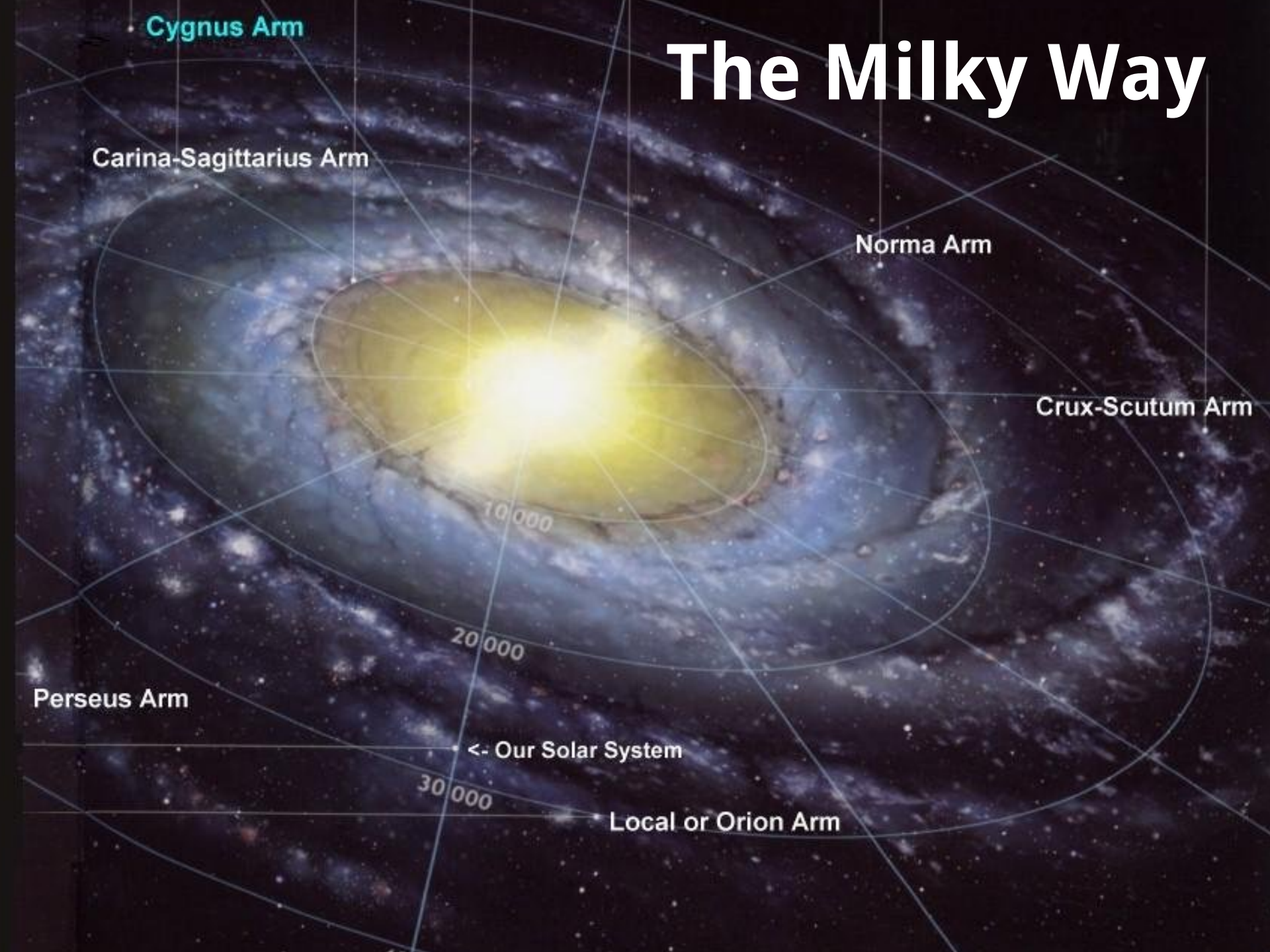
Announcements

- Quiz 9 due tonight at midnight
- Today: Finish discussing Milky Way, start with galaxies in general
  → start reading Chapter 15
- November 12, 8-9pm: Stargazing
  → Earn 1 bonus-point on final grade
- Bonus point opportunities featuring the Moon on D2L (modifications of the solar eclipse bonus points)


Cygnus Arm
The Milky Way
Carina-Sagittarius Arm
Norma Arm
Crux-Scutum Arm
10 000
20 000
Perseus Arm
<- Our Solar System
30 000
Local or Orion Arm

21 cm radio emission is useful in studying the Galaxy because

A

the waves penetrate dusty cocoons to reveal star formation

B

the waves are not absorbed by Galactic black holes

C

it can be used to map the hydrogen gas in the spiral arms

D

radio waves provide a distance measurement like parallax

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What suggests that the mass of our Galaxy extends beyond its visible disk?

A

maps of the spiral arms in 21 cm radio emission

B

the rotation curve of the outer edges of the Galaxy

C

orbits of open clusters in the disk

D

x-ray images of other galaxies

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The Milky Way: Summary

- A galaxy is stellar and interstellar matter bound by its own gravity
- Our Galaxy is a spiral galaxy
- Variable stars (Cepheids, RR-Lyrae) can be used for distance measurement, through the period–luminosity relationship
- True extent of a galaxy can be mapped out using globular clusters
- Star formation occurs primarily in the disk, but not in halo or bulge

The Milky Way: Summary

- Spiral arms may be density waves.
- Galactic rotation curve shows large amounts of undetectable mass at large radii
- This is called dark matter and makes up most of the mass of the Galaxy
- Activity near galactic center suggests presence of a 3.7-million-solar-mass black hole
- Mass is measured from the orbits of stars near the center

Astronomy 103

Galaxies

Please read Chapter 15

What is a galaxy?

A galaxy is a huge collection of stars that is isolated in space and held together by gravity.

We happen to live in one called the Milky Way Galaxy or just the Galaxy (with a capital “G”)

This is a picture of the Whirlpool galaxy – not the Milky Way

Galaxies

In the 1700s the philosopher Immanuel Kant wrote about “island universes,” nebulae in the sky.

Kant thought they were outside our galaxy, but this was not at all clear at the time

Some astronomers thought that they were part of our Galaxy and that our Galaxy made up the whole universe, but others thought that they were other galaxies entirely.

In 1920 the astronomers Harlow Shapley and Heber Curtis debated this question – the “Great Debate”

The Great Debate

Heber Curtis,
Lick Observatory

Harlow Shapley,
Mt Wilson Observatory

- What are “spiral nebulae”?
  - Shapley: clusters of stars within the Milky Way
  - Curtis: other galaxies outside the Milky Way

Neither completely correct, but debate clarified the issues

Galaxies

Then in 1922, Edwin Hubble found a Cepheid variable star in the Andromeda galaxy

He was able to use the Cepheid to measure the distance to the Andromeda galaxy

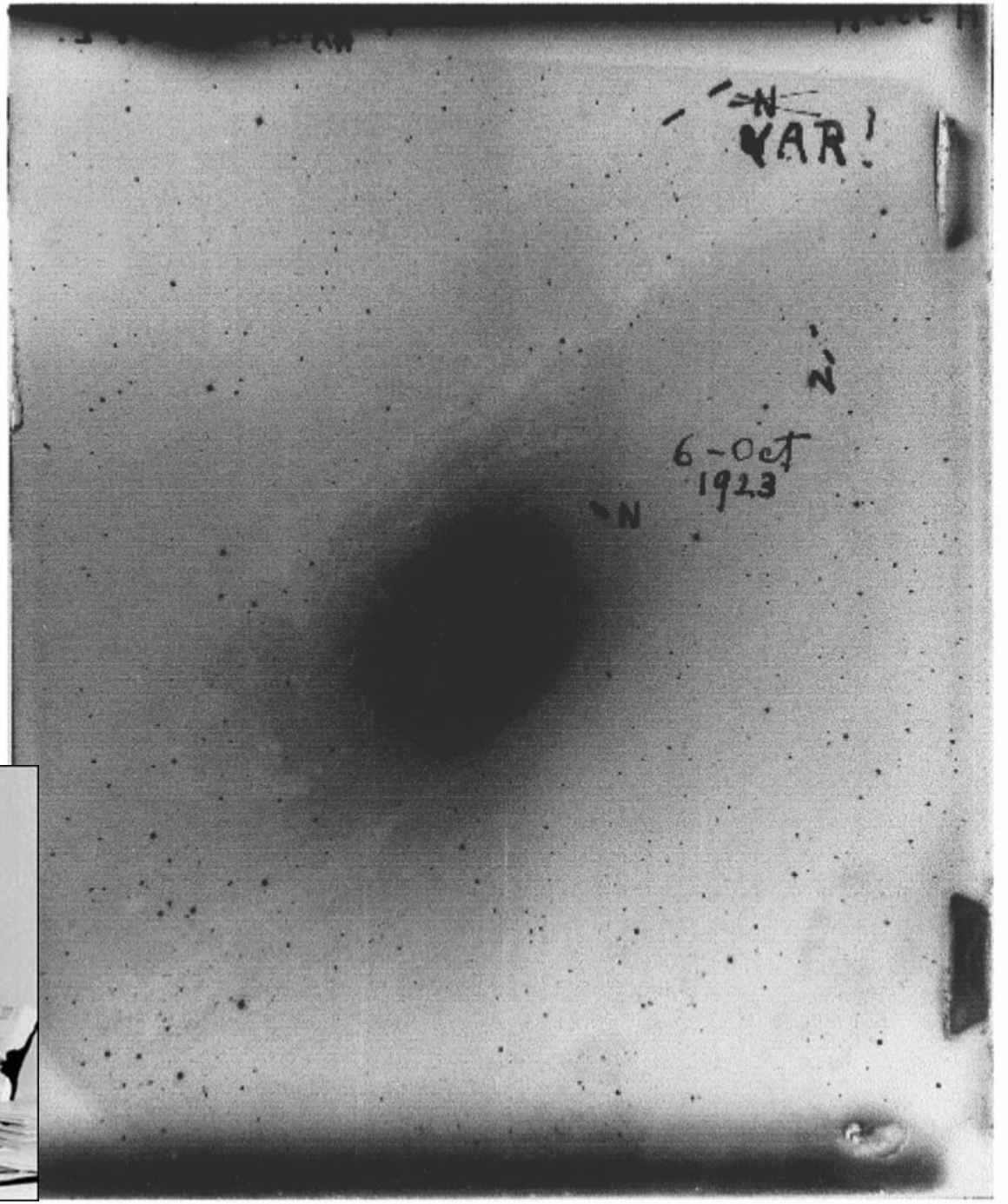
It was much farther than any other star known, and the distance to the Andromeda galaxy was measured to be 2 million light years away - much bigger than the 100,000 light year size of our Galaxy

This showed that other galaxies exist outside the Milky Way

Edwin
Hubble

Andromeda
Galaxy

The image that changed the universe



Galaxies

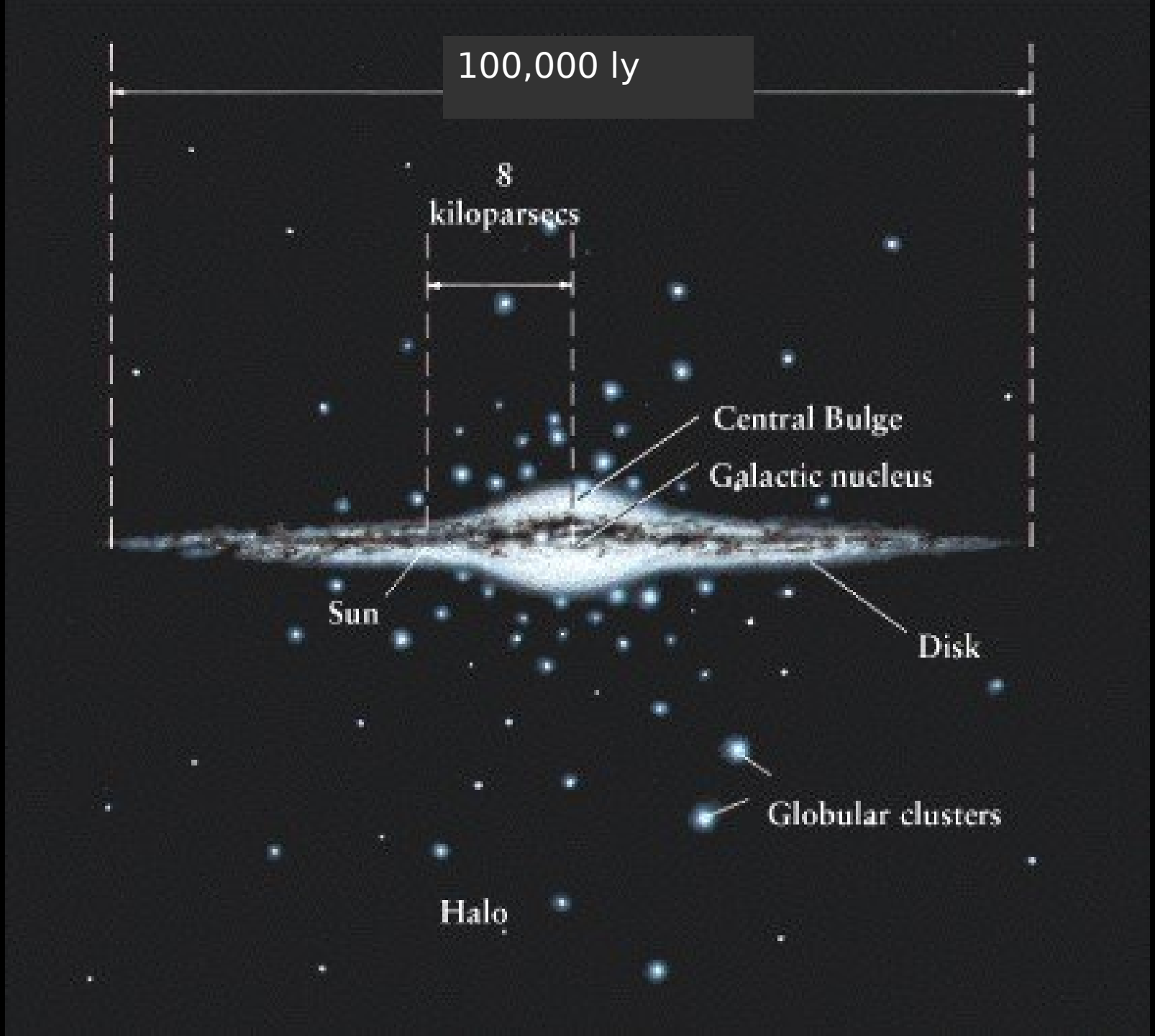
The Milky Way is a spiral galaxy – these are disk galaxies which have spiral arms

Spiral arms

Spiral galaxies

Spiral Galaxies

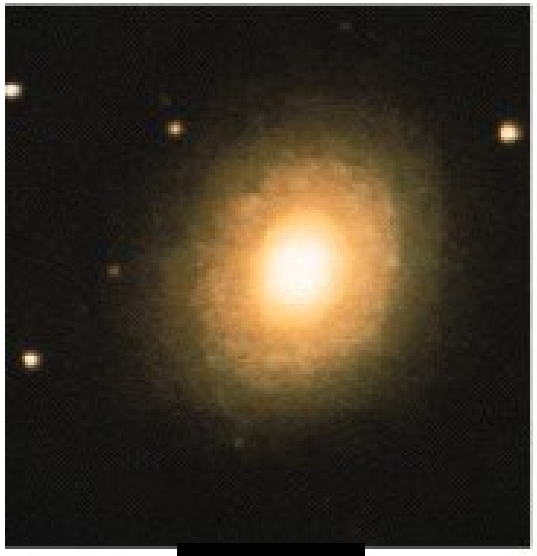
- Spiral galaxies have 4 components which we have already discussed for the Milky Way
  - Flat, rotating disk with spiral arms and younger stars
  - Central bulge of (mainly) older stars
  - A halo of older stars around it (contains globular clusters)
  - Central supermassive black hole
- The spiral arms appear brighter because they have most of the young stars. However, they only have about 5% more stars than the rest of the disk! (Recall that massive stars don't live long and are very luminous)


100,000 ly
8
kiloparsecs
Central Bulge
Galactic nucleus
Sun
Disk
Globular clusters
Halo

Spiral Structure

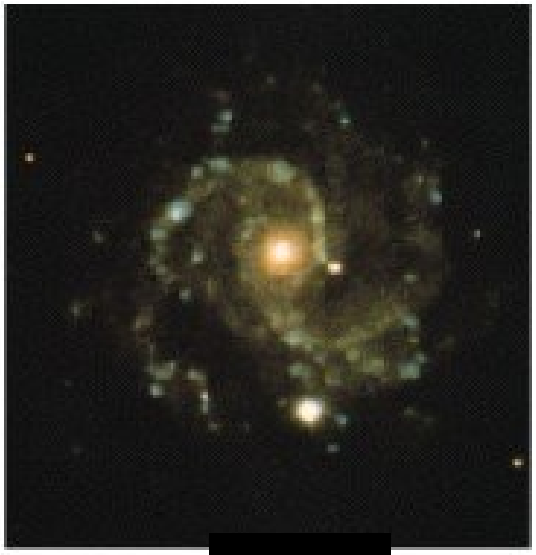
The Spiral structure can vary from galaxy to galaxy:

- Sa – weak spiral
- Sb – visible spiral
- Sc – prominent spiral



Sa

Sb



Sc

Another spiral, viewed closer to edge on

the Sculptor galaxy
(about 11 Mly away)

Barred Spiral Galaxies

More than half of all spiral galaxies also have a central bar in the bulge. The Milky Way is believed to have a bar.

These bars can connect to the spiral arms, but do not always

NGC 1300

Barred Spiral Galaxy NGC 1300

Hubble Heritage

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC05-01

What are the spiral arms?

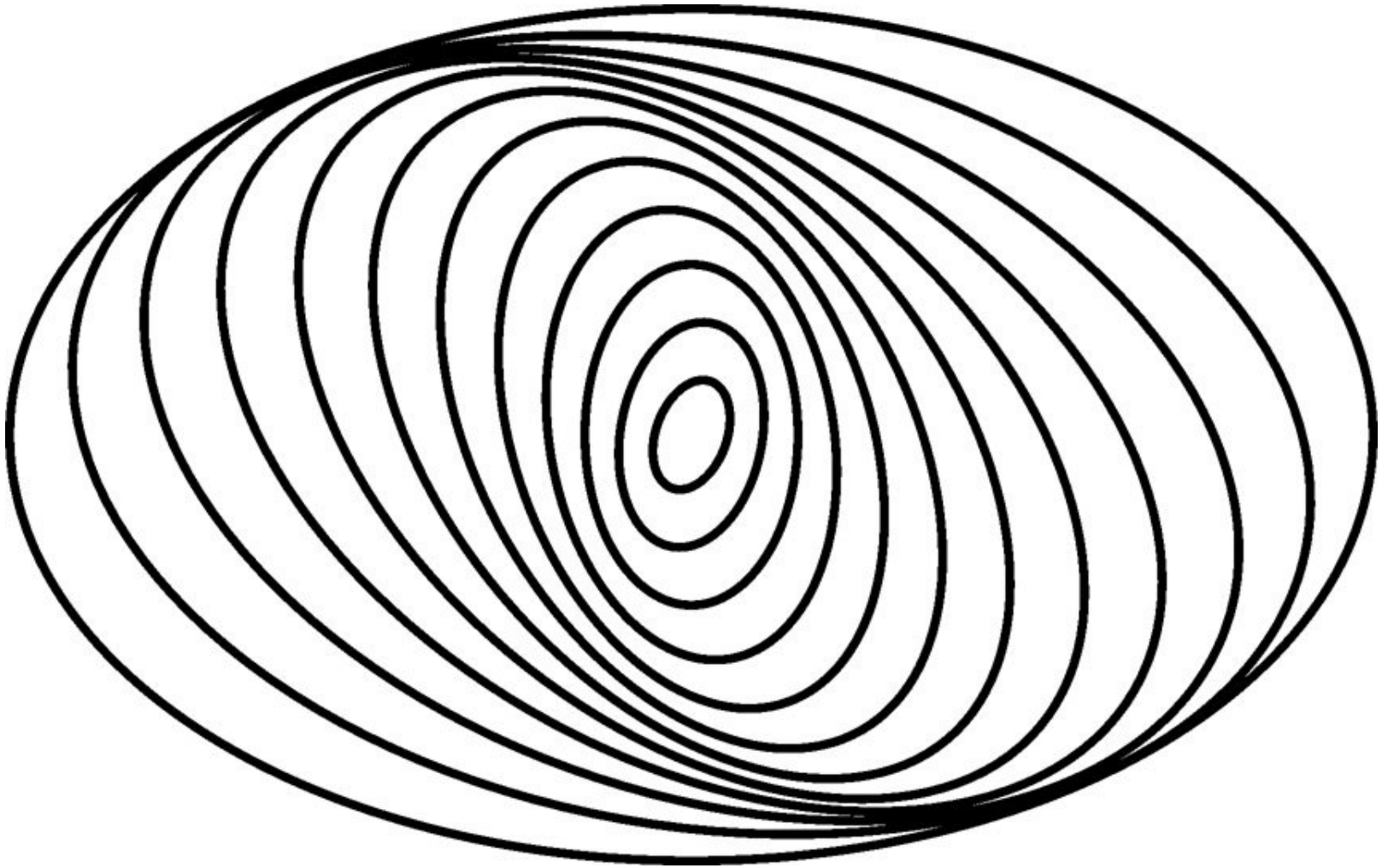
We discussed possible causes for the spiral structure of galaxies when we talked about the Milky Way

Leading theory is that they are **density waves** – regions of higher density that stars and gas move through

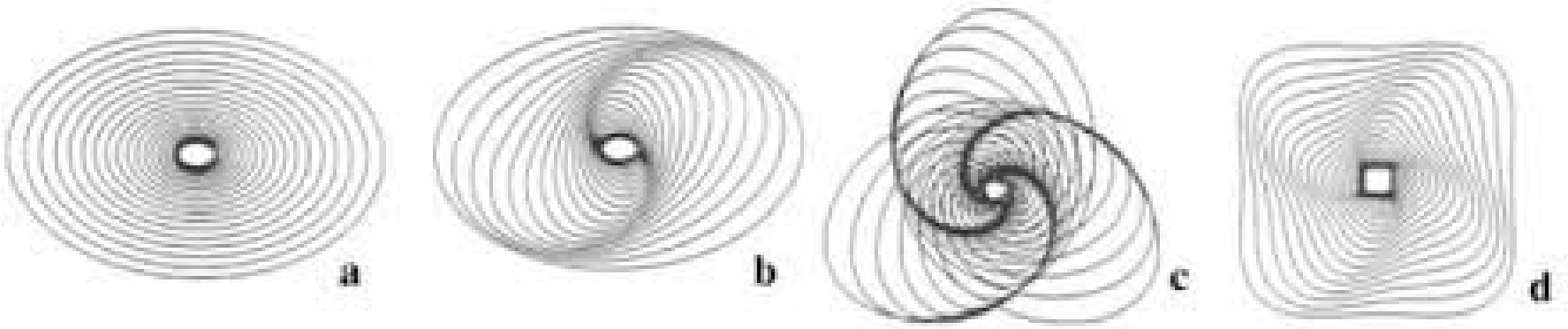
Another theory proposes that spiral arms are caused by waves of star formation

Still being researched!

Spirals and Isophotal twist



Spiral density waves can be created by misaligned, concentric elliptical orbits.



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Elliptical Galaxies

The other major type of galaxy is elliptical

- These are spherical(ish) distributions of old stars
- Smooth – no distinct features and no disk
- Have older stars and little to no current star formation
- Similar to bulges of spiral galaxies, but larger

Elliptical Galaxies

The largest, most massive galaxies in the universe are elliptical

Photo: the Virgo Cluster of galaxies, with several large elliptical galaxies surrounded by smaller ellipticals and spirals

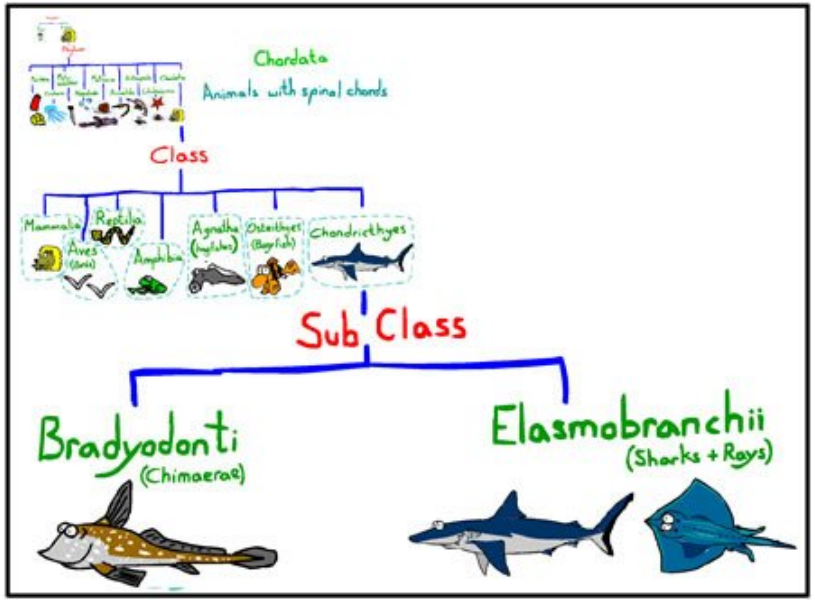
Galaxy classification

In the 1920s, shortly after Hubble discovered that there are many galaxies in the universe, he went about classifying them.

At the time, he knew of spirals and ellipticals that had various degrees of structure.

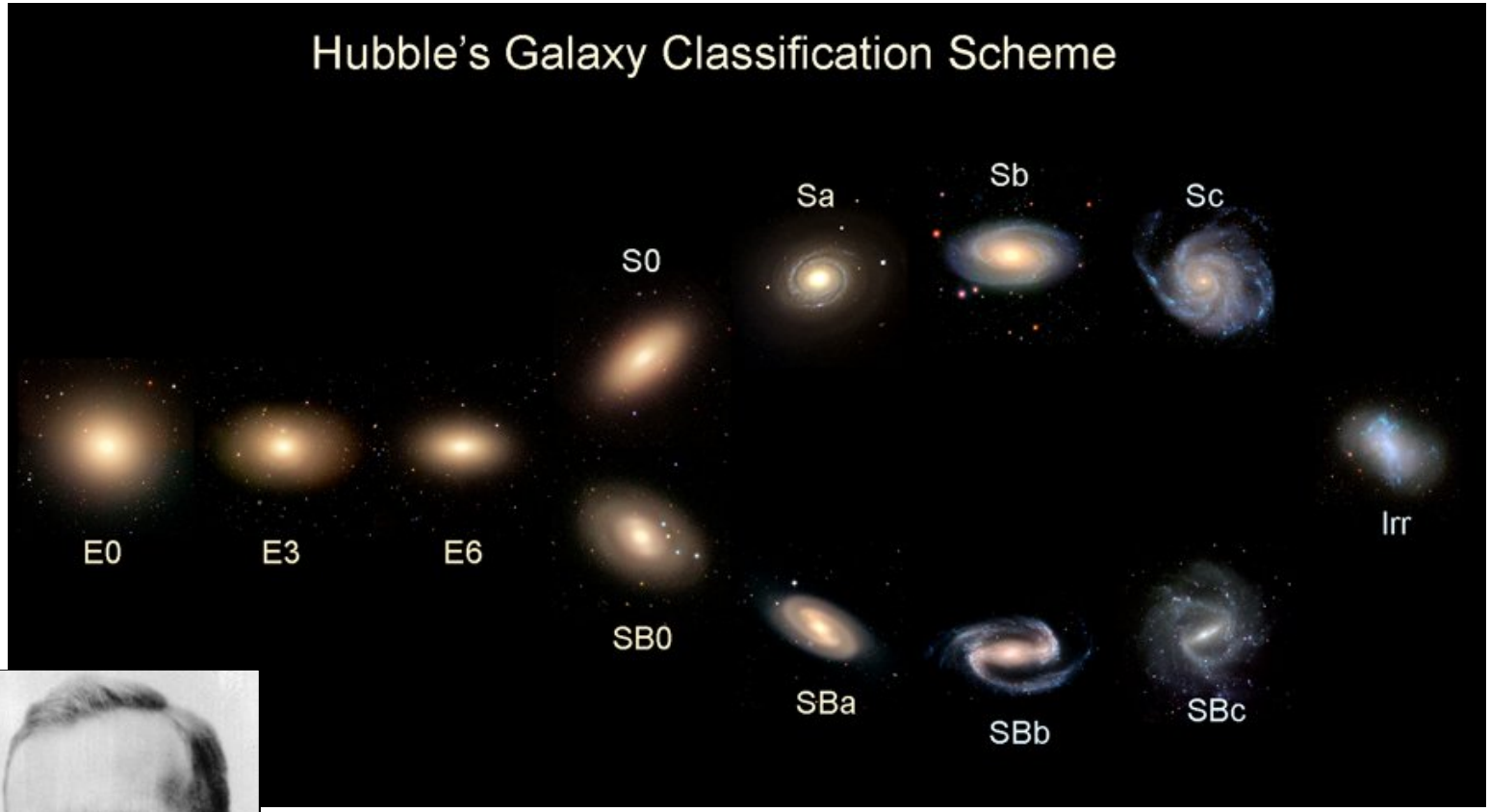
Why classify galaxies?

- Impose order
- Reveal correlations between properties or evolution



- Classification should be complete: include every galaxy
- Classification should be economical: don't include irrelevant detail (but how do we know which details are irrelevant?)

The Hubble Sequence



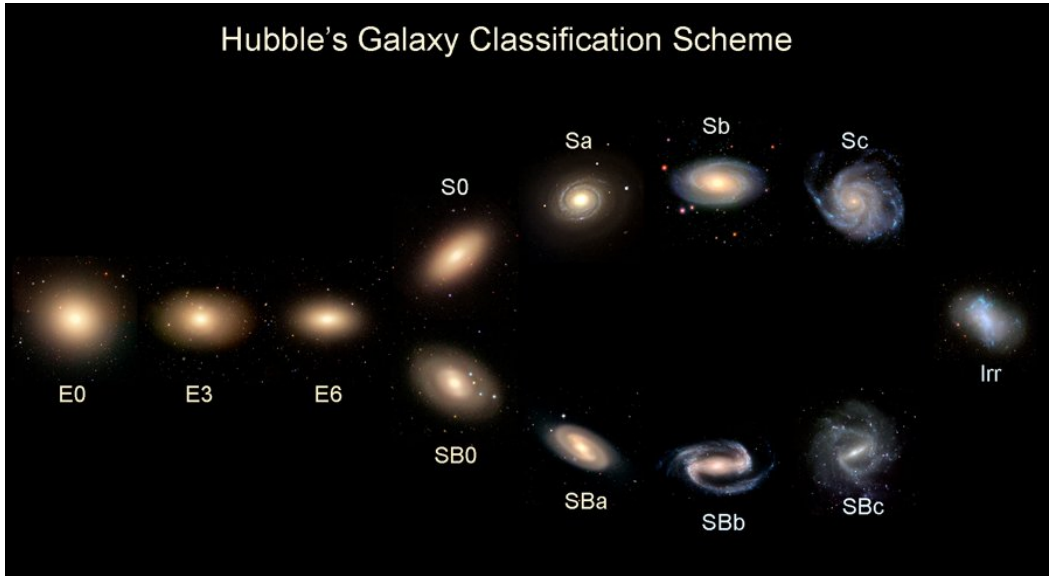
Edwin Hubble again
1926: proposed galaxy classification scheme still used today

Hubble's Classification Scheme

Classification is based on a galaxy's appearance

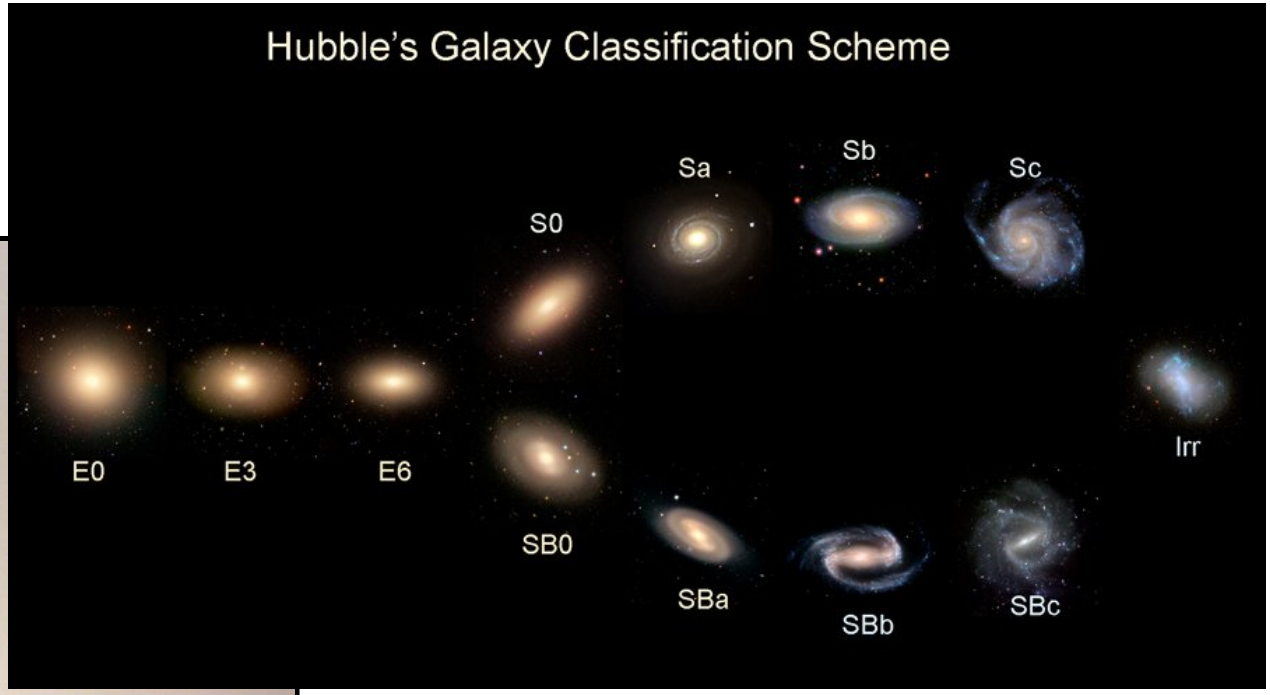
Three main categories:

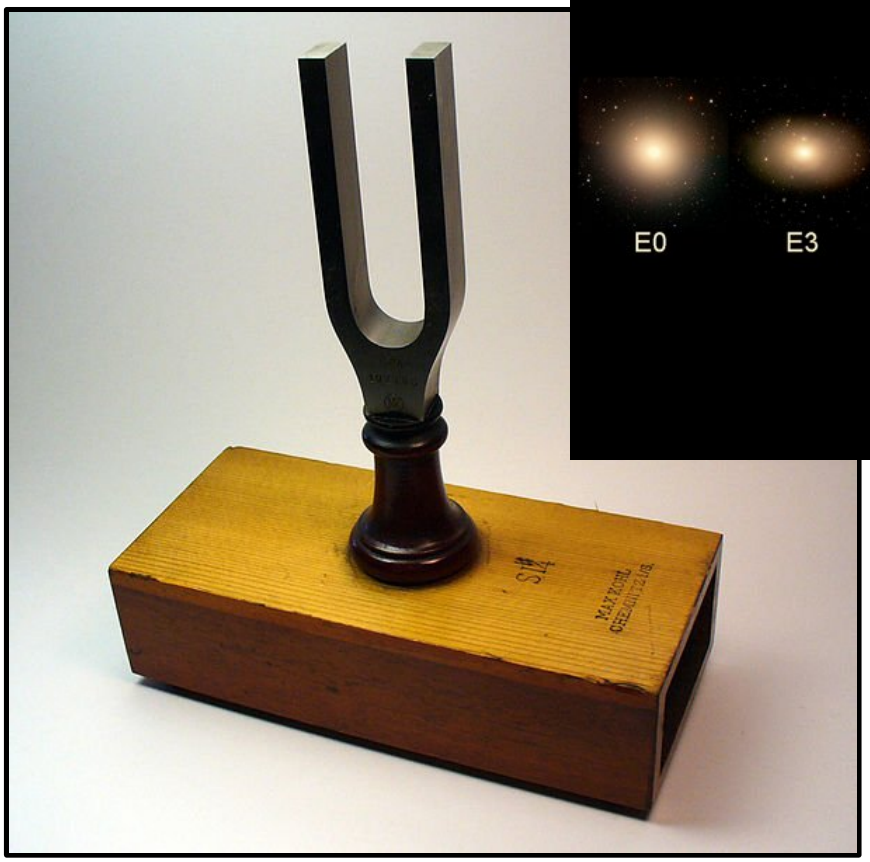
- Ellipticals
- Spirals: normal (S) and barred (Sb)
- Irregular



A galaxy's classification is called its Hubble type

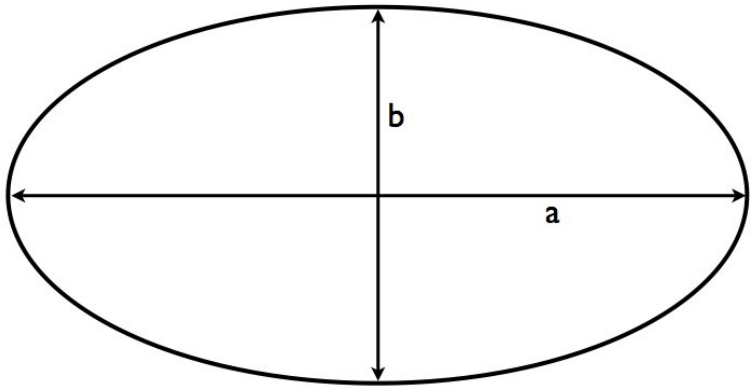
Hubble's “Tuning Fork Diagram”





“tuning fork diagram”

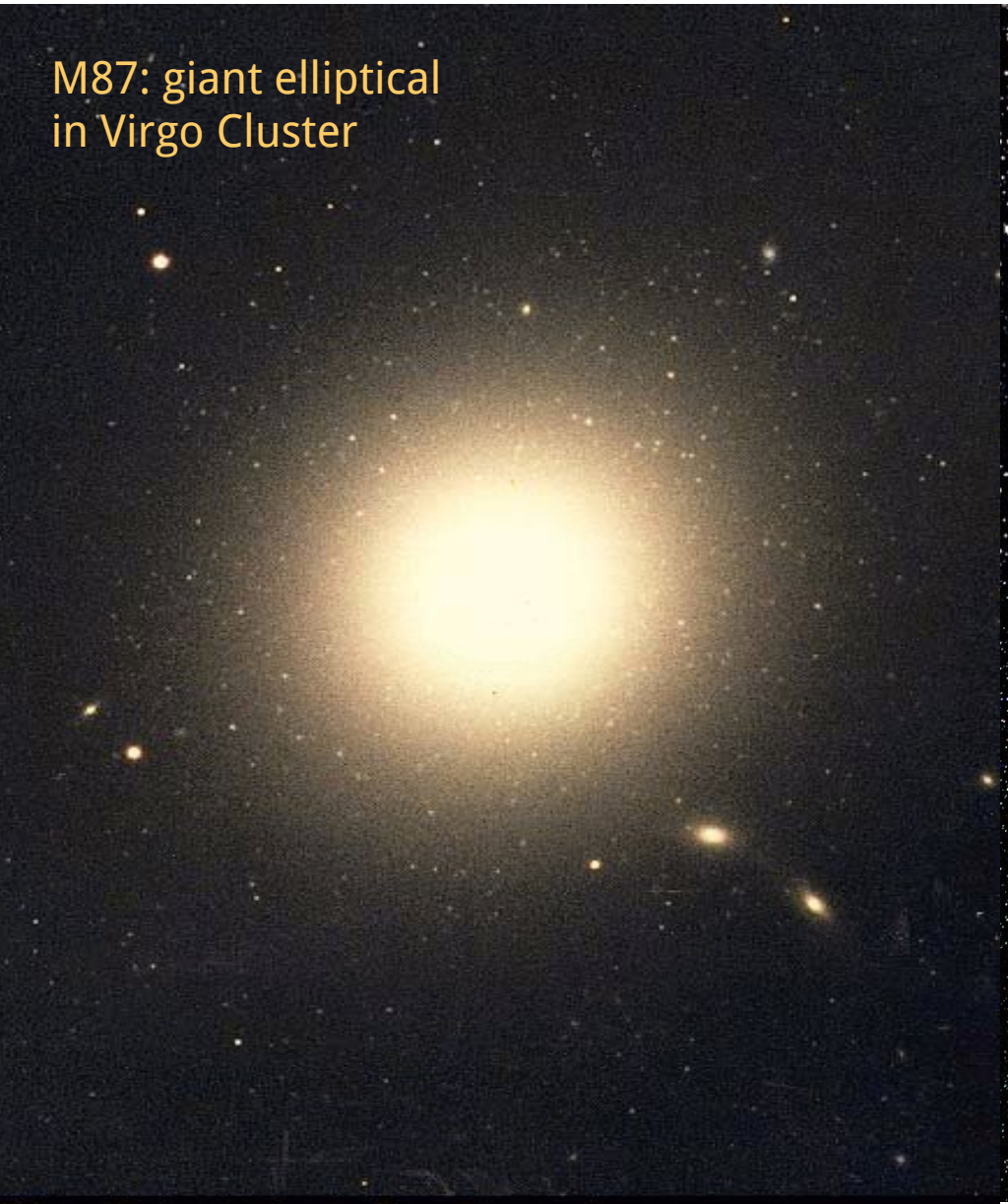
Elliptical Galaxies

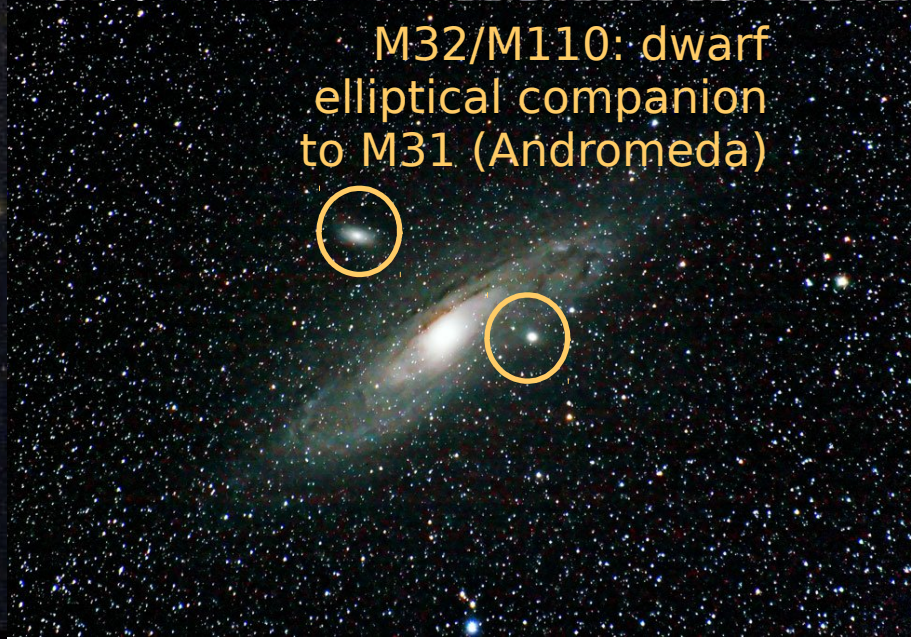


a = major axis
b = minor axis

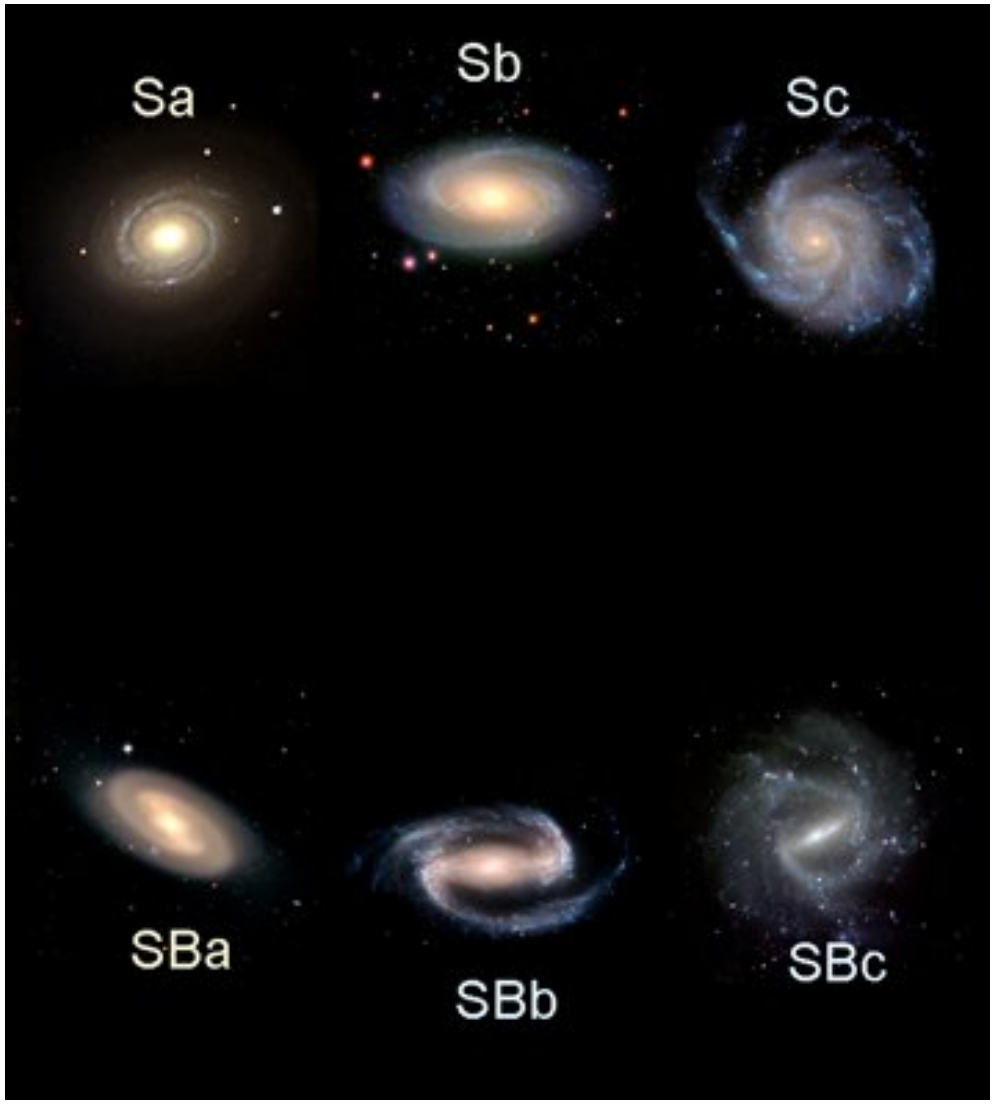
- Classified from E0 to E7 according to observed ellipticity
- Number between 0 and 7 based on ratio of minor and major axes
- Flattest observed are E6, E7
- Obvious problem: depends on viewing angle!

Elliptical Galaxies

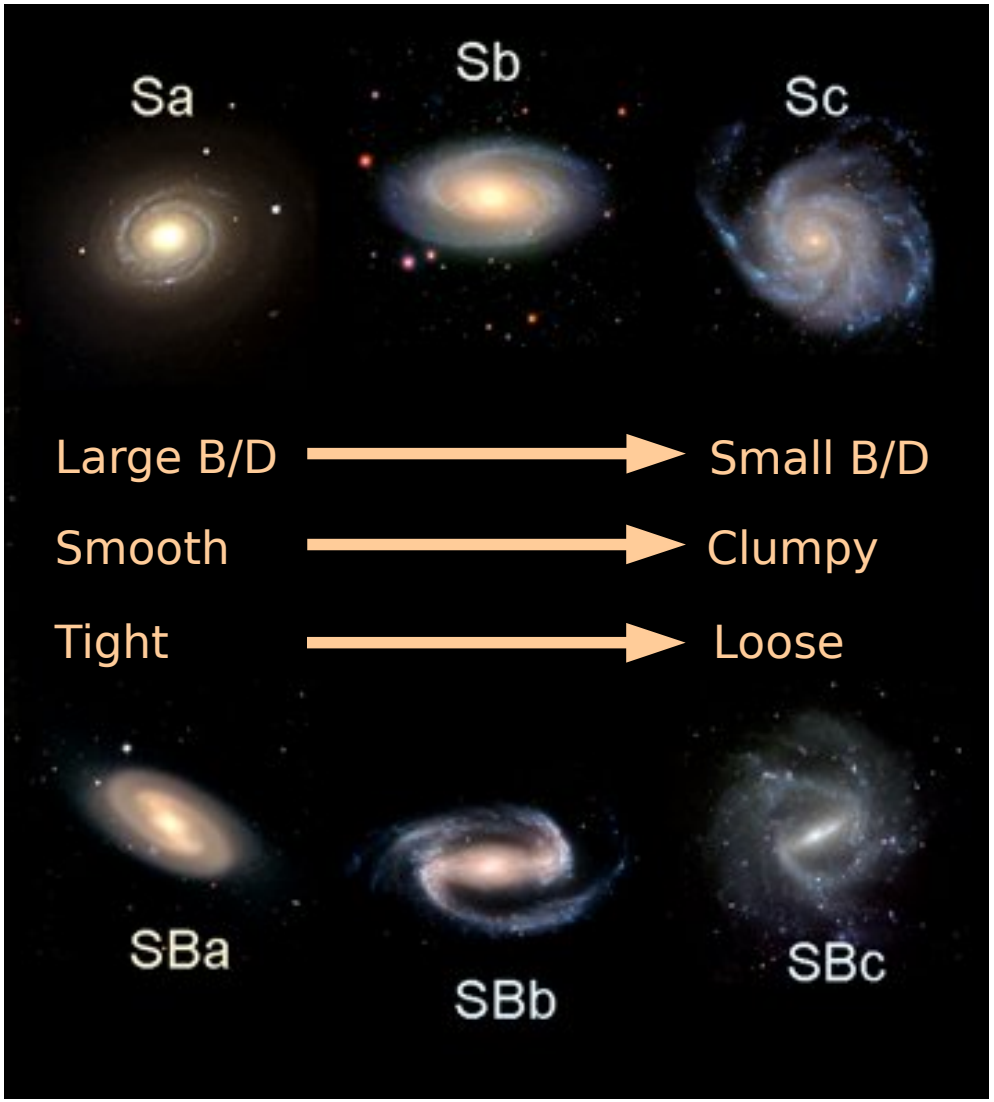




Spiral Galaxies



Spiral Galaxies



Features used to classify spiral galaxies

- Bulge-to-disk ratio (B/D)
- Smoothness of stellar distribution
- Tightness of winding of spiral arms

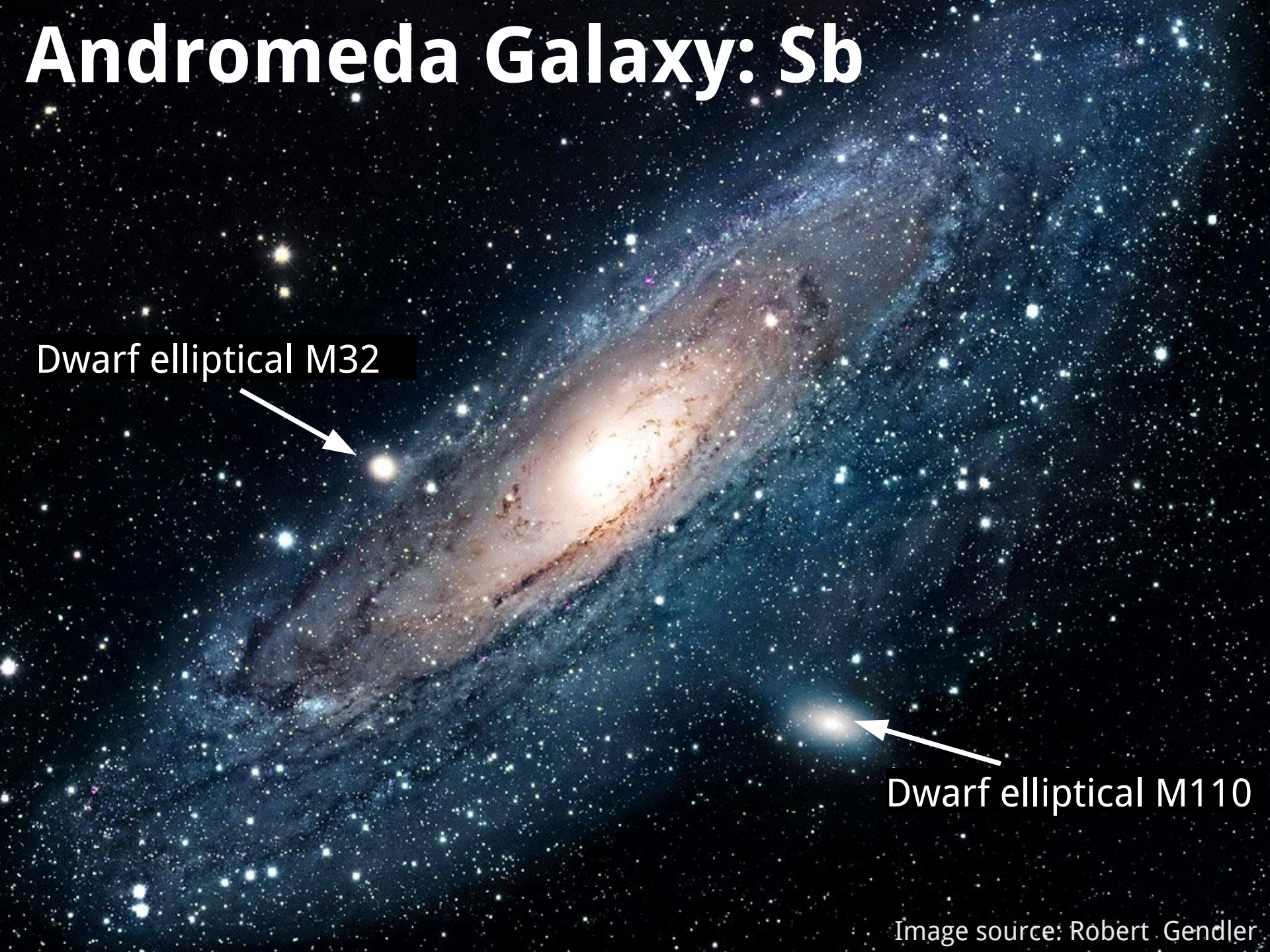
Sombrero Galaxy • M104

Type Sa

Hubble Heritage

NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC03-28

Andromeda Galaxy: Sb



M51 (Whirlpool Galaxy): Sc

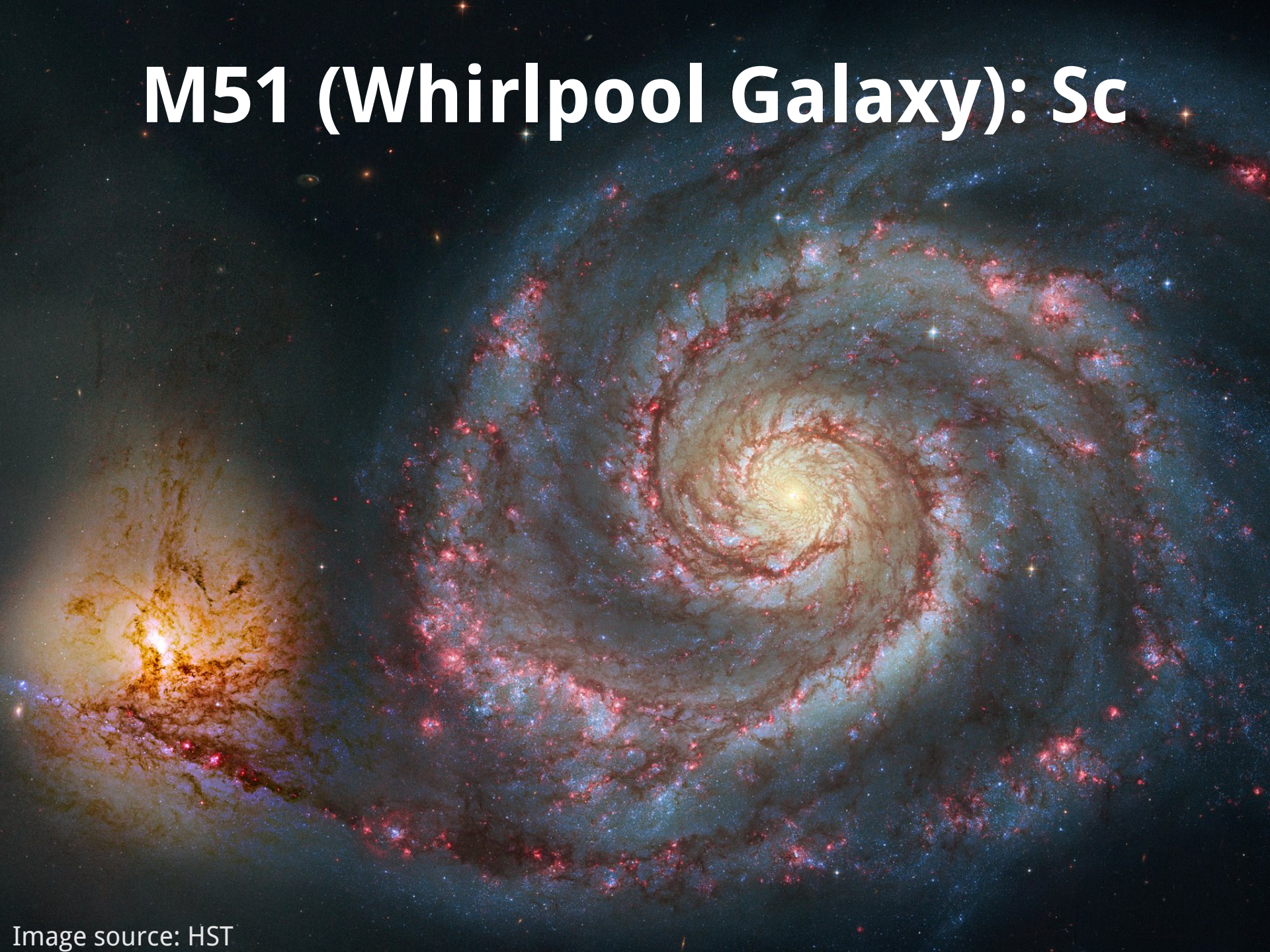


Image source: HST

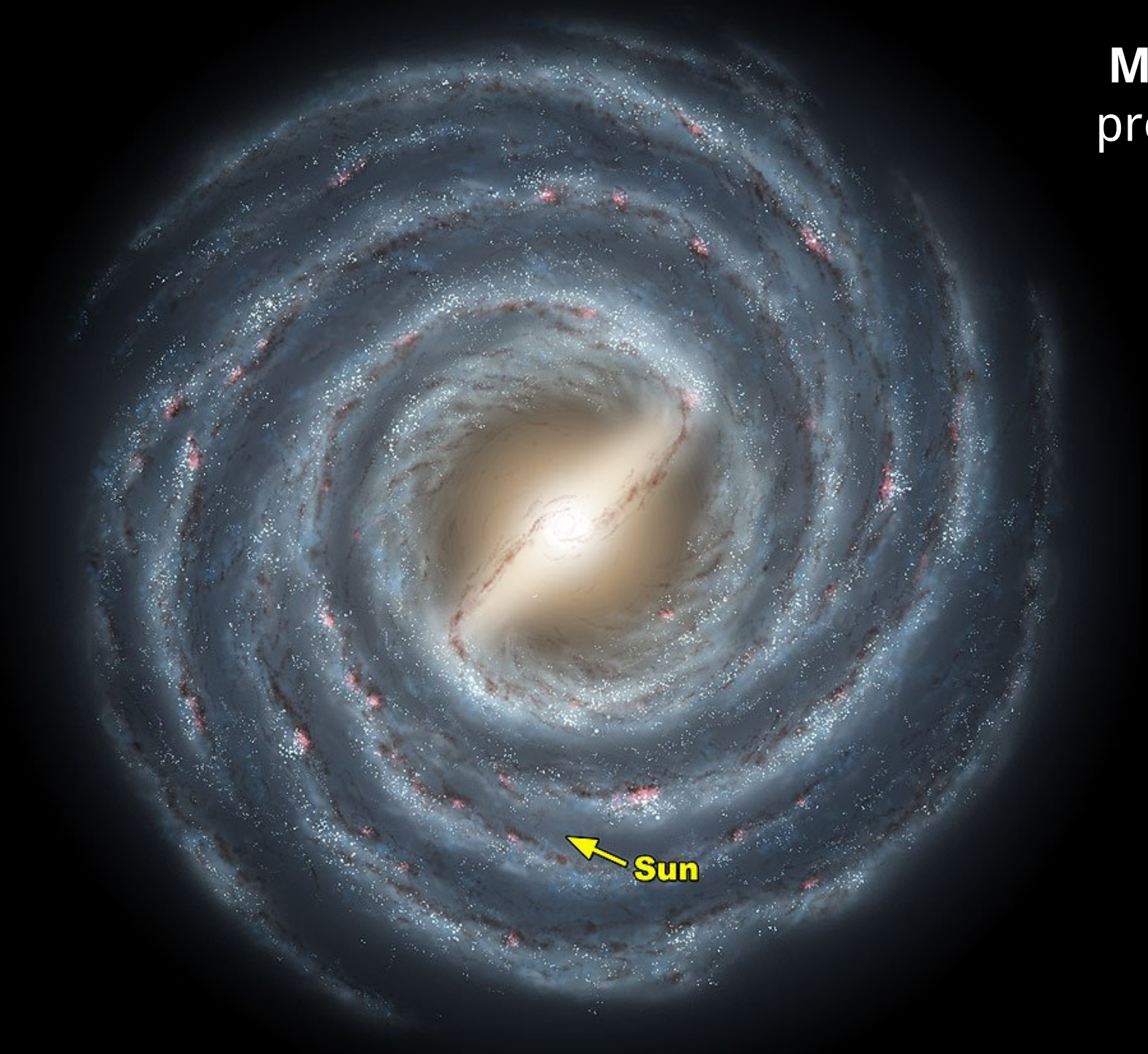
More complicated: M83 (Southern Pinwheel)

SAB(s)c

SAB: intermediate between normal, barred

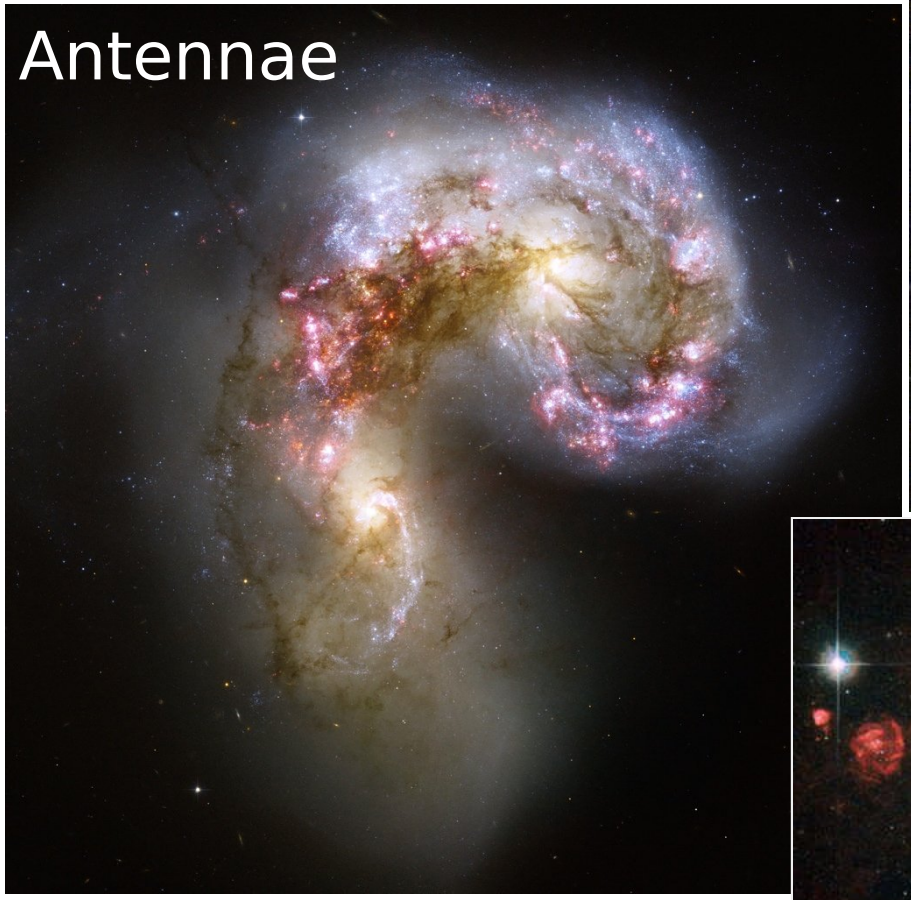
(s): S-shaped

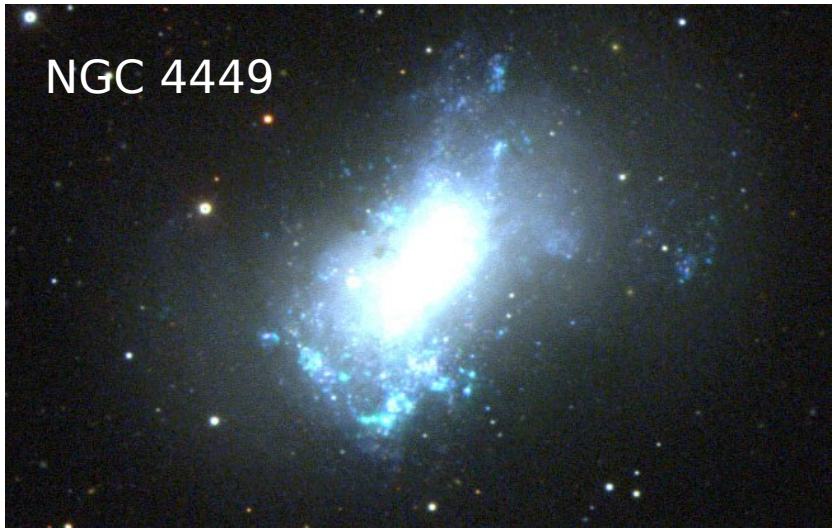
Image source: ESO/VLT



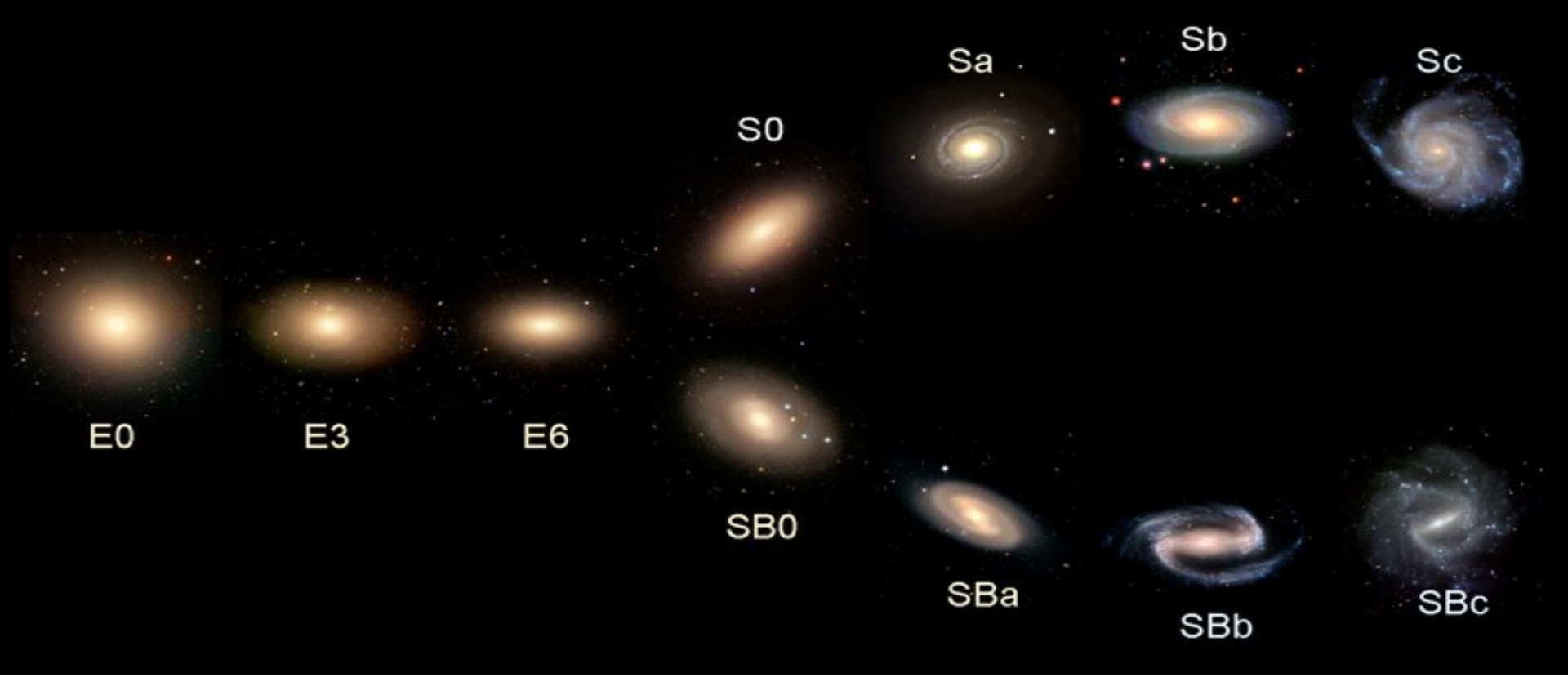
Milky Way:
probably SBb
to SBc

Irregular Galaxies





Usually small
Usually lots of gas and dust
Sometimes interacting

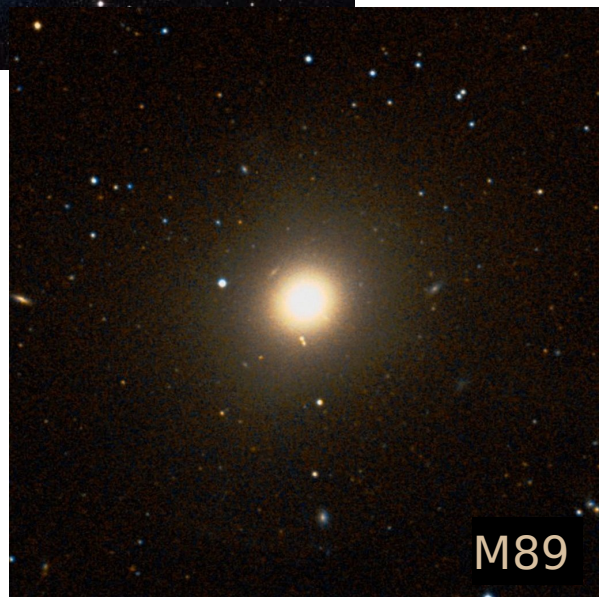


Hubble originally thought classification was evolutionary, and that elliptical galaxies evolved into spiral galaxies

This is not true: galaxies in isolation do not evolve from one type to another

Though they may change types if they merge!
→ More on that later

Trends with Galaxy Type



Spirals blue, ellipticals red

Spirals have more gas and dust than ellipticals

These are related!

Most star formation happens in spiral galaxies, stars form out of gas and dust, and young stars are blue!


M51 (spiral)
with elliptical
companion
Note obvious
difference in
color

Three Types of Nearby Galaxies

Ellipticals	Spirals	Irregulars
Little gas or dust	Gas and dust in disk	Gas and dust throughout
No new stars	New stars in spiral arms, some in nucleus	New stars throughout
Wide range of sizes	Medium size	Usually small

Nearby Galaxies

- New stars form from gas and dust in spiral and irregular galaxies
- Spiral and irregular galaxies have both old and young stars, stars that formed when the galaxy formed and stars that formed more recently
- In spiral galaxies, the spiral arms appear far brighter than the rest of the disk, because most of the youngest, brightest stars are in the spiral arms
- Only about 5% more stars are found in the spiral arms than in the rest of the disk

TABLE 15.1 Basic Galaxy Properties by Type

	Spiral/Barred Spiral (S/SB)	Elliptical (E)[1]	Irregular (Irr)
Shape and structural properties	Highly flattened disk of stars and gas, containing spiral arms and thickening to central bulge. SB galaxies have an elongated central "bar" of stars and gas.	No disk. Stars smoothly distributed through an ellipsoidal volume. No obvious substructure other than a dense central nucleus.	No obvious structure. Irr II galaxies often have "explosive" appearance.
Stellar content	Disks contain both young and old stars; halos consist of old stars only.	Contain old stars only.	Contain both young and old stars.
Gas and dust	Disks contain substantial amounts of gas and dust; halos contain little of either.	Contain hot X-ray emitting gas, little or no cool gas and dust.	Very abundant in gas and dust.
Star formation	Ongoing star formation in spiral arms.	No significant star formation during the last 10 billion years.	Vigorous ongoing star formation.
Stellar motion	Gas and stars in disk move in circular orbits around the galactic center; halo stars have random orbits in three dimensions.	Stars have random orbits in three dimensions.	Stars and gas have very irregular orbits.

[1] As noted in the text, some giant ellipticals appear to be the result of mergers between gas-rich galaxies and are exceptions to many of the statements listed here.

Which of these properties belong to spiral galaxies?

A Ongoing star formation

B A disk, bulge and halo

C Globular clusters in the halo

D All of the above

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