Today's Topics

Monday, April 28, 2025 (Week 13, Lecture 34) – Chapter 27, 28.

1. Accretion disks & jets
2. Supermassive black holes & galaxies
3. Galaxy mergers
4. Clusters & Superclusters

Problem Set #11 is optional (ungraded) and will be posted soon.

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.

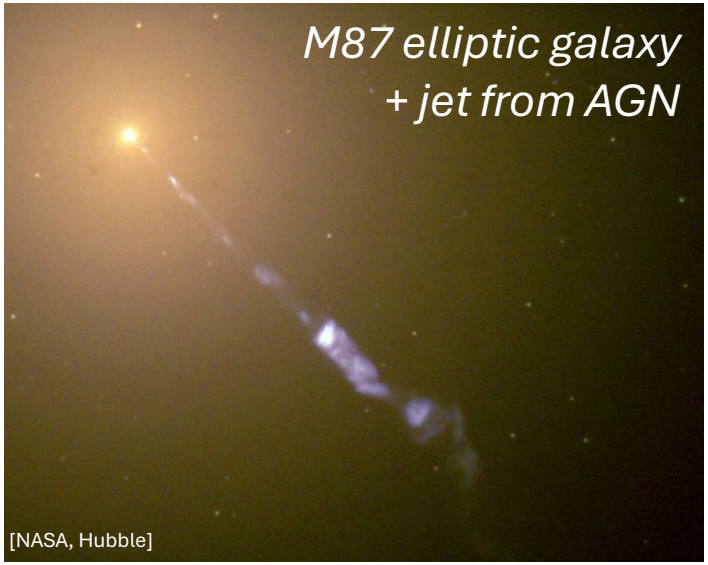
→ All quasars are AGNs.

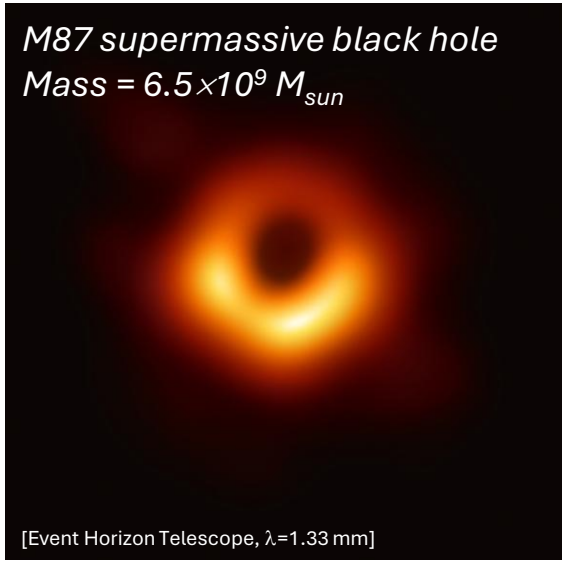
→ Not all AGNs are quasars.

→ Quasars are very active AGNs.

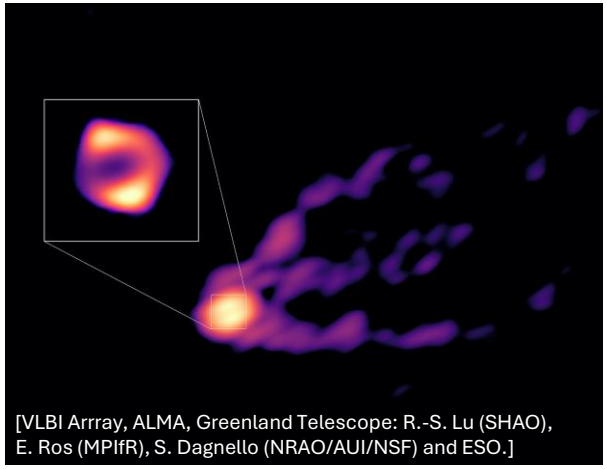
→ AGNs typically have jets of material emitted along the spin axis of the black hole.

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





M87 supermassive black hole with radio jets emanating from it.



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.

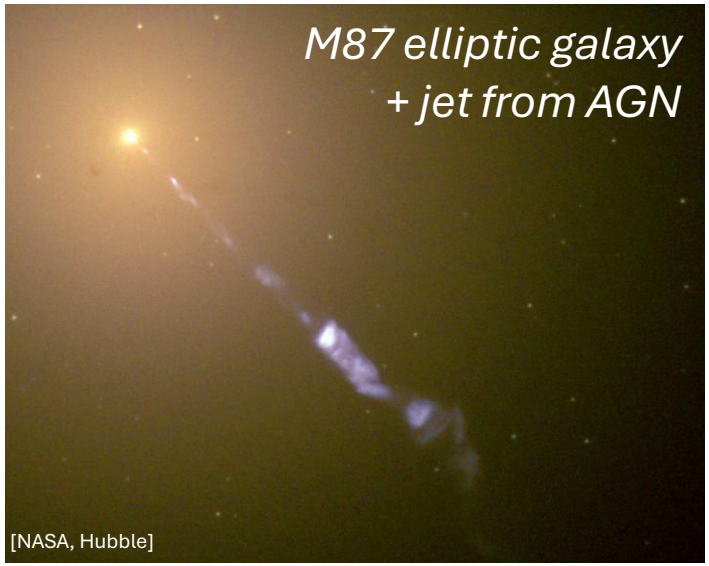
→ All quasars are AGNs.

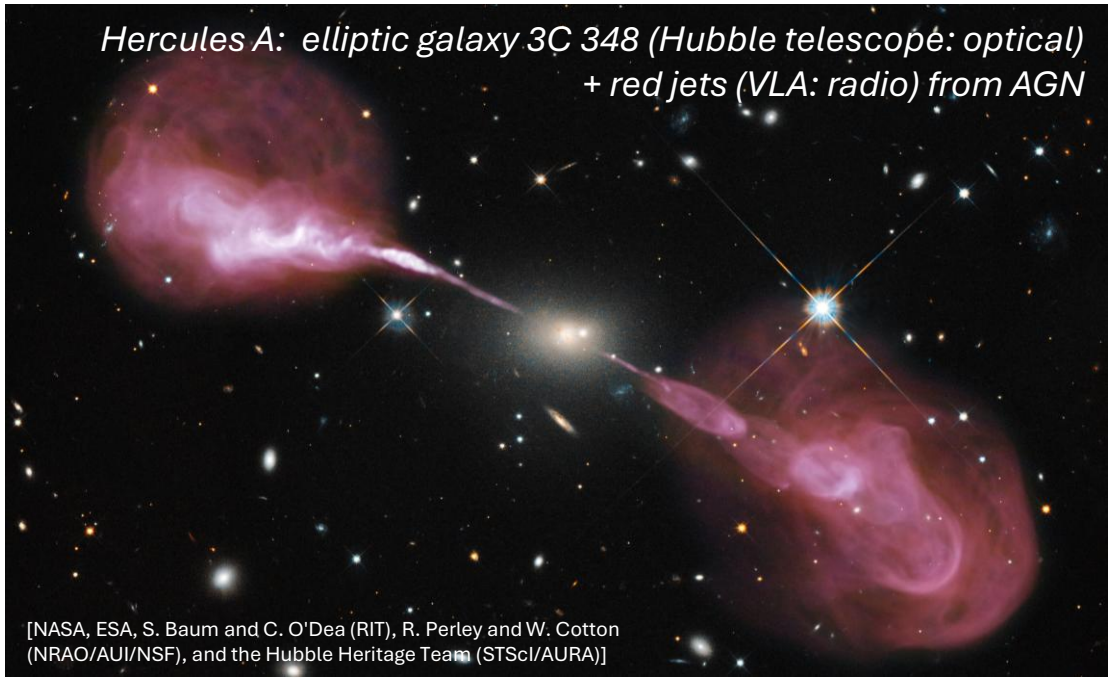
→ Not all AGNs are quasars.

→ Quasars are very active AGNs.

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

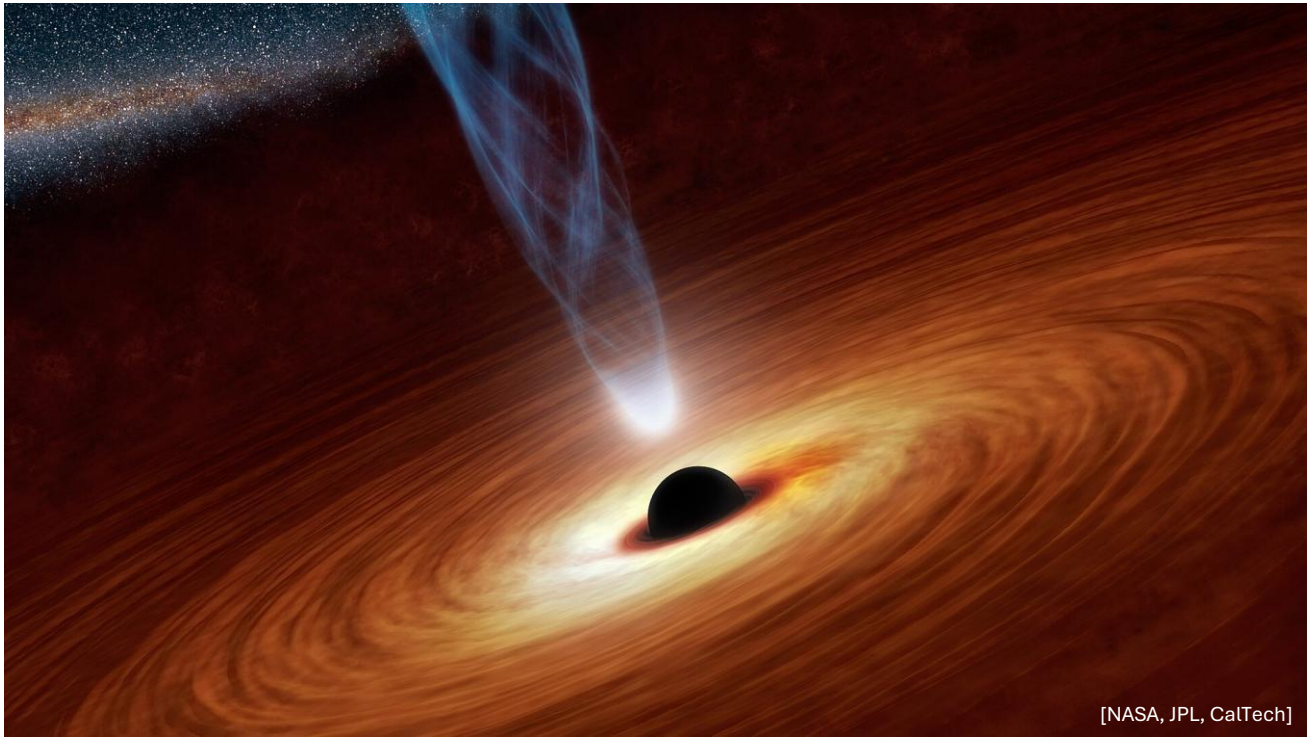
→ The Milky Way supermassive black hole (Sagittarius A*) is NOT an AGN at present.





Accretion Disk and Jets

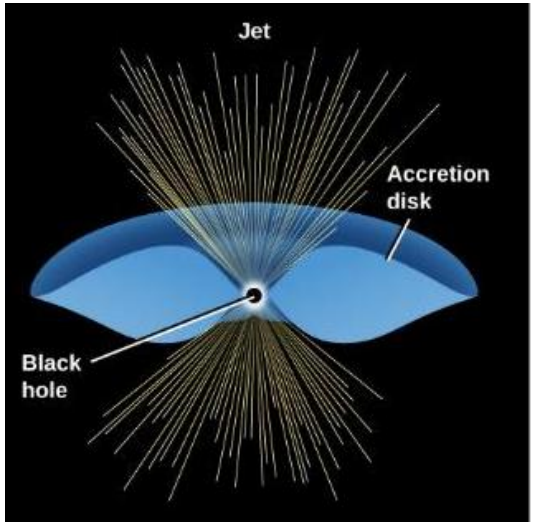
- Accretion disk is relatively well understood.
- As material (gas, dust, stars) orbits the black hole, friction heats up the material.
  - → Millions of degrees → black body radiation.
  - → Efficient conversion of gravitational energy to radiation (efficiency: 6%-32%).
  - → Radiation can push material 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.



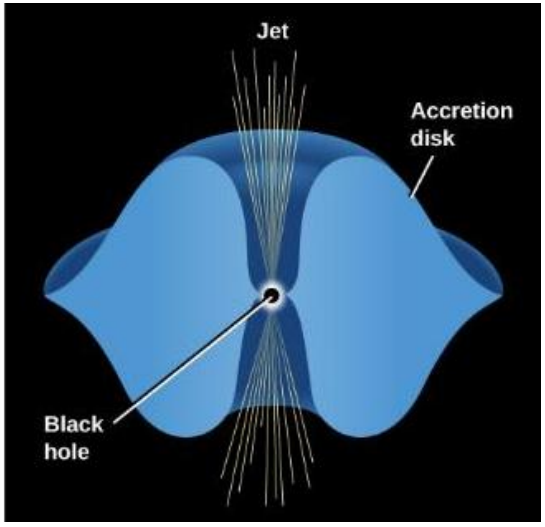
[NASA, JPL, CalTech]

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.



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.

Galaxies & Supermassive Black Holes

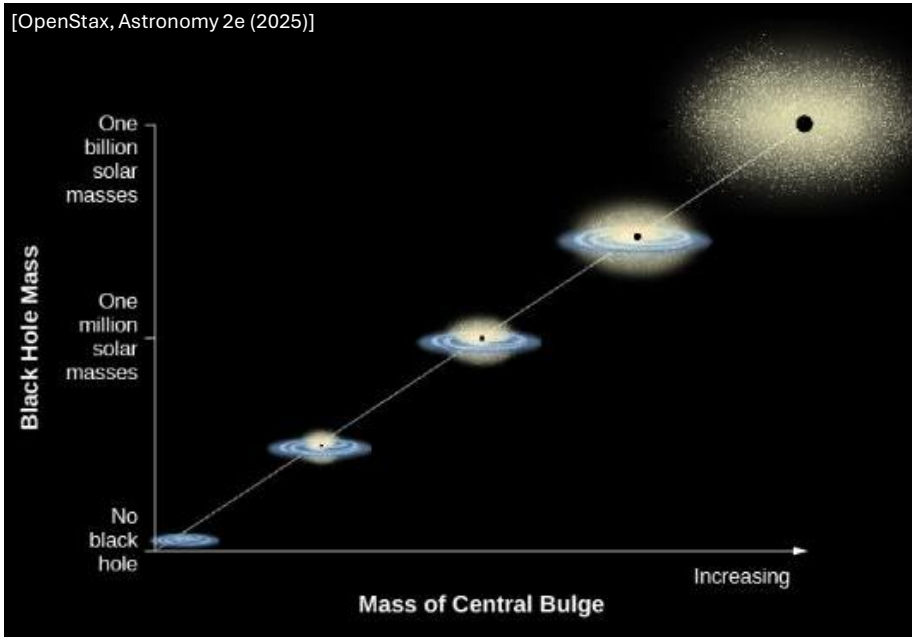
- As far as we can tell, all galaxies have a supermassive black hole at their nucleus.

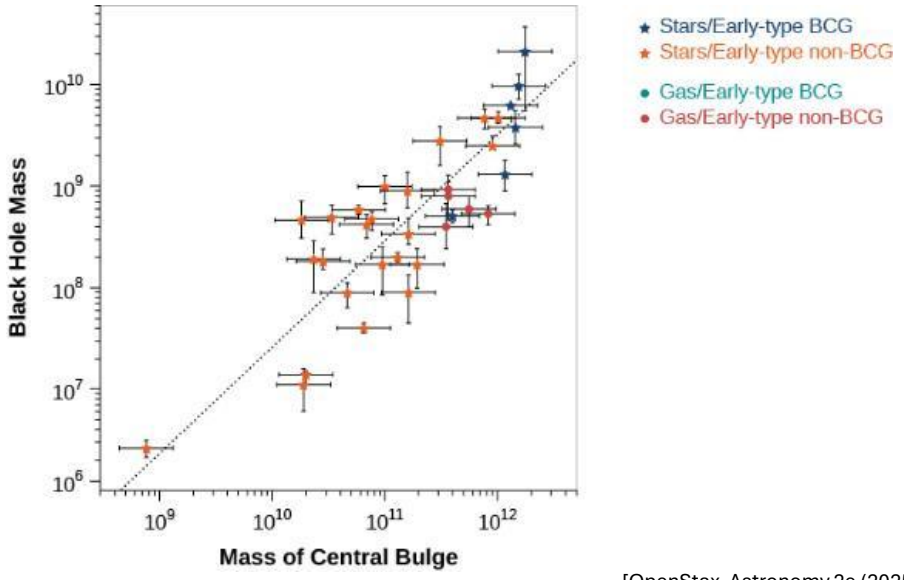
- The origin of these black holes is uncertain.
  - → Perhaps, a **high density** of material coalesced into a black hole.
  - → Perhaps the universe was born with **primordial** black holes.

- 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)]

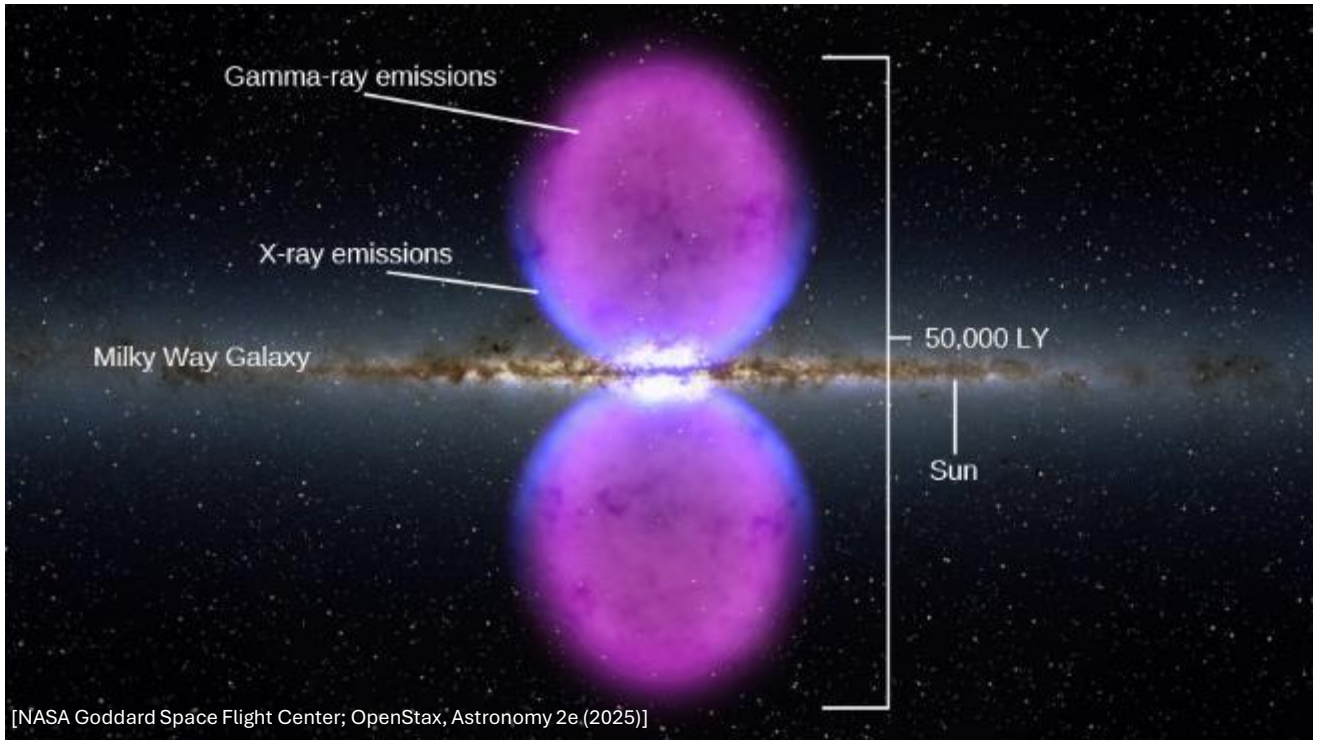




[OpenStax, Astronomy 2e (2025)]

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-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).

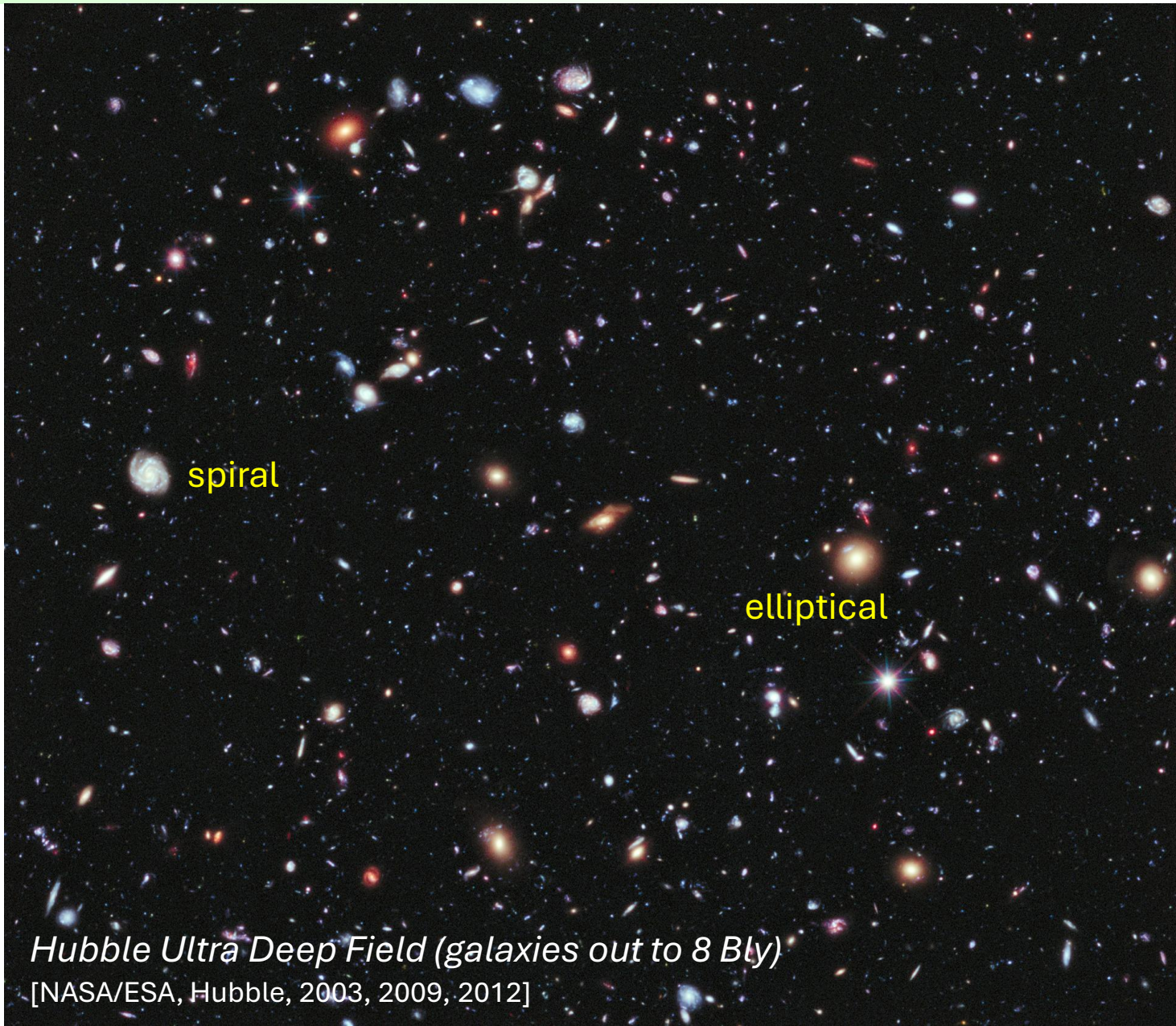
A Galaxy has on the order of 100 billion stars.

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

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]

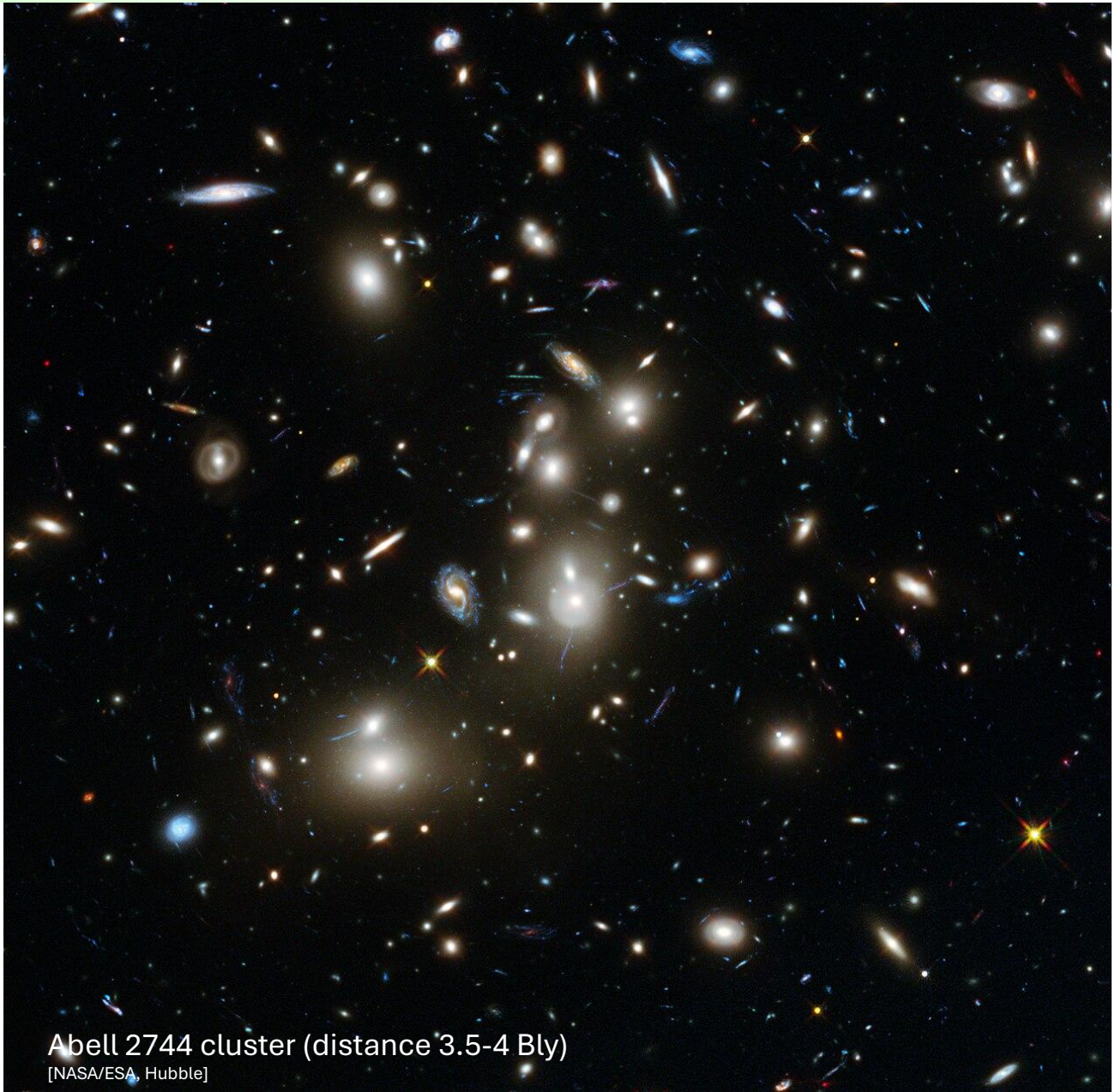
Galaxy Mergers

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.

Galaxy are not that far apart, relatively speaking.

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



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

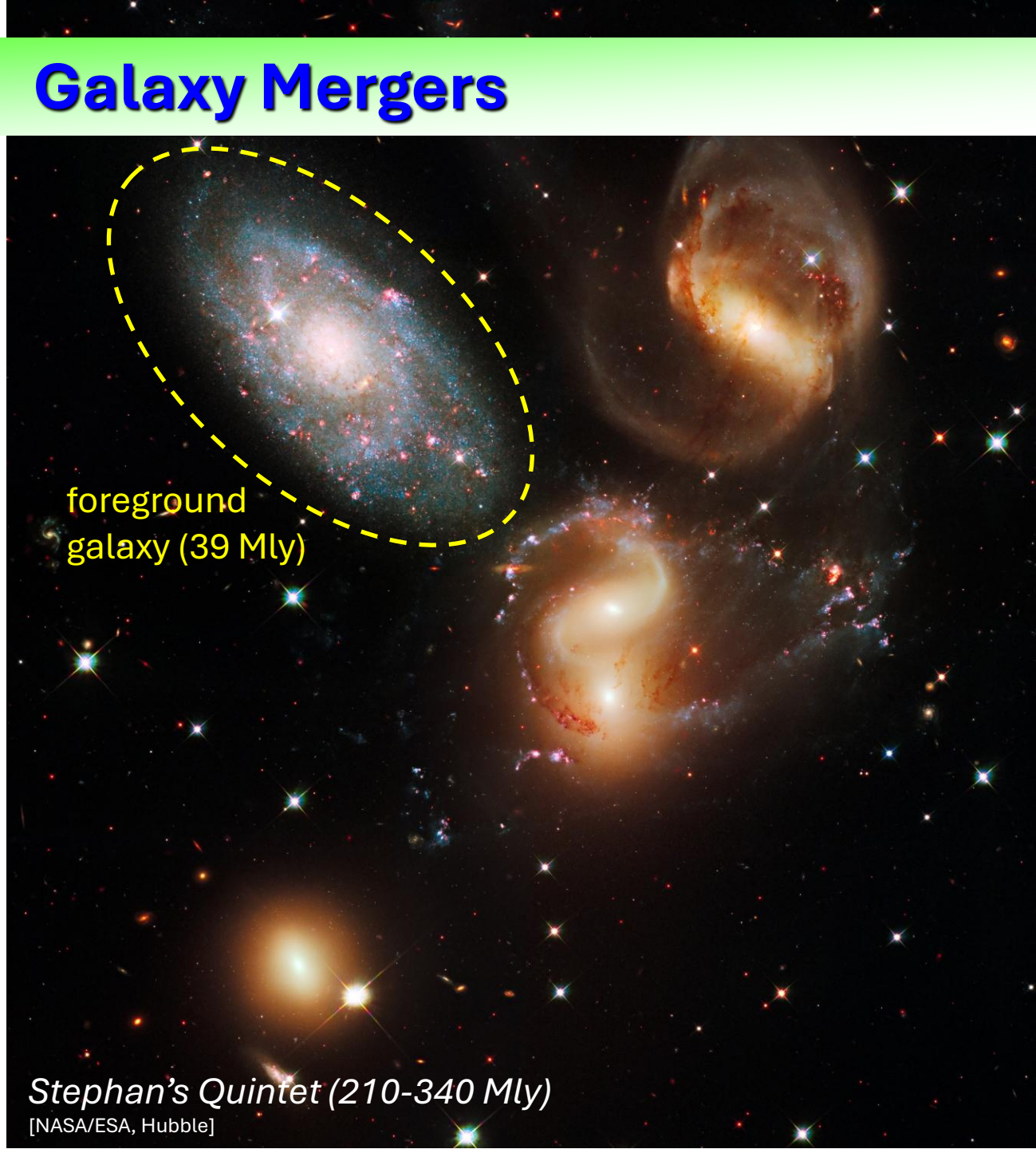
Galaxy Mergers

- 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]

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]

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

Question

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.

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

Galaxy Mergers vs Star Collisions

Question

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.

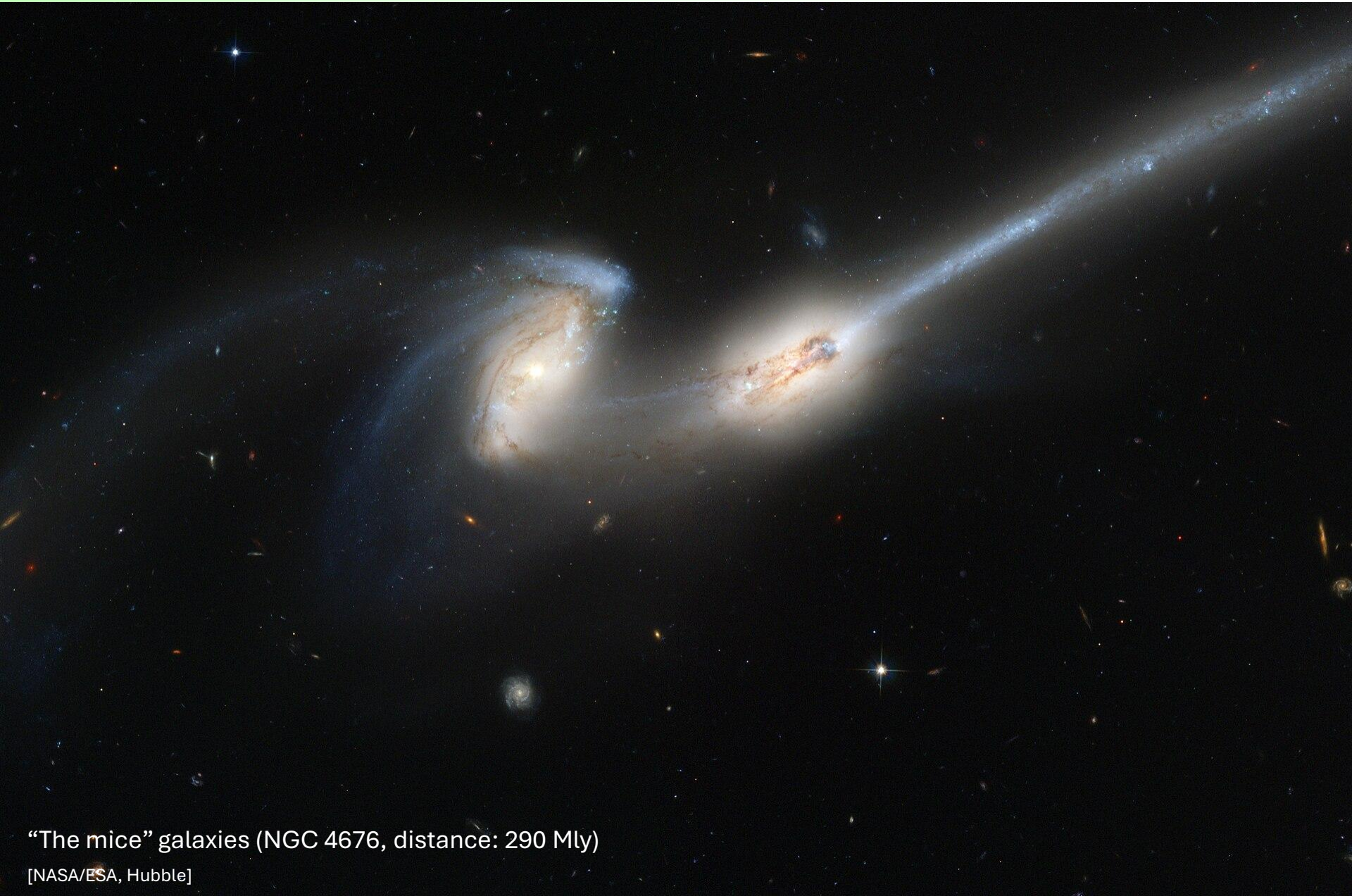
→ Leads to **star formation**.

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

Antenna galaxies (NGC 4038/4039)

[NASA/ESA, Hubble]

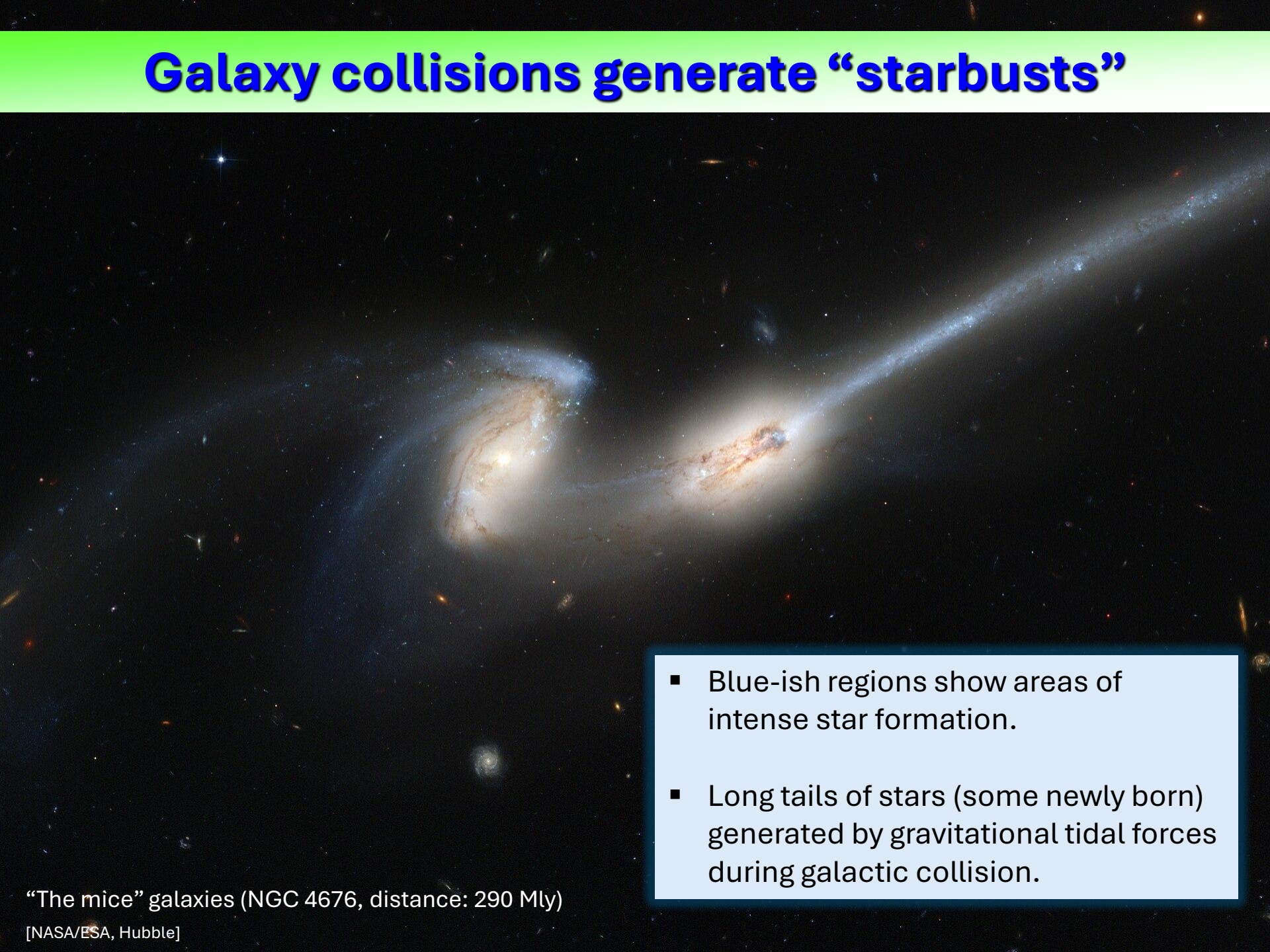
Galaxy collisions generate “starbusts”



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

[NASA/ESA, Hubble]

Galaxy collisions generate “starbusts”



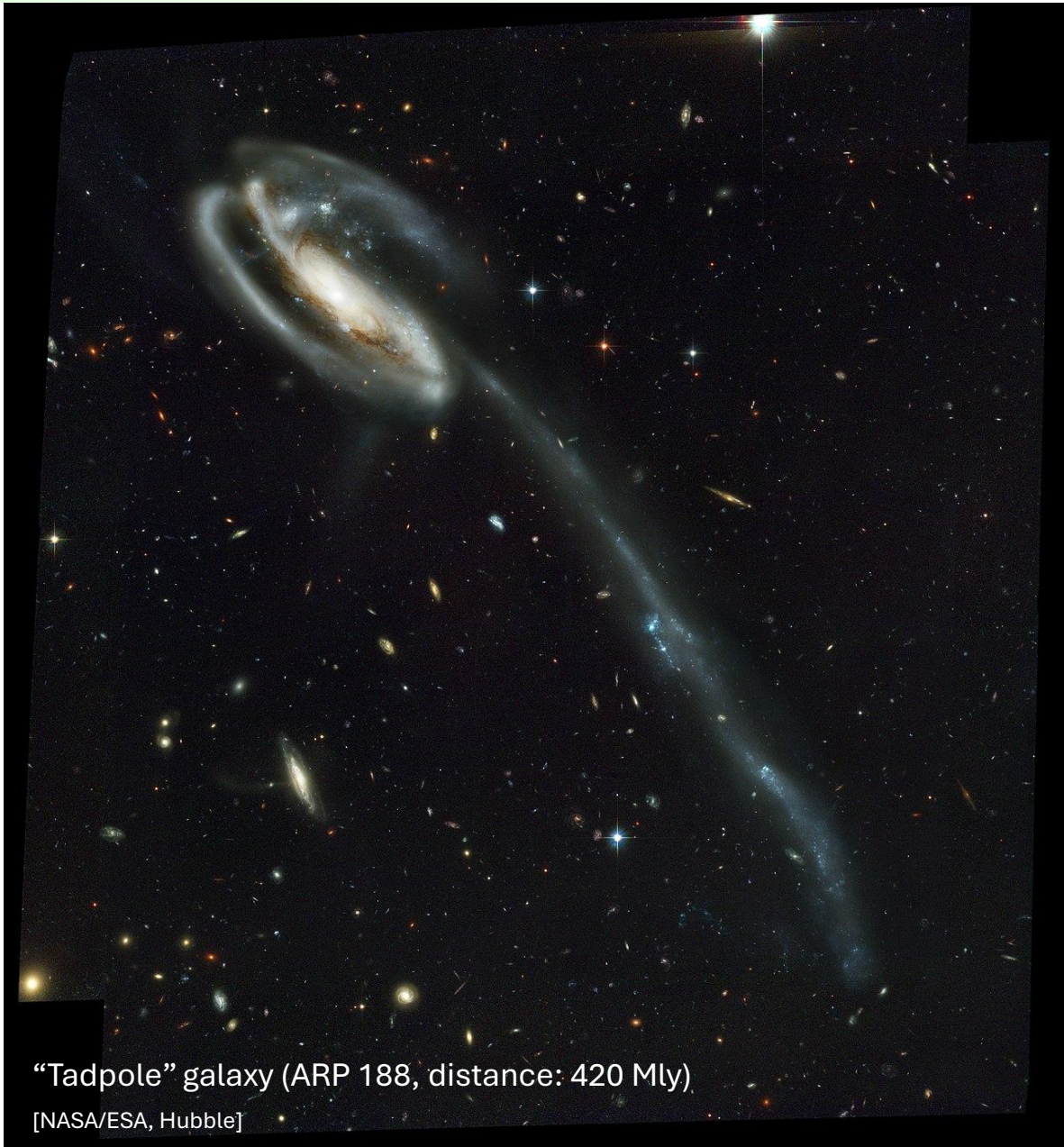
- Blue-ish regions show areas of intense star formation.
- Long tails of stars (some newly born) generated by gravitational tidal forces during galactic collision.

“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]

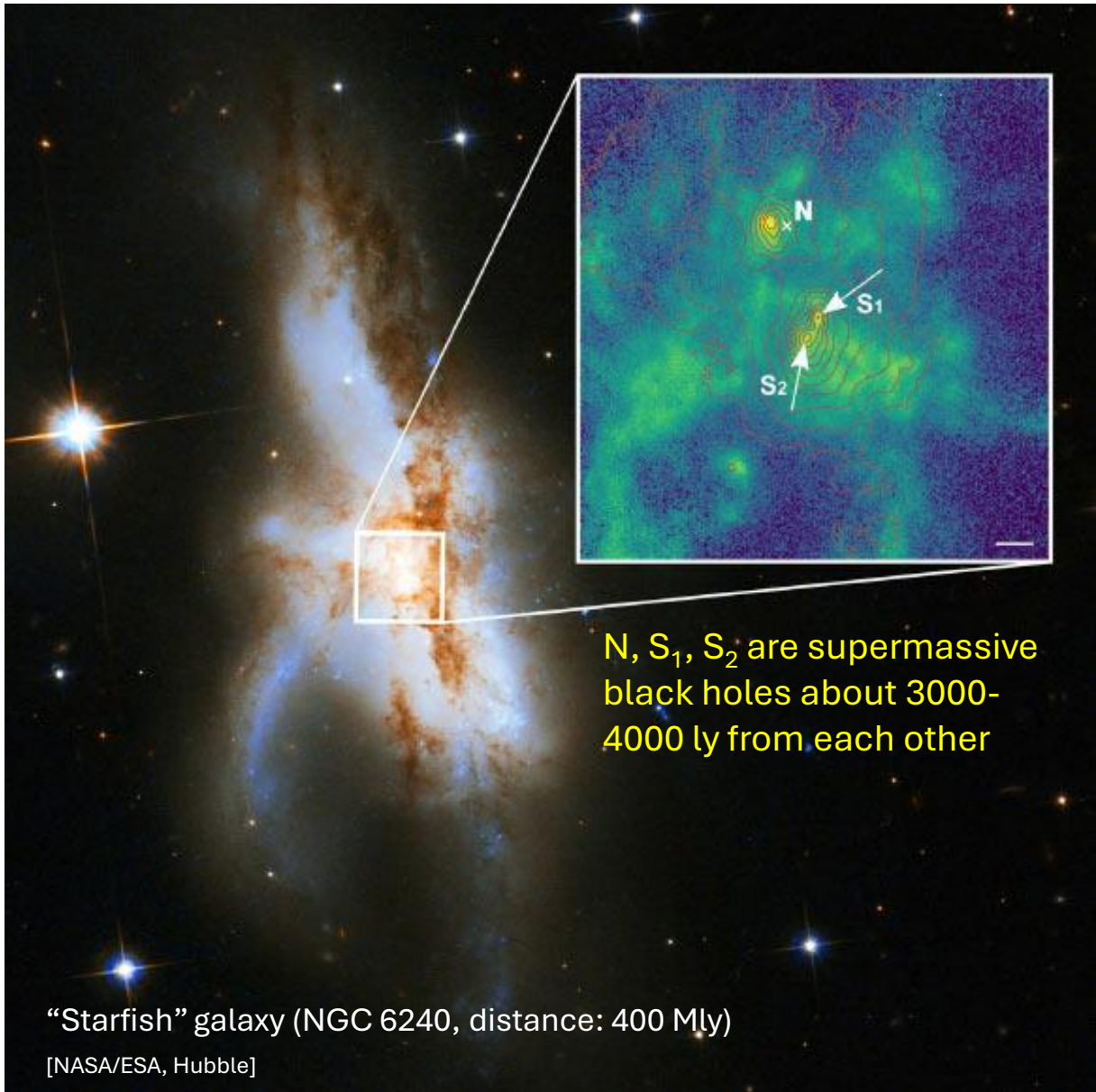
Galaxy Mergers

- 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.

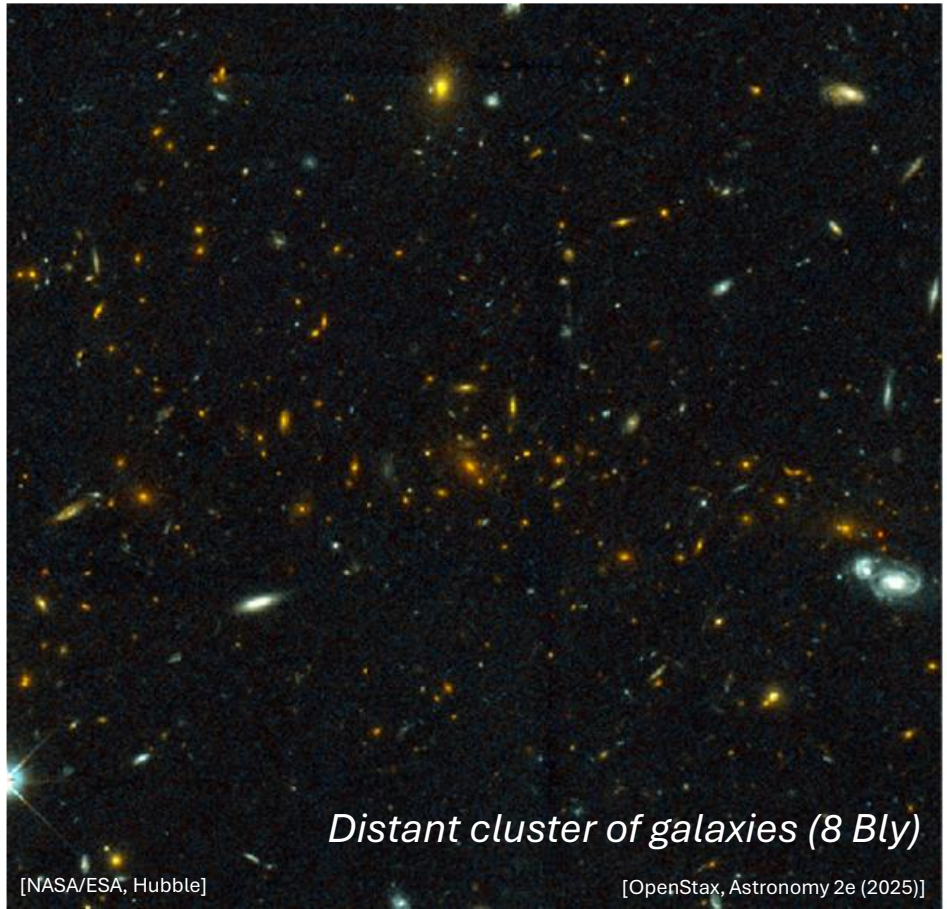
→ Orbits decay due to friction with accretion disks and **gravitational wave** emission.



Galaxy mergers in the past

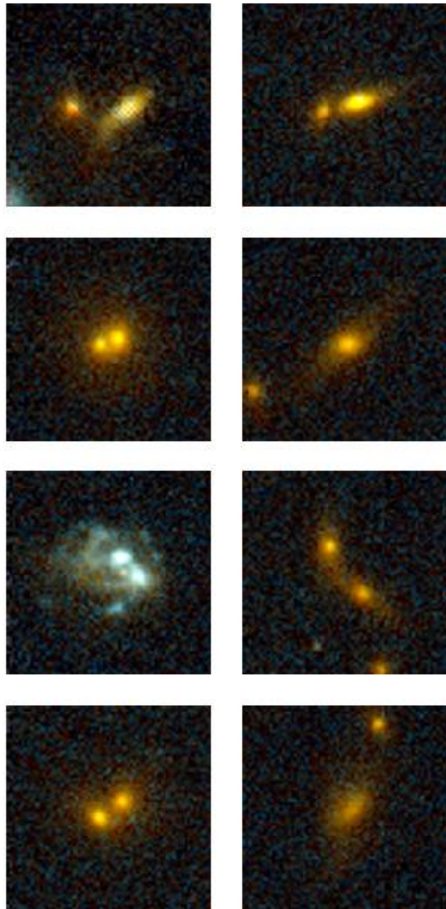
- Galaxy mergers were much more common in the distant past.
- Hubble's law tells us that galaxies were much closer together.
  → Galaxies can collide more easily and frequently.

Of 81 galaxies in this cluster, 13 of them are in 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]

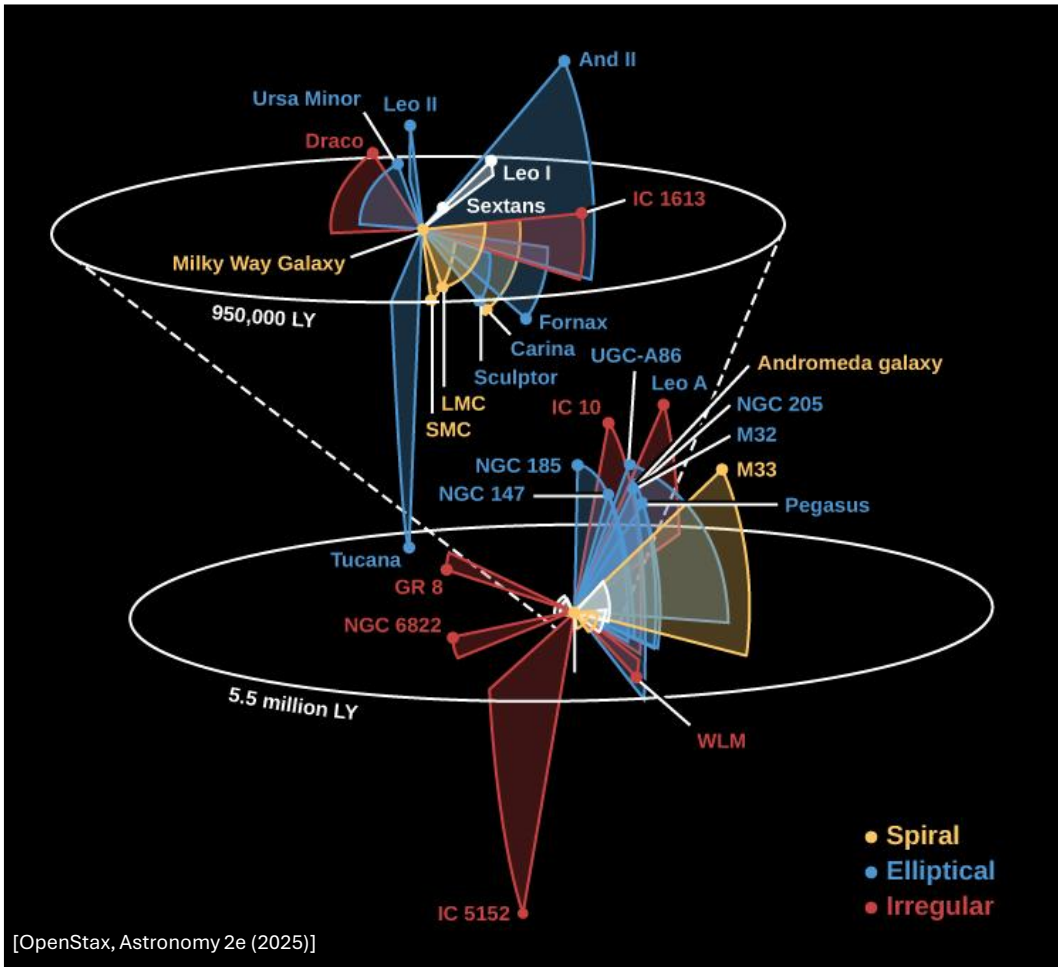
Local group

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

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

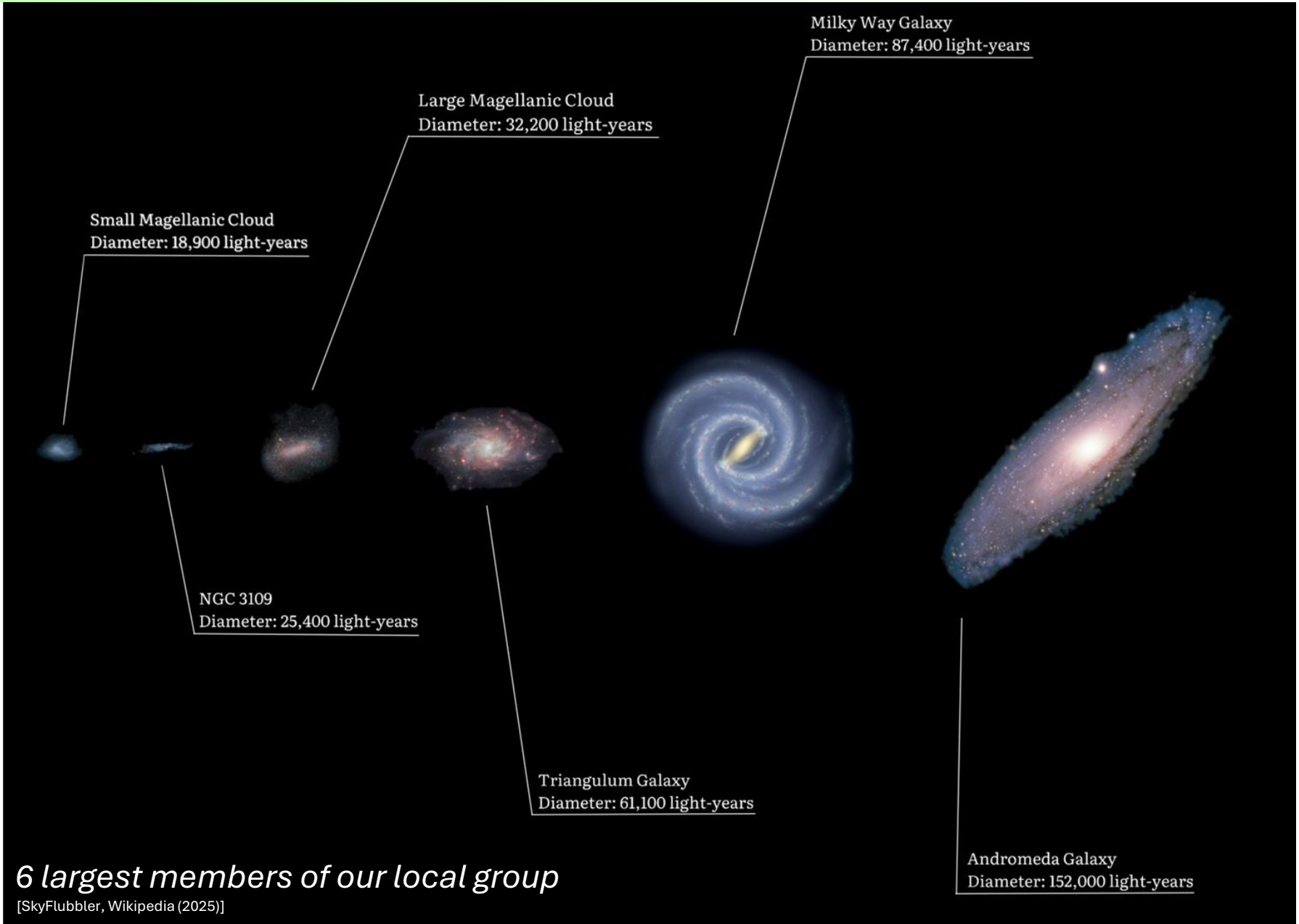
→ *Milky Way, Andromeda (M31), and Triangulum (M33).*

- 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

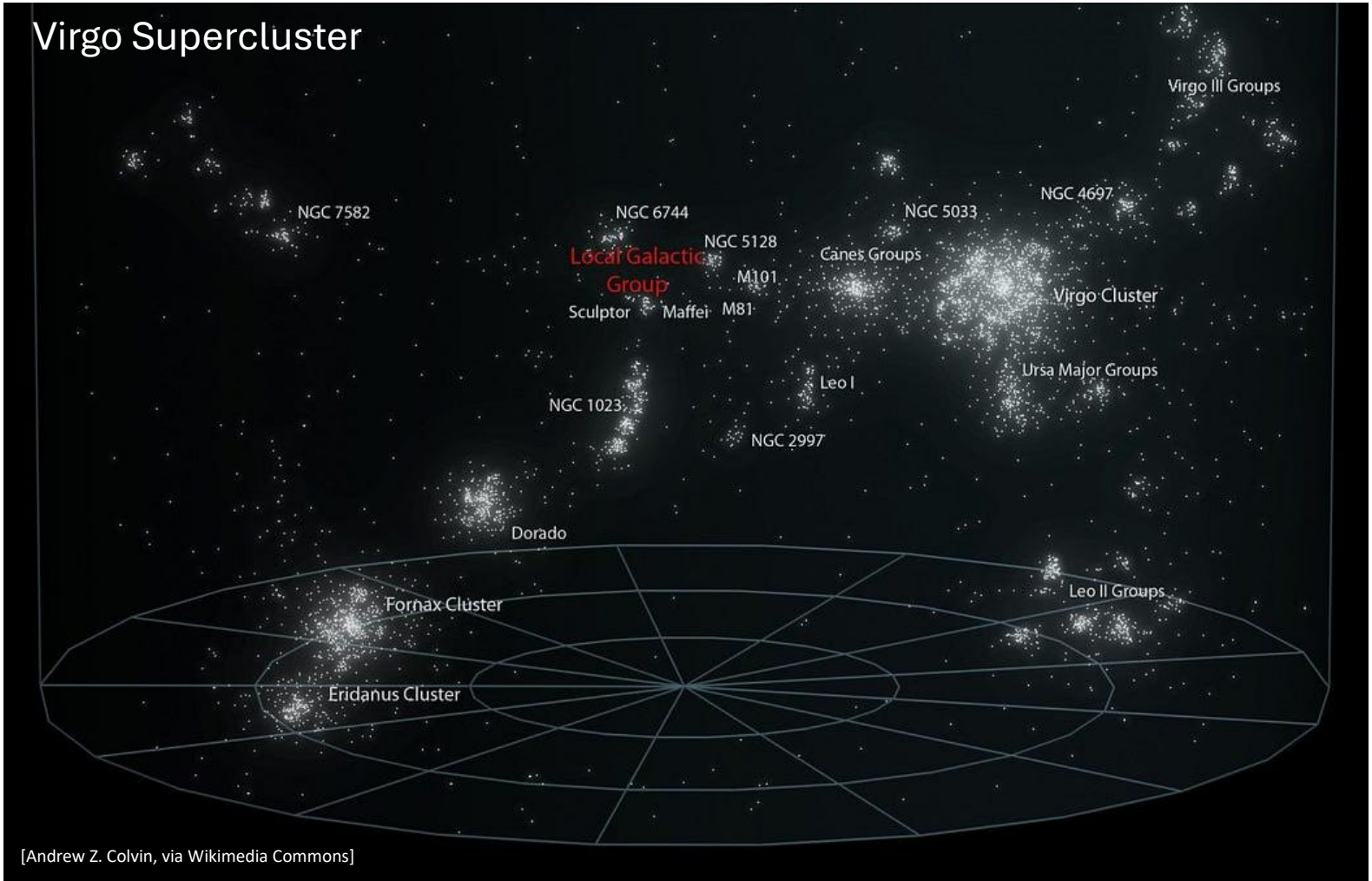


6 largest members of our local group

[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]

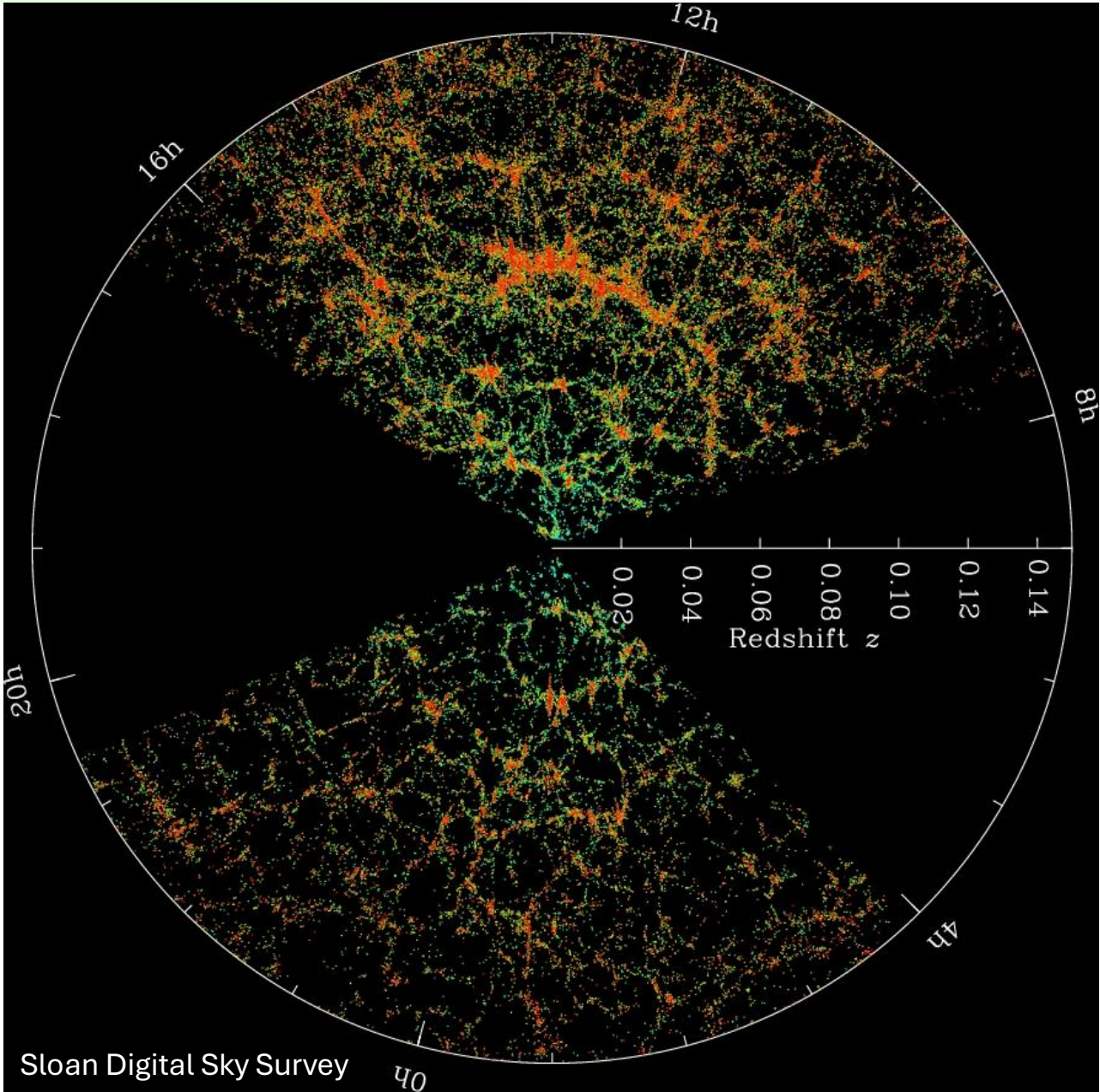
Large Scale Distribution of Galaxies

Sloan Digital Sky Survey

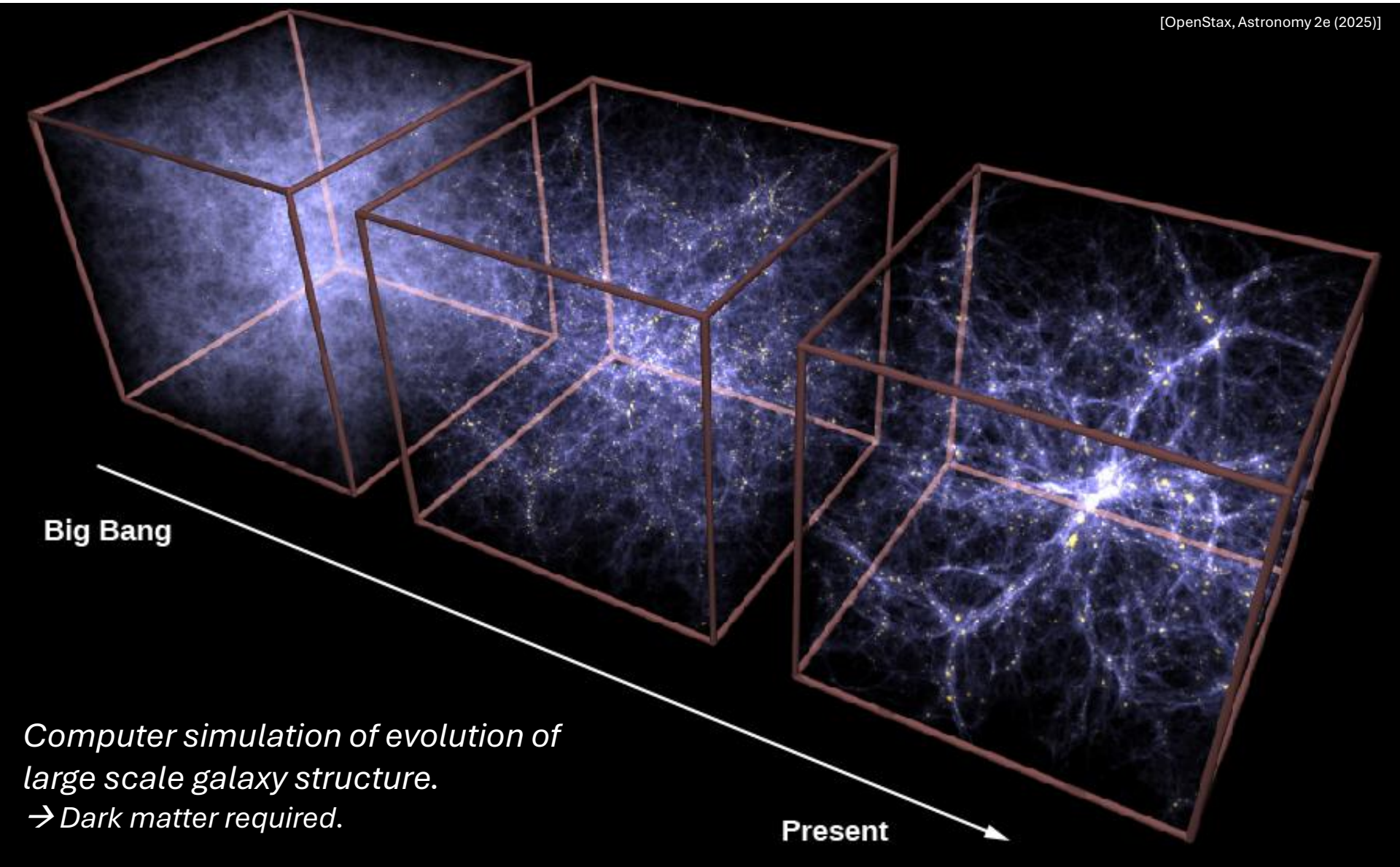
- 980,000 galaxies mapped.

→ 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**…



Large Scale Distribution of Galaxies



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