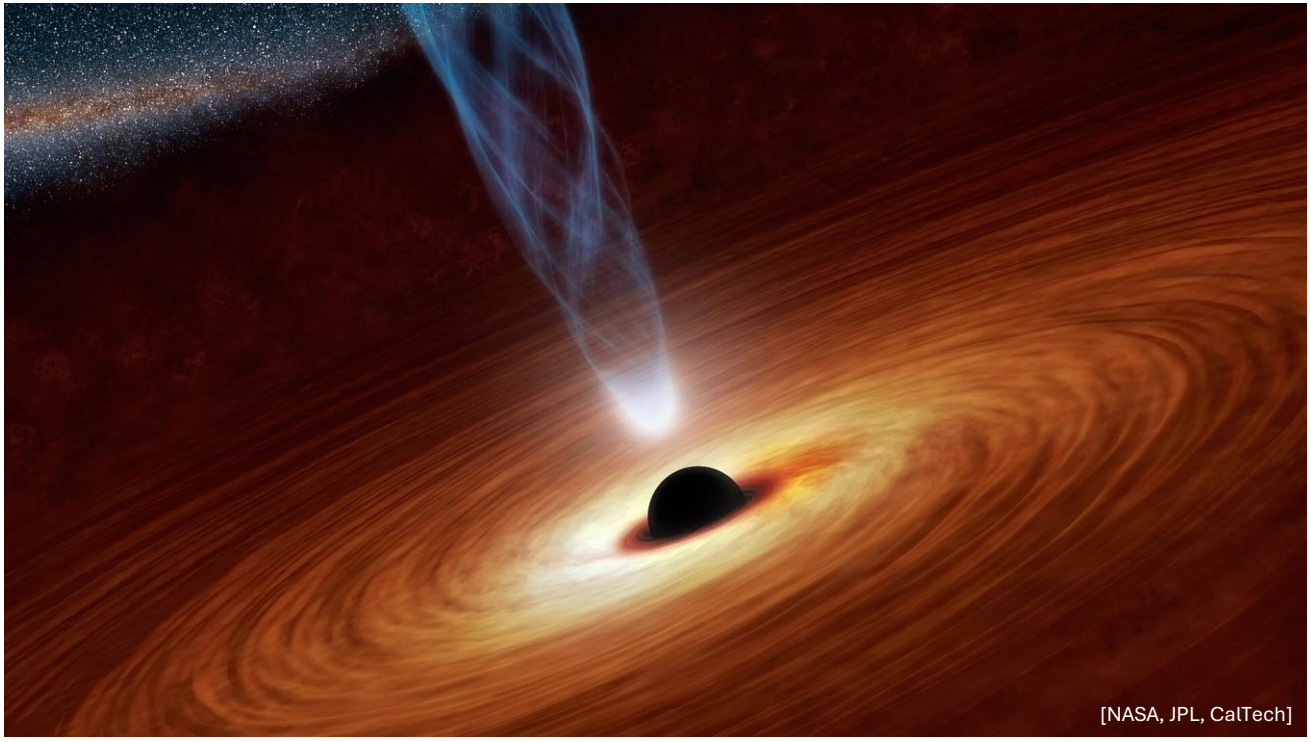




Accretion Disk and Jets

- Accretion disk is relatively well understood.
- As material (gas, dust, stars) orbits the black hole, friction heats up the material.
  - → Millions of degrees → black body radiation.
  - → Efficient conversion of gravitational energy to radiation (efficiency: 6%-32%).
  - → Radiation can push material outward away from accretion disk, which can lead to star formation away from black hole.
  - → If radiation is too intense, it can also turn off star formation in the central part of galaxy.



[NASA, JPL, CalTech]

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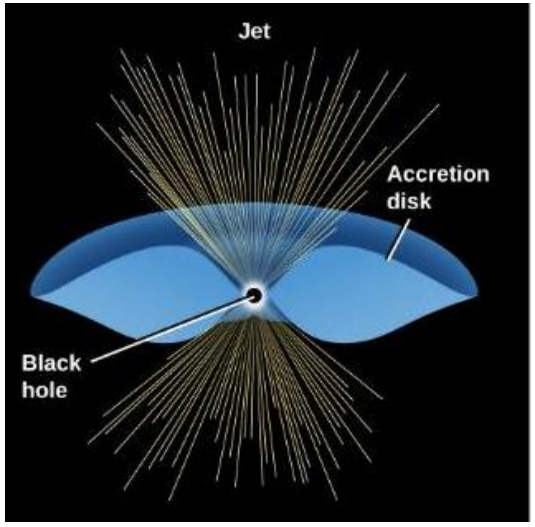
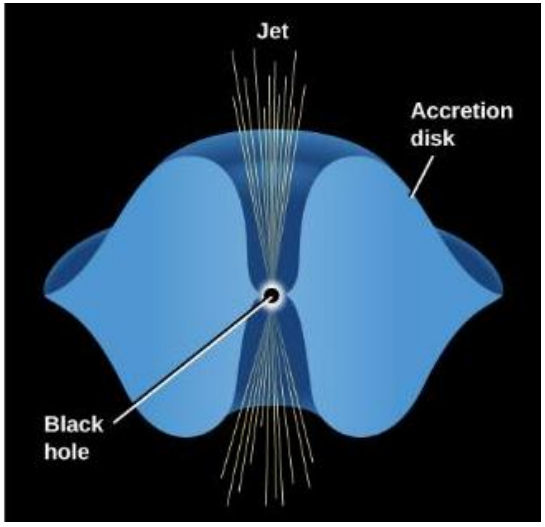


thin disk → diffuse jets



thick disk → narrow jets

- Jet formation is along black hole and accretion disk rotation axis.
  → Jet formation is NOT that well understood.

[OpenStax, Astronomy 2e (2025)]

How does a black hole “eat” a star?

- The star’s orbit decays due to friction with accretion disk gas and emission of gravitational waves.
- As the star gets close to the black hole **tidal forces** deform it.
- Once the star is inside the “Roche limit”, it becomes part of the accretion disk, which eventually falls into black hole.

  → Material gets very hot from friction, so black hole region will get momentarily brighter.

[NASA/CXC/M. Weiss; OpenStax, Astronomy 2e (2025)]

Galaxies & Supermassive Black Holes

- As far as we can tell, all galaxies have a supermassive black hole at their nucleus.

- The origin of these black holes is uncertain.
  → Perhaps, a **high density** of material coalesced into a black hole.
  → Perhaps the universe was born with **primordial** black holes.

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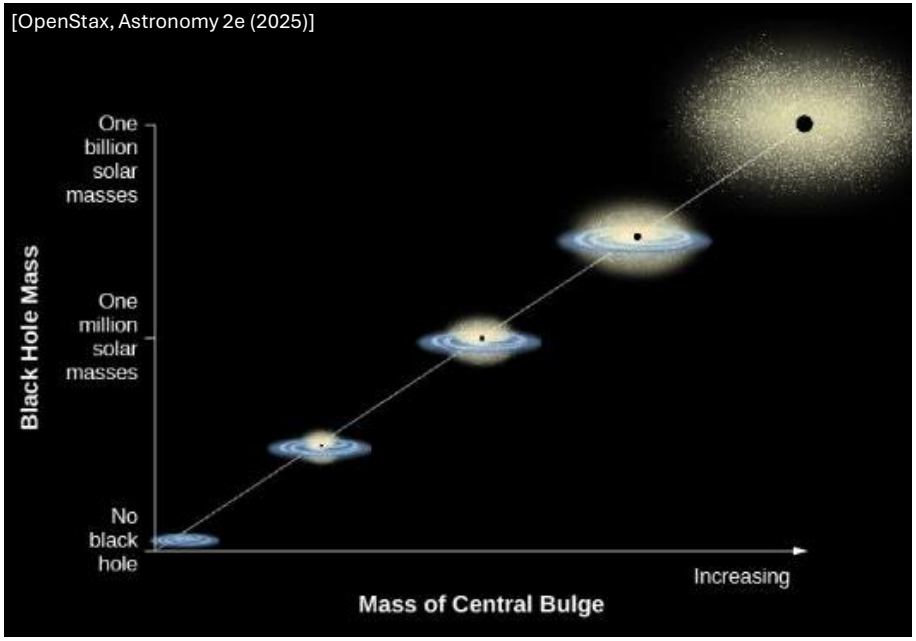
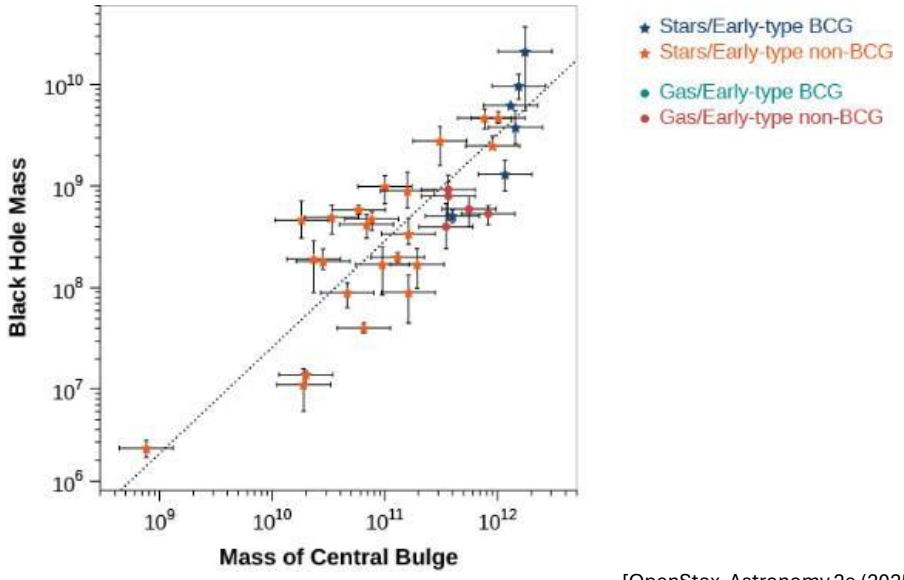
- The supermassive black hole tends to have **1/200th of the mass** of its host galaxy.
  - → The "why" is not well understood.

- The supermassive black hole can **foster star formation** in its vicinity, but if it gets too active, then it can also **turn off star formation**.

[OpenStax, Astronomy 2e (2025)]

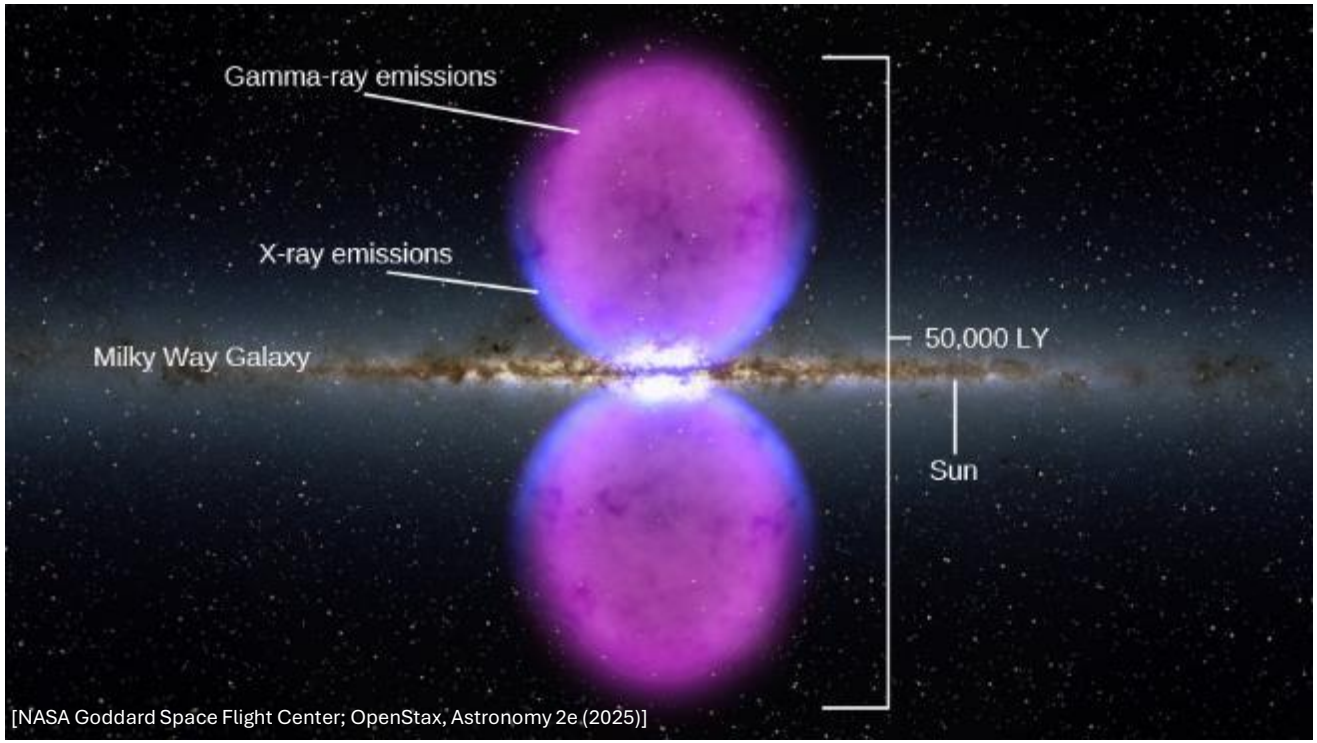




[OpenStax, Astronomy 2e (2025)]

Milky Way's Supermassive Black Hole

The Milky Way's supermassive black hole was probably much more active in the past.



Fermi Bubbles in the Galaxy: Giant bubbles shining in gamma-ray light lie above and below the center of the Milky Way Galaxy, as seen by the Fermi satellite.

→ The gamma-ray and X-ray image is superimposed on a visible-light image of the inner parts of our Galaxy.

→ The bubbles may be evidence that the supermassive black hole at the center of our Galaxy was more quasar/AGN-like a few million years ago.

Galaxy Mergers

There are estimated to be about 2 trillion (2×10^{12}) galaxies in the observable universe (out to 13.8 billion light years away, or to 13.8 billion years ago).

A Galaxy has on the order of 100 billion stars.

Hubble Ultra Deep Field (galaxies out to 8 Bly)
[NASA/ESA, Hubble, 2003, 2009, 2012]

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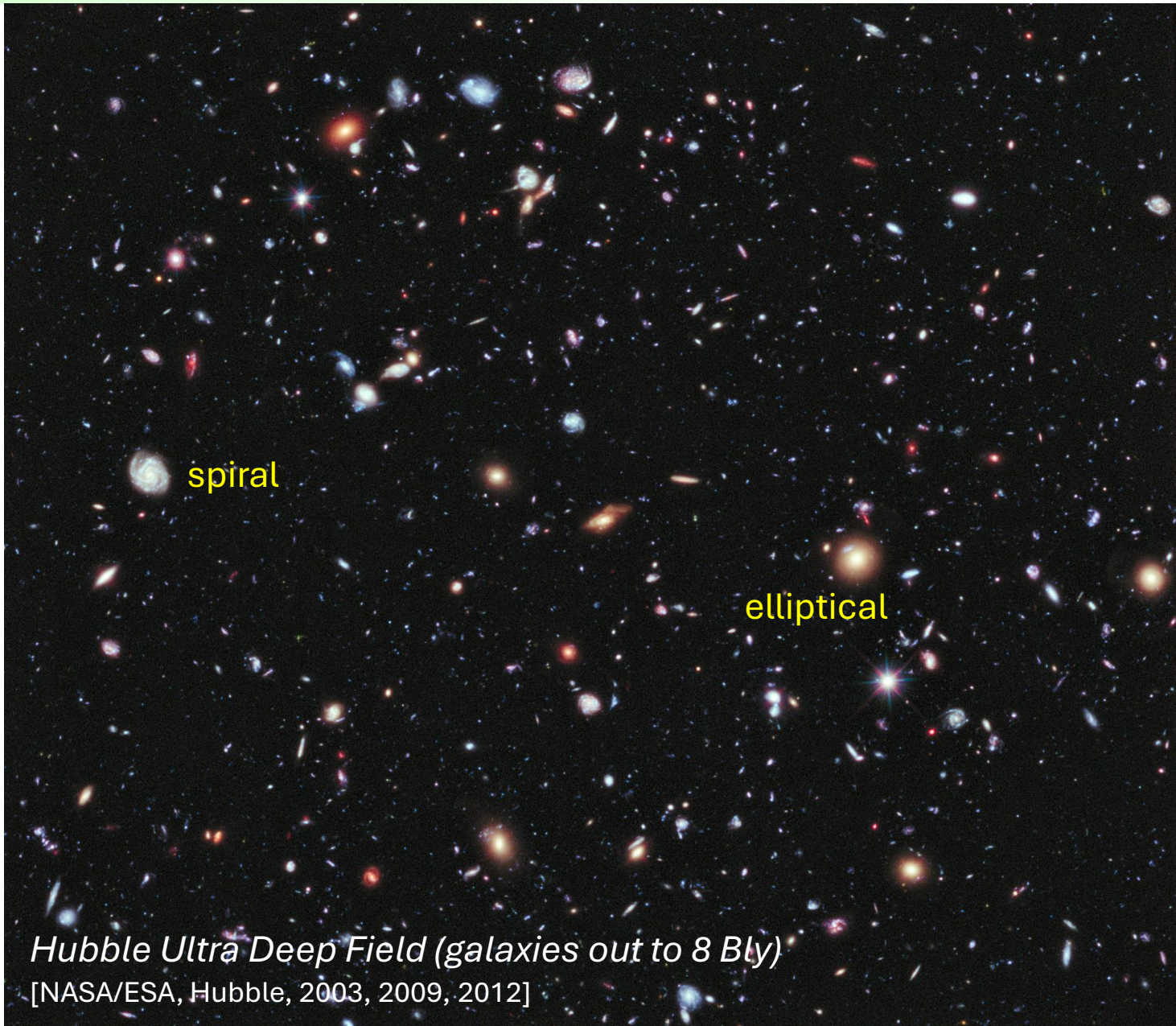

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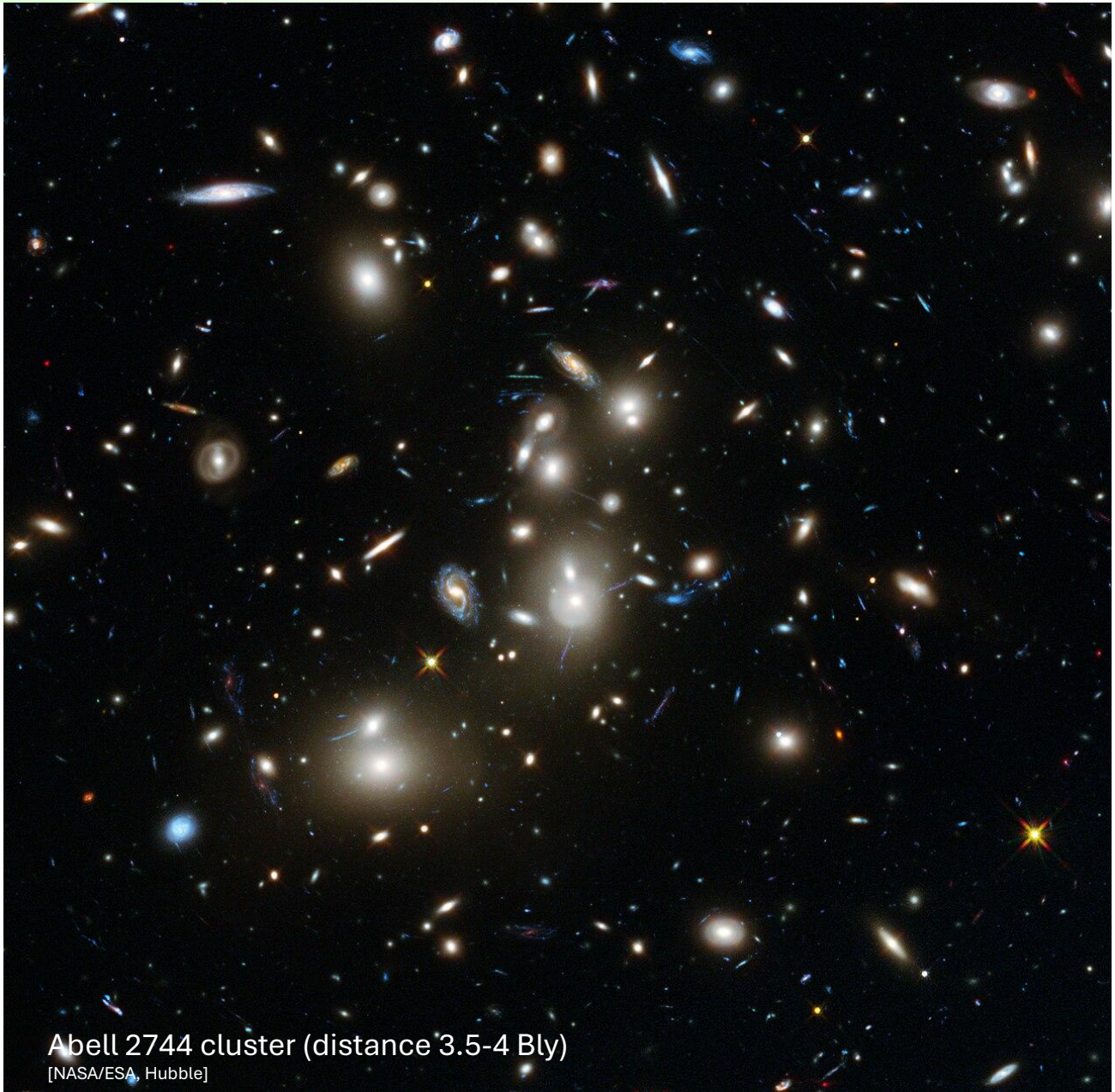
Galaxies attract each other and can sometimes collide and even merge.



Abell 2744 cluster (distance 3.5-4 Bly)
[NASA/ESA, Hubble]

Galaxy Mergers

- Galaxy are **not that far apart**, relatively speaking.
- Galaxies attract each other and can sometimes **collide** and **even merge**.
- Galaxy collisions and mergers **are relatively frequent**.
- Galaxy collisions and mergers can have a **significant impact on galaxy evolution.**

Stephan's Quintet (210-340 Mly)
[NASA/ESA, Hubble]

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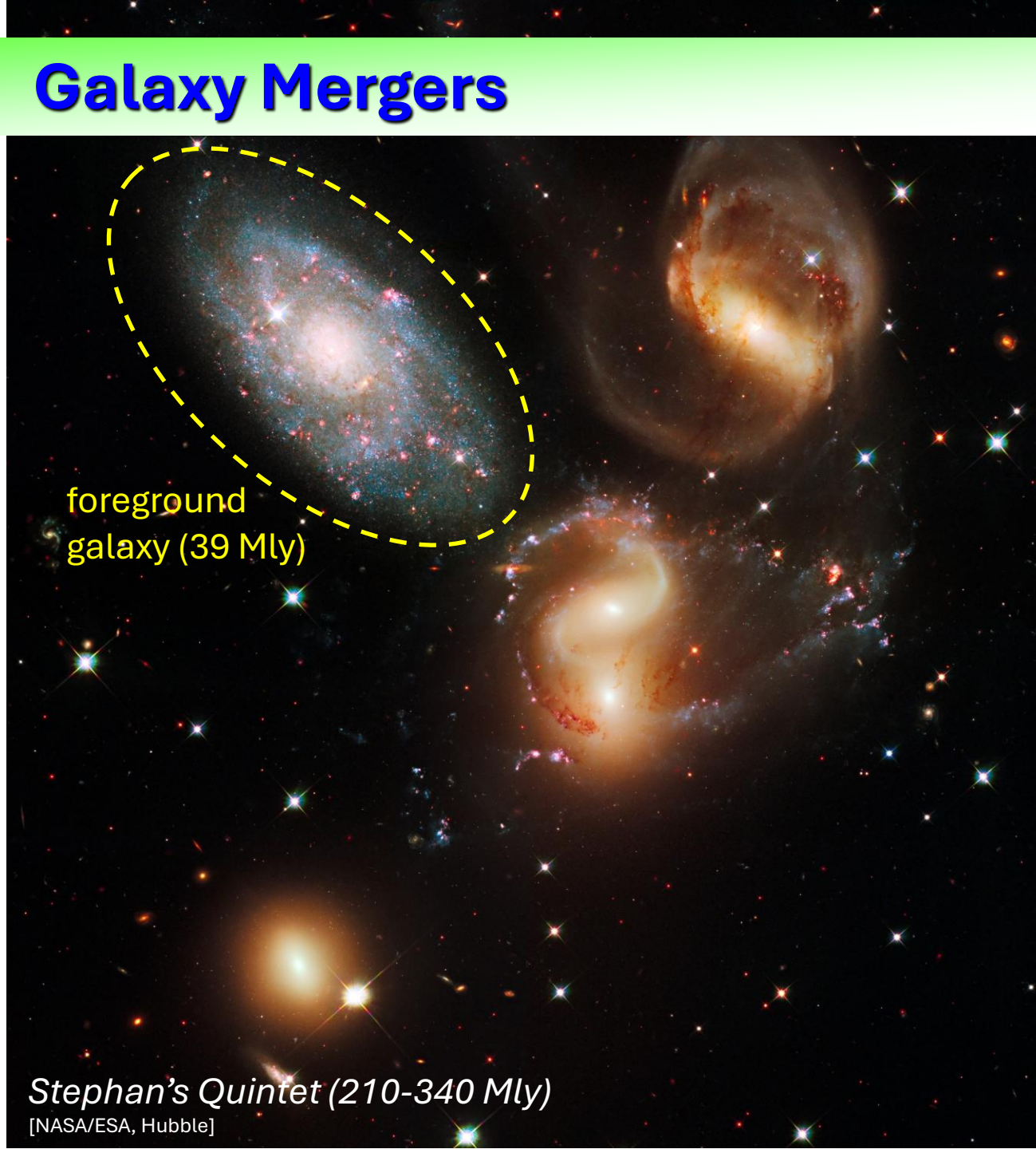

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Galaxy Mergers vs Star Collisions

Question

Why do we see numerous galactic collisions, but star-star collisions are rare?

Antenna galaxies (NGC 4038/4039)
[W4sm astro, Wikipedia (2025)]

Galaxy Mergers vs Star Collisions

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Why do we see numerous galactic collisions, but star-star collisions are rare?

Answer

- Interstellar spacing is much larger than stellar radii.
- intergalactic spacing is not so different than galactic radii.

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Galaxy Mergers vs Star Collisions

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Why do we see numerous galactic collisions, but star-star collisions are rare?

Answer

- Interstellar spacing is much larger than stellar radii.
- intergalactic spacing is not so different than galactic radii.

- Collisions and deformations of **interstellar gas clouds** (and dust) is quite common in galaxy collisions.

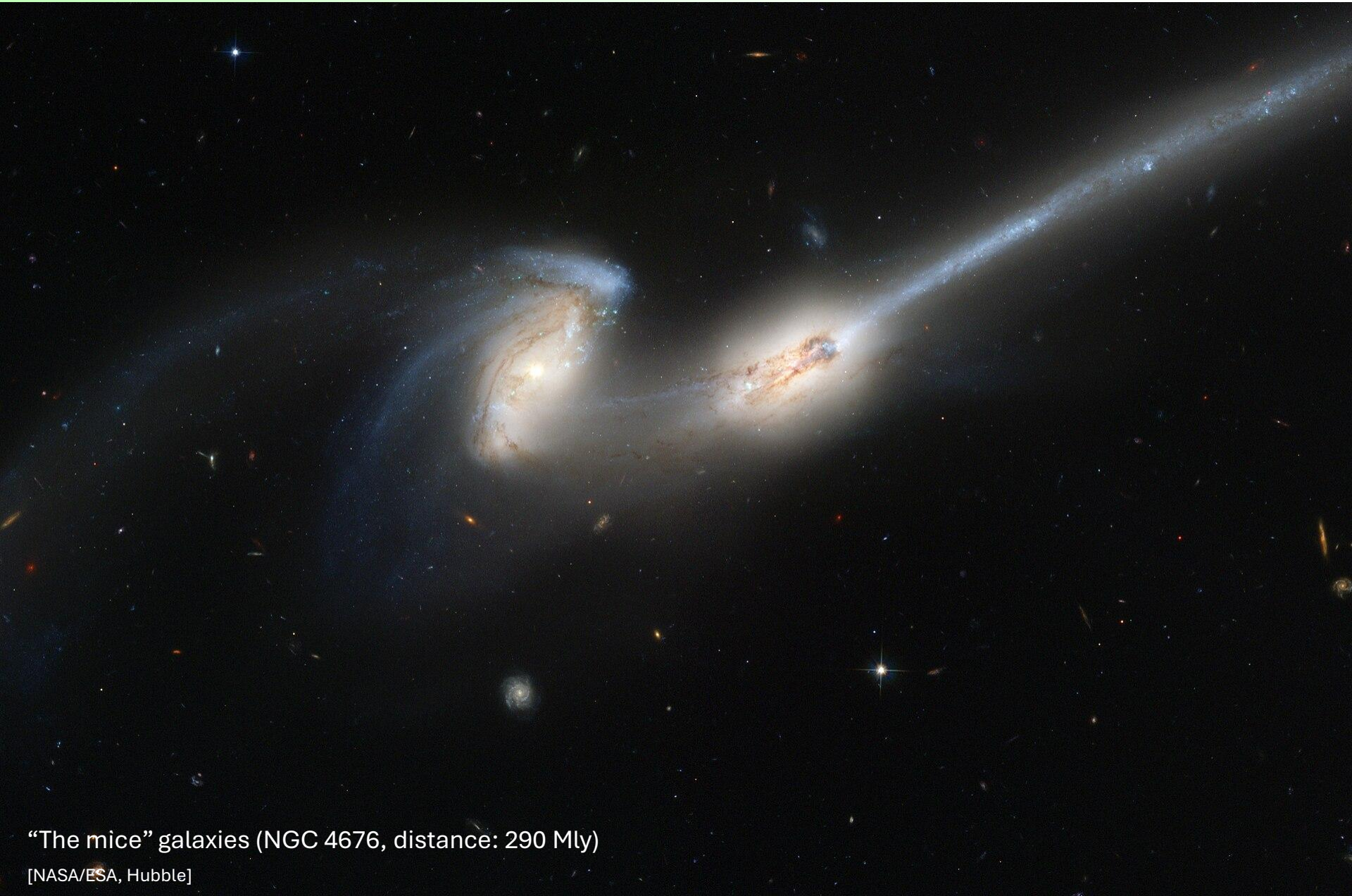
→ Leads to **star formation**.

(often seen as numerous large blue stars … very bright, but short-lived.)

Antenna galaxies (NGC 4038/4039)

[NASA/ESA, Hubble]

Galaxy collisions generate “starbusts”



“The mice” galaxies (NGC 4676, distance: 290 Mly)

[NASA/ESA, Hubble]

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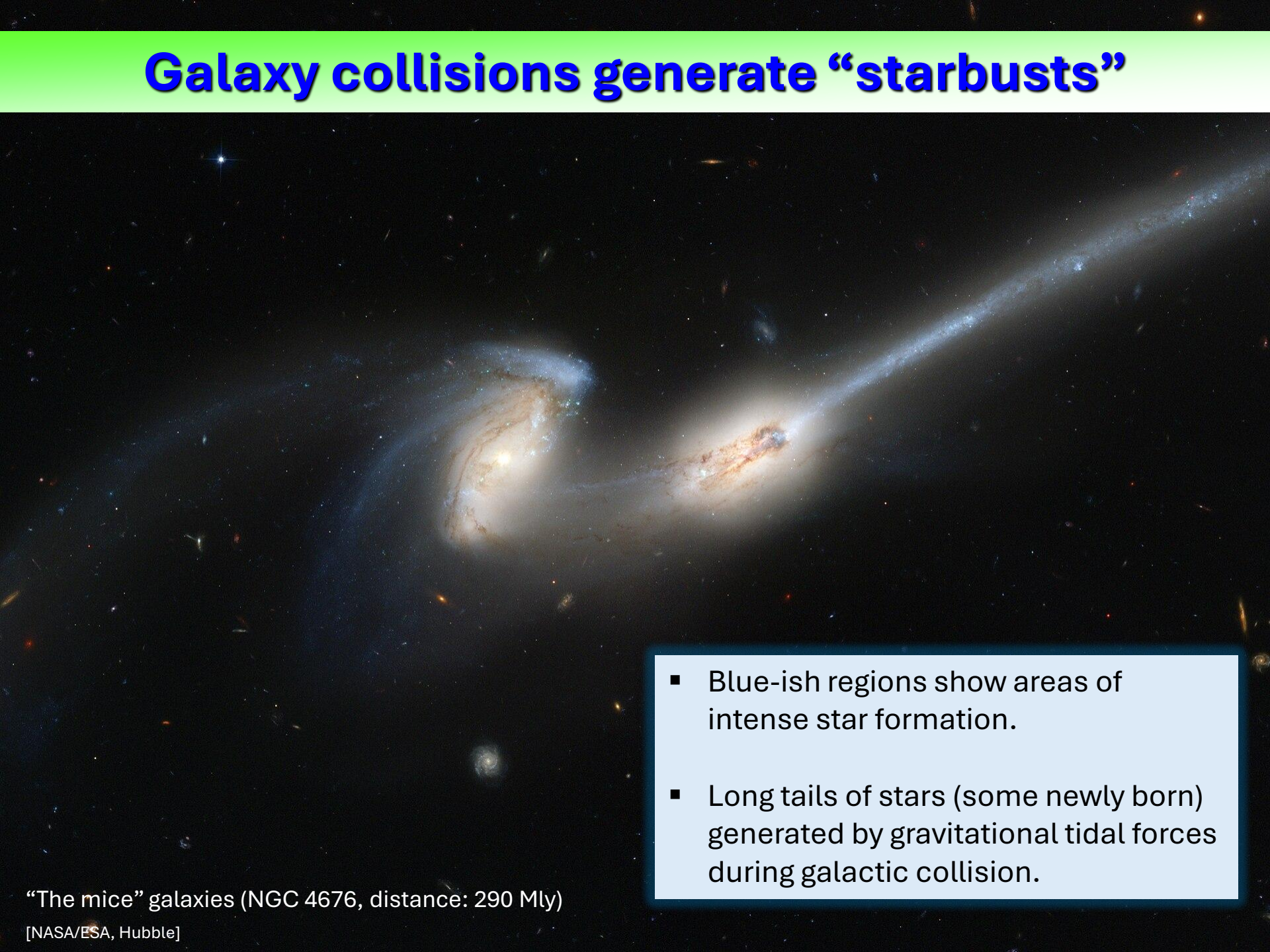


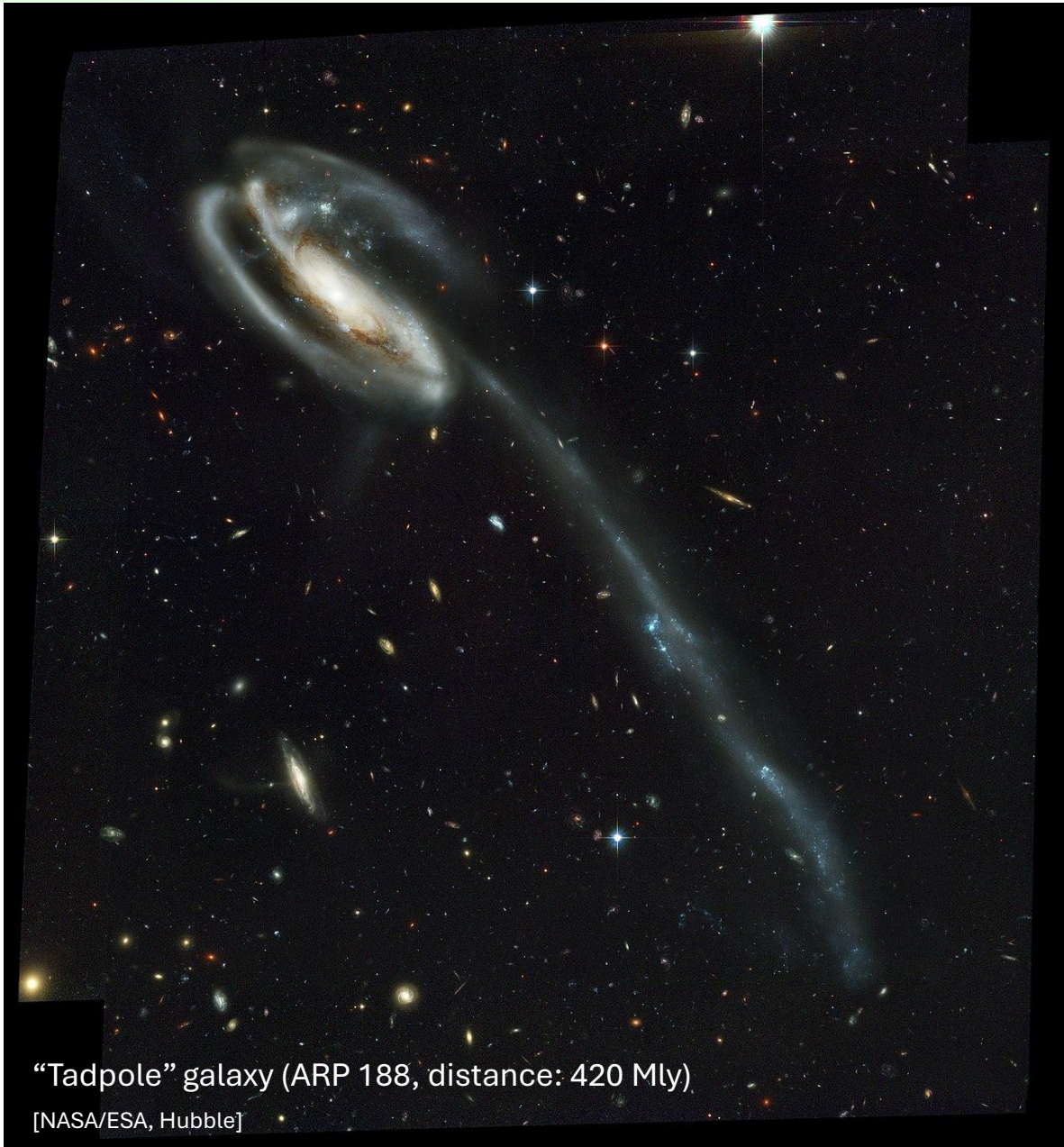
- Blue-ish regions show areas of intense star formation.
- Long tails of stars (some newly born) generated by gravitational tidal forces during galactic collision.

“The mice” galaxies (NGC 4676, distance: 290 Mly)

[NASA/ESA, Hubble]

Galaxy Collision Properties

- Interstellar matter (gas, dust) can be compressed by up to a factor of 100.
- Higher density gas leads to intense **starbusts**.
- Sometimes these starburst exhaust the available gas in a few millions years (via intense star formation).
- Collisions can produce mergers, but not always.
- Slow collisions of **two spiral galaxies** can produce a **single elliptical galaxy** (distant past).
- Collision can yield an **Active Galactic Nucleus** (AGN).



"Tadpole" galaxy (ARP 188, distance: 420 Mly)

[NASA/ESA, Hubble]

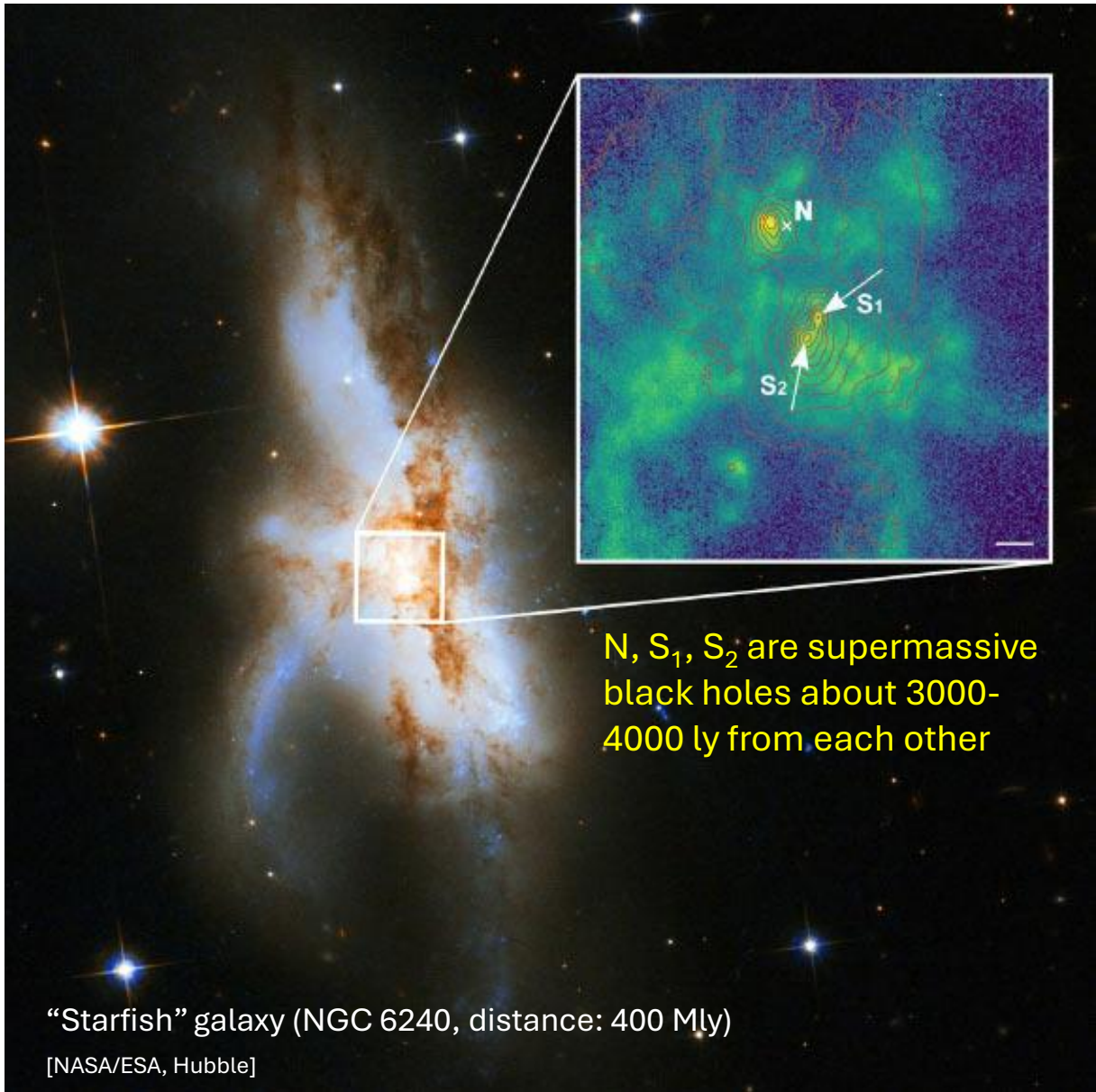
Galaxy Mergers

- Galaxy mergers or galaxy “cannibalism” can lead to AGNs.
- Merger can trigger a **quasar** at the nucleus.
- Galactic nuclei can merge.

→ Two supermassive **black holes will merge**.

→ They will orbit each other for a long time, before merging.

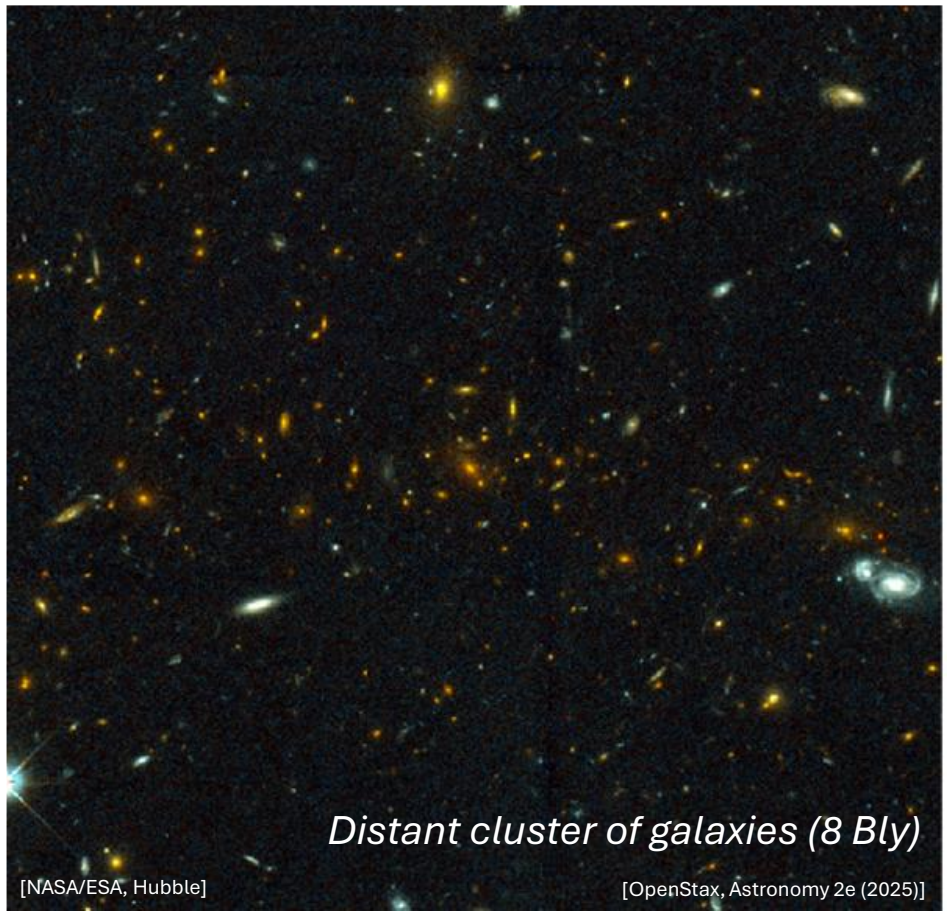
→ Orbits decay due to friction with accretion disks and **gravitational wave** emission.



Galaxy mergers in the past

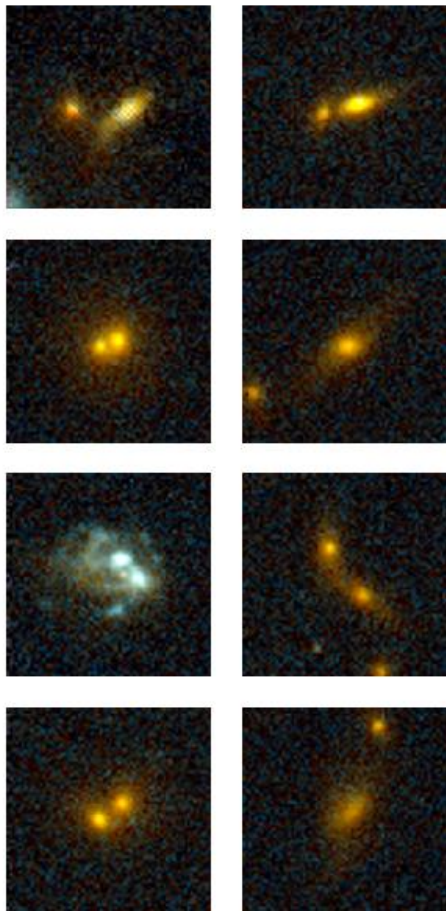
- Galaxy mergers were much more common in the distant past.
- Hubble's law tells us that galaxies were much closer together.
  → Galaxies can collide more easily and frequently.

Of 81 galaxies in this cluster, 13 of them are the result of recent collision/merger.



Distant cluster of galaxies (8 Bly)

[NASA/ESA, Hubble]



[OpenStax, Astronomy 2e (2025)]

PollEv Quiz: PollEv.com/sethaubin

Galaxy Clusters

- Galaxies attract each other and form local groups.
- Groups of galaxies can form a larger cluster of galaxies.
- Clusters of galaxies can form a supercluster.

Virgo Cluster (54 Mly to center)
[Sun.org]

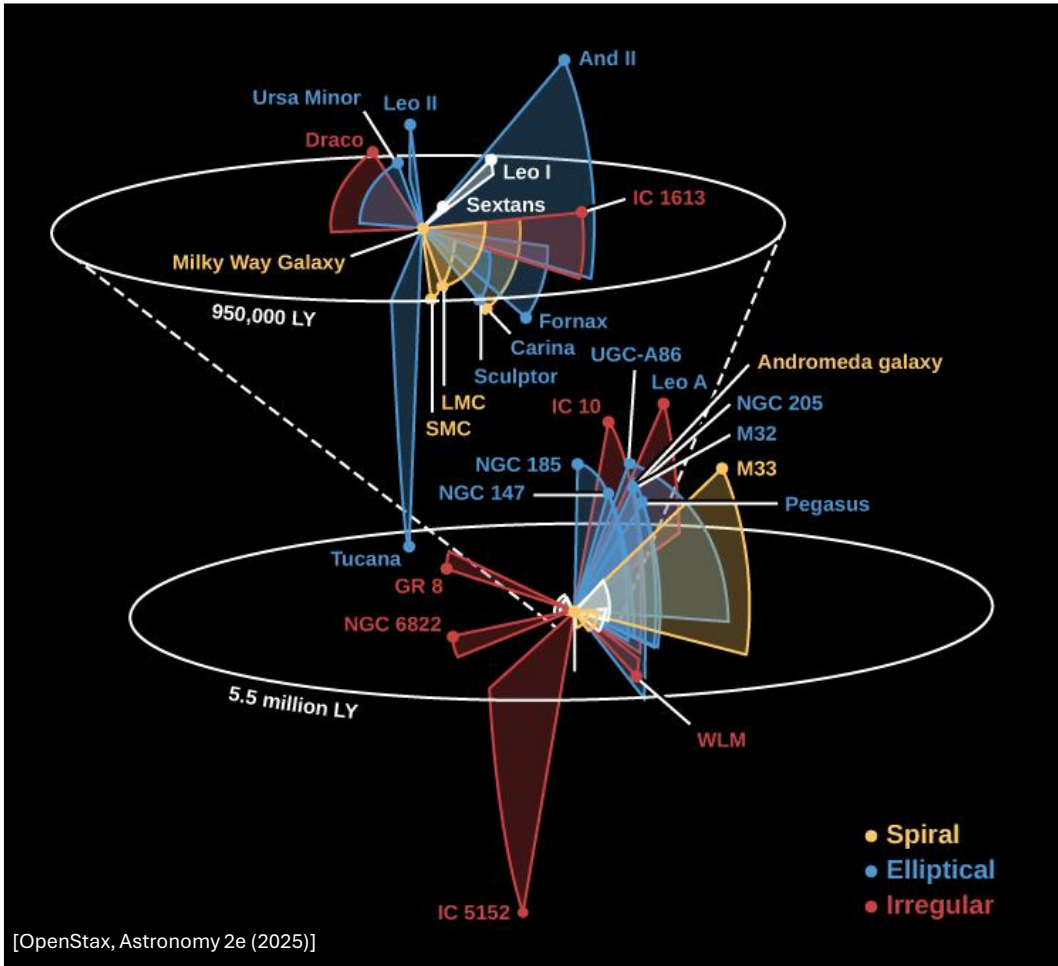
Local group

We define a **"group"** of galaxies when they are mutually gravitationally bound.

- About 80-130 galaxies.
- 10 million light years across.
- 3 large spirals.

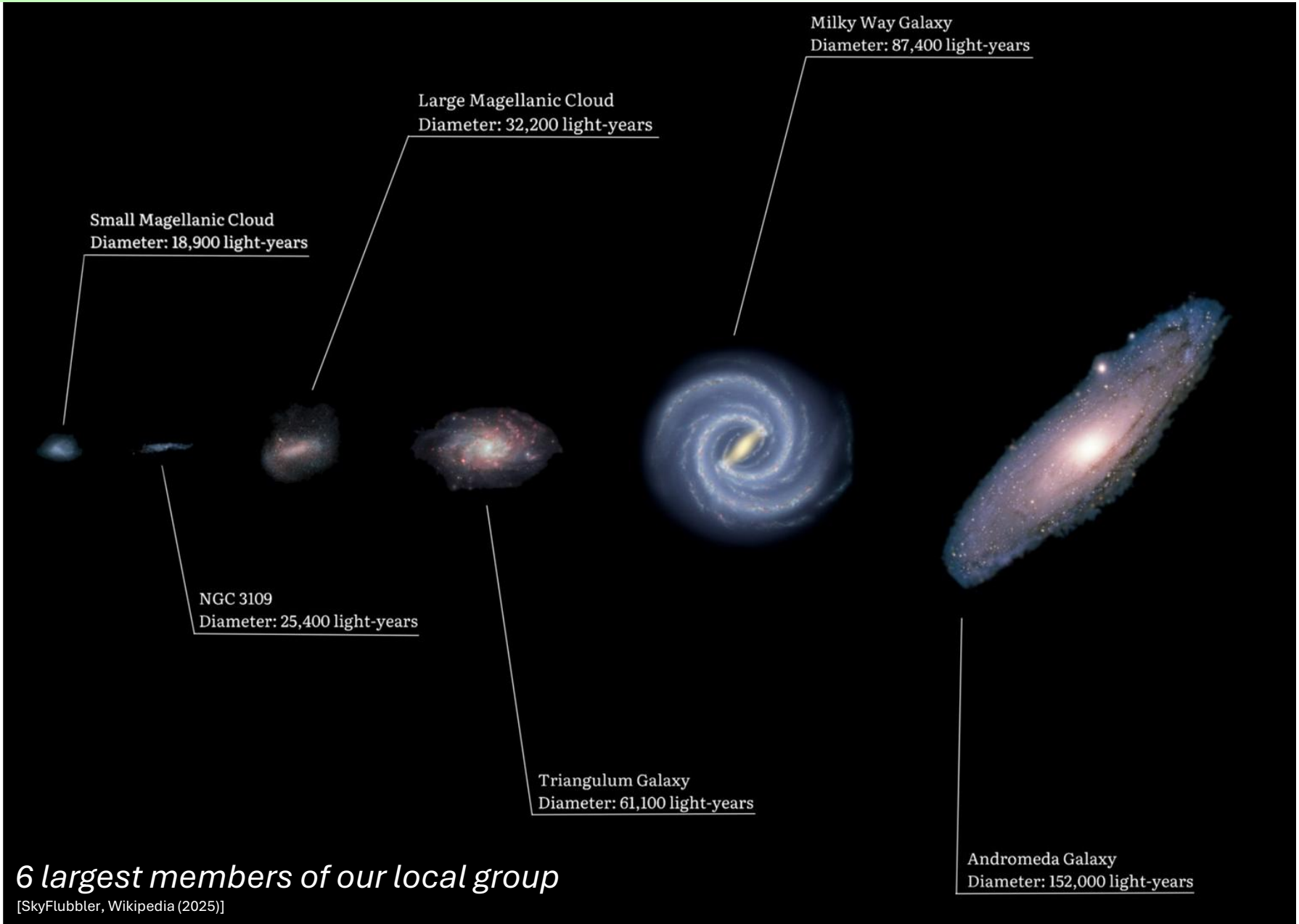
→ *Milky Way, Andromeda (M31), and Triangulum (M33).*

- 2 intermediate-size **ellipticals**
- Lots of **dwarf galaxies**, smaller irregulars, many of which are companions of the big spirals



[OpenStax, Astronomy 2e (2025)]

Local group

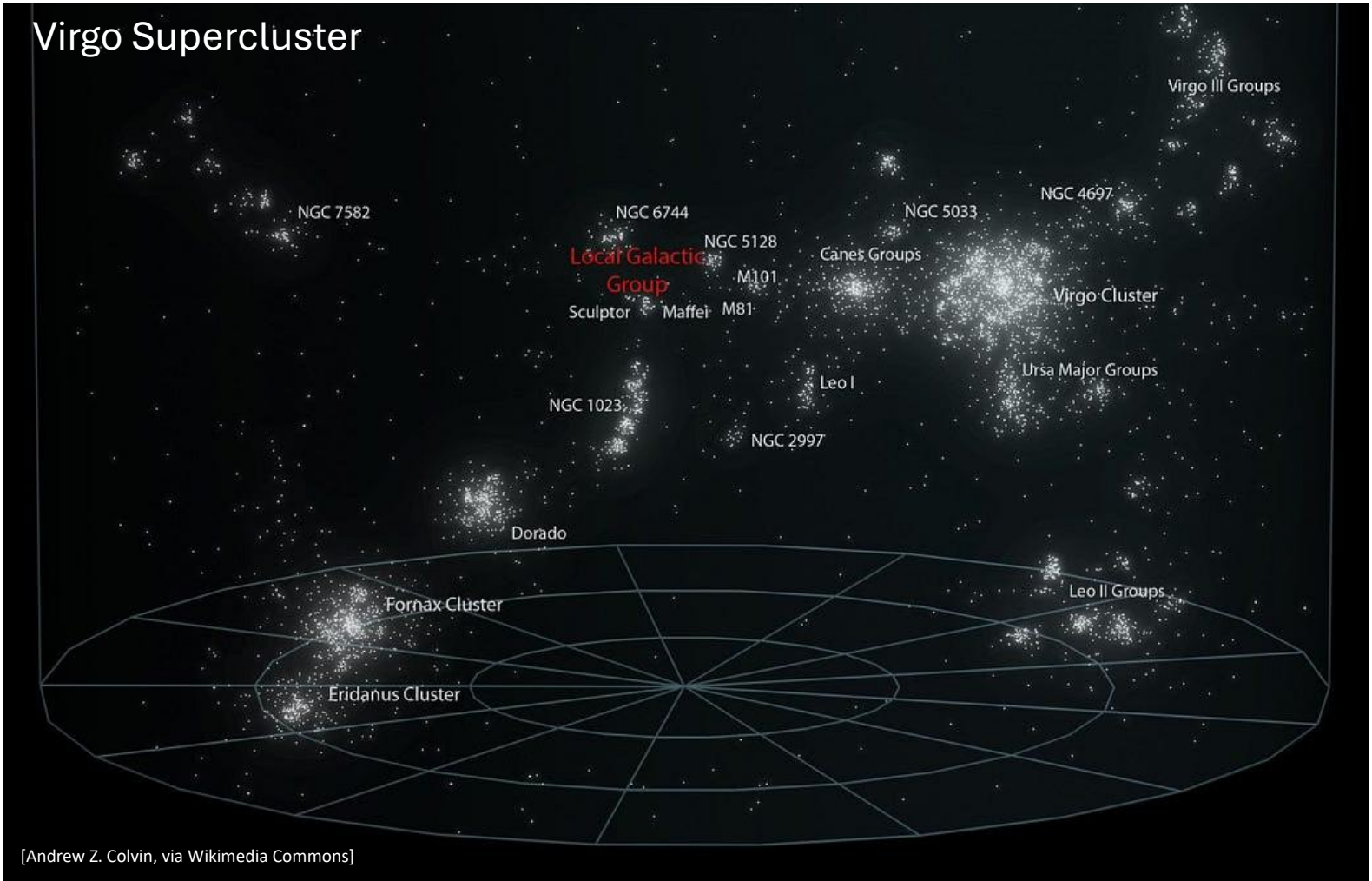


6 largest members of our local group

[SkyFlubbler, Wikipedia (2025)]

Virgo Cluster & Supercluster

- Nearest cluster of galaxies is the Virgo cluster: about 2000 galaxies (distance: 50 Mly).
- The local group and the Virgo cluster are part of the Virgo Supercluster.
  → *Consists of about 100 clusters and groups.*



[Andrew Z. Colvin, via Wikimedia Commons]

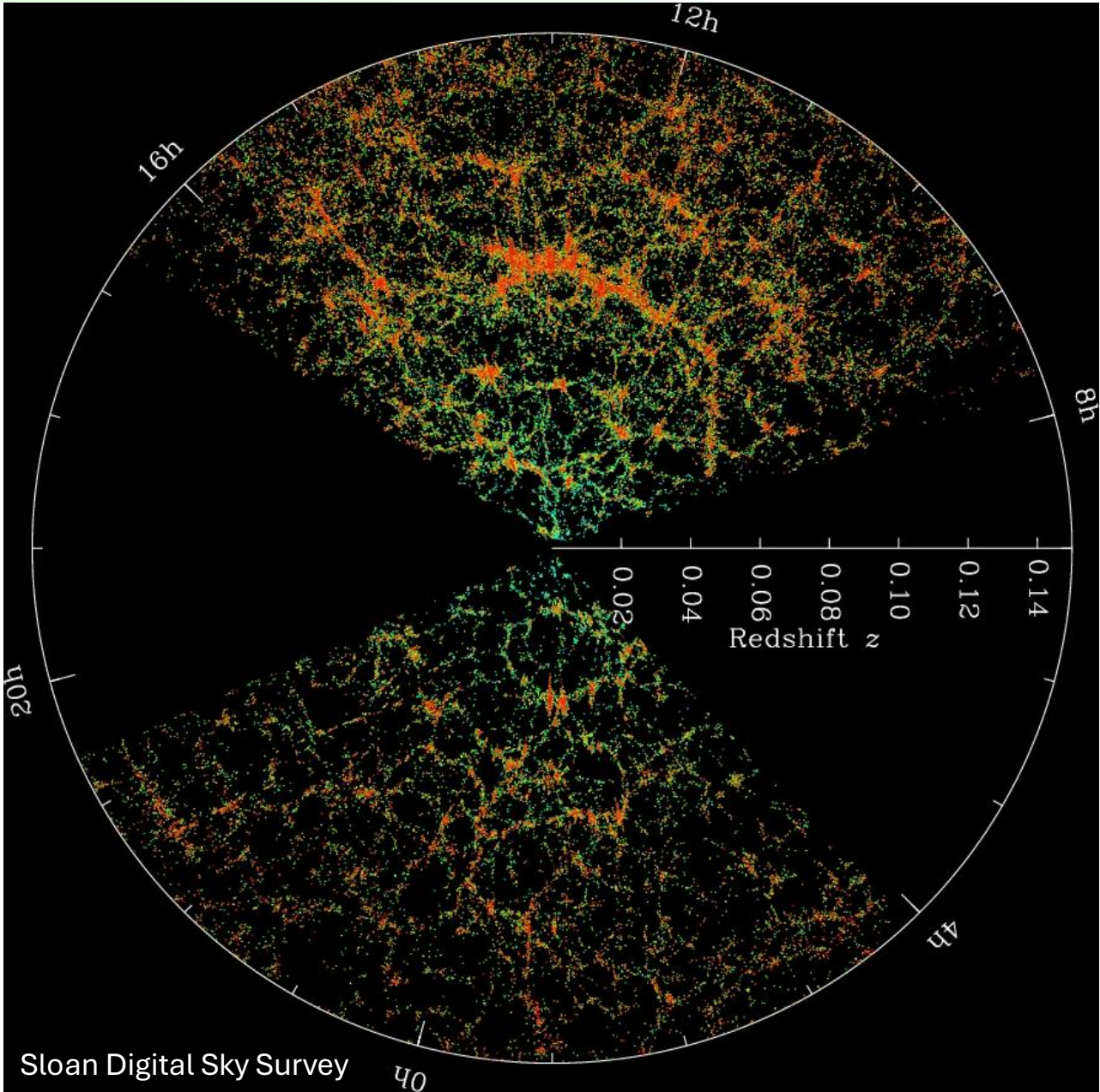
Large Scale Distribution of Galaxies

Sloan Digital Sky Survey

- 980,000 galaxies mapped.

→ Image: slice through sky
(black regions blocked by Milky Way dust)

- Distance from the center of the circle is redshift (*i.e.* distance from us).
- Circle is 2 billion light years in radius.
- Filamentary structure of superclusters (string-like or pancake like).
- Huge **Voids.**
- Overall structure is like a **sponge**, or **Swiss cheese**…



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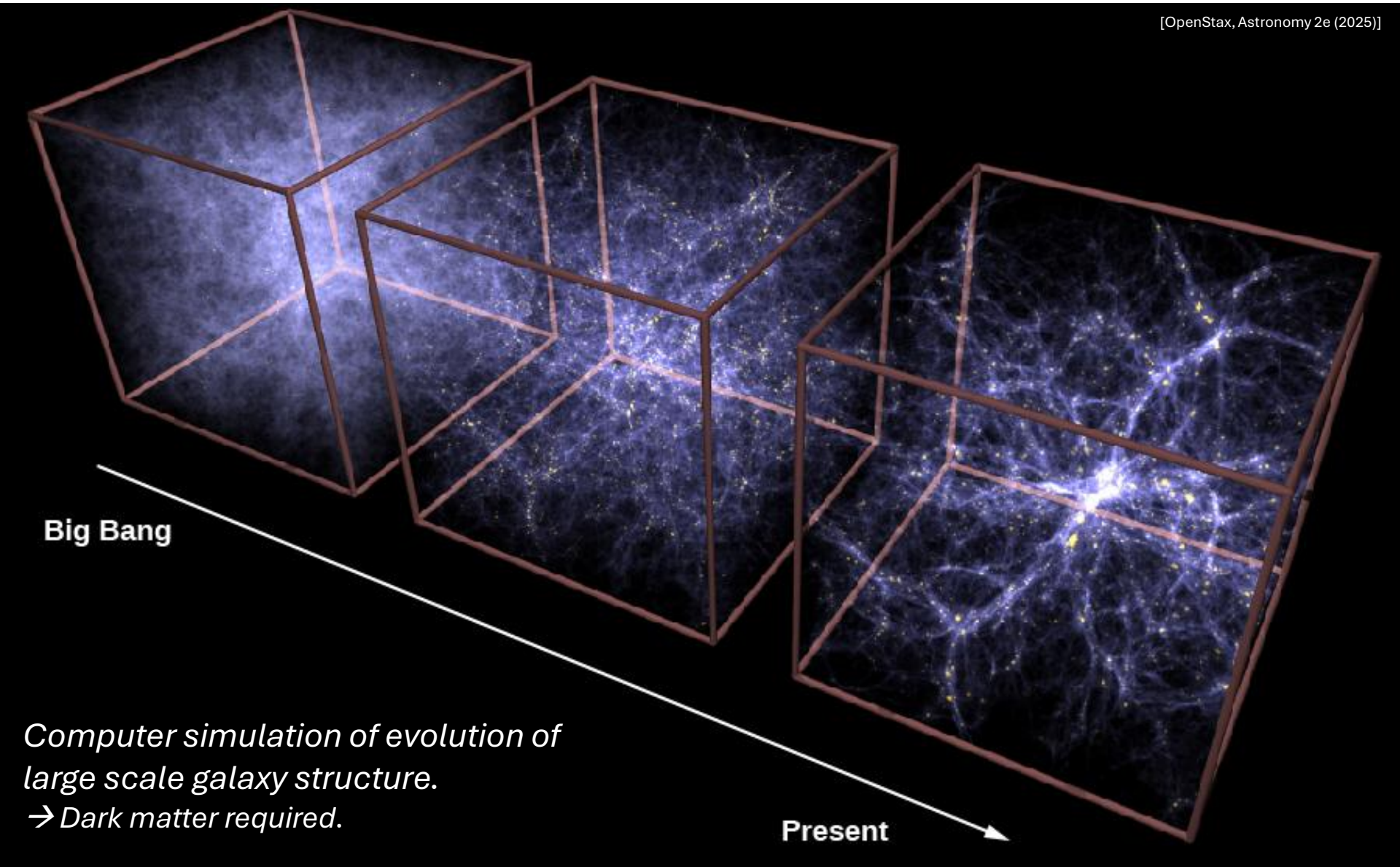

Computer simulation of evolution of large scale galaxy structure.
→ Dark matter required.