Announcements

- **Quiz 10** on the solar system due today
  - Problem set 10 for practice
- Today: start Chapter 15, Galaxies
- **Midterm 3: Wednesday April 23**
  - Neutron stars and black holes (Ch 13)
  - The solar system (Chs 4, 6, 7, + bits of Ch 5 [Earth] and 8 [moons of Jupiter, Saturn])
  - The Milky Way Galaxy (Ch 14)
- Review on Monday April 21

Reminder: Stargazing Extra Credit

- For extra credit (+1% on final grade), attend one of the sessions listed below and write a short summary of what you did and observed – info is on D2L
- Where: UWM Physics Observatory Deck. Take the elevator at the east end of the Physics building to the 4th floor and make a left to climb the staircase that leads to the roof. Follow Observatory signs.
- Remaining dates:
  - Mon April 21 (9:00-10:00 p.m.)
  - Tue April 22 (9:00-10:00 p.m.)
  - Wed April 23 (9:00-10:00 p.m.)
  - Thu April 24 (9:00-10:00 p.m.)
  - Wed May 14 (9:00-10:00 p.m.) – too late for credit, but another chance to see things

Extra Credit #3

- Short research paper on an astronomical topic
- Choose a topic that interests you
  - Must be approved: email me or ask in class
- Write short paper (1 page minimum) about topic
- At least three sources required, must be given
- Acceptable sources:
  - Published books and magazines
  - Webpages from universities (.edu) and government organizations (e.g. NASA)
  - Wikipedia is not an acceptable source but is a great place to start – follow the references!
- Due by last day of classes, May 7
- +1% on final grade

Total Lunar Eclipse Tonight

Total eclipse of the Moon
Delta T: 67.0s

MILWAUKEE, WISCONSIN
o ' o '
W087 57, N43 03

Central Daylight Time

		h m	Moon's Azimuth o	Altitude o
Moonrise	2014 Apr 14	19:11	102.3	----
Moon enters penumbra	2014 Apr 14	23:52.0	163.5	35.2
Moon enters umbra	2014 Apr 15	00:58.0	183.1	36.4
Moon enters totality	2014 Apr 15	02:06.4	202.9	33.5
Middle of eclipse	2014 Apr 15	02:45.7	213.2	30.1
Moon leaves totality	2014 Apr 15	03:25.0	222.7	25.7
Moon leaves umbra	2014 Apr 15	04:33.4	237.0	16.3
Moon leaves penumbra	2014 Apr 15	05:39.2	248.9	5.9
Moonset	2014 Apr 15	06:18	255.3	----

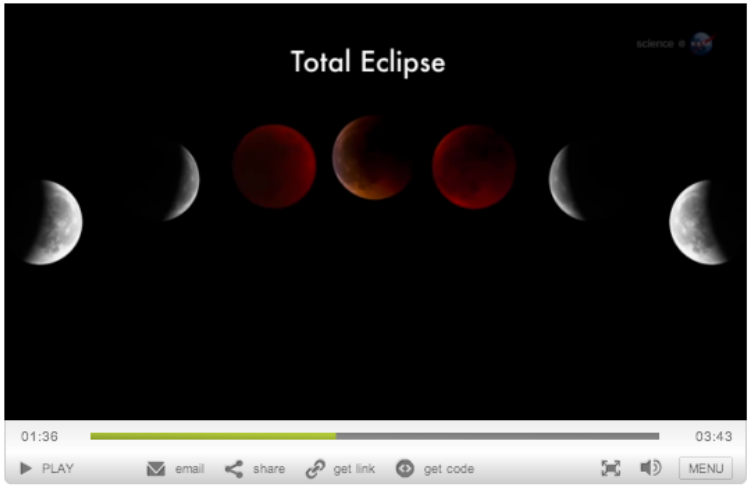
Data from http://aa.usno.navy.mil/data/docs/LunarEclipse.php

Totality starts 2:06 am, ends 3:25 am

Total Lunar Eclipse Tonight

Four Blood Moons: Total Lunar Eclipse Series Not a Sign of Apocalypse

Geoff Gaherty Starry Night Education | April 09, 2014 12:30pm ET



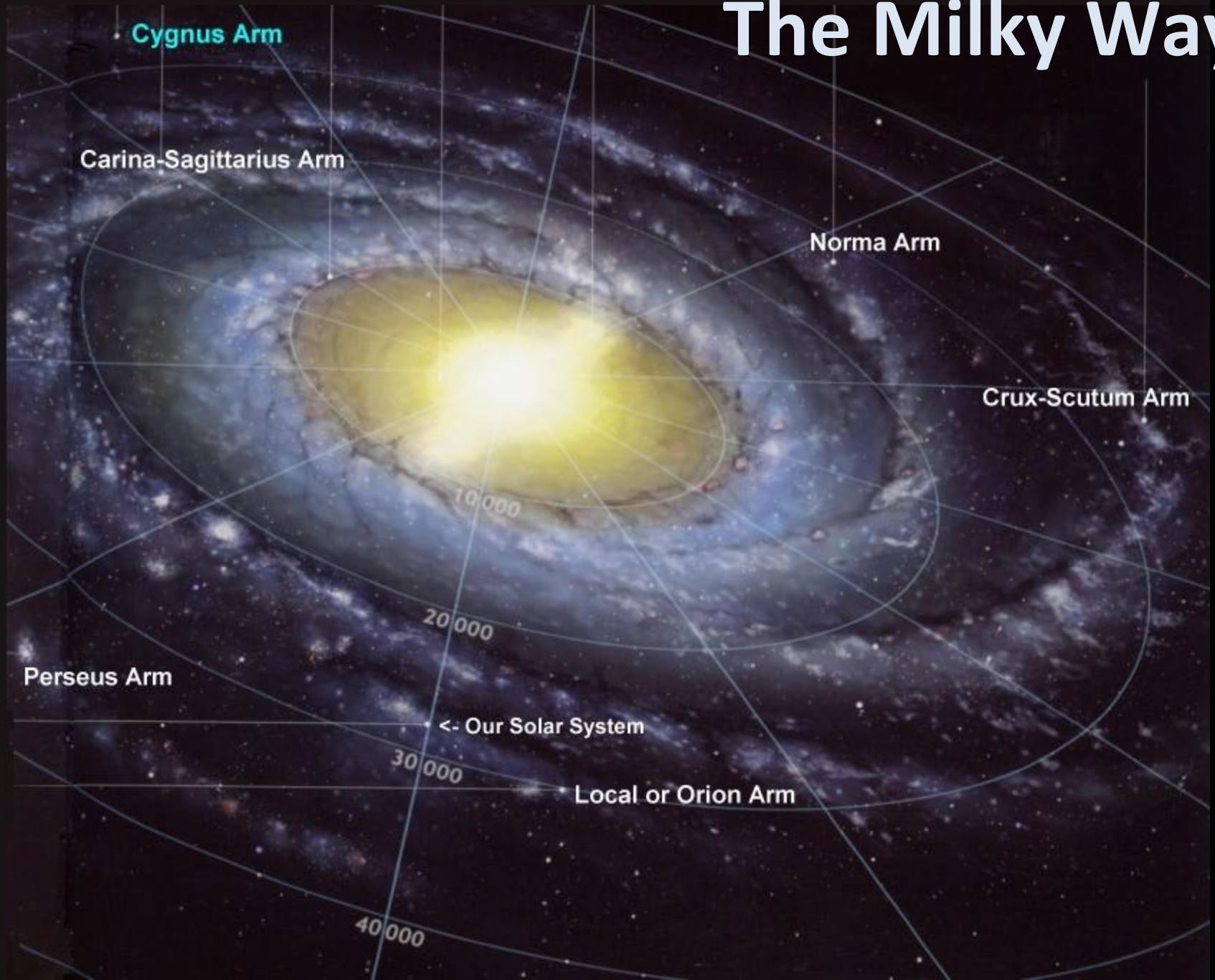
There has been a lot of interest recently in an upcoming series of lunar eclipses that begins April 15. These are usually described as "four blood moons" and taken by some to prophesy upcoming disasters.

This NASA graphic shows the months with total lunar eclipses between April 2014 and September 2015. This

The total lunar eclipse of April 15 will begin a so-called tetrad series of eclipses that is making the rounds online as a potential harbinger of doom, due in part to a recent book on the four blood moons that makes the dubious claim.

Astronomers rarely if ever use the term blood moon. When they do, they are usually using it as an alternate name for the Hunter's Moon, the full moon that follows the Harvest Moon, usually in late October. The Hunter's Moon, like the Harvest Moon, rises slowly on autumn evenings so that it

The Milky Way



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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D — radio waves provide a distance measurement like parallax

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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D

x-ray images of other galaxies

The Milky Way: Summary

- A galaxy is stellar and interstellar matter bound by its own gravity
- Our Galaxy is a spiral galaxy
- Variable stars 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

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'')

The structure of our Galaxy looks like:

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 the "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 at Mt Wilson Observatory

Andromeda Galaxy

Galaxies

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

Spiral arms

Spiral galaxies

NGC 5247

Messier 100 (NGC 4321)

NGC 1300

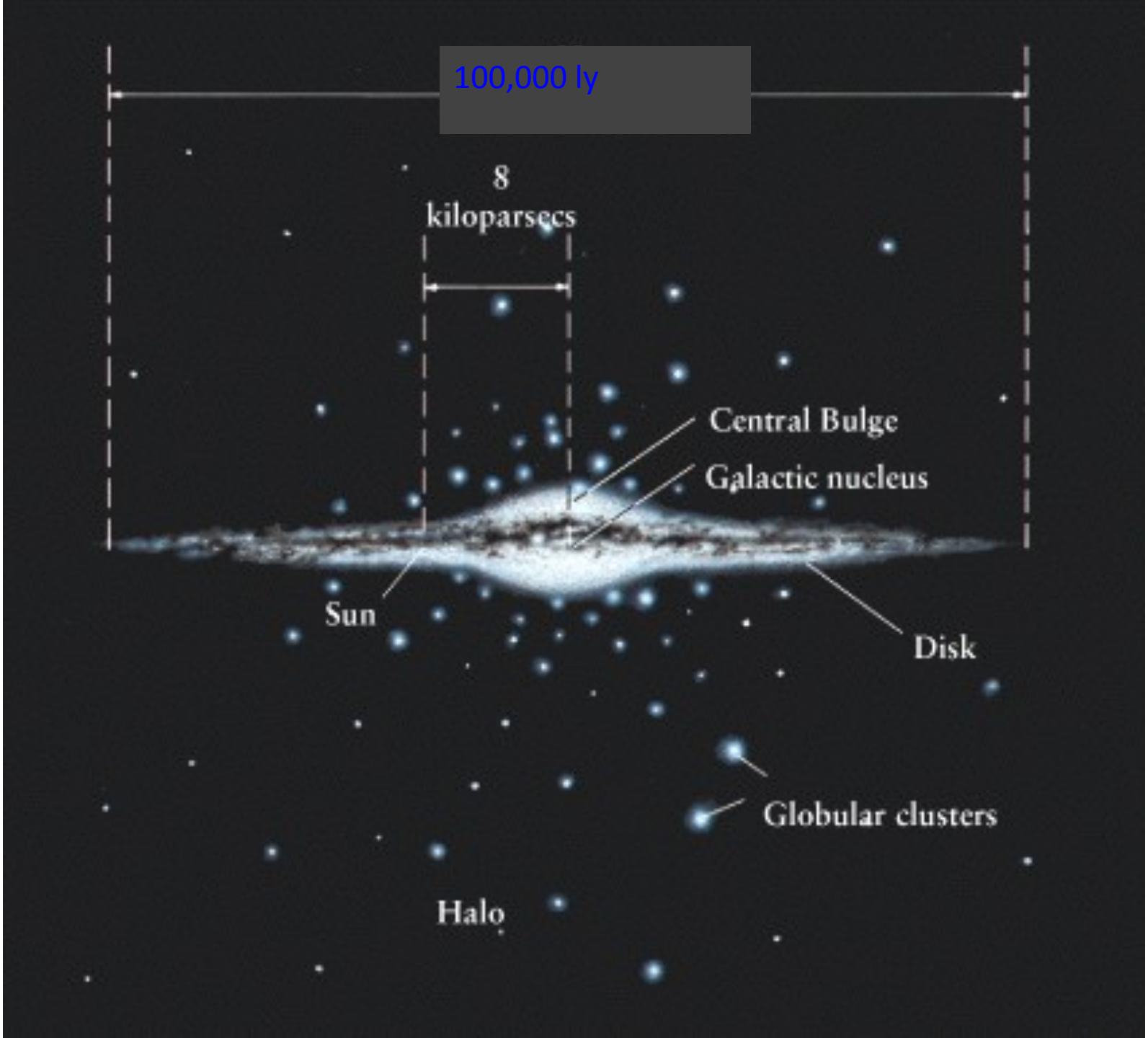
NGC 4030

NGC 2997

NGC 1232

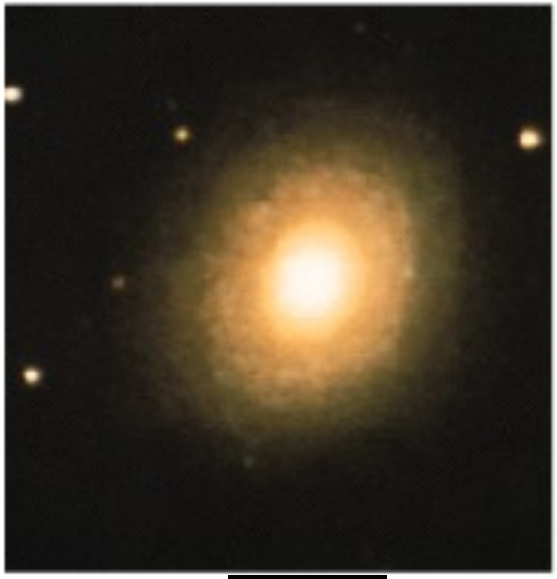
Spiral Galaxies

- 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

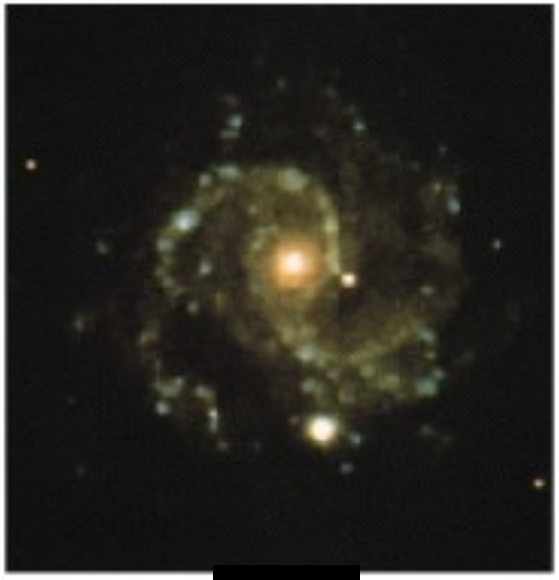
Spiral Structure

- The Spiral structure can vary from galaxy to galaxy:
  - Sa – weak spiral
  - Sb – visible spiral
  - Sc – prominent spiral



Sa

Sb



Sc

Spiral Structure

- 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

Another spiral, viewed closer to edge on

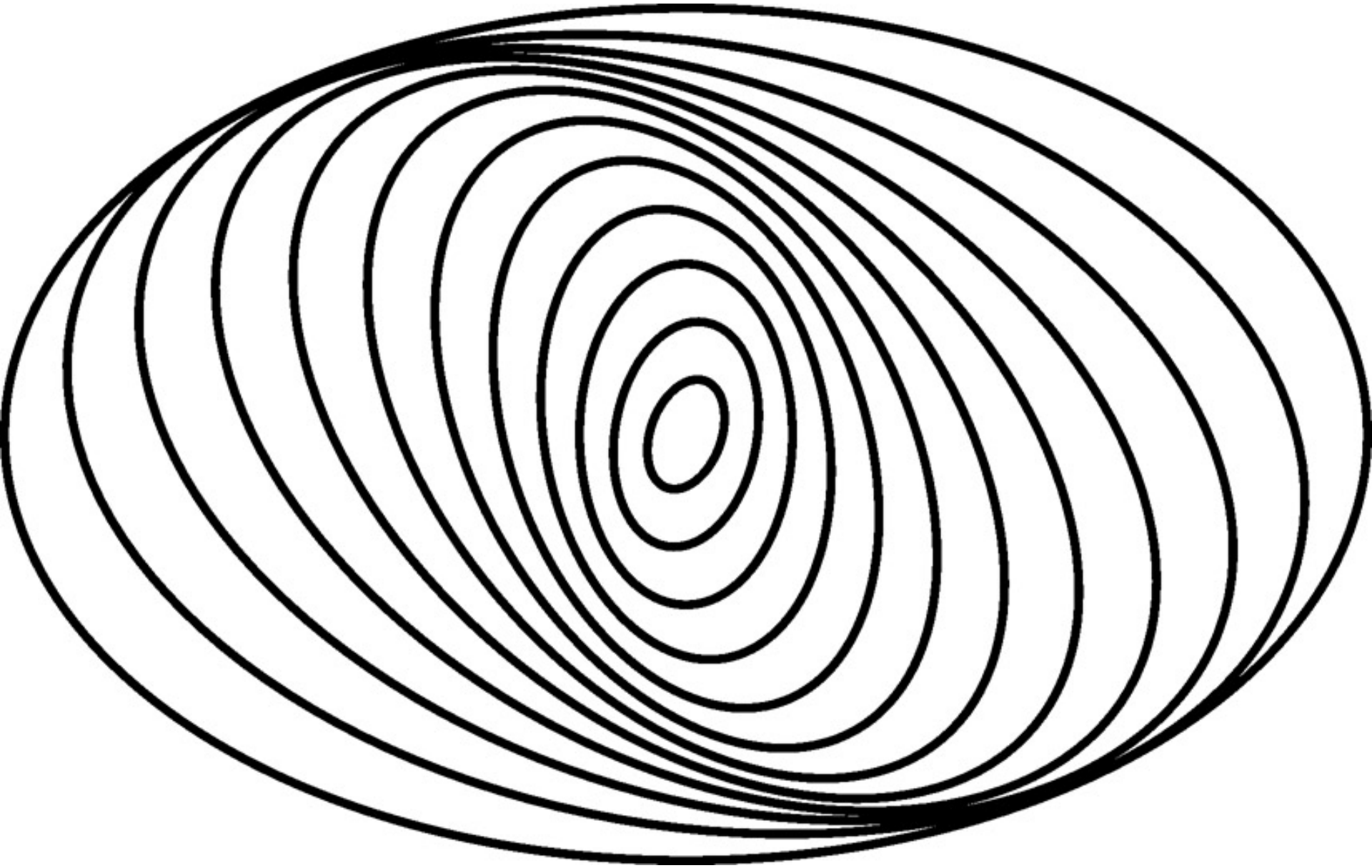
Barred Spiral Galaxy NGC 1300

Hubble Heritage

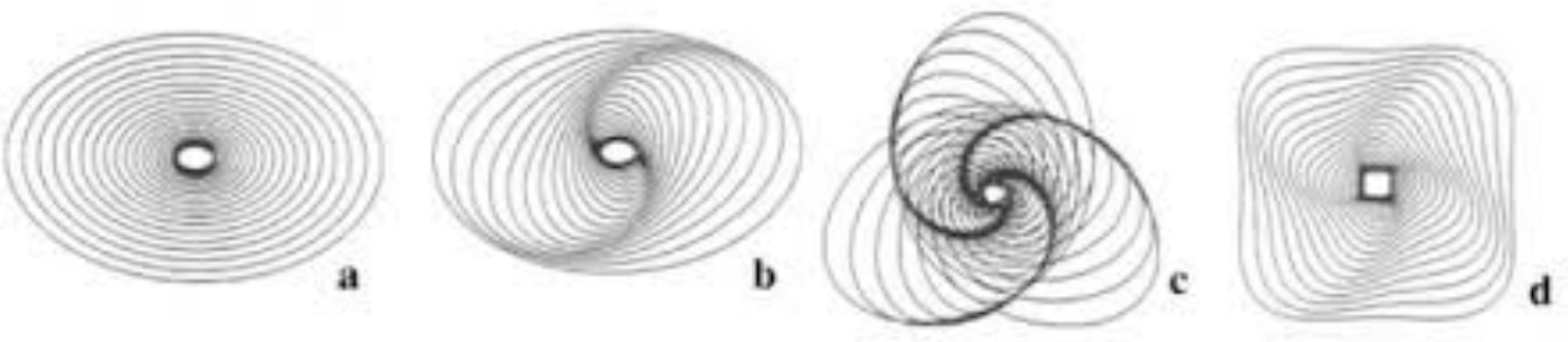
NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC05-01

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!



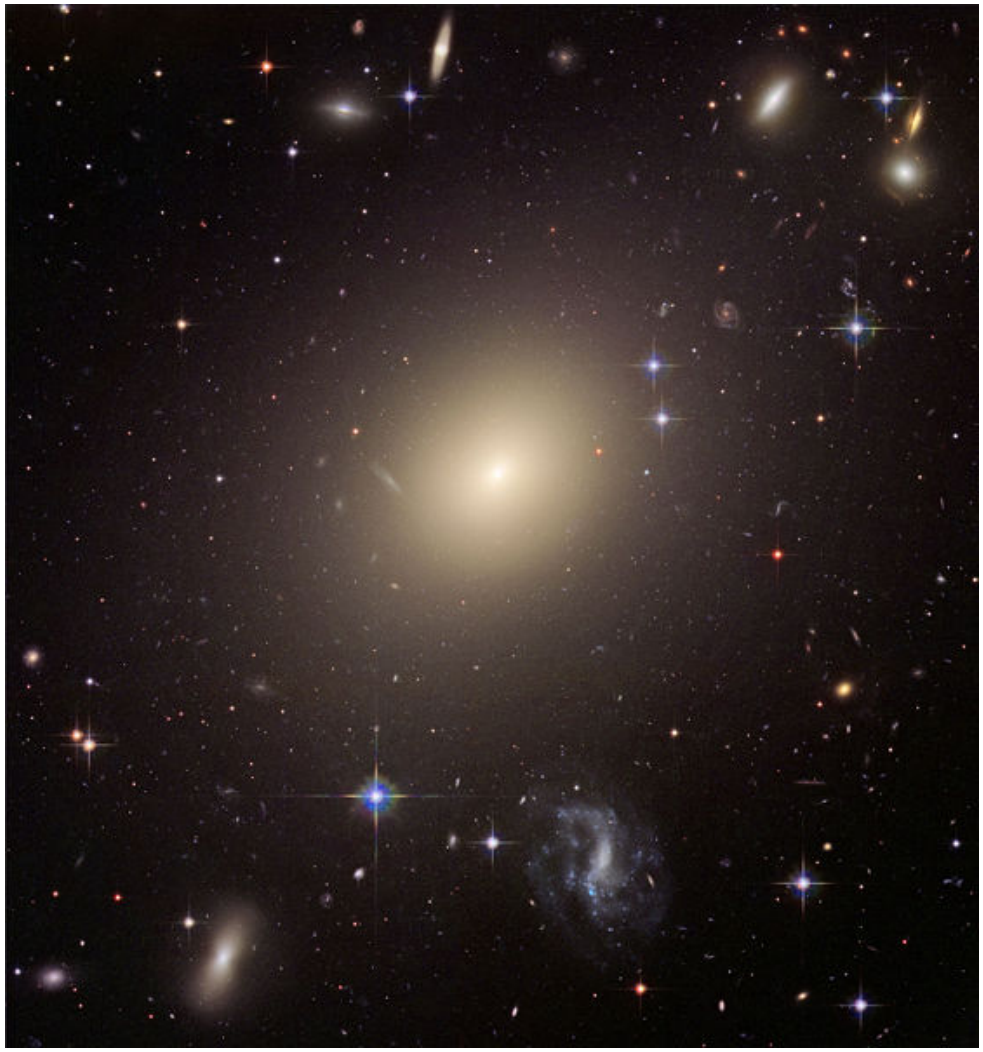
Spiral density waves can be created by misaligned, concentric elliptical orbits.



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

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

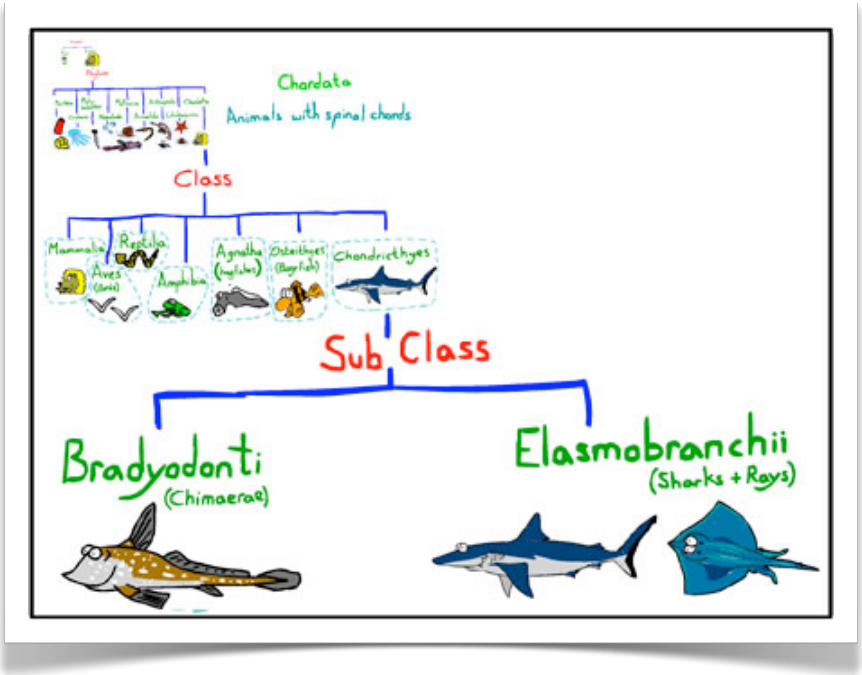
- The largest, most massive galaxies in the universe are elliptical
- Photo: the Virgo Cluster of galaxies, with several large elliptical galaxies surrounded by smaller ellipticals and spirals

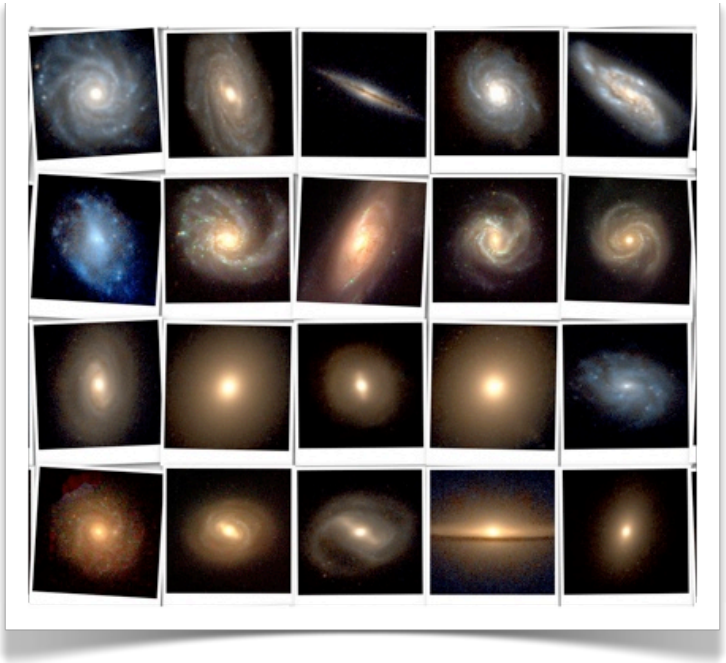
Galaxy classification

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.

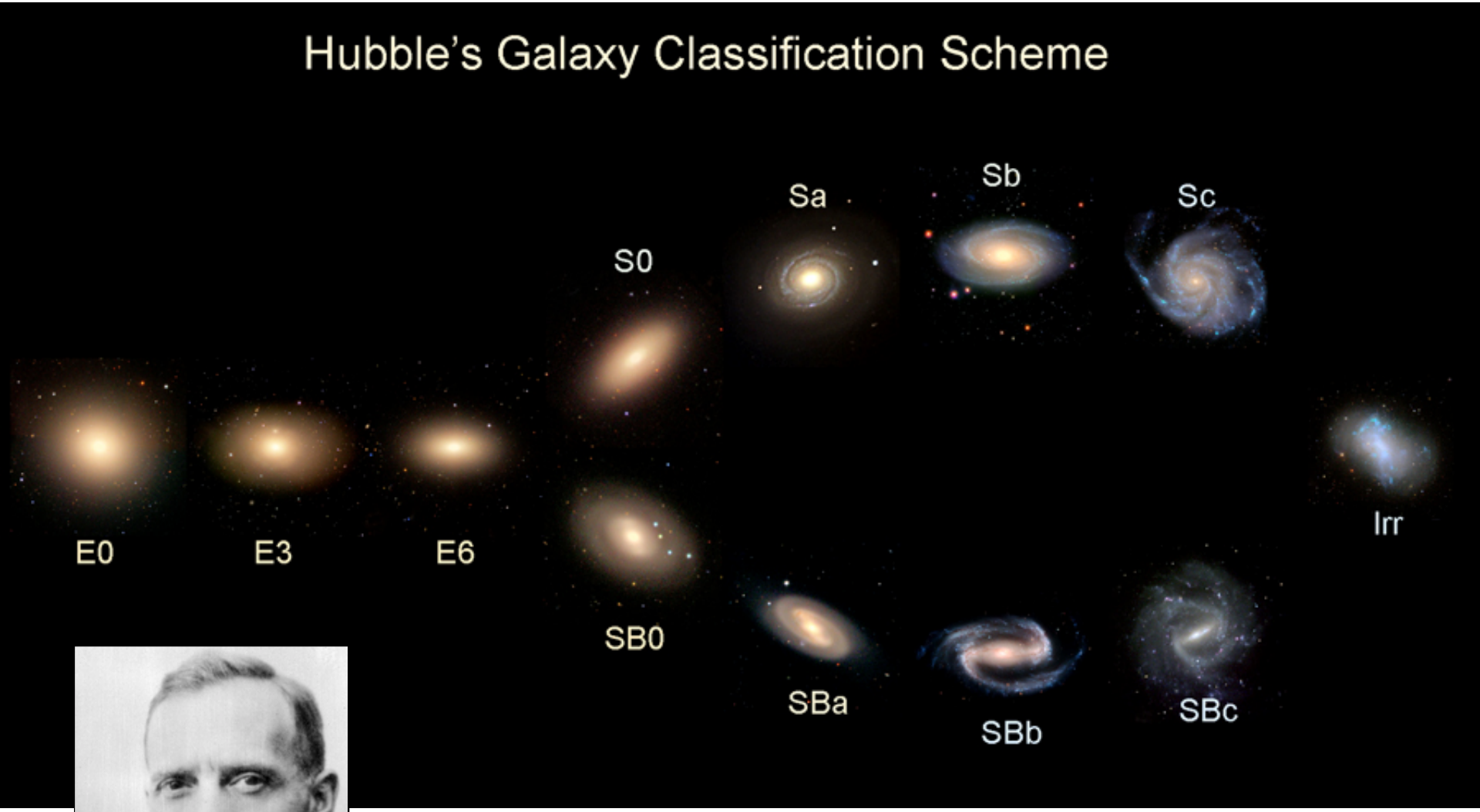
Why classify galaxies?





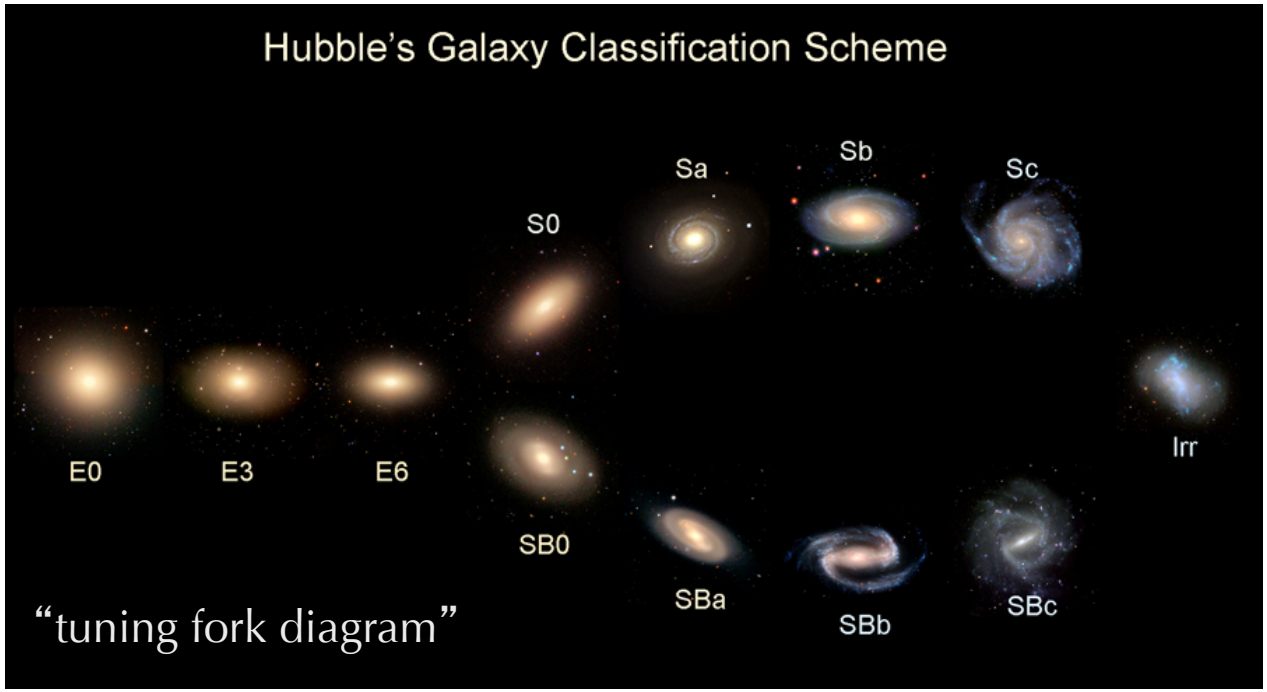
- Impose order
- Reveal correlations between properties or evolution
- Classification should be complete: include every galaxy
- Classification should be economical: don't include irrelevant detail (but how do we know which details are irrelevant?)

The Hubble Sequence



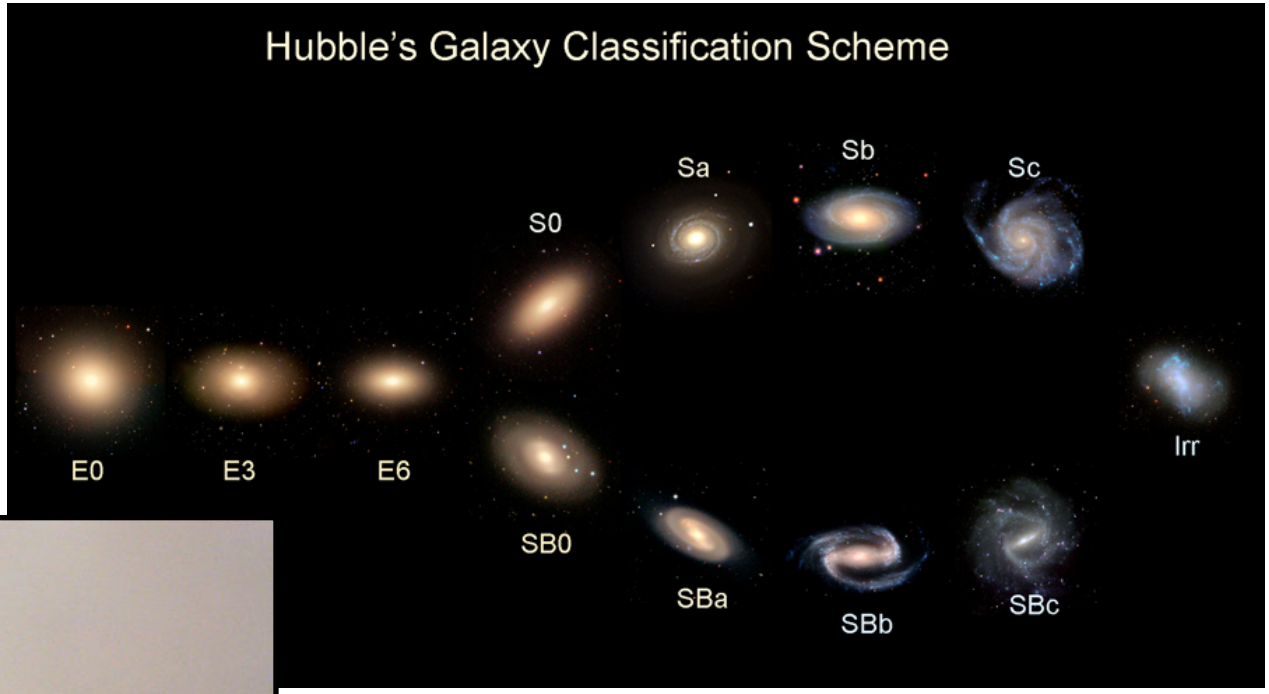
Edwin Hubble again

1926: proposed galaxy classification scheme still used today

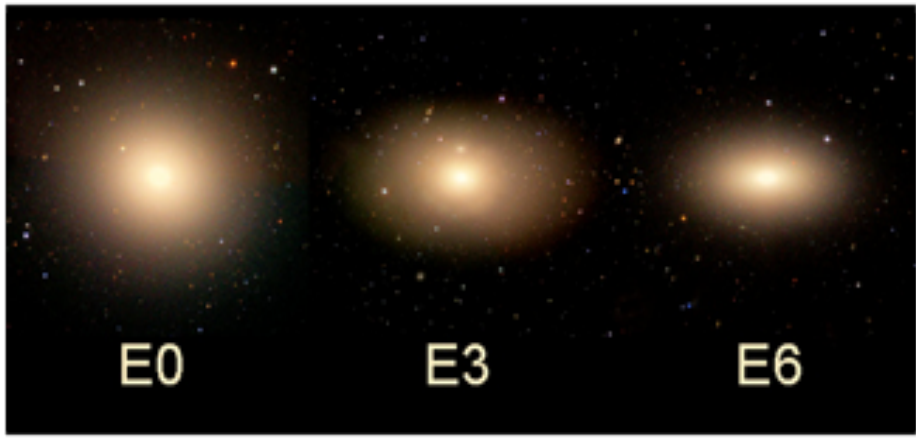


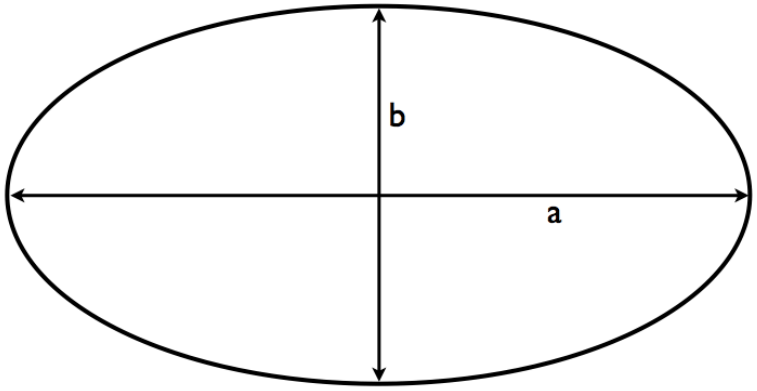
- Classification is based on a galaxy's appearance
- Three main categories:
  - **Ellipticals**
  - **Spirals**: normal (S) and barred (Sb)
  - **Irregular**
  - A galaxy's classification is called its **Hubble type**

"tuning fork diagram"



Elliptical Galaxies

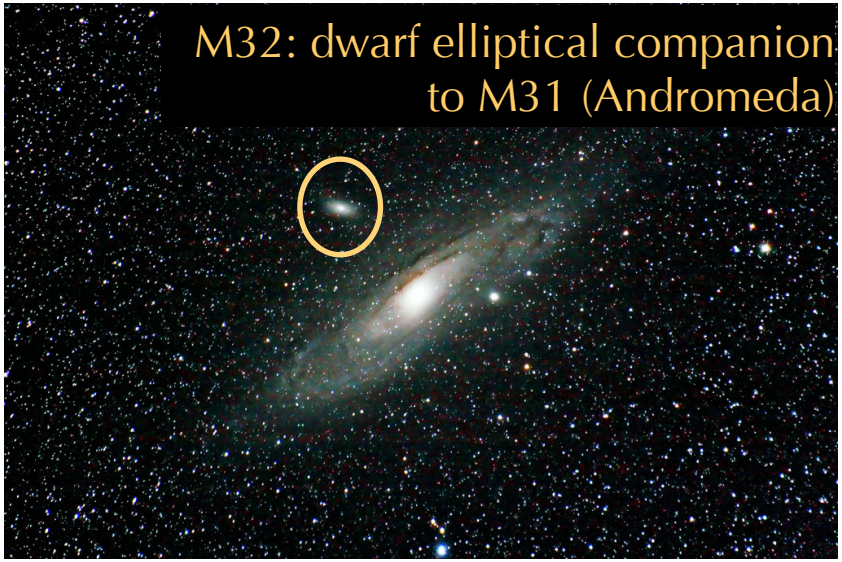




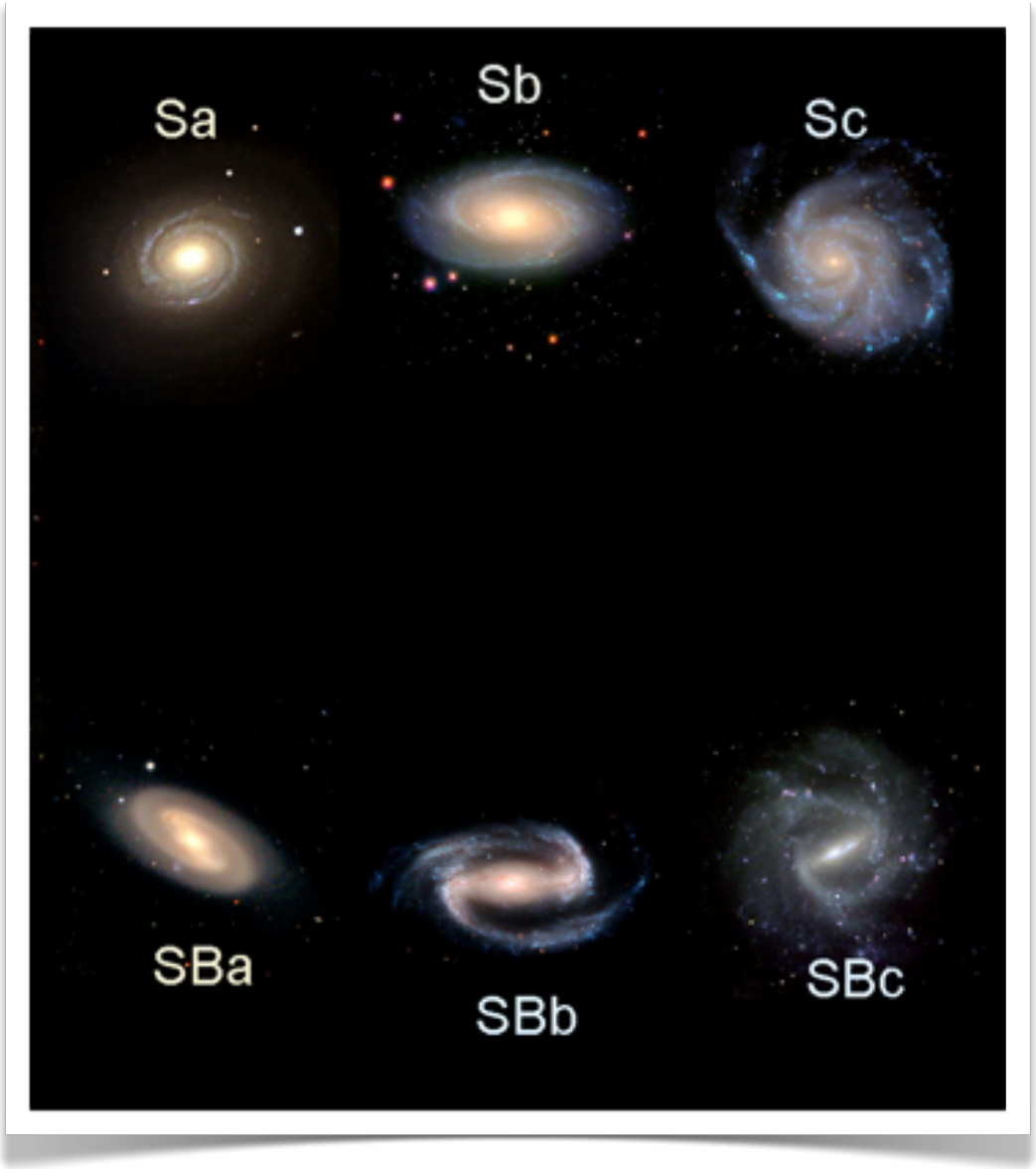
a = major axis
b = minor axis

- 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!

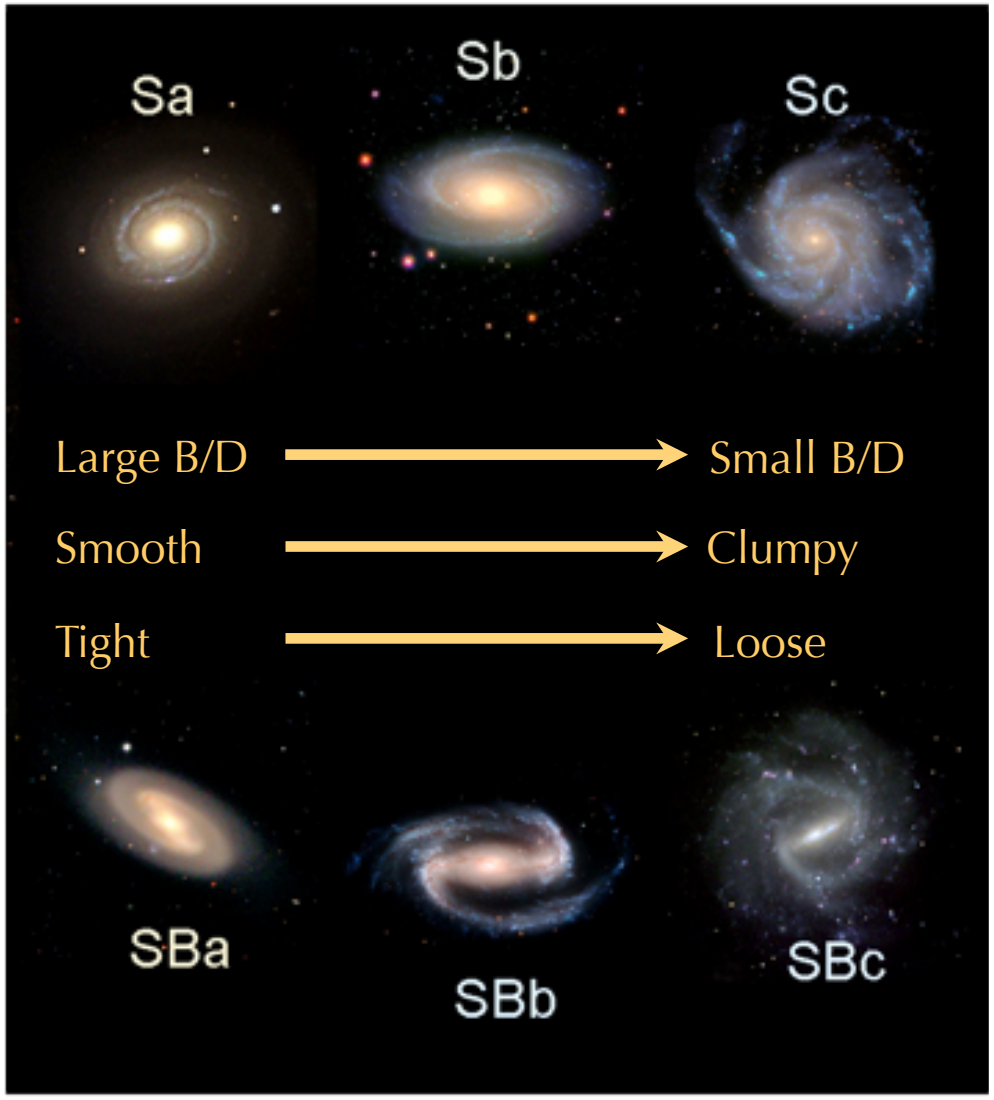
Elliptical Galaxies



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: Sa


Andromeda Galaxy: Sb
Dwarf elliptical M32

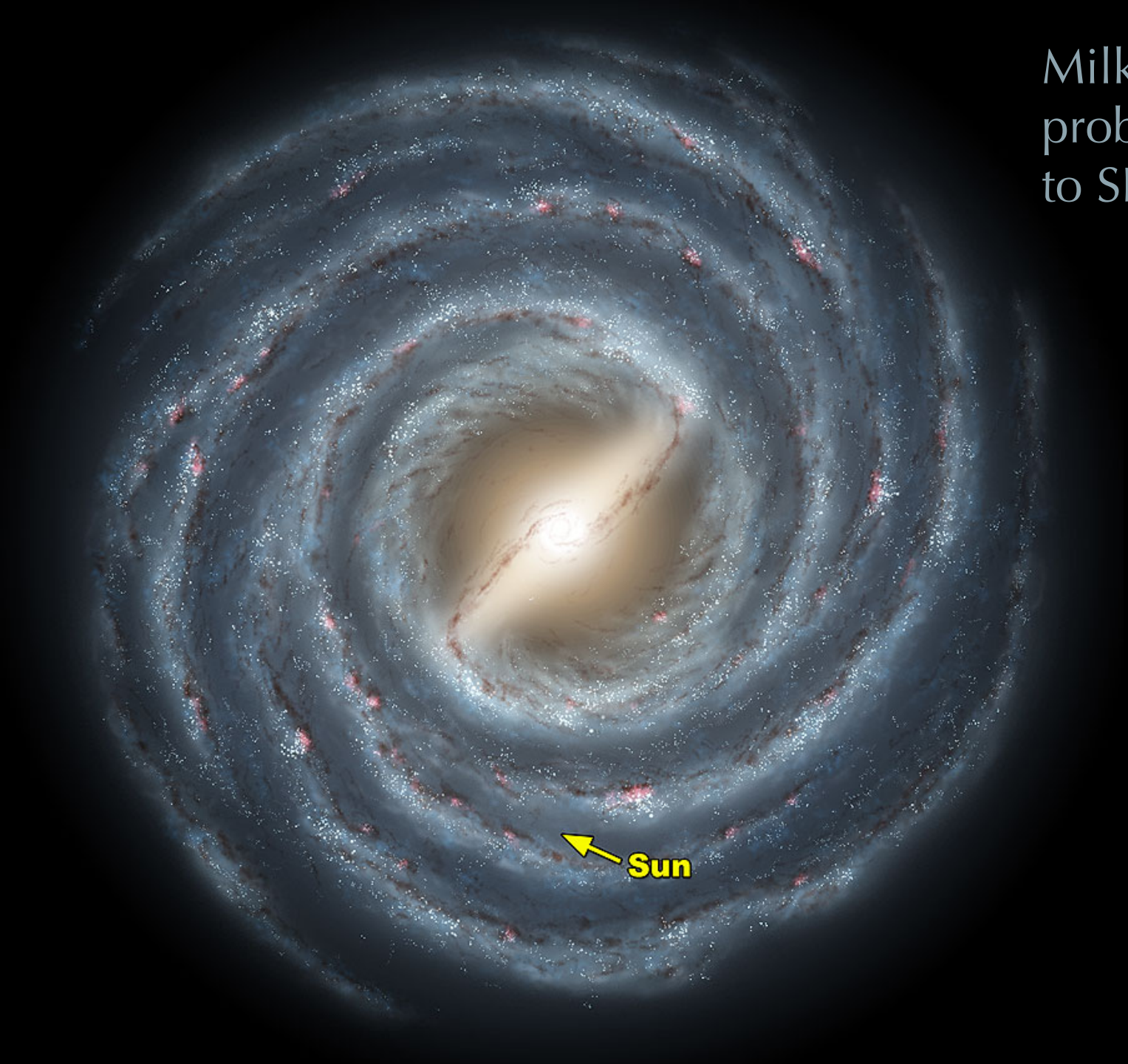
- M51 (Whirlpool Galaxy): Sc

More complicated: M83 (Southern Pinwheel)

SAB(s)c

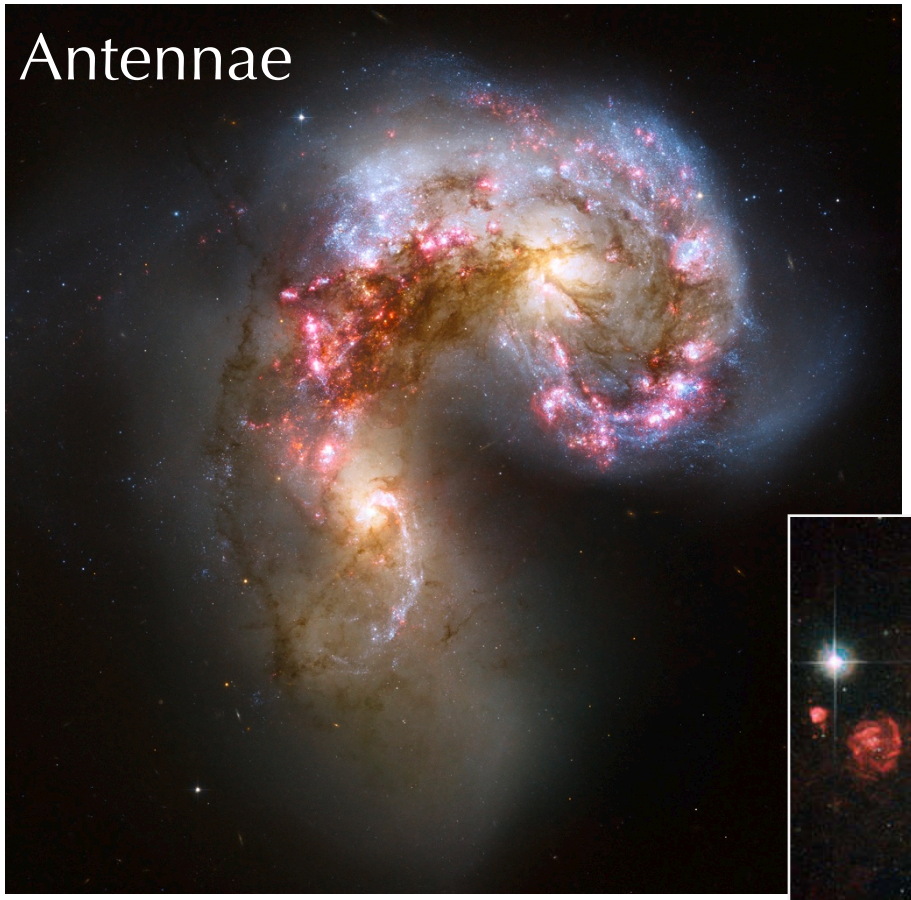
SAB: intermediate between normal, barred

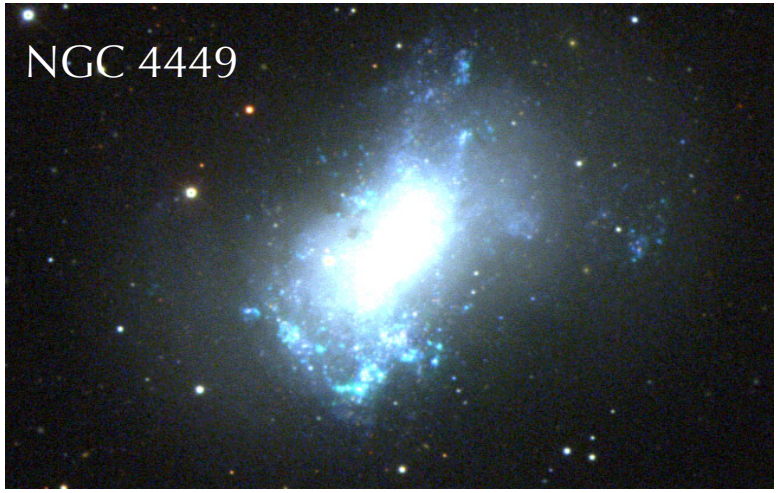
(s): S-shaped

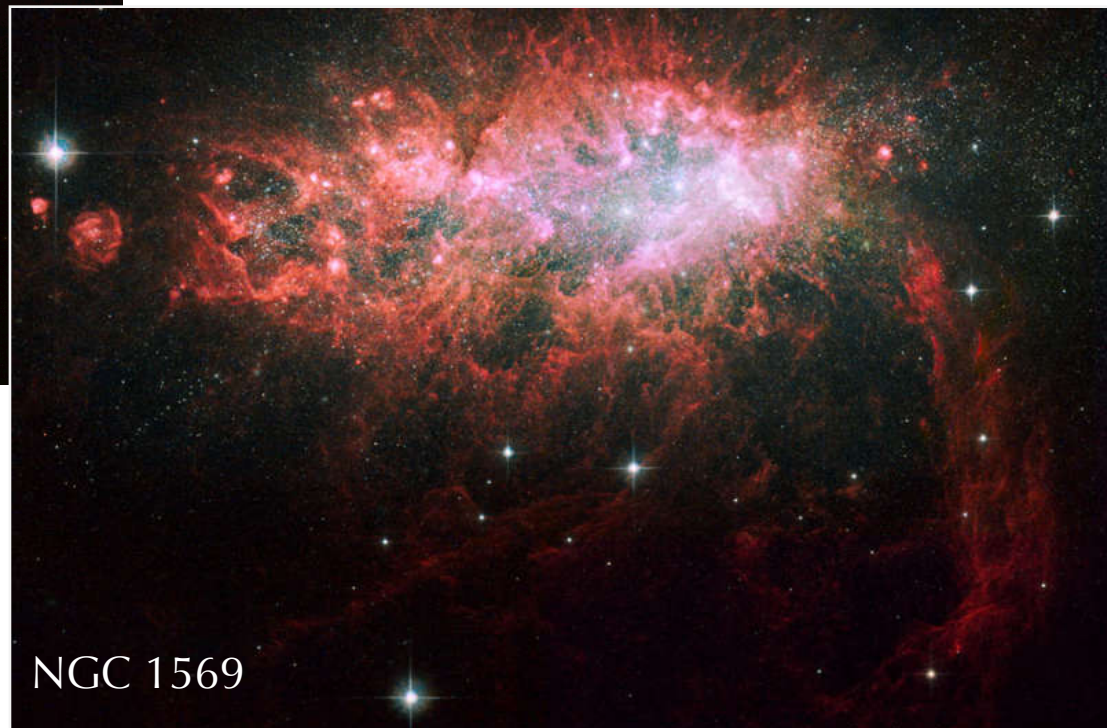


Milky Way:
probably SBb
to SBc

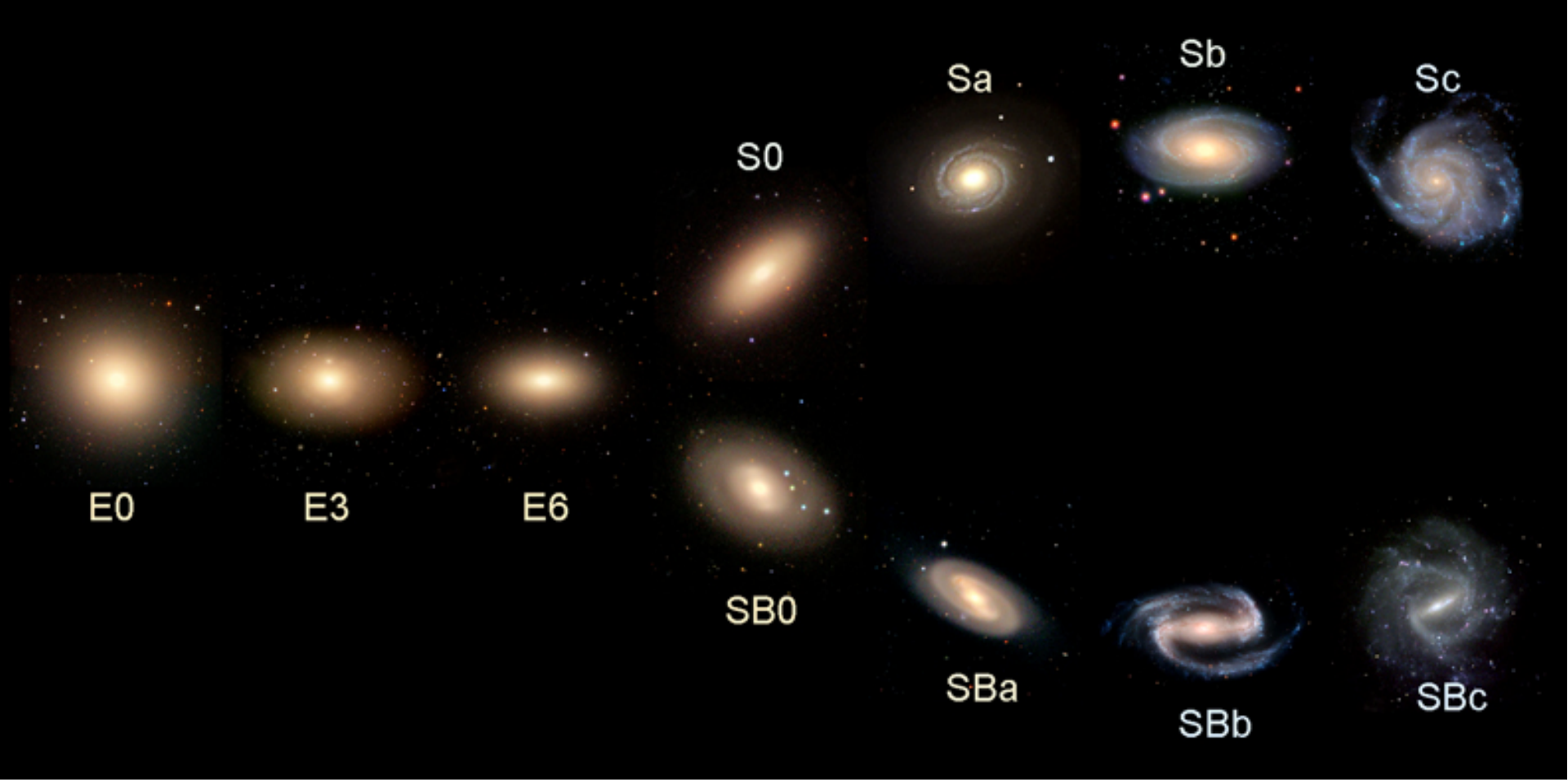
Irregular Galaxies



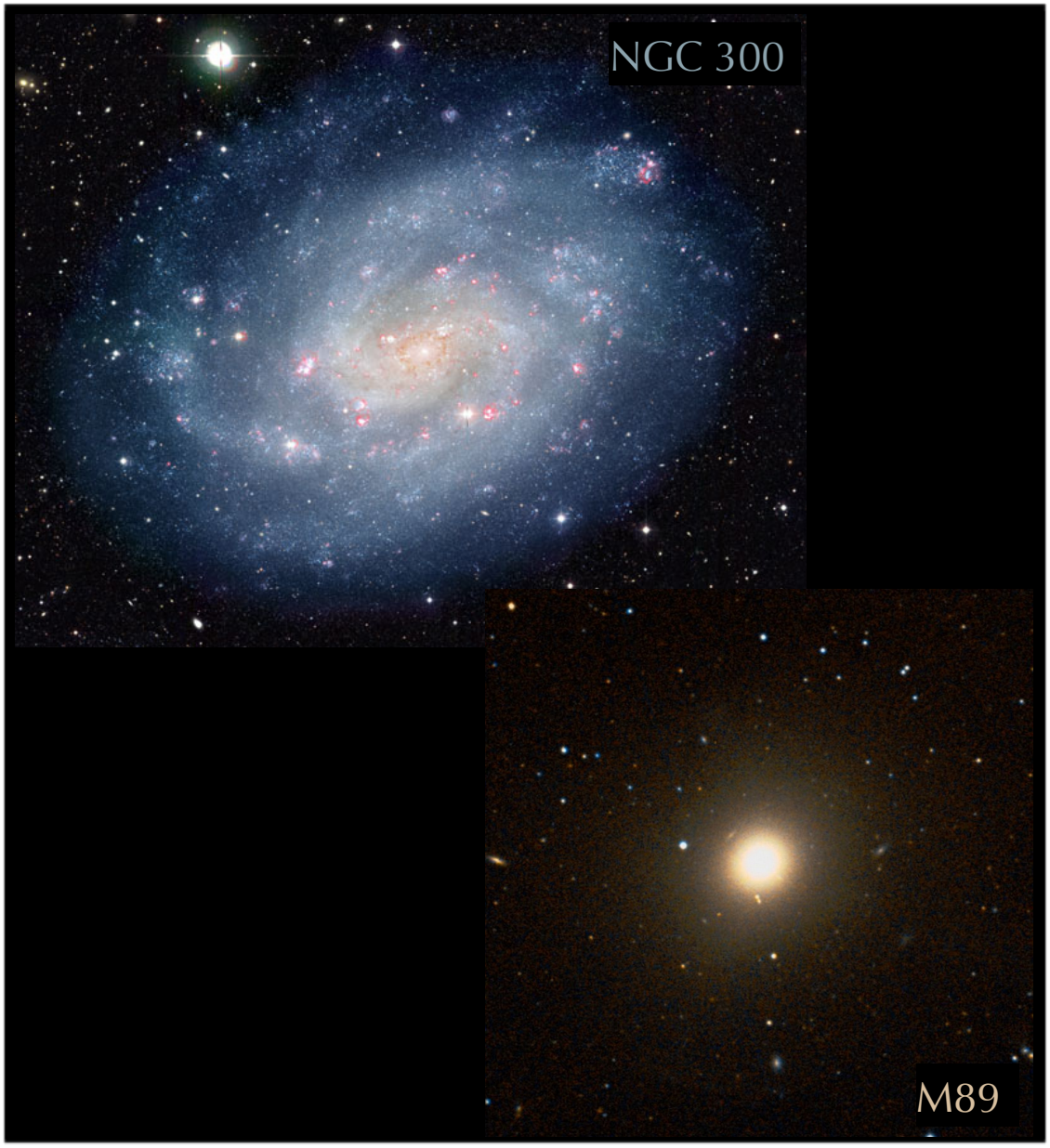




Usually small
Usually lots of gas and dust
Sometimes interacting



- 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

Nearby Galaxies

- Elliptical galaxies look something like giant globular clusters, with little gas or dust
- The stars in elliptical galaxies formed when the galaxy formed
- Elliptical galaxies are redder than spirals or irregulars, because they have no new stars and therefore no blue main sequence stars
- Galaxies age slowly, changing their appearance only after billions of years

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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