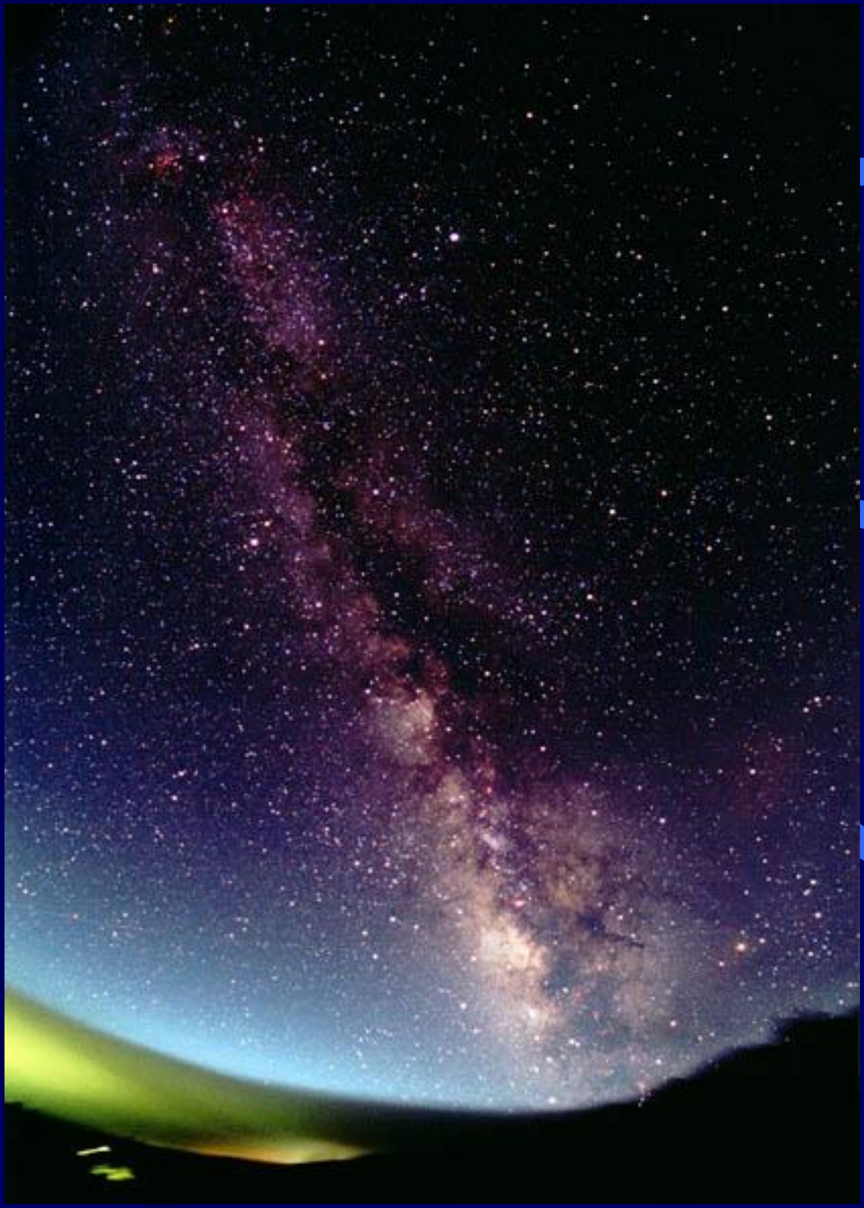
The Milky Way & Galaxies

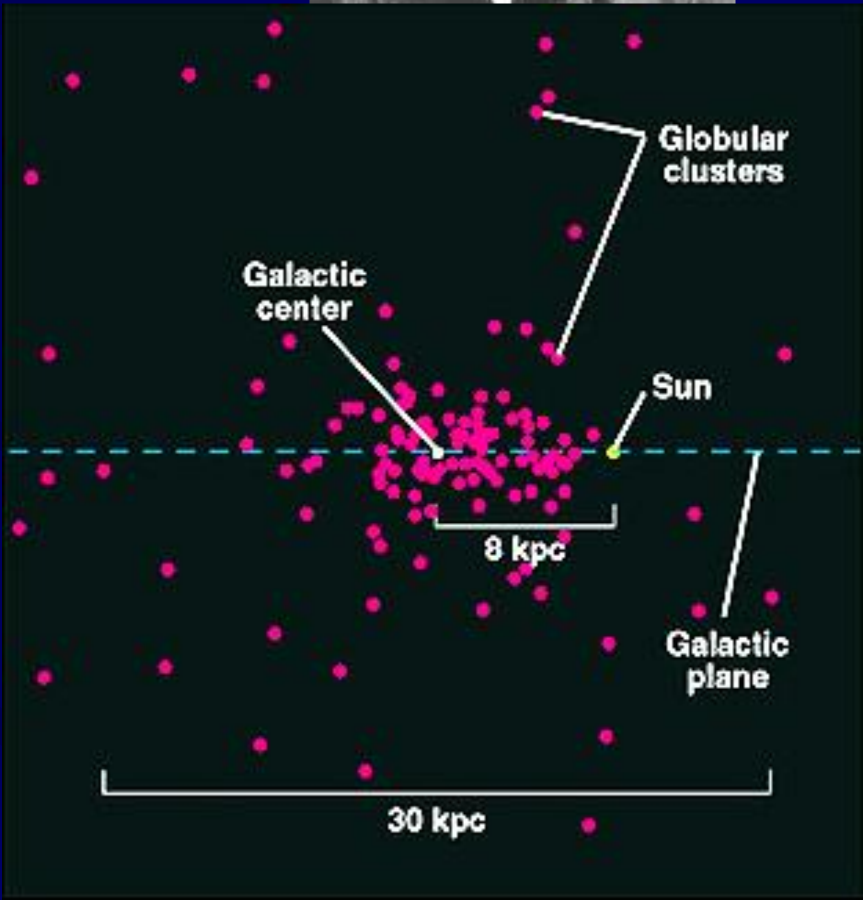
The Milky Way

- Appears as a milky band of light across the sky
- A small telescope reveals that it is composed of many stars (Galileo again!)
- Our knowledge of the Milky Way comes from a combination of observation and comparison to other galaxies



Where is the Center of the Milky Way?

- Harlow Shapley used variable stars, e.g. RR Lyrae stars, to map the distribution of globular clusters in the galaxy
- Found a spherical distribution about 30 kpc (30,000 pc) across
  - This is the true size of the galaxy
- Sun is (naturally!) not at the center – it's about 26,000 ly out



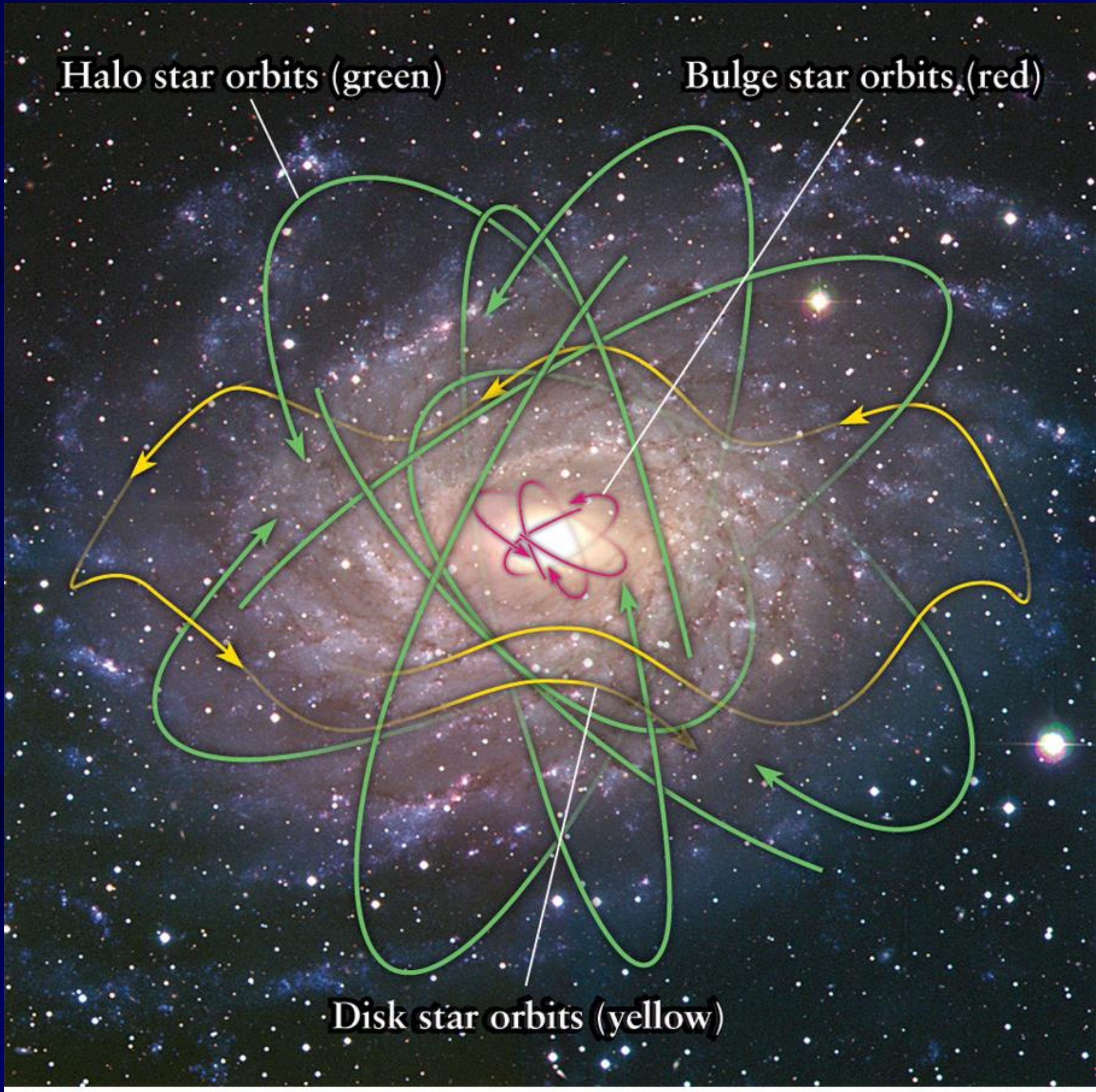
Standing on the shoulders of Giants

- Shapley used methods developed by others to measure the distance to globulars
- Cepheid variables show luminosity-period correlations discovered by Henrietta Leavitt

- Shapley single-handedly increase the size of the universe tenfold!

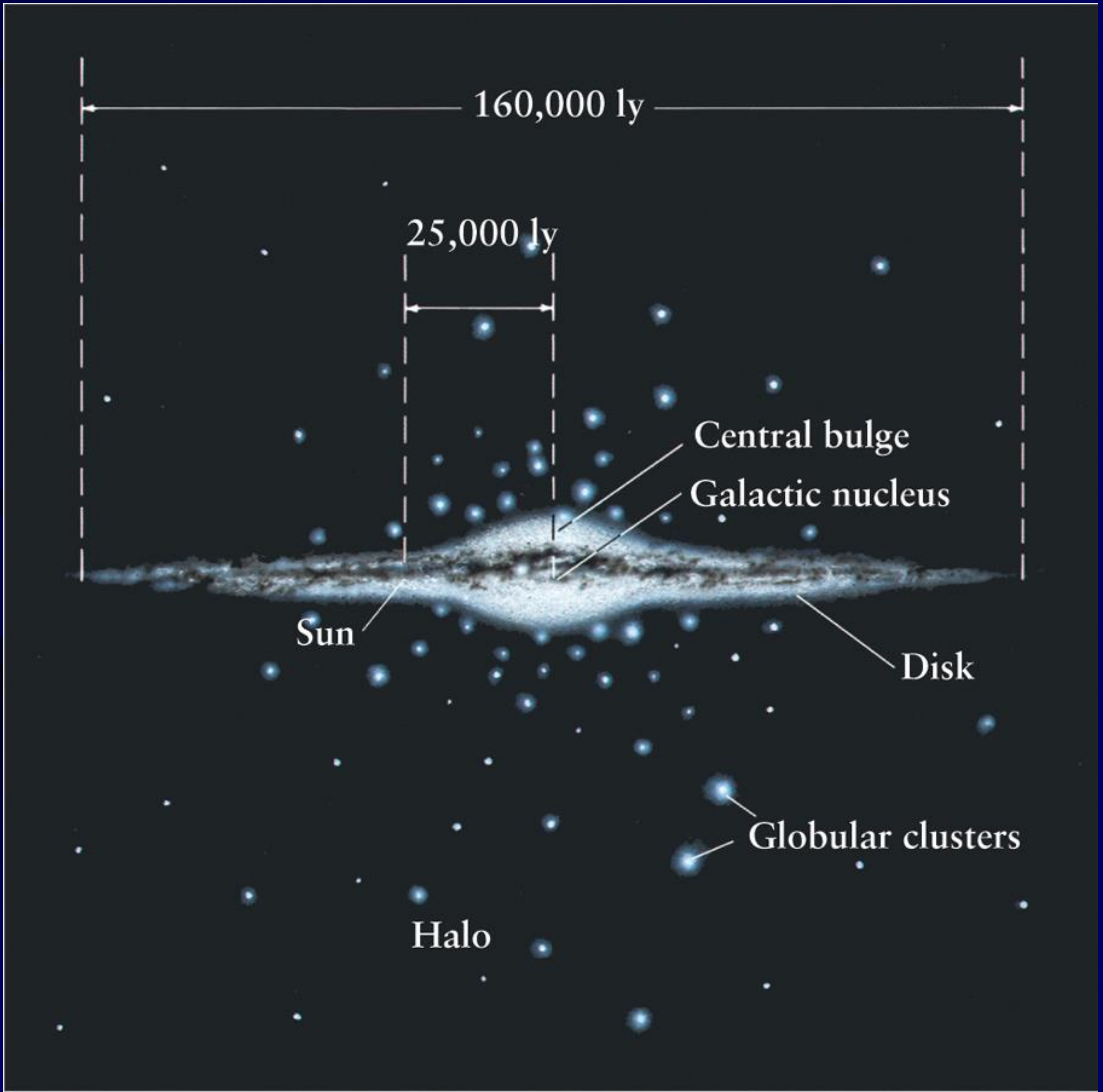
Structure of a Spiral Galaxy

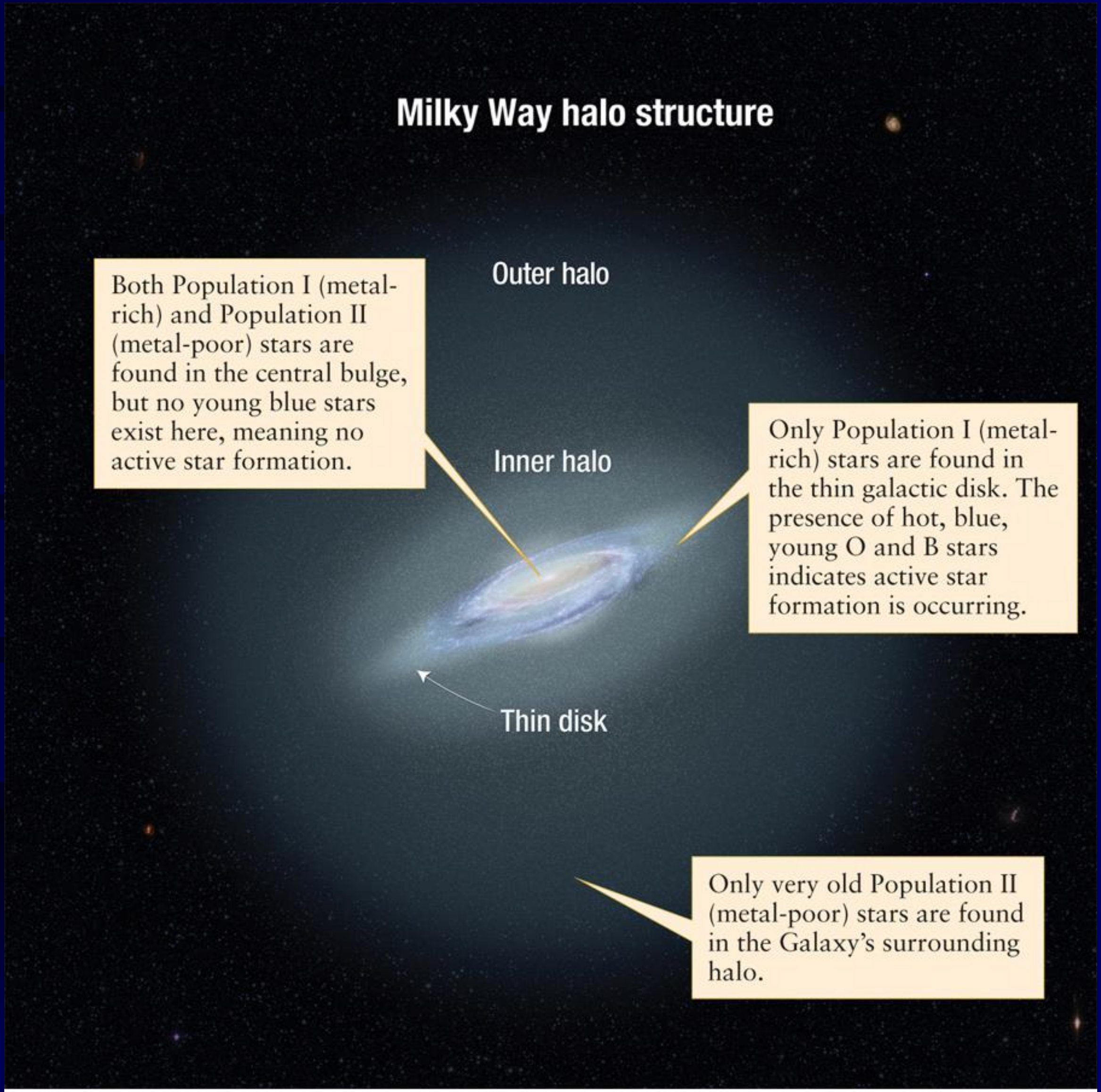
- Three main parts of a galaxy:
  - **<u>Bulge</u>** (center of galaxy)
  - **<u>Disk</u>** (rotating around center)
  - **<u>Halo</u>** (orbiting around bulge with randomly inclined orbits)



1999–2002, Australian Astronomical Observatory; photograph by S. Lee, C. Tinney, and D. Malin

The shape of our Milky Way



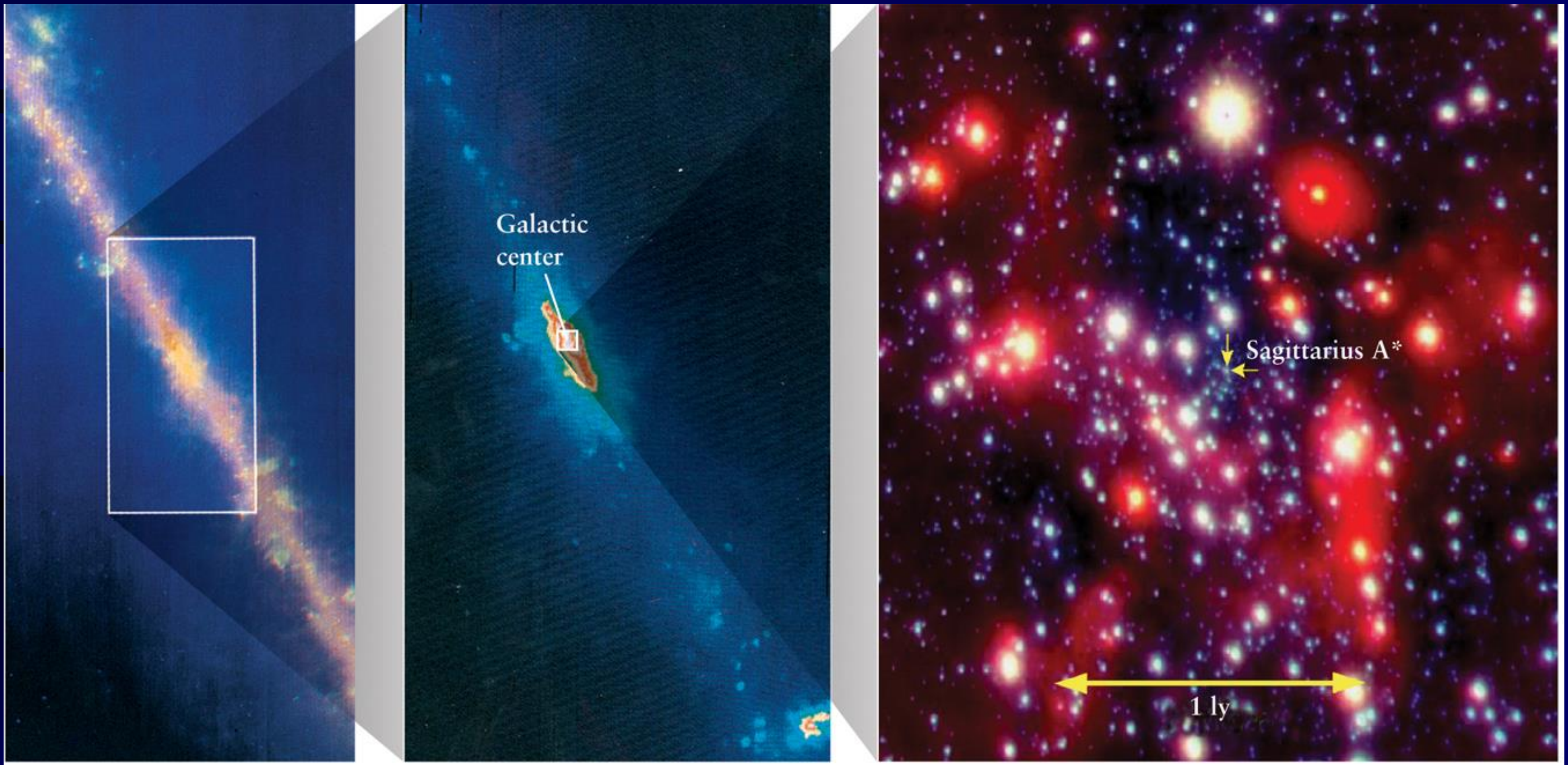


NASA, ESA, and A. Feild [STScI]

Properties of Bulge, Disk and Halo

Disk	Halo	Bulge
Highly flattened	spherical	football-shaped
young and old stars	only old stars	young and old stars
has Gas and dust	none	lots in center
Star formation	none since 10 billion yrs	in inner regions
White colored, blue spiral arms	reddish	yellow-white

Looking through dust at the Galactic Center



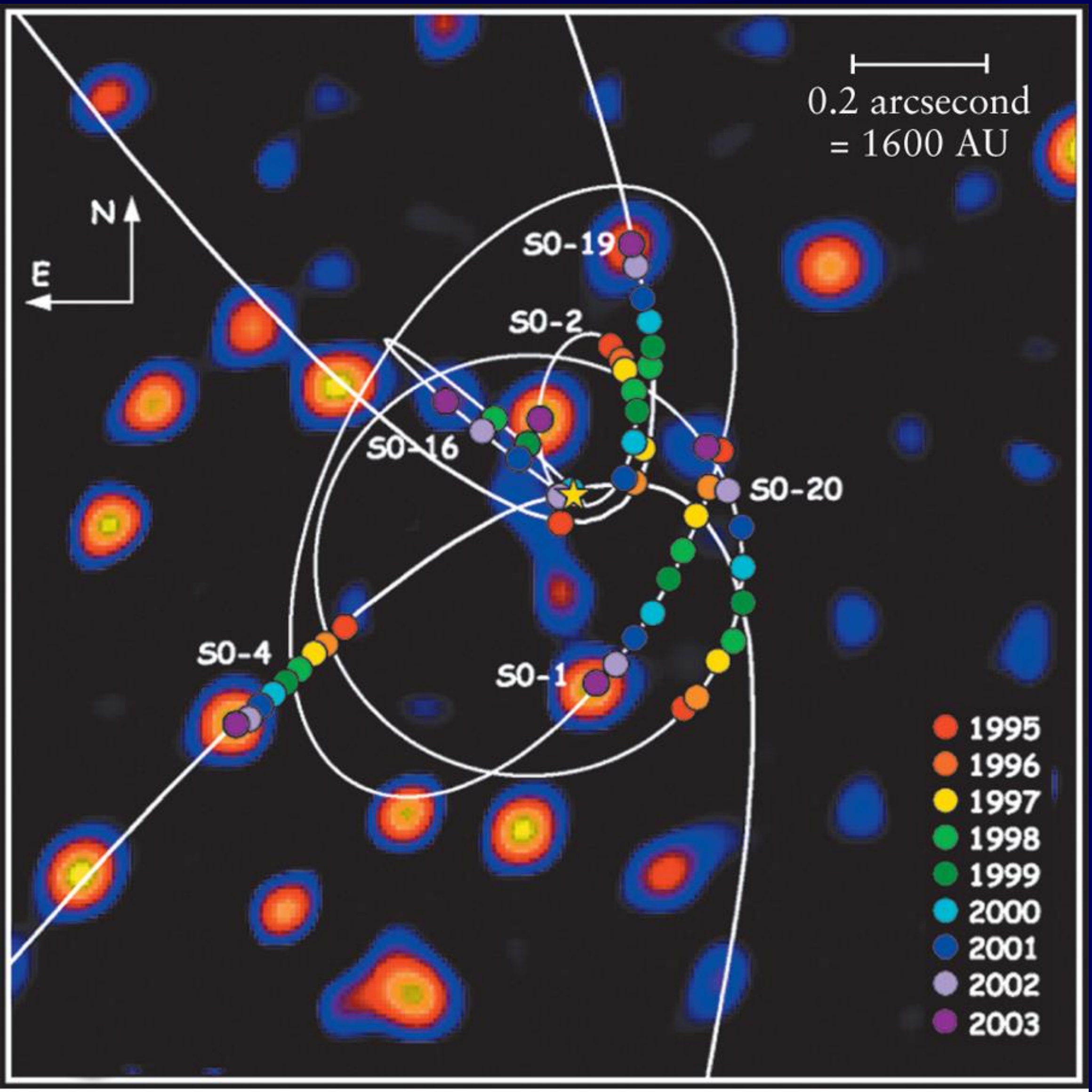
(a) A wide-angle infrared view

(b) A close-up view shows a more luminous region at the galactic center.

(c) An extreme close-up view centered on Sagittarius A*, a radio source at the very center of the Milky Way Galaxy, shows hundreds of stars within 1 ly (0.3 pc).

a, b: NASA; c: R. Schödel et al., MPE/ESO

Evidence for the supermassive Black Hole at the Center: objects near it move incredibly fast



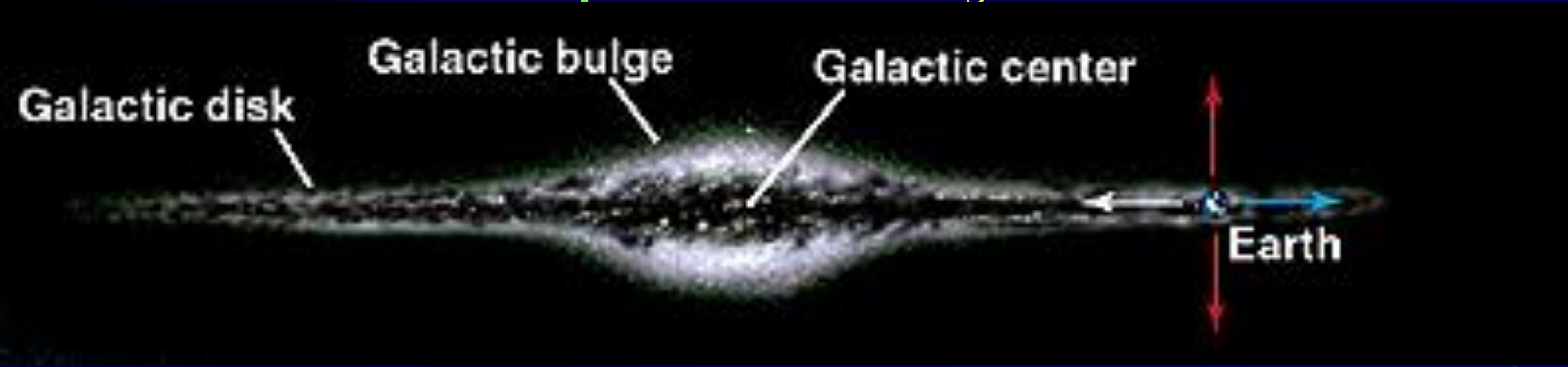
These images/animations were created by Prof. Andrea Ghez and her research team at UCLA and are from data sets obtained with the W. M. Keck Telescopes. Image creators include Andrea Ghez, Sylvana Yelda, Leo Meyer, Jessica Lu, Seth Hornstein, and Angelle Tanner. UCLA Galactic Center Group

Other Galaxies: Hubble supersedes Shapley

- Edwin Hubble identified single stars in the Andromeda nebula ("turning" it into a galaxy)
- Measured the distance to Andromeda to be 1 million Ly (modern value: 2.2 mill. Ly)
- Conclusion: it is 20 times more distant than the milky way's radius ➔ Extragalacticity!

➔ Shapley's theory falsified!

Q: How do we know we live in a Spiral Galaxy?



- After correcting for absorption by dust, it is possible to plot location of O- and B- (hot young stars) which tend to be concentrated in the spiral arms
- Radio frequency observations reveal the distribution of hydrogen (atomic) and molecular clouds
- Evidence for
  - galactic bulge
  - spiral arms

Rotation of the Galaxy

- Stars near the center rotate faster; those near the edges rotate slower (Kepler)
- The Sun revolves at about 250 km/sec around the center
- Takes 200-250 million years to orbit the galaxy – a “galactic year”

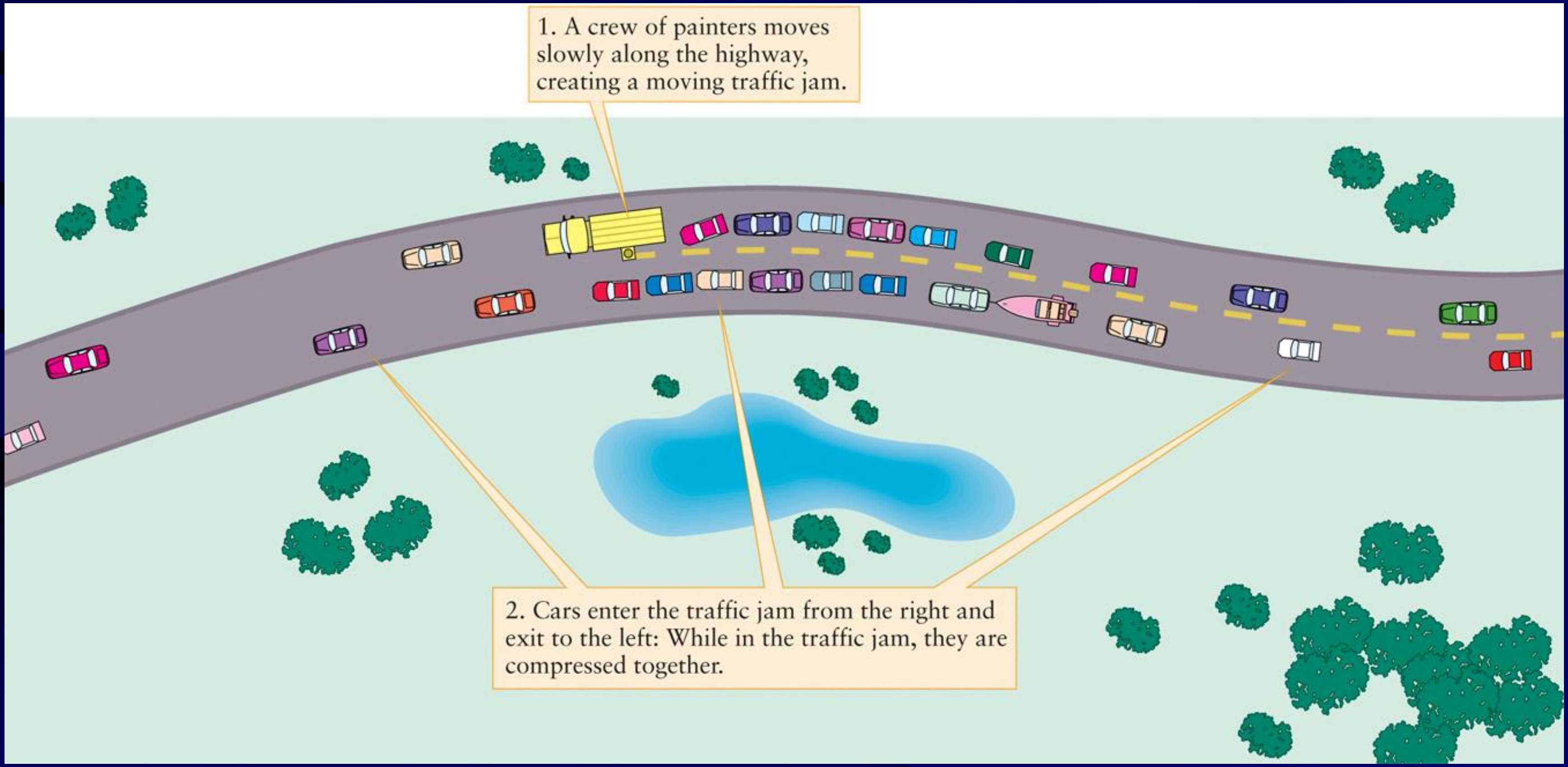
How do spiral arms persist?

➔ Why don't the "curl up"?

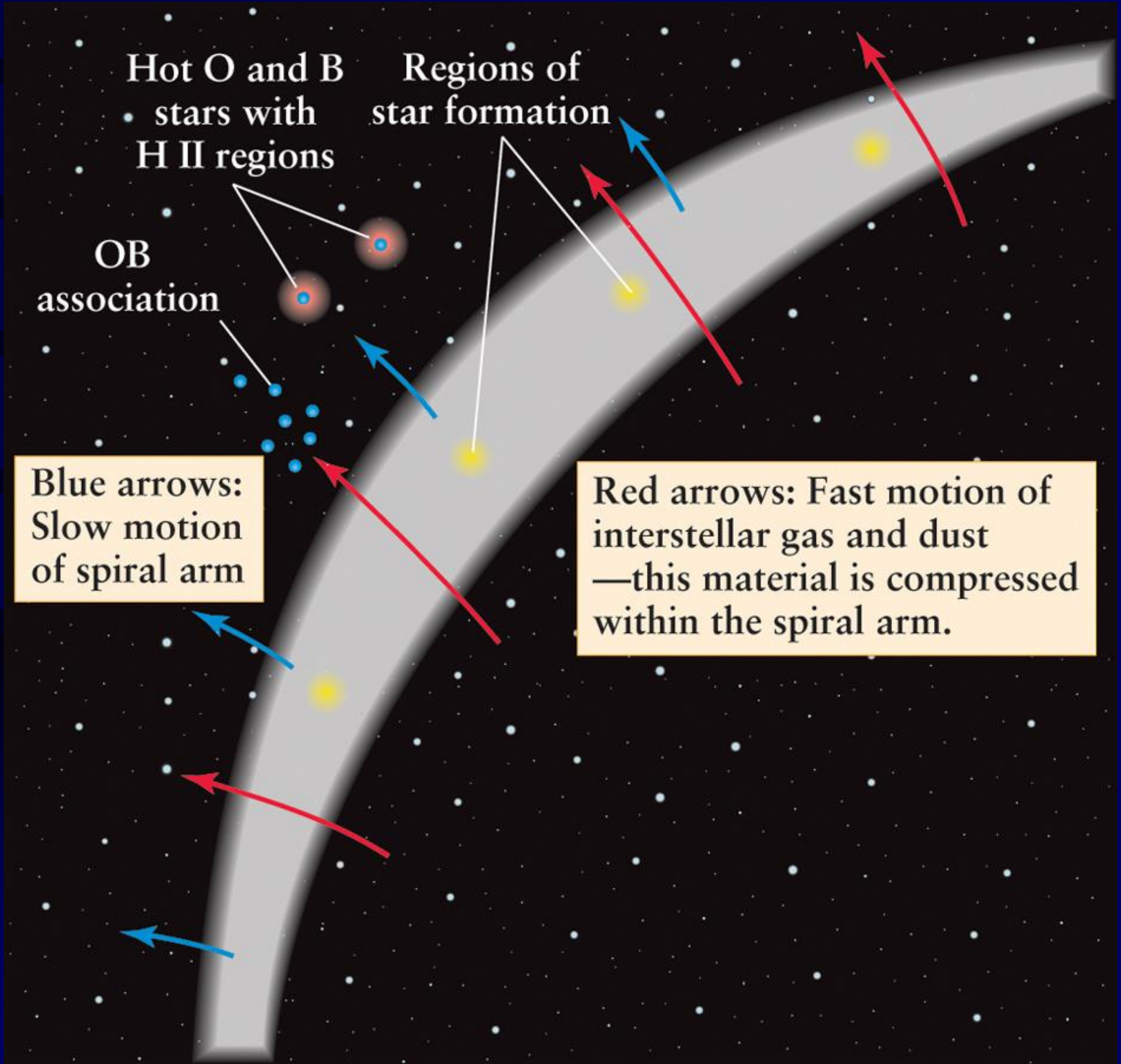
"Spiral Density Waves"

- A spiral compression wave (a shock wave) moves through the Galaxy
- Triggers star formation in the spiral arms
- Explains why we see many young hot stars in the spiral arms

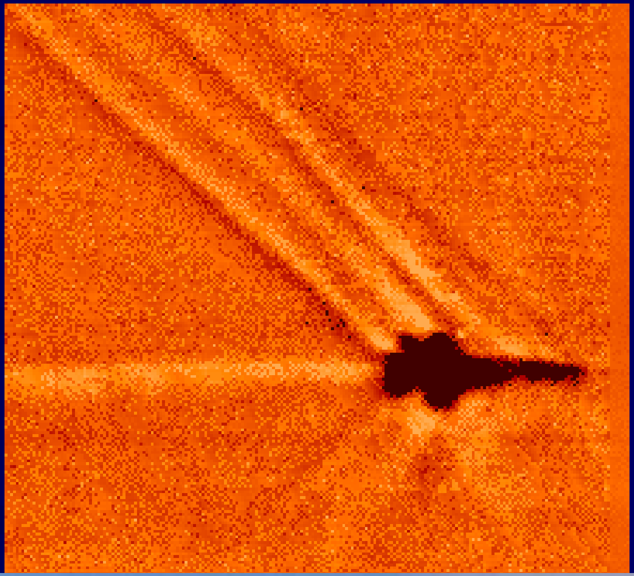
Analogy: Cars are closer together in traffic jam

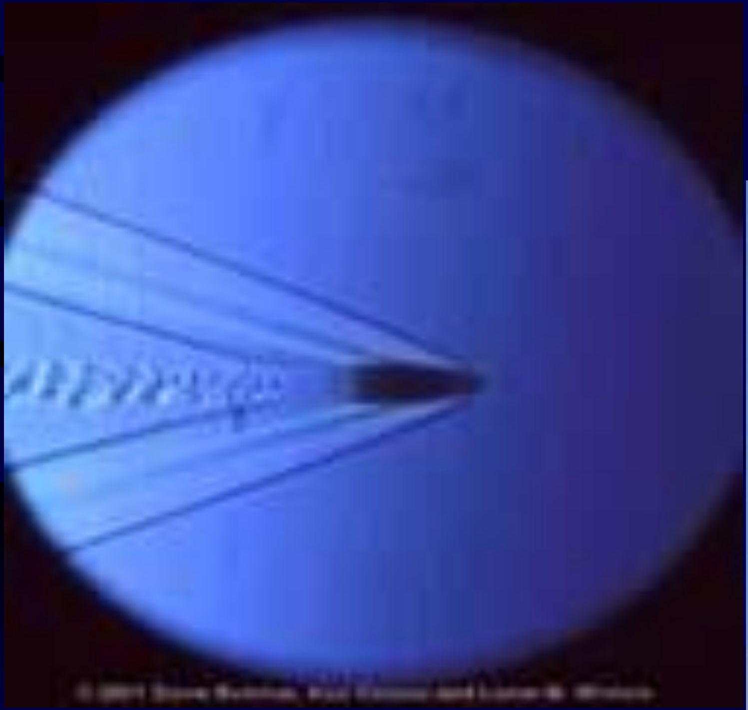


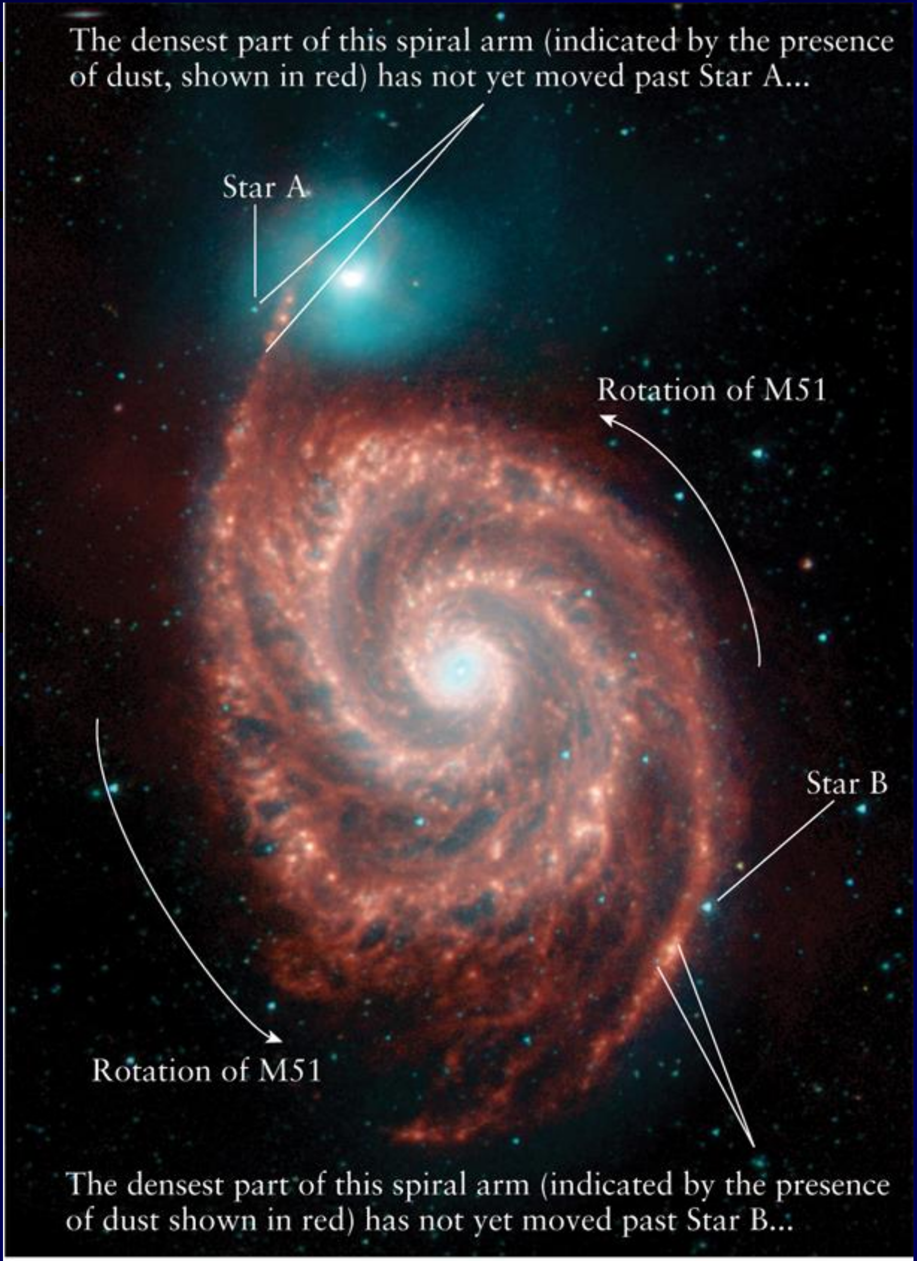
… just like gas & dust is compressed in spiral arms



Density (Shock) Waves



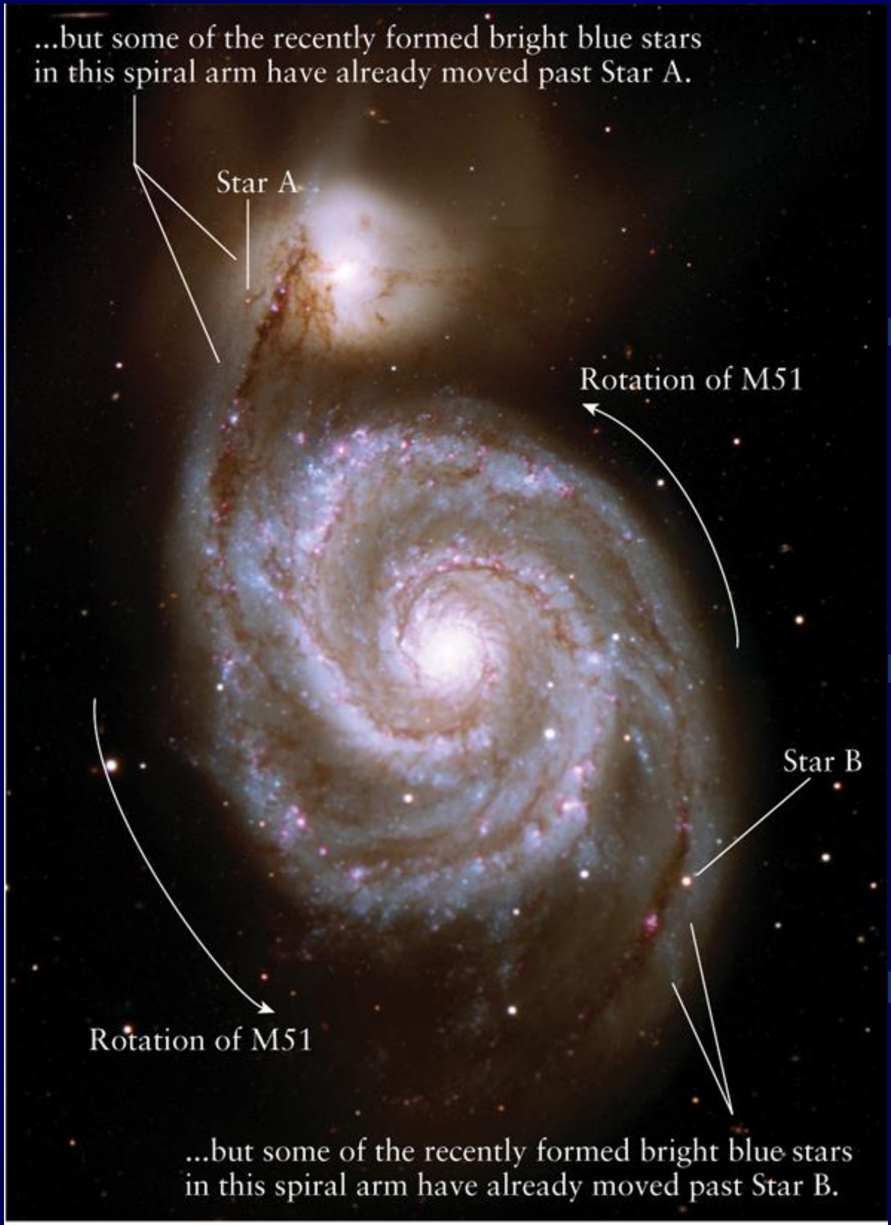




R I V U X G

(a) An infrared view of M51 shows the locations of dust

NASA, JPL-Caltech, and R. Kennicutt [U. of Arizona]



R I V U X G

(b) A visible-light view of M51 shows the locations of young stars

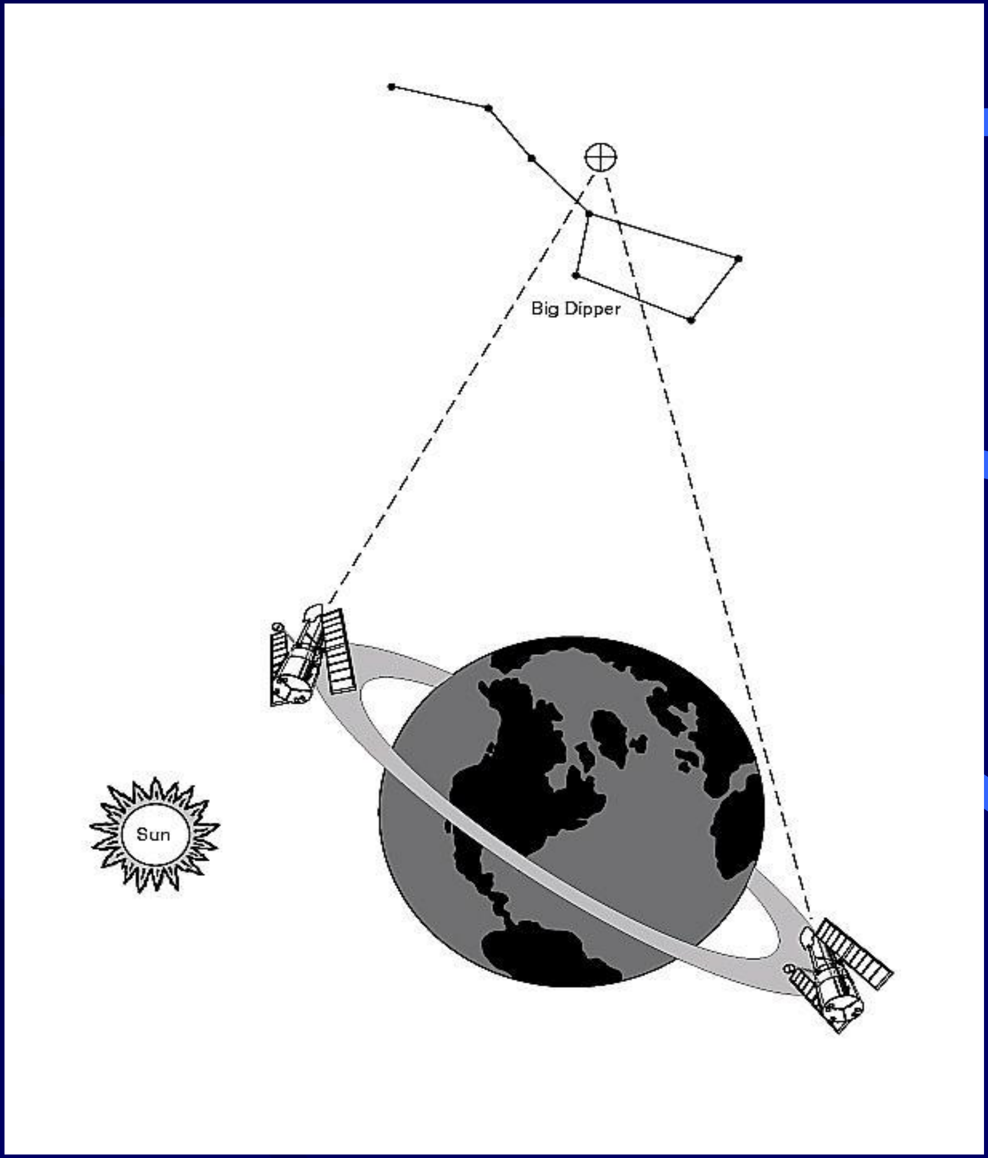
NASA, ESA, S. Beckwith [STScI], and The Hubble Heritage Team [STScI/AURA]

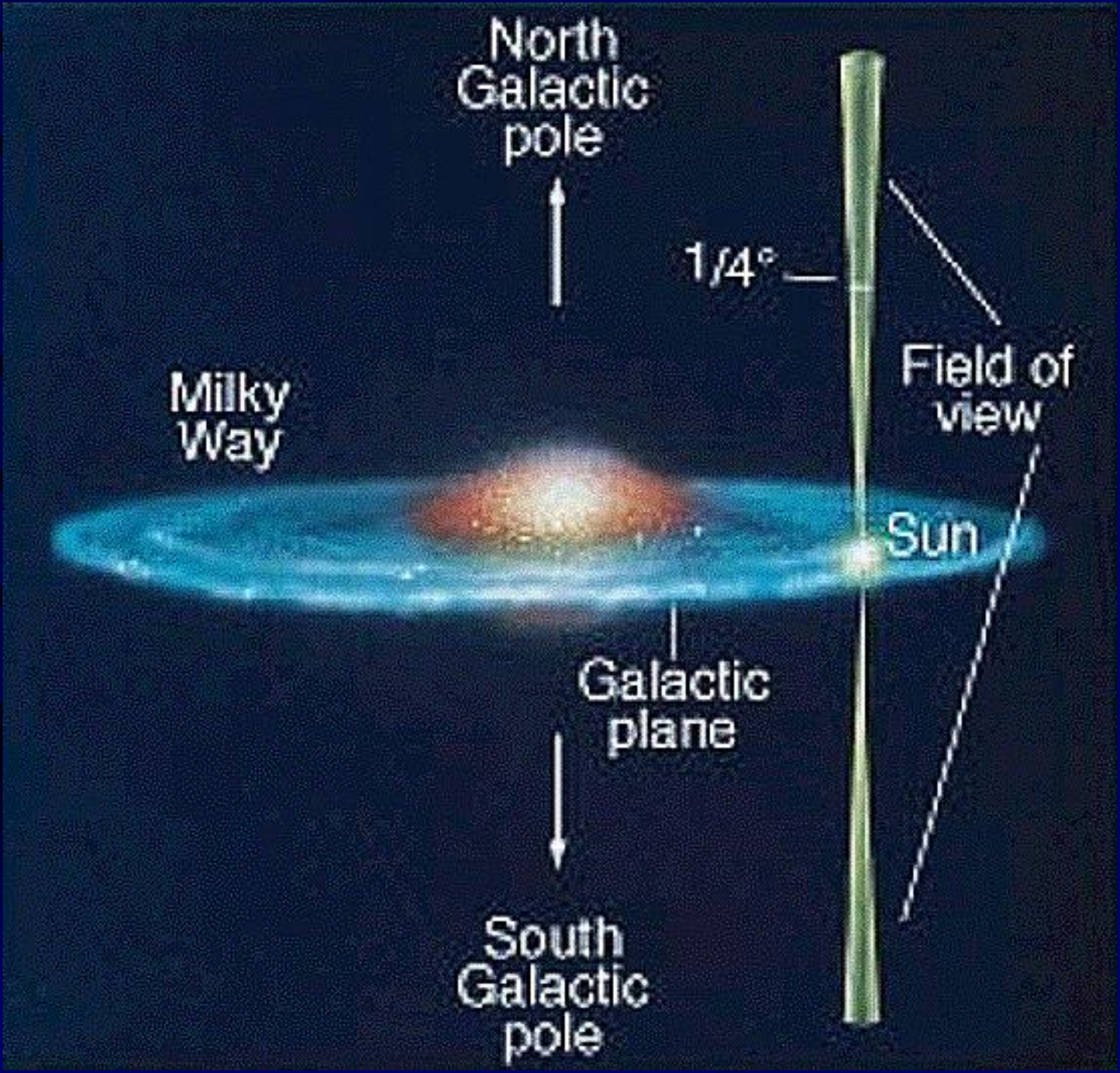
Activity

- Milky Way Scales
- Please work in groups of 3-5
- Hand in one worksheet per group with all the group members' names on

Q: How many galaxies are there?

- Hubble Deep Field Project
  - 100 hour exposures over 10 days
  - Covered an area of the sky about 1/100 the size of the full moon
- Probably about 100 billion galaxies visible to us!




North Galactic pole
1/4°
Field of view
Milky Way
Sun
Galactic plane
South Galactic pole

- About 1,500 galaxies in this patch alone
- Angular size ~ 2 minutes of arc

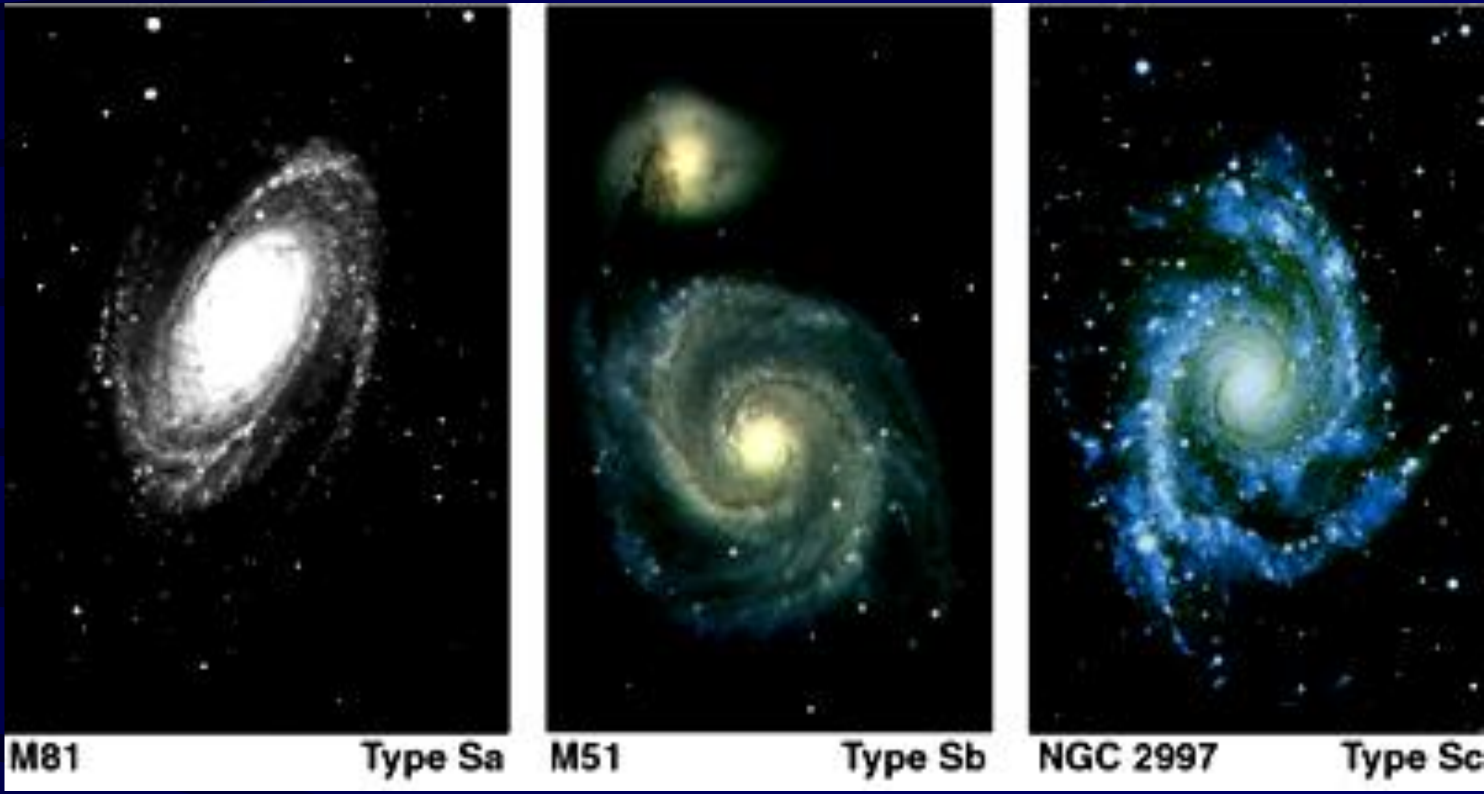
Other Galaxies

- there are ~ 100 billion galaxies in the observable Universe
- measure distances to other galaxies using the period-luminosity relationship for Cepheid variables
- Type I supernovae also used to measure distances
  - Predictable luminosity – a standard candle
- Other galaxies are quite distant
  - Andromeda (M31), a nearby (spiral) galaxy, is 2 million light-years away and comparable in size to Milky Way
- "Island universes" in their own right

Hubble Classification Scheme

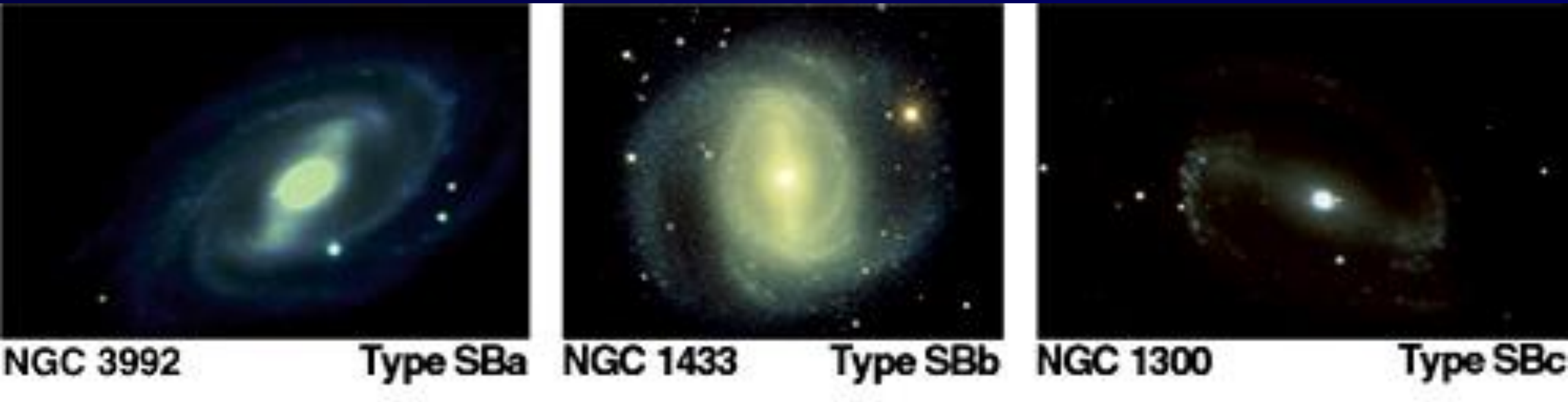
- Edwin Hubble (~1924) grouped galaxies into four basic types:
  - Spiral
  - Barred spiral
  - Elliptical
  - Irregular
- There are sub-categories as well

Spirals (S)



- All have disks, bulges, and halos
- Type Sa: large bulge, tightly wrapped, almost circular spiral arms
- Type Sb: smaller bulge, more open spiral arms
- Type Sc: smallest bulge, loose, poorly defined spiral arms

Barred Spirals (SB)



- Possess an elongated “bar” of stars and interstellar mater passing through the center

Elliptical (E)

- No spiral arms or clear internal structure
- Essentially all halo
- Vary in size from “giant” to “dwarf”
- Further classified according to how circular they are (E0–E7)

S0/SB0

- Intermediate between E7 and Sa
- Ellipticals with a bulge and thin disk, but no spiral arms

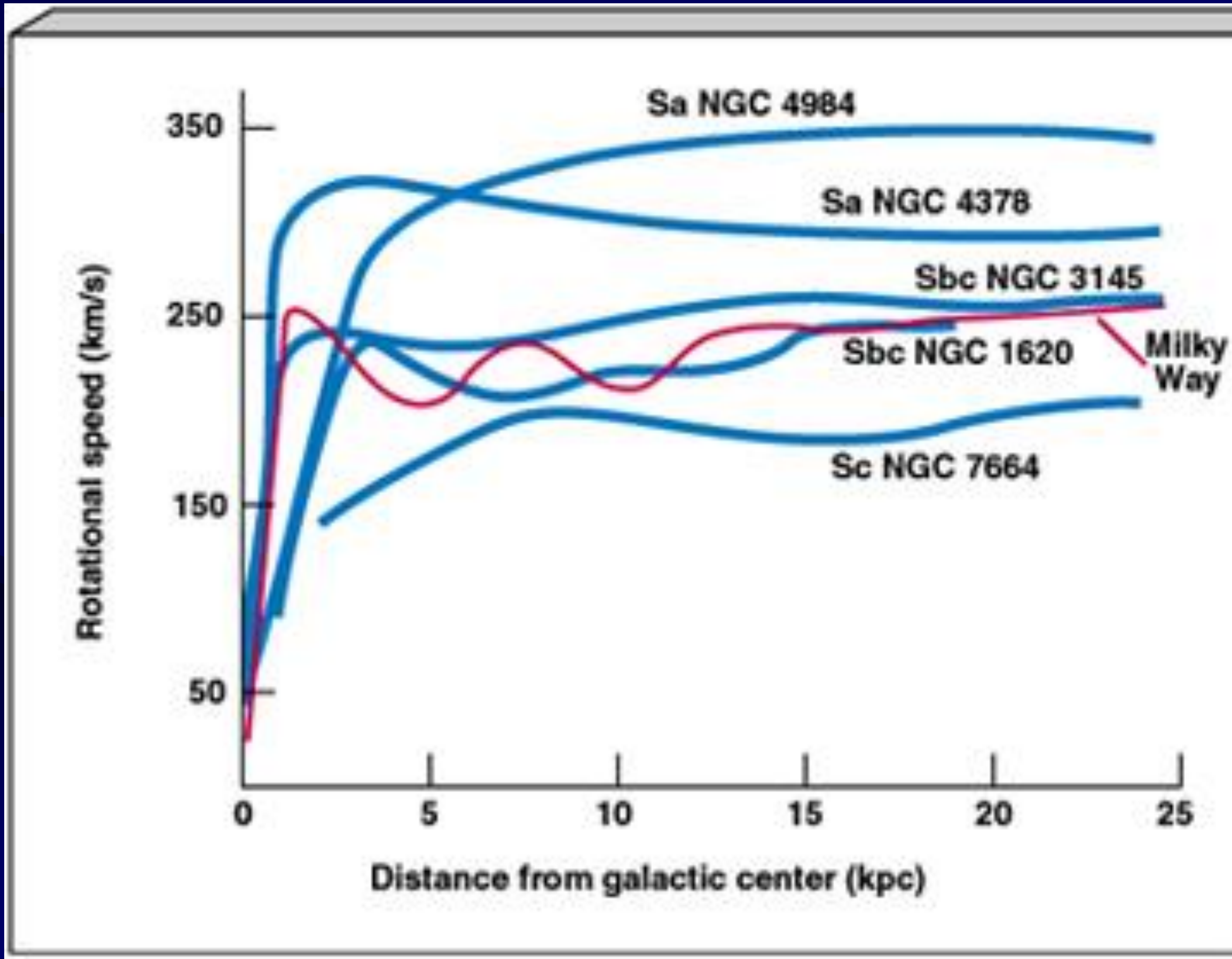
The Mass of the Galaxy

- Can be determined using Kepler's 3rd Law
  - Solar System: the orbital velocities of planets determined by mass of Sun
  - Galaxy: orbital velocities of stars are determined by total mass of the galaxy contained within that star's orbit

- Two key results:
  - large mass contained in a very small volume at center of our Galaxy
  - Much of the mass of the Galaxy is not observed
    - consists neither of stars, nor of gas or dust
    - extends far beyond visible part of our galaxy ("dark halo")

Galaxy Masses

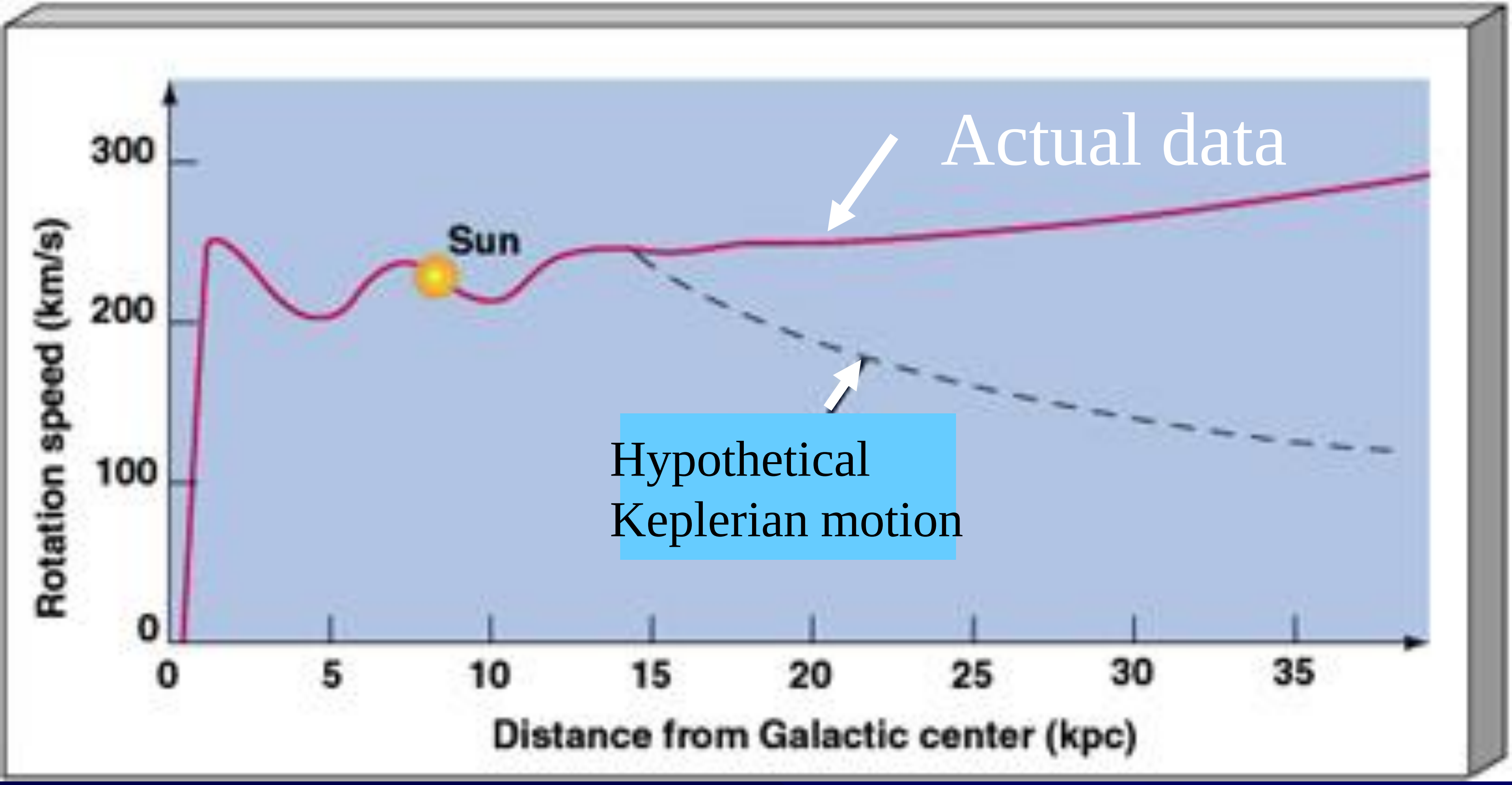
- Rotation curves of spiral galaxies comparable to milky way
- Masses vary greatly



The Missing Mass Problem

- Dark Matter is dark at all wavelengths, not just visible light
- The Universe as a whole consists of up to 25% of Dark Matter! → Strange!
- What is it?
  - Brown dwarfs?
  - Black dwarfs?
  - Black holes?
  - Neutrinos?
  - Other exotic subatomic particles?
- Actually: Most of the universe (70%) consists of Dark Energy → Even stranger!

Missing Mass Problem



- Keplerian Motion: more distance from center → less gravitational pull → slower rotational speed