The Milky Way, Distances, and the Galaxies

Slides from November 3, 5, 7, 10

Astronomy 1101

Key Ideas:

The *Milky Way* is our Galaxy

- Diffuse band of light crossing the sky
- Milky Way consists of many faint stars

The Nature (structure) of the Milky Way

- Speculations: Wright & Kant: Shell vs. disk
- Star Counts: Herschels & Kapteyn: disk

Distances from pulsating stars.

RR Lyraes & Cepheids: Period-Lum relation

Globular Cluster Distribution: Shapley

We are not at the center!

The importance of dust and obscuration.

The Milky Way

Diffuse band of light crossing the night sky

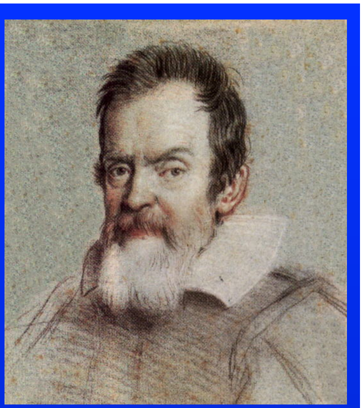
All cultures have named it:

- Celestial River
- Celestial Road or Path

Our names are derived from Greek and Latin:

- Greek: *Galaxias kuklos* = "Milky Band"
- Latin: *Via Lactea* = "Road of Milk"

"The Starry Messenger"



1610: Galileo observed the Milky Way with his new telescope.

Published his findings in his pamphlet, *Siderius Nuncius* (The Starry Messenger)

"For the Galaxy is nothing else than a congeries of innumerable stars distributed in clusters."

A Star field in the Milky Way

Wright’s Shell of Stars

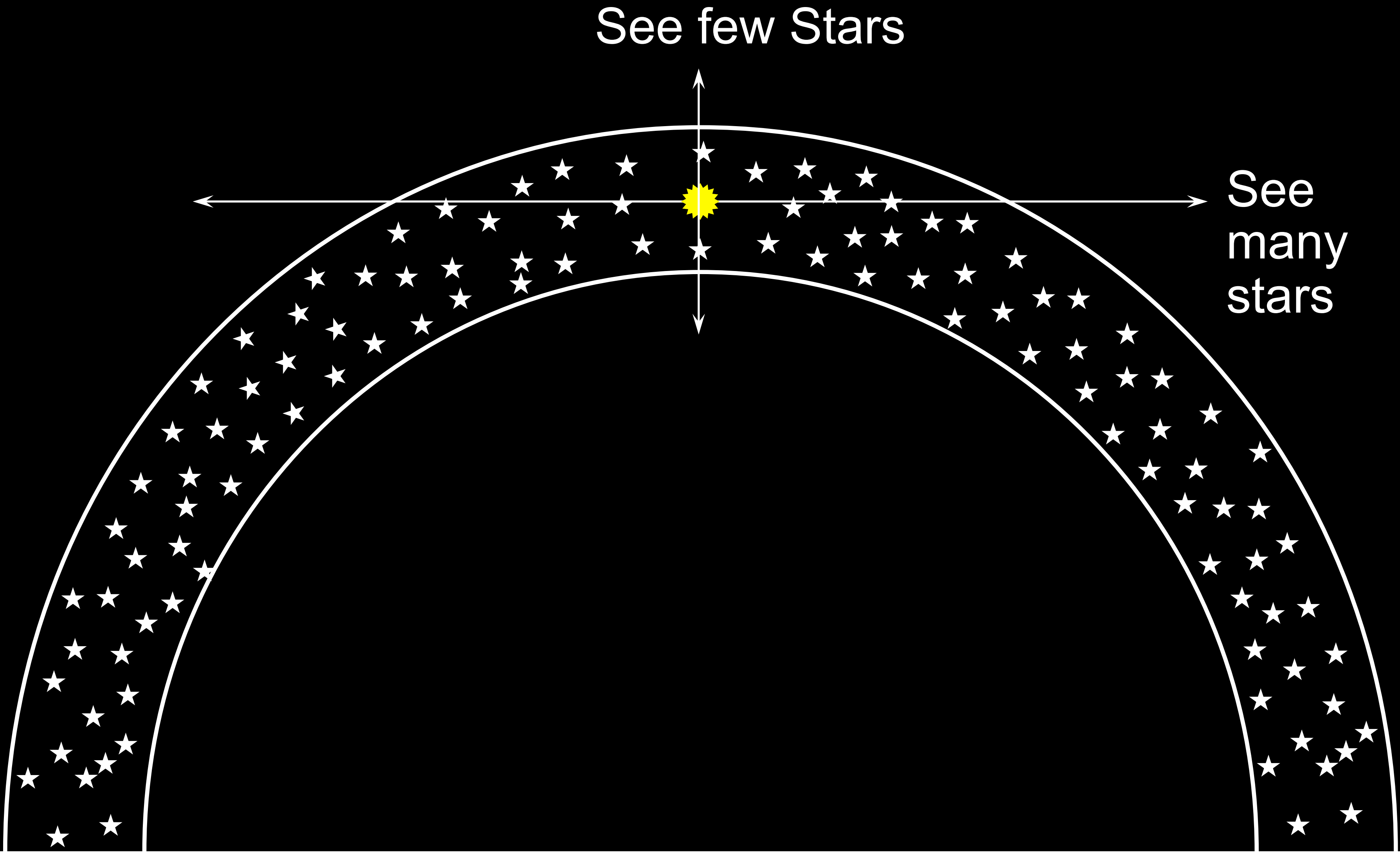
Thomas Wright (1750):

- Motivated primarily by theological considerations
- Wright made no new observations.

Model:

- Milky Way is a thin spherical shell of stars
- Sun is located inside the shell roughly midway between the inner and outer edges.

Wright's Milky Way (1750)



Kant: Milky Way as disk

Immanuel Kant (1755):

- Misread a newspaper account of Wright's model.
- Also made no observations of his own.

Model:

- Lens-shaped disk of stars rotating about its center, held together by gravity. Like the solar system, but on **much** larger scales.
- No particular special location for the Sun.
- Other blobs of light are just "Milky Ways" like our own.

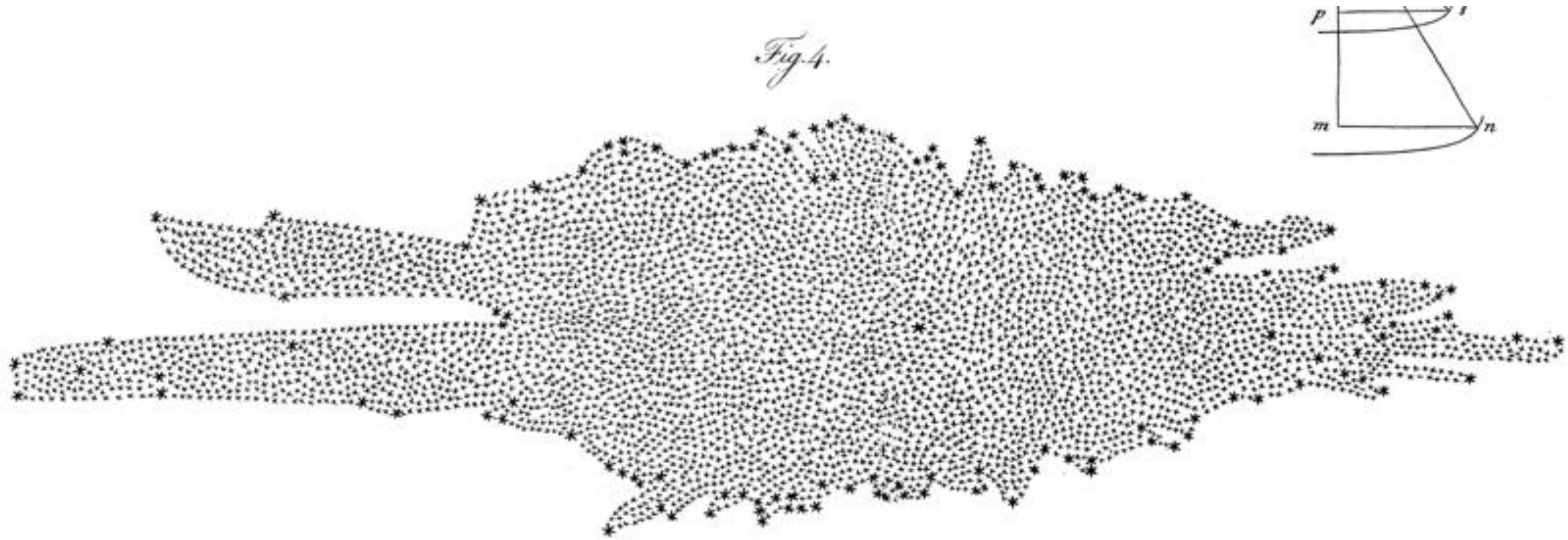
William & Caroline Herschel (1785)

- Counted stars along 683 lines of sight using their 48-inch telescope.
- Assumed all stars are the same luminosity, so relative brightness gives relative distance.
- Assumed that they could see all the way to the edges of the system.

Model:

- Flattened Milky Way (“grindstone”)
- Sun is located very near the center

The Herschels' Milky Way Map (1785)



Phil. Trans. Roy. Soc. v75, 213 (1785)

The Kapteyn Universe

Jacobus Kapteyn (1901 thru 1922):

- Used photographic star counts
- Estimated distances *statistically* based on parallaxes & motions of nearby stars.
- Neglected interstellar absorption of starlight (dust; assumed fainter stars just farther away).

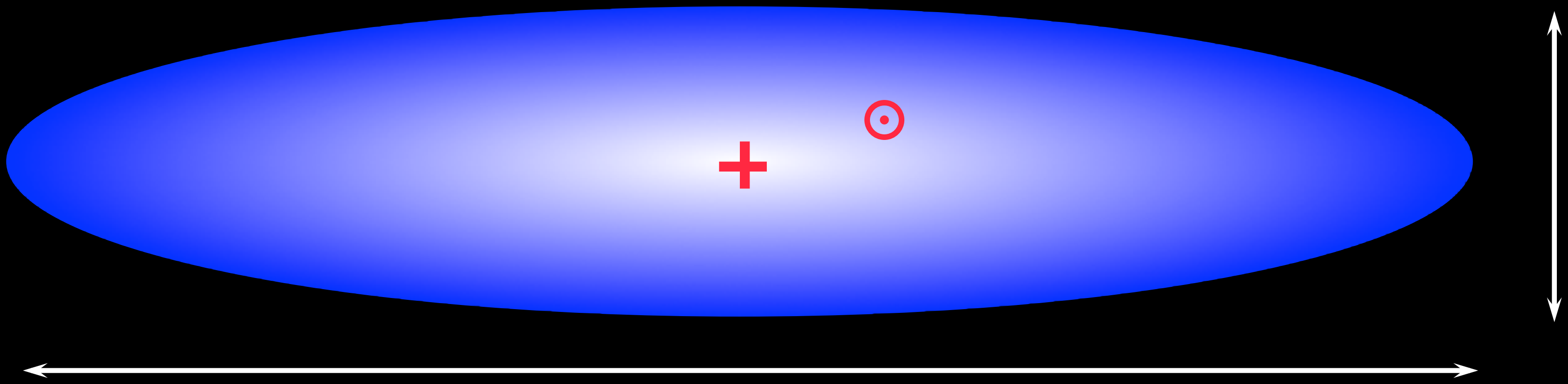
Model:

- Flattened disk 15 kpc across & 3 kpc thick
- The Sun is located slightly off center

Broad question: Where are we in the universe? What is our place?

Kapteyn Milky Way Model (1922)

"First attempt at a theory of the arrangement and motion of the sidereal system"



~15 kpc

1 kpc = 1 kiloparsec = 1000 pc   1pc = 3.26 lyr

Measuring accurate distances remains the biggest problem in Astronomy.

Distances are necessary for estimating:

- Total energy released by objects (Luminosity)
- Physical sizes of objects
- Masses of objects
- Distribution of objects in space

Without the distance, you have none of these.

Without *d*, difficult to understand Milky Way.

Direct distances from parallax, but only works for objects within ~1kpc with modern tools.

If you **know** the luminosity of a “standard candle”, distance is easy!

- Measure the object’s *Apparent Brightness*, B
- Assume/know the object’s *Luminosity*, L
- Solve for the object’s *distance*, *d*, by applying the *Inverse Square Law of Brightness*

$$B = \frac{L}{4\pi d^2} \Rightarrow d = \sqrt{\frac{\boxed{L}}{4\pi \textcircled{B}}}$$

???

"observable"

A Standard Candle: Periodic Variable Stars

Stars whose brightness varies regularly with a characteristic, periodic pattern.

Distance-Independent Property:

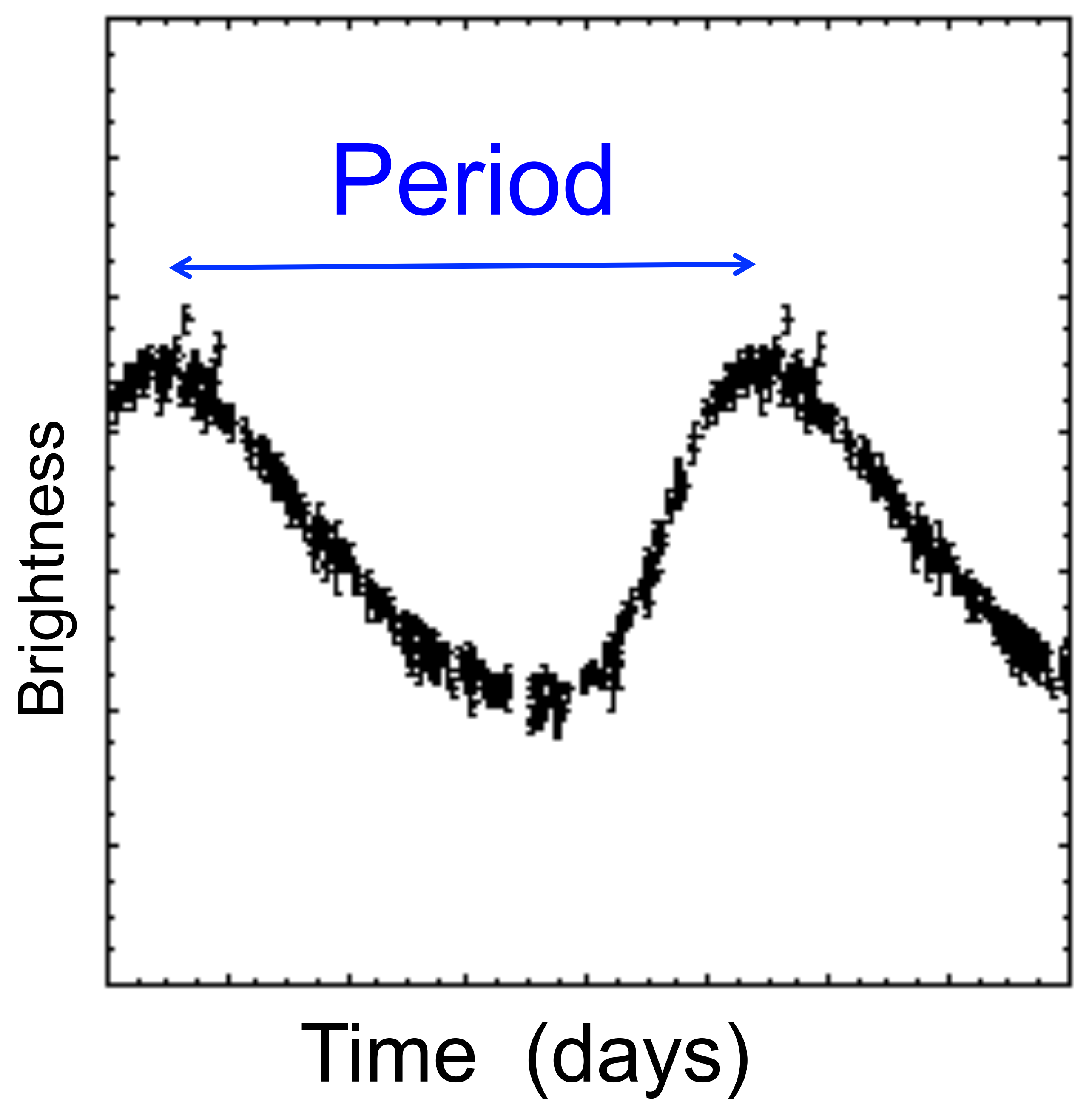
Period (repetition time) of their cycle of brightness variations.

Physics:

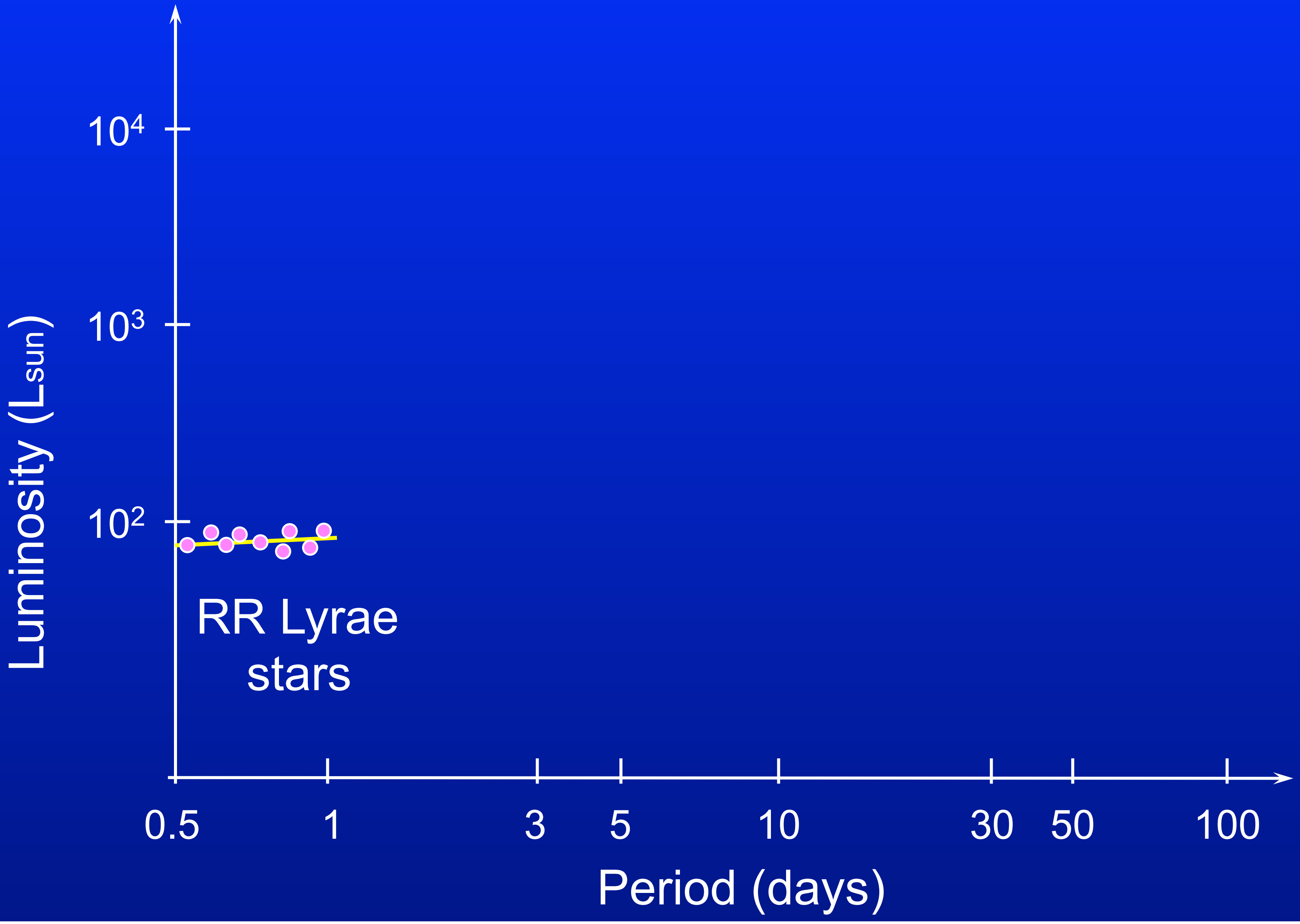
Period-Luminosity Relations exist for certain classes of periodic variable stars.

Measuring the Period gives the Luminosity.

Pulsating star
“Light Curve”



Period-Luminosity Relationship



RR Lyrae Variables

$$d = \sqrt{\frac{L}{4\pi B}}$$

Pulsating Horizontal-Branch stars:

- Luminosity of ~50 L_{sun}
- Brightness vairation: factor of ~ 2–3
- Period Range: Few hours up to ~ 1 day.

Period-Luminosity Relation

- All RR Lyraes have about the same *L* of ~50 L_{sun}

Since you know *L* and can measure *B*, you can find the distance *d*.

Limitations: not that luminous, so only useful for nearby galaxies; only a few with parallax, so uncertain; mostly exist with old stars (low metallicity).

Harlow Shapley (1915-1921)

Astronomer at Harvard

Noticed two facts about Globular Clusters:

1. Uniformly distributed above & below the Milky Way on the sky
2. Concentrated on the sky toward Sagittarius (the Galactic Center).

Observations:

1. Globular Cluster distances from RR Lyrae stars
2. Used these distances to map the globular cluster distribution in space.

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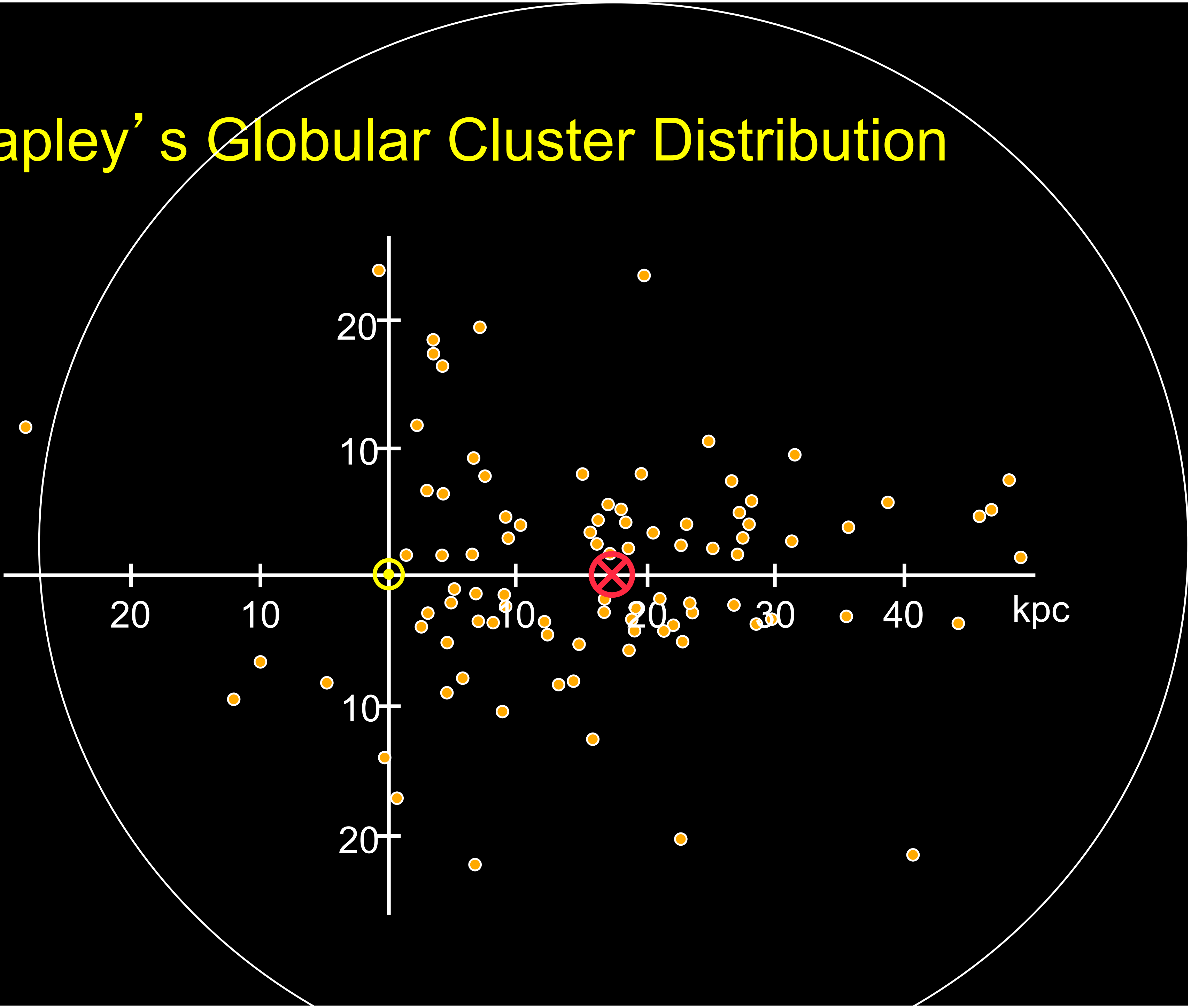
Shapley's Globular Cluster Distribution



The Greater Milky Way

Shapley's Results (1921):

- Globular clusters form a system of clusters, almost a sphere, centered on the Milky Way.
- The Sun is 16 kpc from the MW center.

We are not at the center!

- MW is a flattened disk ~100 kpc across

Right basic result, but too big:

- Shapley ignored interstellar absorption by dust
- Caused him to overestimate the distances

The Problem of Absorption

$$d = \sqrt{\frac{L}{4\pi B}}$$

Absorption of Starlight

- Interstellar space is filled with gas & dust
- Dust absorbs/scatters light, making distant objects look fainter, dimmer.
- Overestimate distances

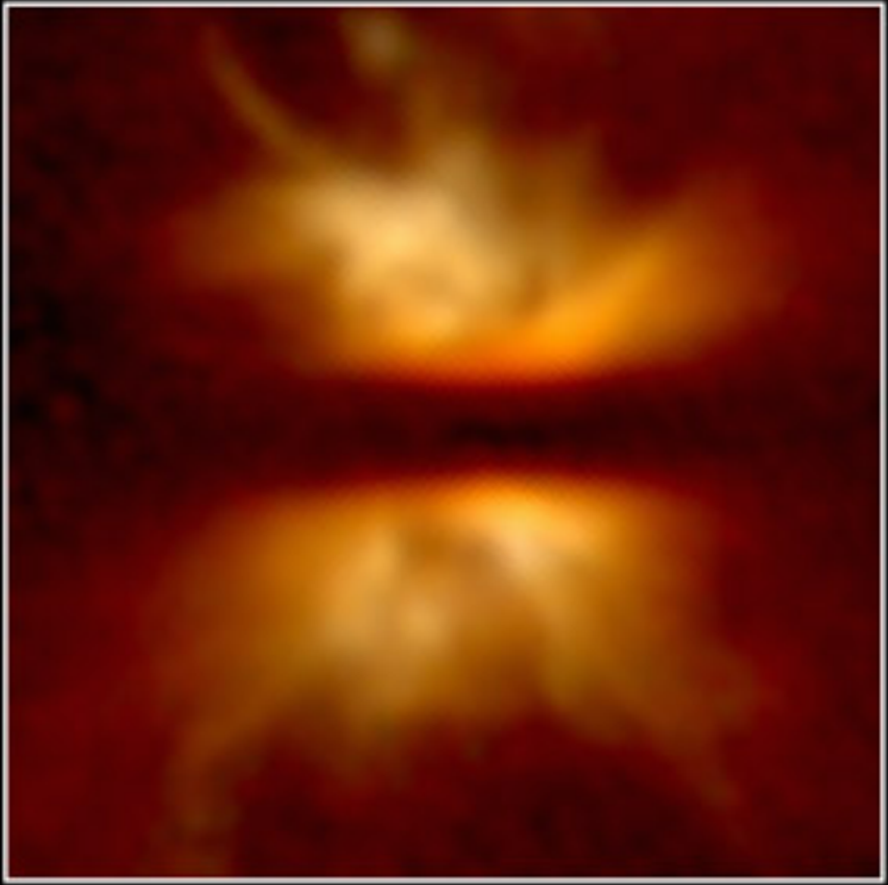
Affects all maps of the Milky Way:

- Shapley & Kapteyn thought it was smaller than it really is.
- Trumpler (1930) showed it was significant.

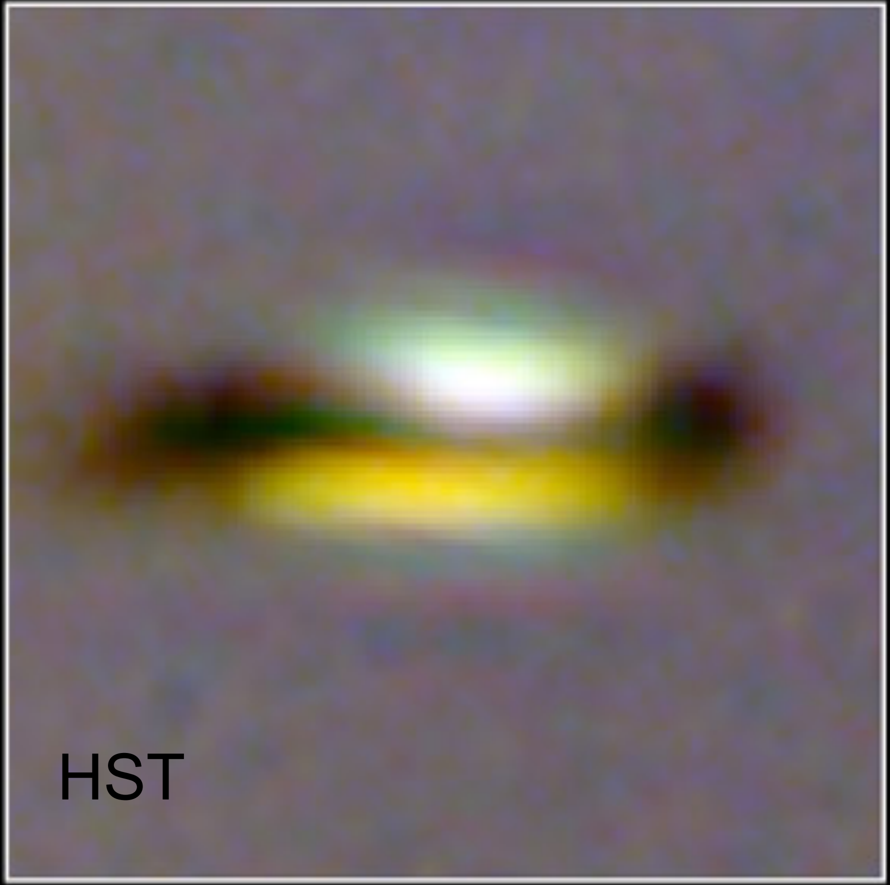
What about the “*Spiral Nebulae* ”?

Gas & dust disks observed around young stars

IRAS 04302+2247



Orion 114-426



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Spiral Nebulae

William Parsons, 3rd Earl of Rosse

Built a 72-inch telescope known as the "Parsonstown Leviathan" (c. 1845)

Discovered the "Spiral Nebulae"

- Disks with a spiral pattern
- Some edge-on disks with dark bands
- Did not resolve them into stars.

Are the spiral nebulae nearby forming solar systems, or are they distant galaxies like the Milky Way?

Island Universe Hypothesis

Kant’s idea (1755) revived by
Alexander von Humboldt (1845):

- Spiral Nebulae are other Milky Ways (or *galaxies*) made of stars.
- Very *distant* and *external* to our own Galaxy.

Big Picture:

The Milky Way is just one of many galaxies in a vast Universe of Milky Ways

Nebular Hypothesis

Revival of a "Solar System" model of Pierre Simone Laplace (1796):

- The Spiral Nebulae are swirling gas clouds
- They are *nearby* and *internal* to our Milky Way
- They might be forming solar systems
  - What we think of now as "proto-planetary" disks.

Big Picture:

The Milky Way *is* the Universe and the spiral nebulae are *inside.*

The Great Debate

The problem hinges on the finding *distances*:

- How big is the Milky Way? 1kpc, 1Mpc?
- How distant are the Spiral Nebulae? 1pc? 1Mpc?

Island Universe Hypothesis:

- The Spiral Nebulae are more distant than the "edge" of our Galaxy, and as big as our Galaxy. The universe is much much bigger than the Milky Way.

Nebular Hypothesis:

- The Spiral Nebulae are nearby and inside our Galaxy, and thus much smaller than it. The Milky Way is the universe.

Henrietta Swan Leavitt

A"computer" at Harvard.

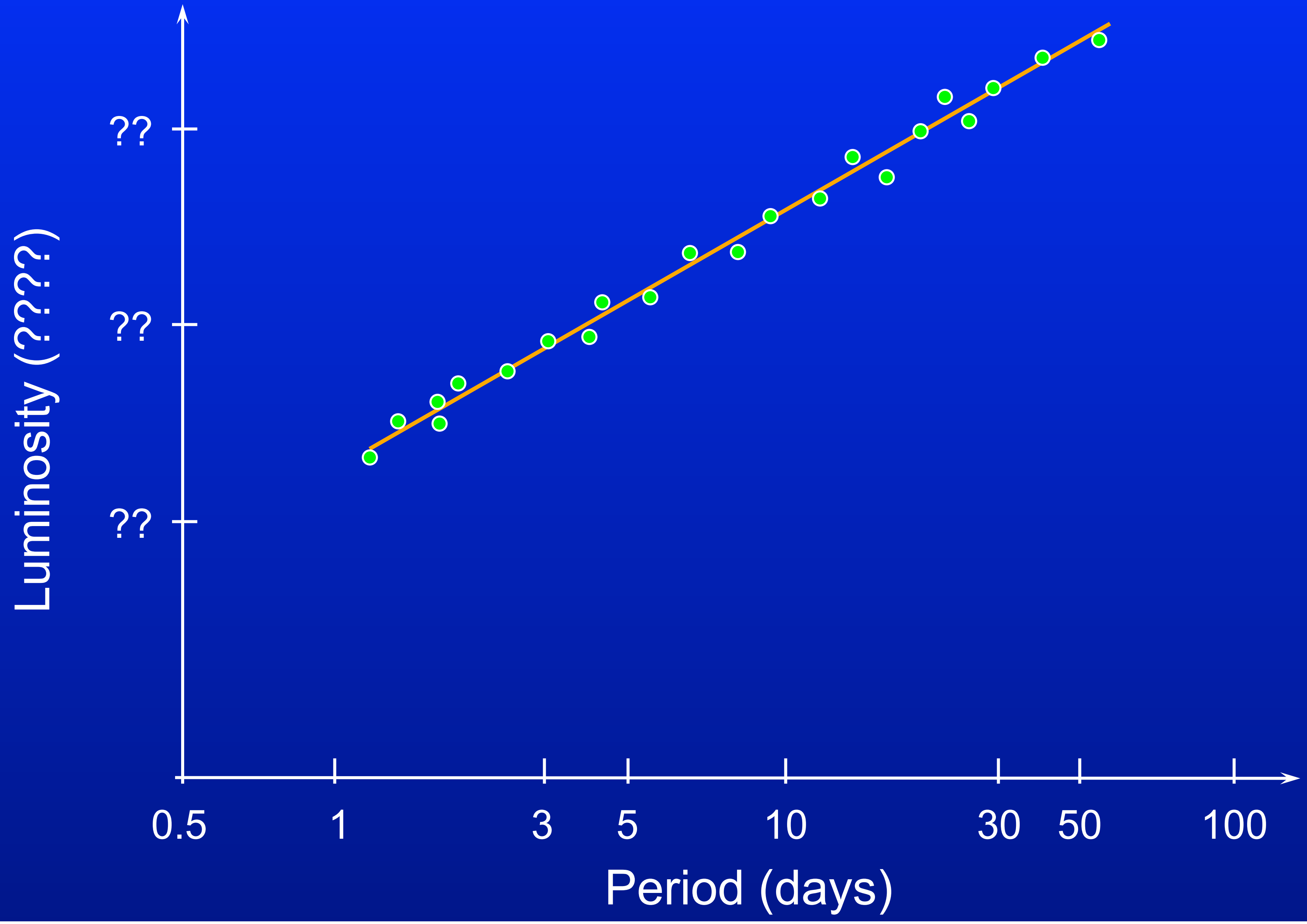
Given the task of finding variable stars in photographs of the Magellanic Clouds

By 1912 she found that:

- Brighter variables had longer periods
- Not RR Lyraes.
- They fit onto **some** new *Period-Luminosity Relation*

But, she did not know their luminosities because she did not know the distance to the LMC and SMC.

Period-Luminosity Relationship



The Stepping Stone

Pickering kept Leavitt from following up her discovery of the P-L Relation

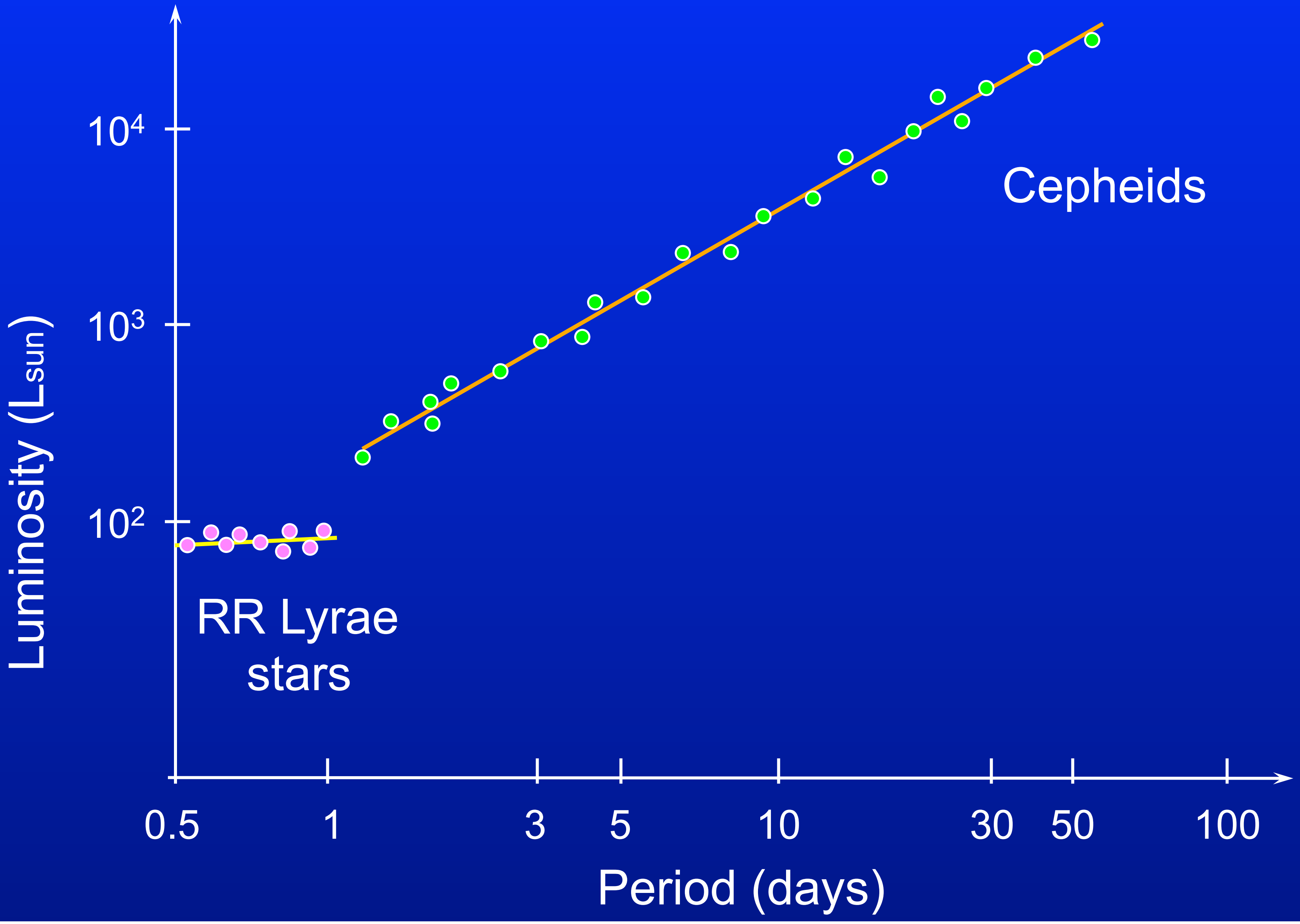
Hertzsprung (1913):

- Recognized Leavitt's variables as Cepheids.
- Did the necessary luminosity calibration.

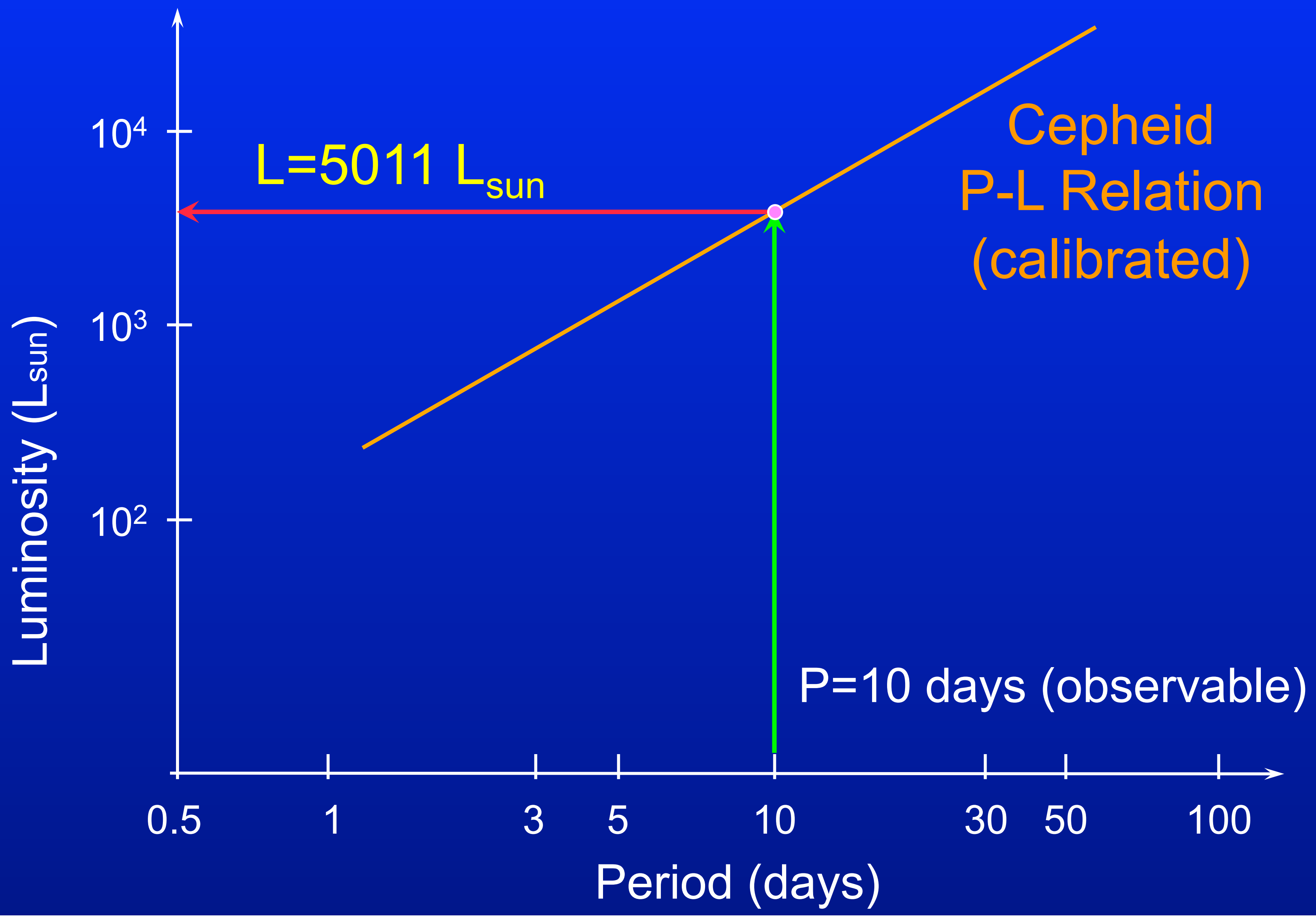
Shapley (after 1915):

- Refined the calibration of the P-L Relation.
- Used the RR Lyrae version to get distances to Globular Clusters, estimated size of MW

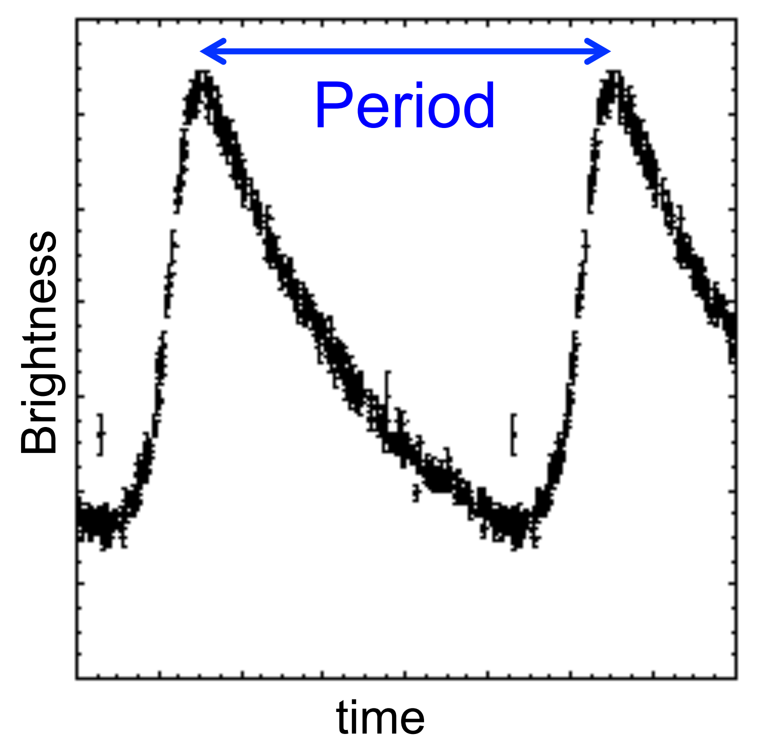
Period-Luminosity Relationship



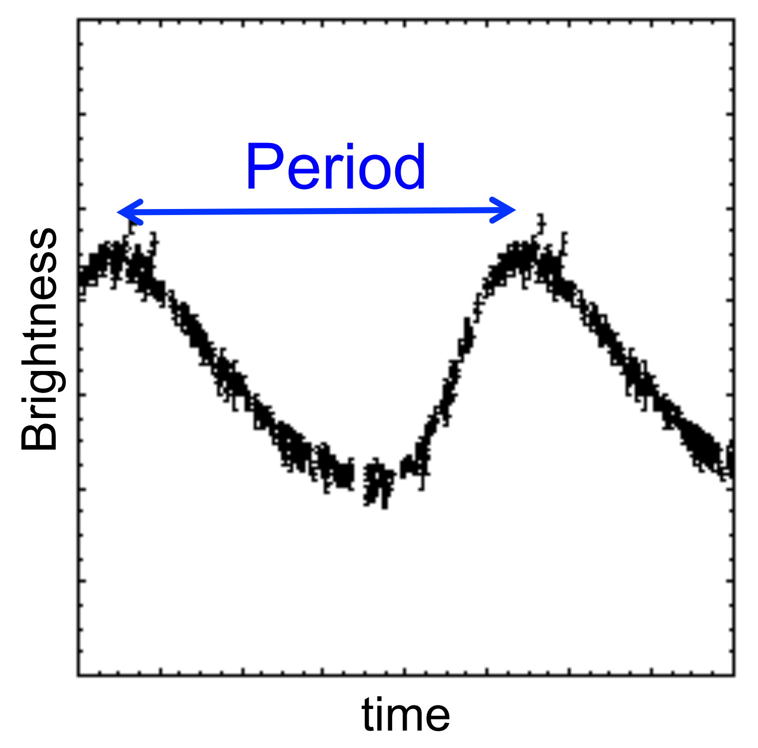
Example: Cepheid with a 10-day period



Typical Cepheid Light Curves



LCB 171
P ~ 3 days
More luminous.



LCB 272
P ~ 2 days
Less luminous.

Cepheid Variables: crucial for measuring distances to nearby galaxies.

Rhythmically Pulsating Supergiant(!) stars:

- Only found in young star clusters
- High Luminosities of ~ 10^{3-4} L_{sun}
- Period Range: 1 day to ~50 days.

Period-Luminosity Relation:

- *Longer* Period = *Higher* Luminosity
- P = 3 days, L ~ 10^3 L_{sun}
- P = 30 days, L ~ 10^4 L_{sun}
- (Modern limit: can be seen to 40 Mpc! With Hubble

The Shapley-Curtis Debate

1920 Debate on *The Scale of the Universe*

Sponsor: National Academy of the Sciences

Harlow Shapley: (Harvard)

- Defended his model for the Galaxy and the “conventional” Nebular Hypothesis.

Heber Curtis: (Lick Observatory)

- Defended the Kapteyn Model and the “alternative” Island Universe Hypothesis.

The Battleground Questions:

What is the size of the Milky Way Galaxy?

- Kapteyn’s star counts vs. Shapley’s clusters
  - About 15 kpc versus 100 kpc.

What is the distance to the Andromeda Nebula, the largest spiral nebula?

- Tried to estimate using “nova” in 1885, but they did not really know what it was.
- No one had found a Cepheid variable.
- RR Lyraes too dim for Andromeda.

What are the motions of the Spiral Nebulae?

- Proper Rotation & Radial Velocities

Shapley' s Arguments

The Galaxy is 100 kpc across (from globular clusters)

The 1885 "nova" in Andromeda gave a distance of ~10 kpc (assuming true L known!):

- This is smaller than 100 kpc for the Galaxy, hence it is *internal* to the Milky Way.
- If external, would imply huge luminosity. Far larger than the luminosity of any explosion yet seen.

Van Manaan's "Rotation" of M101:

- If very distant, it implies a rotation speed faster than the speed of light!

Curtis’s Arguments

Nova of 1885 implies a distance of 150 kpc, assuming luminosity known. Because the Galaxy is only 10-20 kpc in size, Andromeda is external to the Milky Way.

Dark obscuring bands of dust seen in edge-on spiral nebulae, just like what we see in the Milky Way.

Doppler shifts (radial velocity) of the spiral nebulae are 100-500 km/s, much larger than stars (10 km/s), which implies that they are not bound to the Galaxy and would fly away!

The Outcome...

… was inconclusive:

- Shapley had better arguments, but in the end was wrong.
- Curtis was right, but his arguments were weak.

Issues preventing a conclusion:

- Nobody had a good distance to Andromeda
- Nobody knew the luminosities of “novae”
- Nobody could reproduce van Manaan’s rotation observations.

Hubble Ends the Debate by finding first Cepheid

Edwin Hubble (1923):

- Using the new 100-inch telescope on Mt. Wilson in California.
- P-L relationship implies D ~ 300 kpc

By 1925:

- Hubble had measured 10 Cepheid variables
- Refined P-L relation implied: Distance to Andromeda of about 1000 kpc = 1Mpc.

Hubble's Cepheid in Andromeda

100-inch Telescope
(Mt. Wilson)

The Realm of the *Galaxies*

We call the Milky Way "The Galaxy"

Spiral "Nebulae" now called Spiral Galaxies:

- Stellar systems like the Milky Way
- Typical sizes are ~10-50 kpc across
- Typical distances are many Mpc.

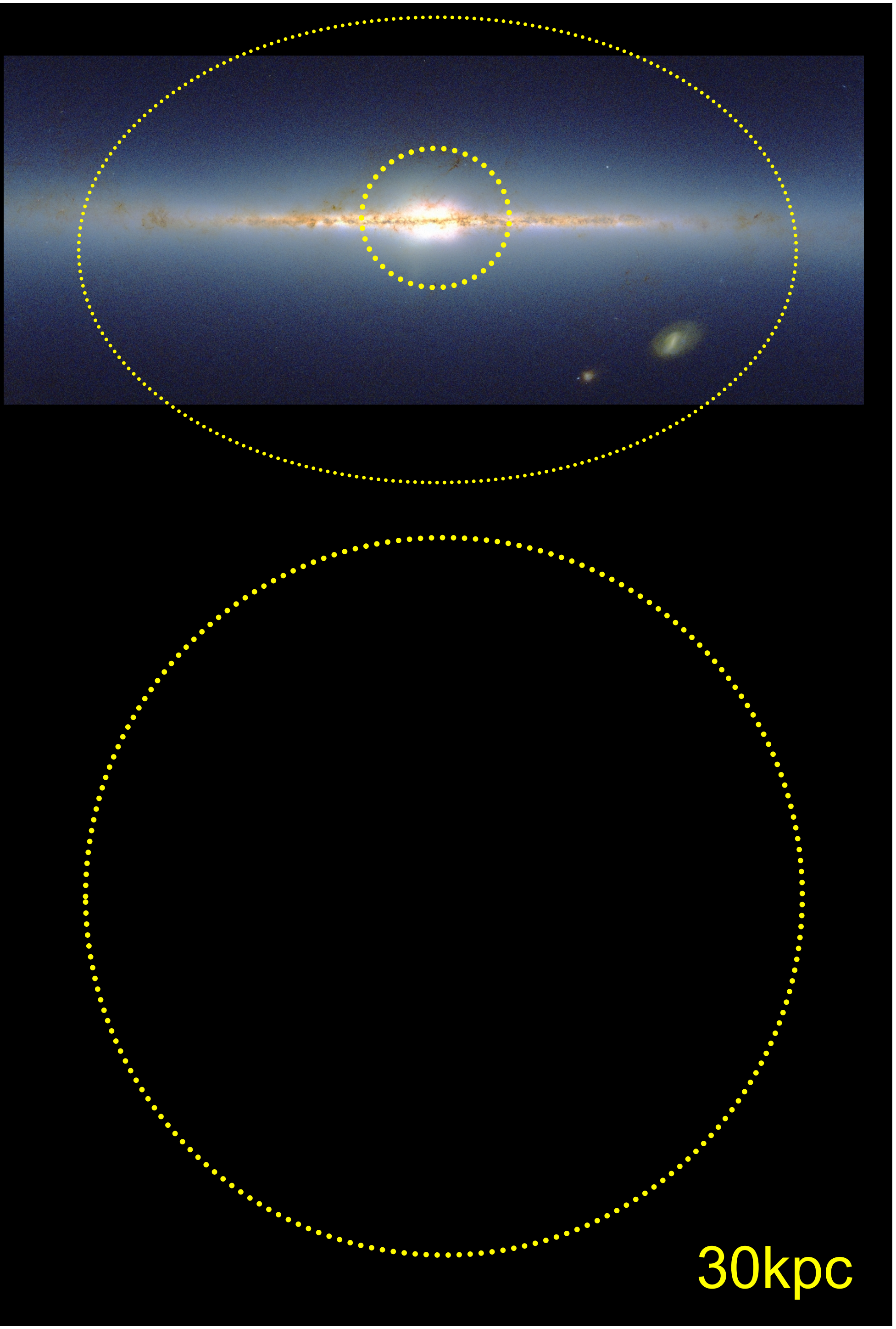
Many galaxies now observed at many Gpc (!) distances. (If the MW is 1 ft across, Andromeda is 100 ft away, furthest galaxies 1000 miles away).

The Universe suddenly became a **much** bigger place.

A galaxy is just a huge collection of stars, dust, and gas.

The Milky Way

- 3-part structure: A flattened disk of stars with a central “bulge”, large stellar halo
- Sun is ~8 kpc from the center in Sagittarius
- ~30 kpc in diameter and ~1 kpc thick
- Galactic Center obscured by dust in the plane of the Galaxy



Andromeda

Nearest big spiral: D~0.8Mpc

Similarities to the Milky Way

- Large spiral galaxies
- 3-part structure: disk+bulge +halo.
- Dust lanes.
- Star formation.
- Bigger bluge, bigger BH.

Andromeda gives us an approximate outside view of our own Galaxy.

Disk, Bulge, Halo/Spheroid

Disk: stars, gas, and dust

- Spiral arms with blue stars: young stellar population, active star formation

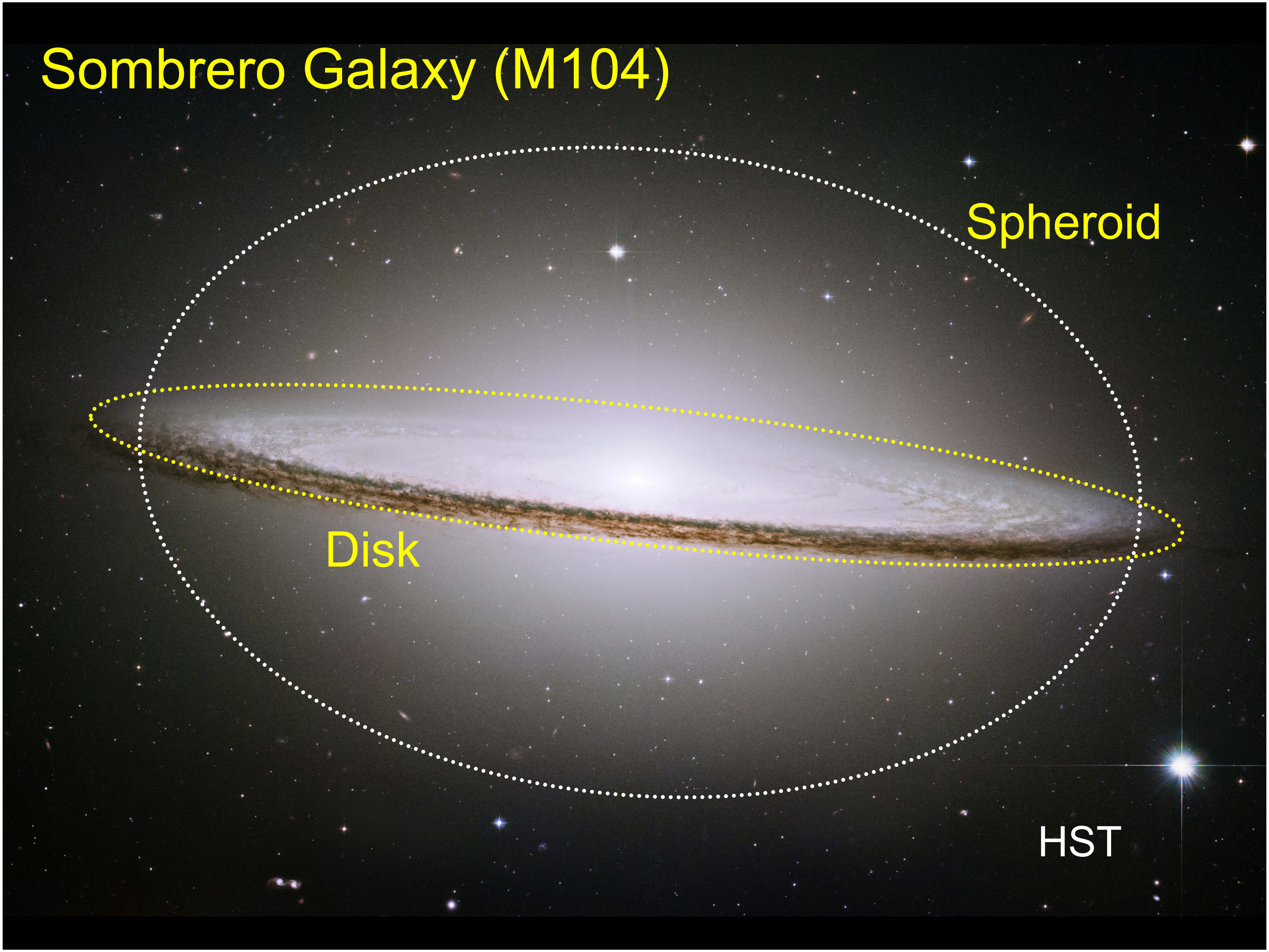
Bulge:

- Thick, centrally concentrated spheroid of stars
- Little gas or dust
- Yellow/red colors: older stellar population: few Gyr

Spheroid:

Diffuse spheroid, extends to many kpc, no star formation, old population

Sombrero Galaxy (M104)



3 part structure

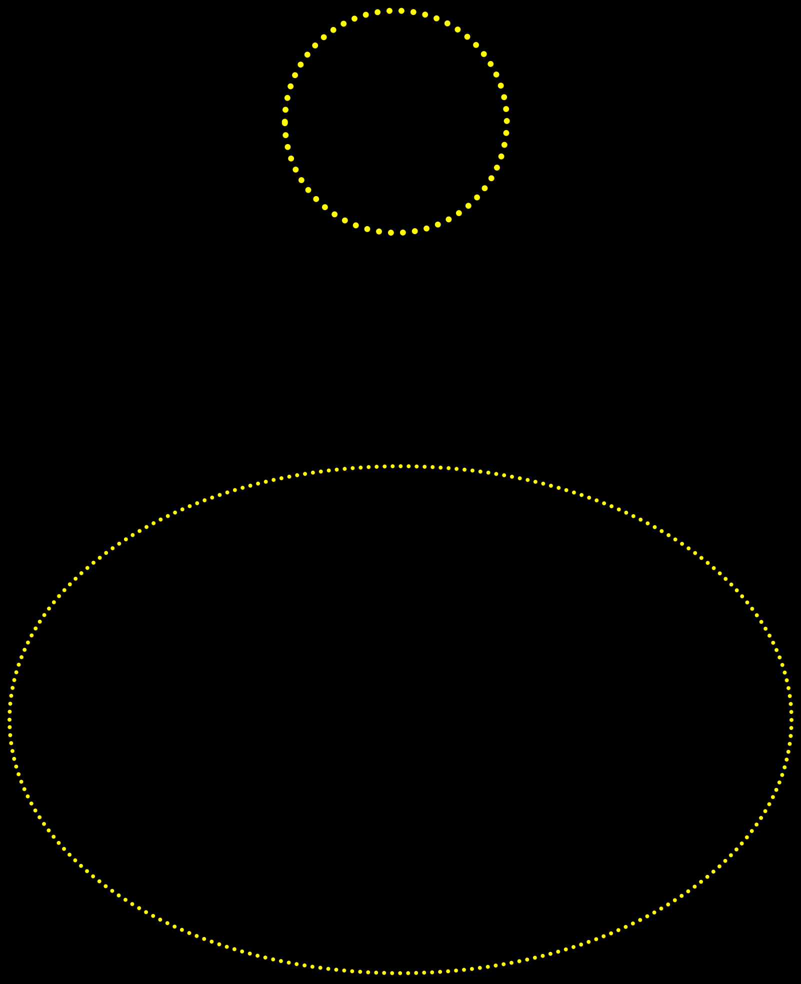
Disk: Dust, gas, star formation

Bulge: Where inner spheroid & disk merge

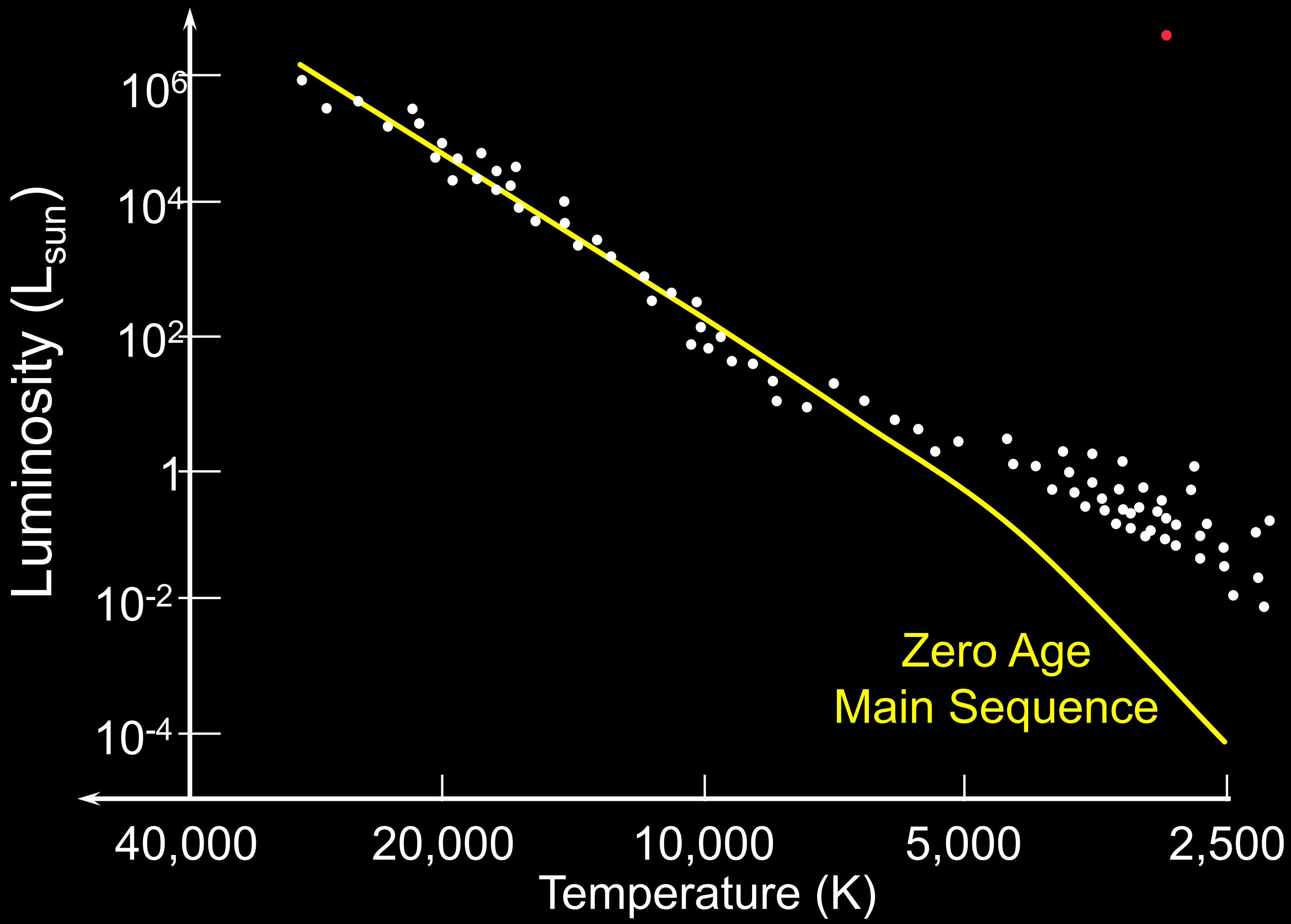
  - A little gas & dust

Halo: sparse outer spheroid

  - Old metal-poor stars
  - Globular clusters

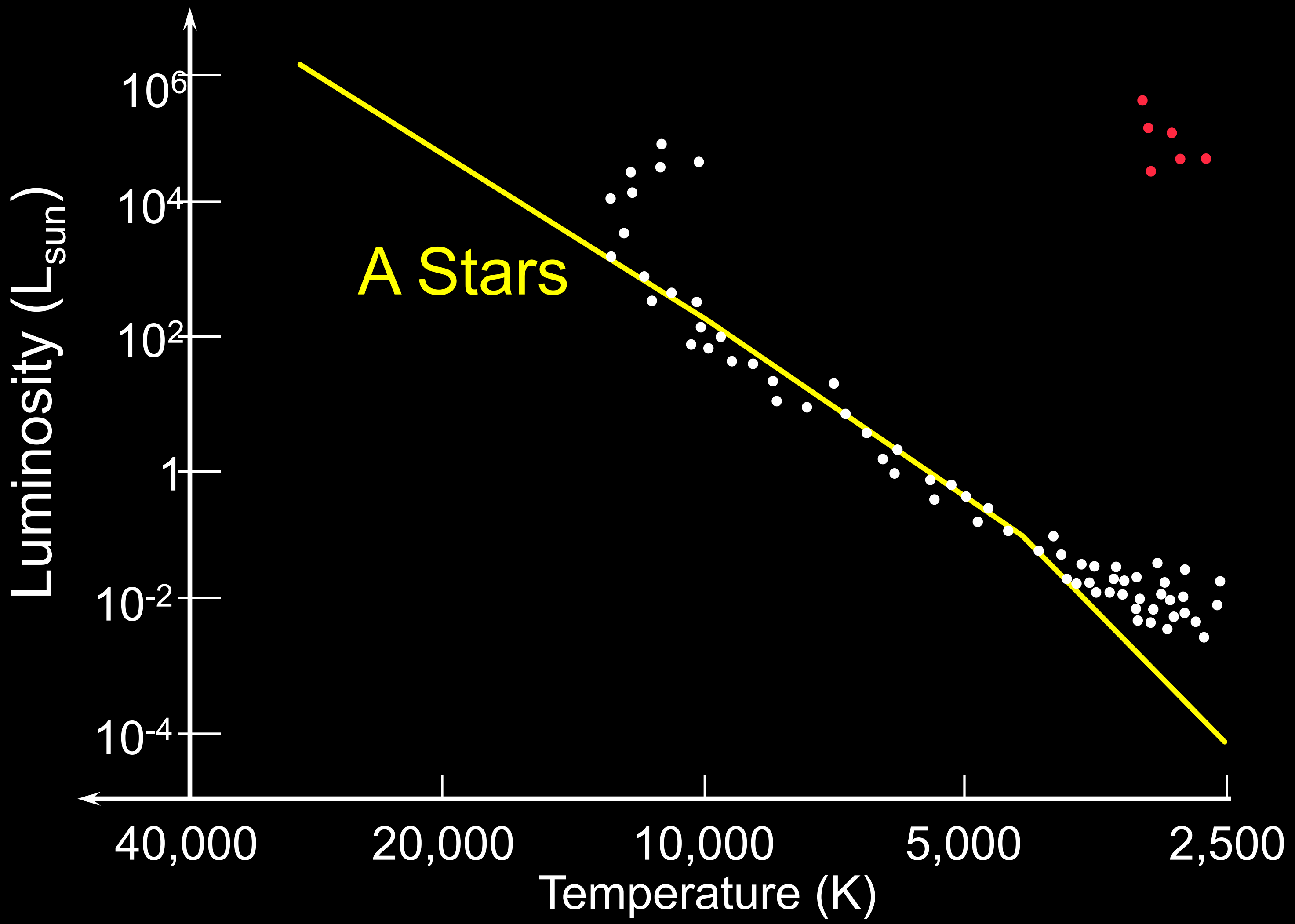


Age: ~1 Myr

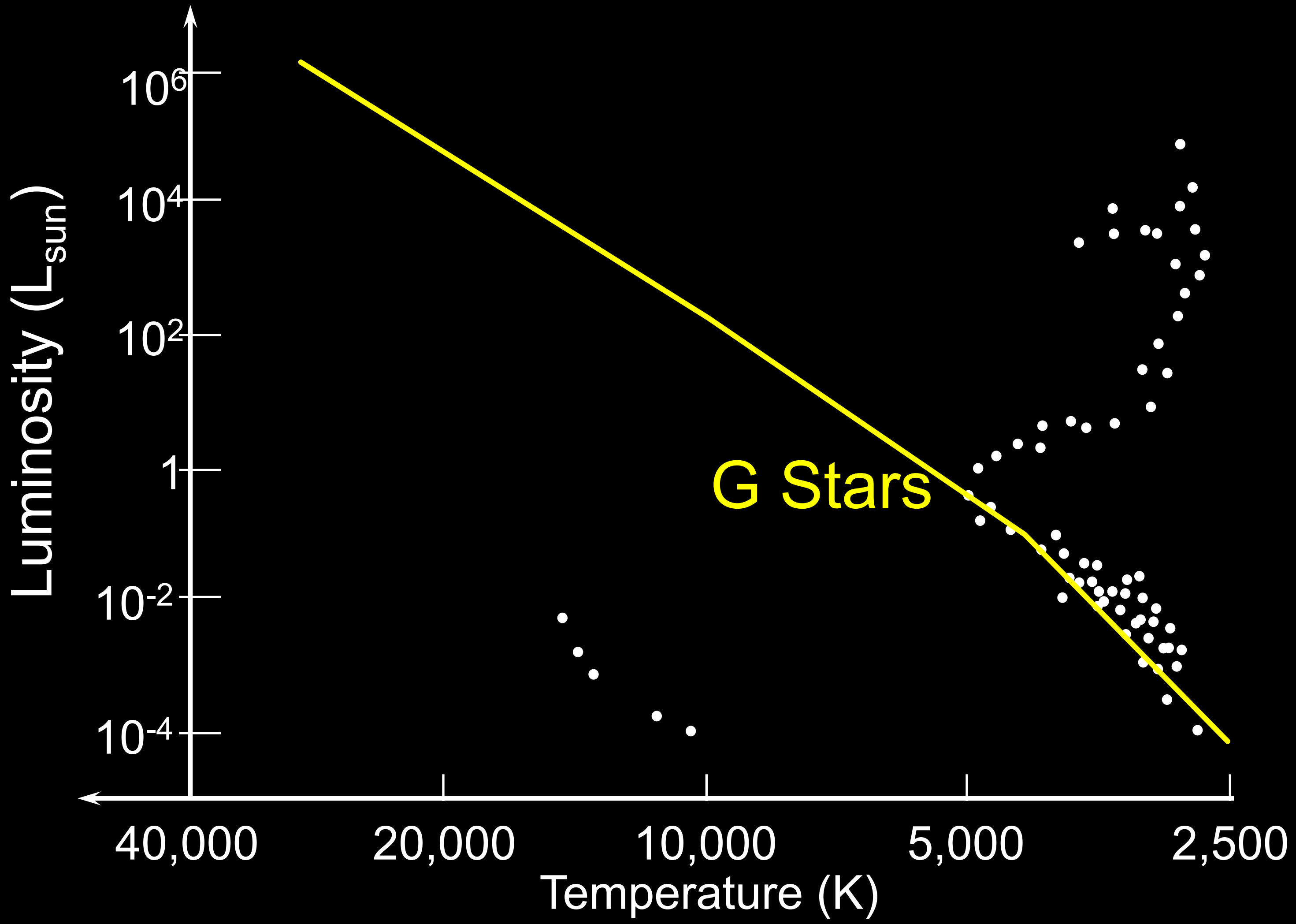


Luminosity (L_{sun})
10^6
10^4
10^2
1
10^{-2}
10^{-4}
40,000
20,000
10,000
5,000
2,500
Temperature (K)
Zero Age
Main Sequence

Age: ~100 Myr


A Stars
Luminosity (L_{sun})
10^6
10^4
10^2
1
10^{-2}
10^{-4}
40,000
20,000
10,000
5,000
2,500
Temperature (K)

Age: ~10 Gyr

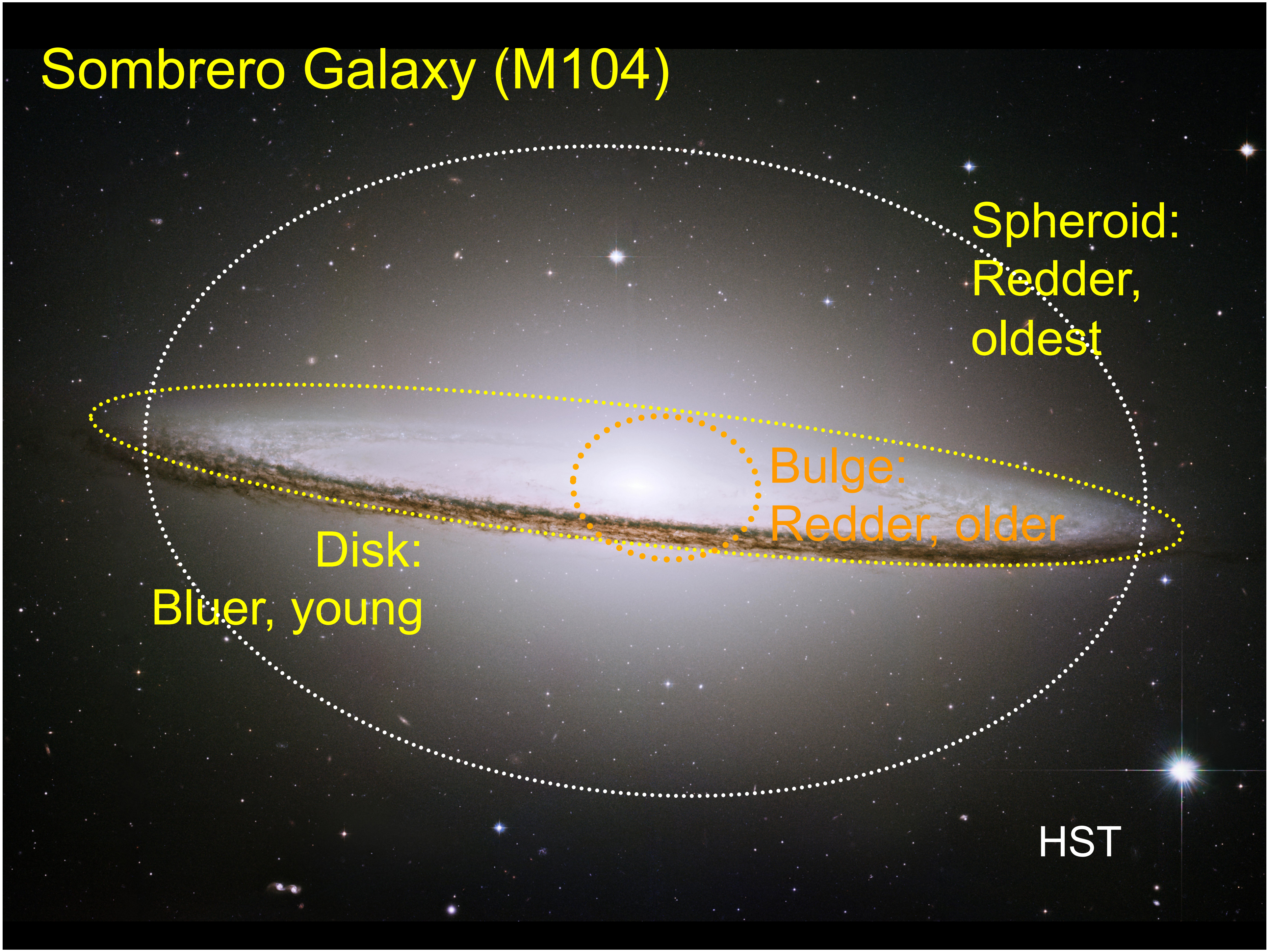


G Stars
Luminosity (L_{sun})
10^6
10^4
10^2
1
10^{-2}
10^{-4}
40,000
20,000
10,000
5,000
2,500
Temperature (K)

Young

Old

Sombrero Galaxy (M104)



Divide stars into broad populations

Population I: metal rich

Population II: metal poor

Population III: *Stars formed from primordial gas.*

Population I: Stars like the Sun

Location: Disk and Open Clusters

Ages: Mix of young and old stars

Composition: Metal rich

- 70% Hydrogen
- 28% Helium
- ~1-2% "metals"

Environment:

Sometimes gas rich, especially for young stars, but other regions too, including bulge.

Population II: Ultra Metal Poor

Location: Spheroid and
Globular Clusters

Ages: Oldest stars, 10−13 Gyr

Composition: Metal Poor

- 75% Hydrogen
- 24.99% Helium
- ~0.01% “metals”

Environment:

- Gas poor, with no recent star formation, old, old, old

Population III: Hypothesized

Location: Unknown, but probably in the spheroids of galaxies. Find them!

Ages: nearly 13.8 Gyr

the first stars

Composition: Primordial

75% Hydrogen
24.99% Helium
0.0% “metals”

Environment: Unknown, but probably totally gas-poor regions

?

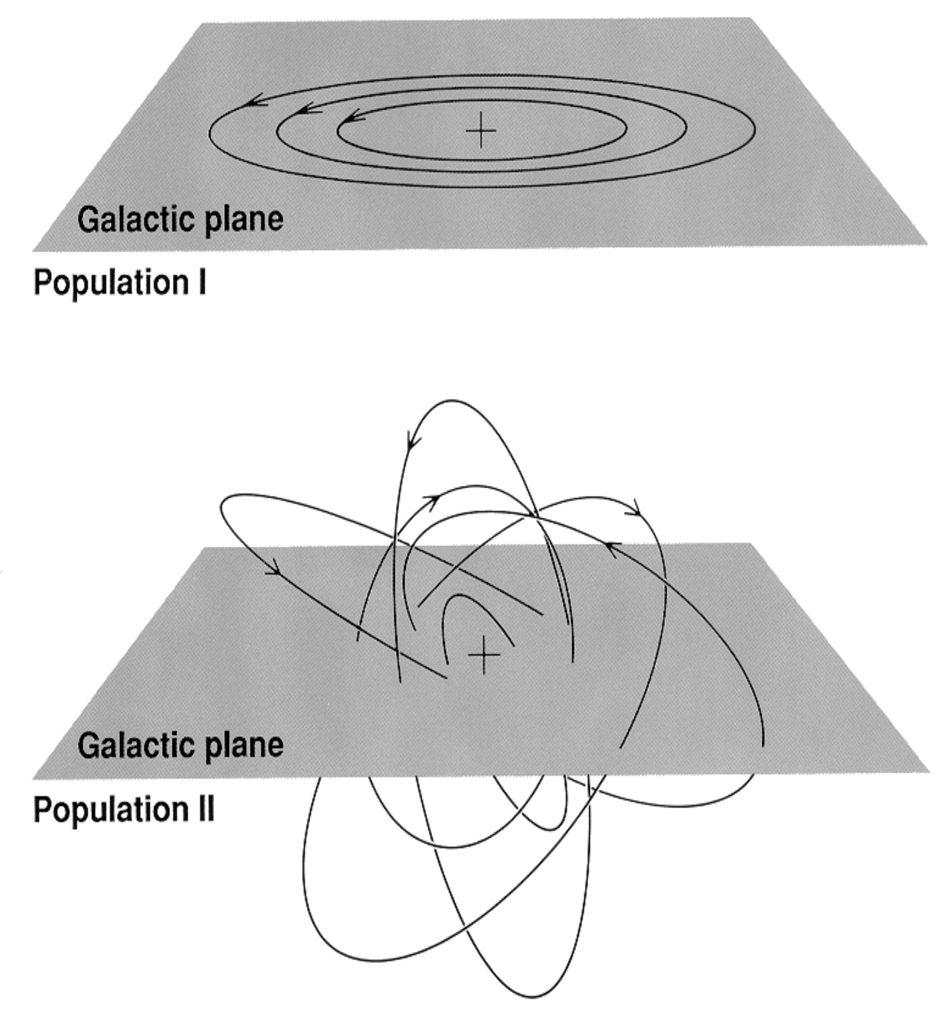
Stellar Orbits

Pop I Disk Stars:

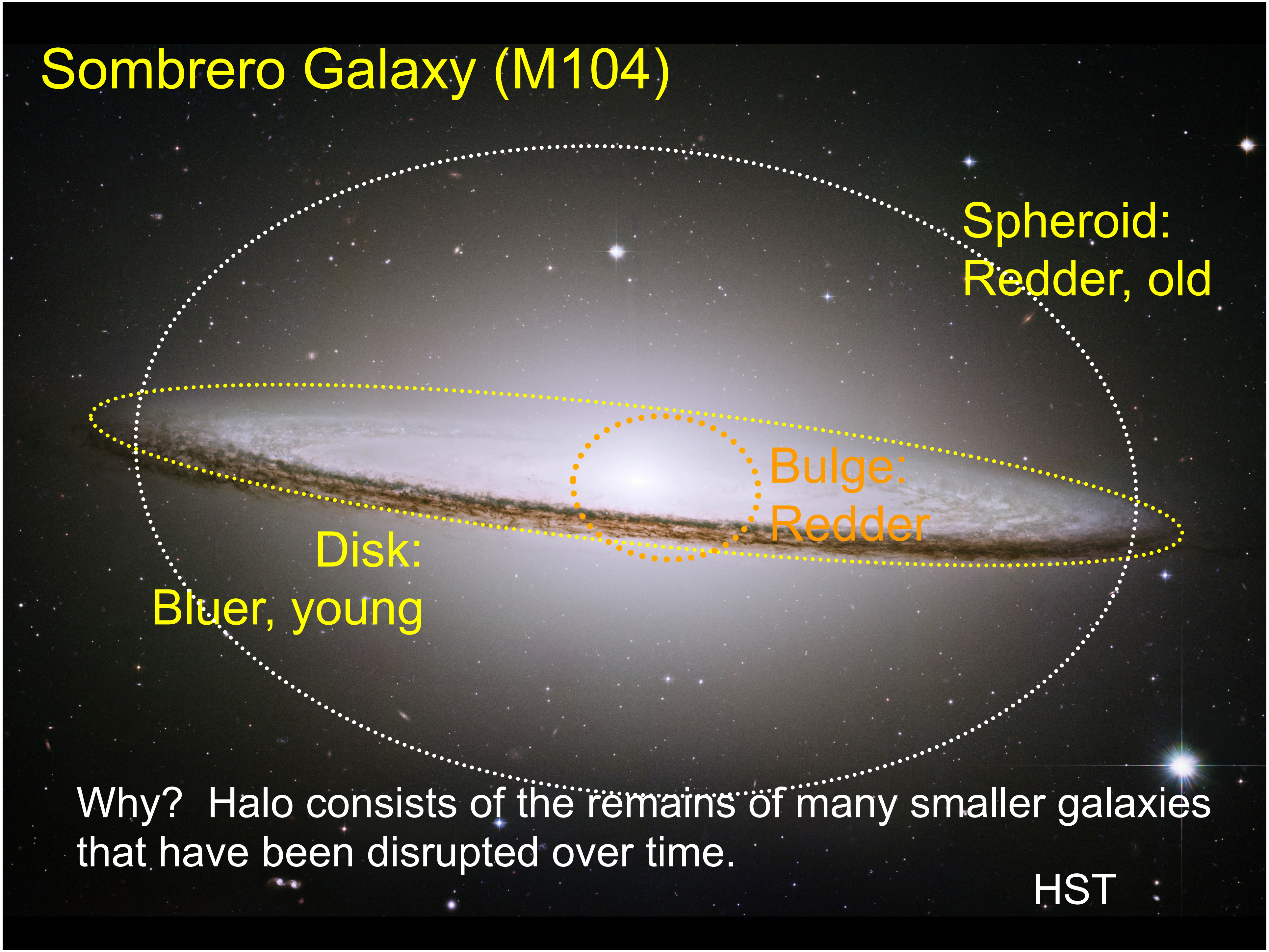
- Ordered circular orbits confined to a plane
- Same orbit direction
- Speeds similar at a given radius
- But, also bulge stars

Pop II Spheroid Stars:

- Disordered elliptical orbits at all inclinations



Sombrero Galaxy (M104)



Spheroid:
Redder, old

Bulge:
Redder

Disk:
Bluer, young

Why? Halo consists of the remains of many smaller galaxies that have been disrupted over time.

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Contrast & Compare

Population I	Population II
• Disk & Open Clusters	• Spheroid & Globulars
• Young & Old Stars	• Oldest Stars
• Metal-rich	• Metal-Poor
• Blue M-S stars	• No blue M-S stars
• Ordered, circular orbits	• Random elliptical orbits
• Disk-like, bulge though too	• Sphere-like
• Can have gas-rich environment, just formed	• Gas-poor environment

Chemical Evolution

Metals are created by fusion inside of massive stars.

Supernovae enrich the interstellar medium.

The next generation of stars form out of the metal-enriched interstellar gas.

A star’s chemical composition is basically fixed for life.

Successive generations get more metal rich.

Higher Metal Content in *Later* Generations.

First generation (Pop III): no metals, no CNO

Next generation (Pop II): some metals, early galaxies

Next generation (Pop I): now, Sun, lots of metals

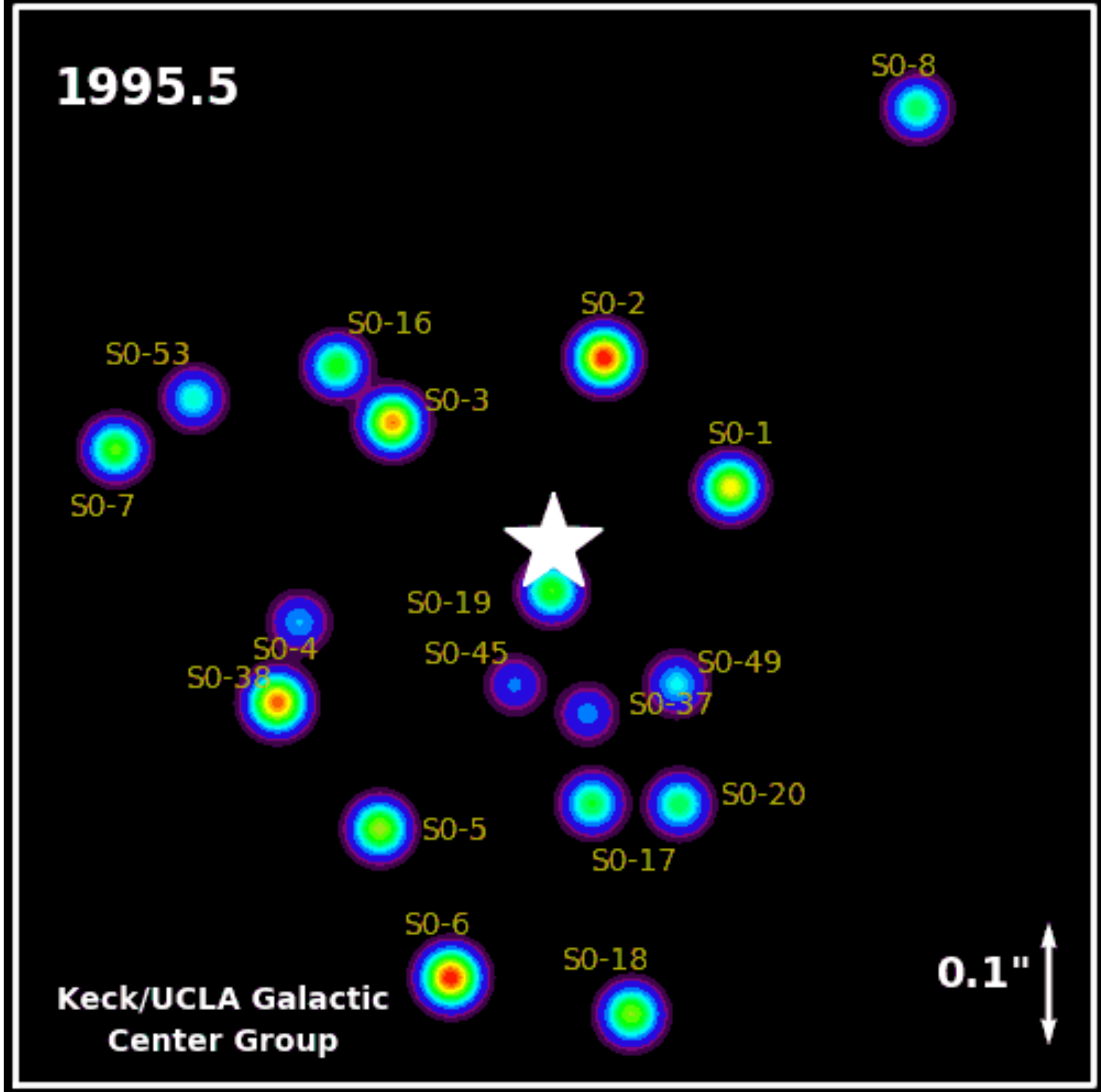
Supermassive black holes.

Deep in the centers of the Milky Way and Andromeda are supermassive black holes

- Masses >1 Million M_{sun}!

Found by the effects of their gravity on the innermost stars:

- Stars orbiting much faster than expected from the number of stars present.
- Evidence of excess X-ray and radio emission.
- Use the orbital speeds and sizes to estimate the mass of the central dark object.



Stars orbiting the black hole:

$M = 3.7 \times 10^6 M_{sun}$
Black Hole at the Center of the Milky Way

Andromeda’s Central Black Hole

$M_{BH} \sim 1 – 2 \times 10^8 M_{sun}$

Nearly 100 x bigger than in the Milky Way.

Detected by watching stars very close to the nucleus.

Supermassive Black Holes

Such black holes are very large:

R_s ~ 8 million km, for $M_{BH} = 4 \times 10^6 M_{sun}$.

Surprising fact: $M_{BH} \sim 0.002\ M_{Bulge}$

Questions:

- What are such large black holes doing at the centers of our Galaxy and Andromeda?
- Why are the BH masses connected with the mass of the host galaxies?
- How could such large black holes form?
- Do other galaxies harbor similarly large black holes in their centers?

The Galaxy Zoo

Spirals

& Ellipticals

& Irregulars

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Key Ideas:

What do Galaxies look like?

- Spirals, Ellipticals, Irregulars, dwarfs

Differ in terms of

- Relative Stellar & Gas content
- Star Formation History
- Internal Motions

What you see when you look up:

All *bright* galaxies fall into one of three broad classes according to their *shape*:

- Spiral Galaxies (~75%)
- Elliptical Galaxies (20%)
- Irregular Galaxies (5%)

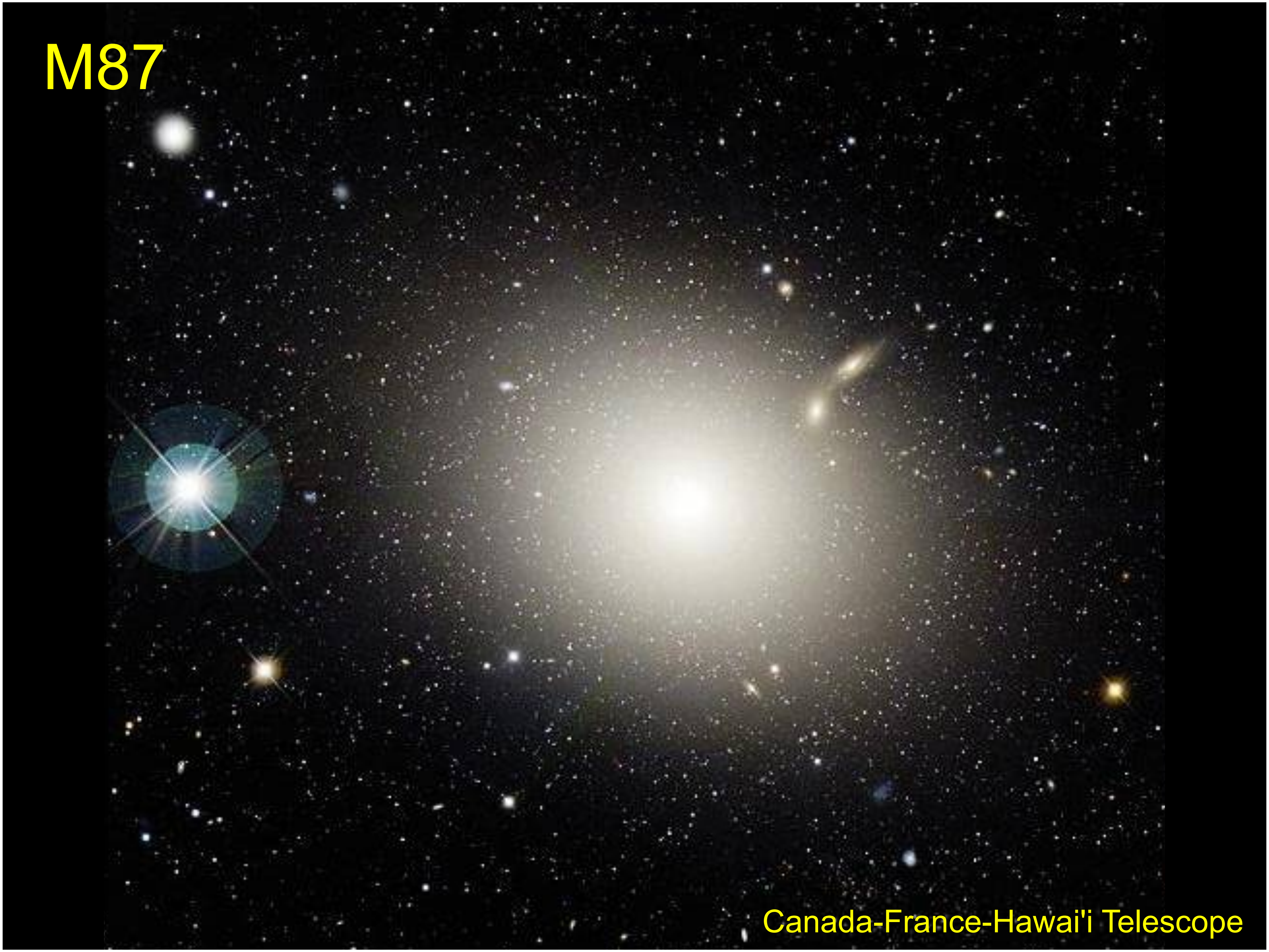
Basic classification system was developed by Edwin Hubble in the 1930s, and refined in later decades.

Ellipticals

Little internal structure:

- Elliptical in shape
- No disks, spiral arms, dust lanes, blue stars
- Brightest stars are red giants
- Yellow/red color = old

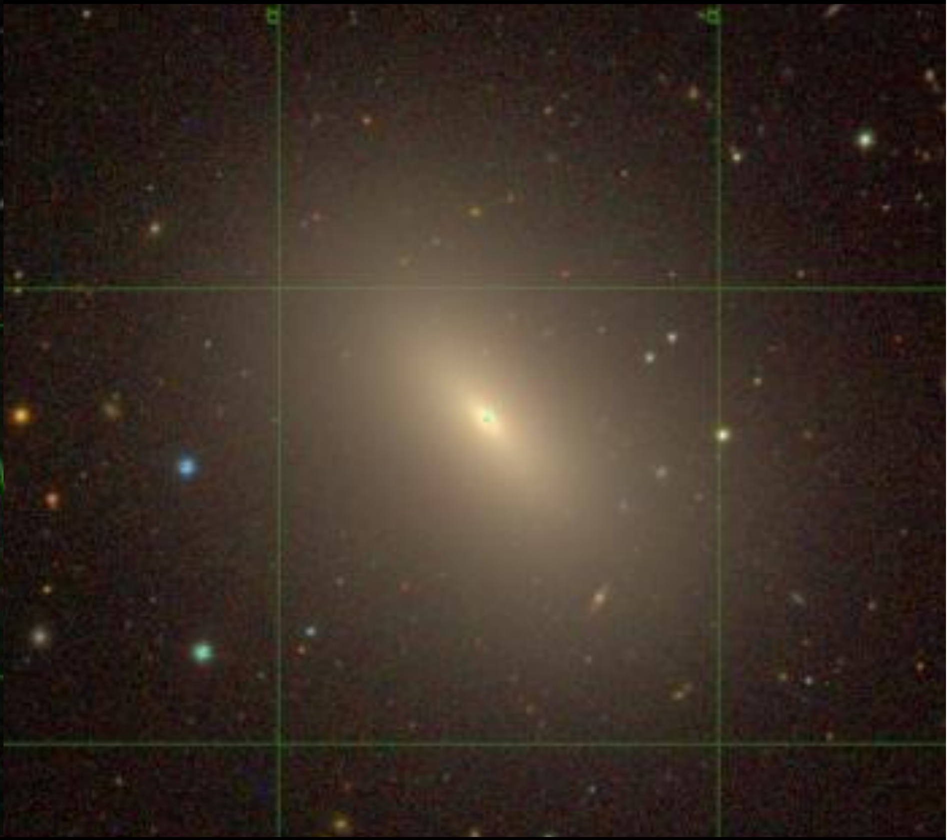
M87



Canada-France-Hawai'i Telescope

Elliptical Galaxies

Nearly spherical



Flatter

Sloan Digital Sky Survey

Spirals

Range from no bulge to big bulge.

Active ongoing star formation. Bright blue stars.

Lots of gas.

Spiral arms, dust lanes.

Spiral galaxies

Big bulge

Smaller bulge

Smaller still

Big bulge: older stellar population

Big bulge = big central black hole.

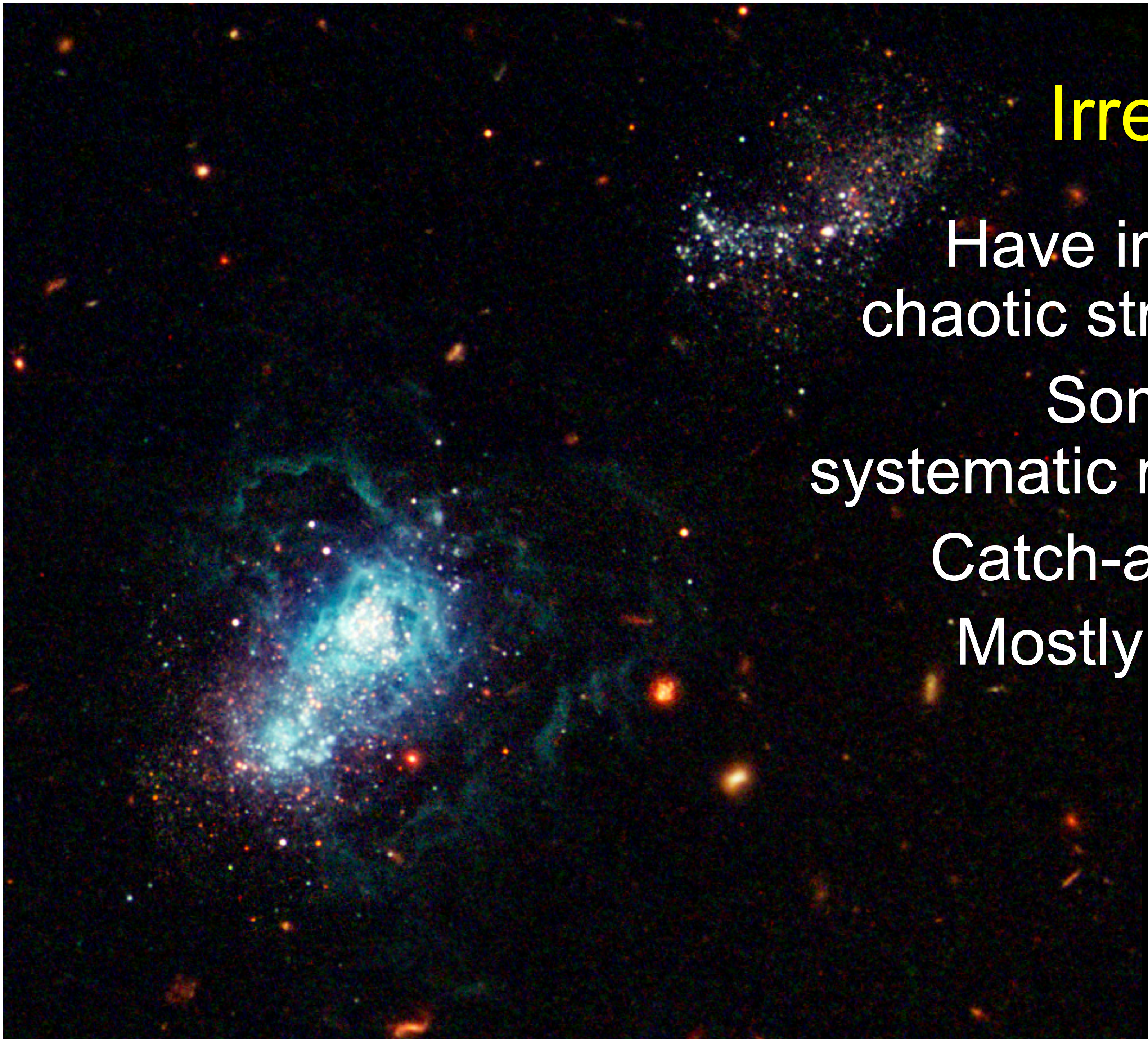
No bulge = no black hole?

Barred Spirals

Central *stellar bar*:

- Bar rotates as a unit (solid body rotation)
- Spiral arms emerge where the bar ends
- Older stellar pop.

About as numerous as normal spirals.



Irregulars

Have irregular, chaotic structures

Sometimes systematic rotation.

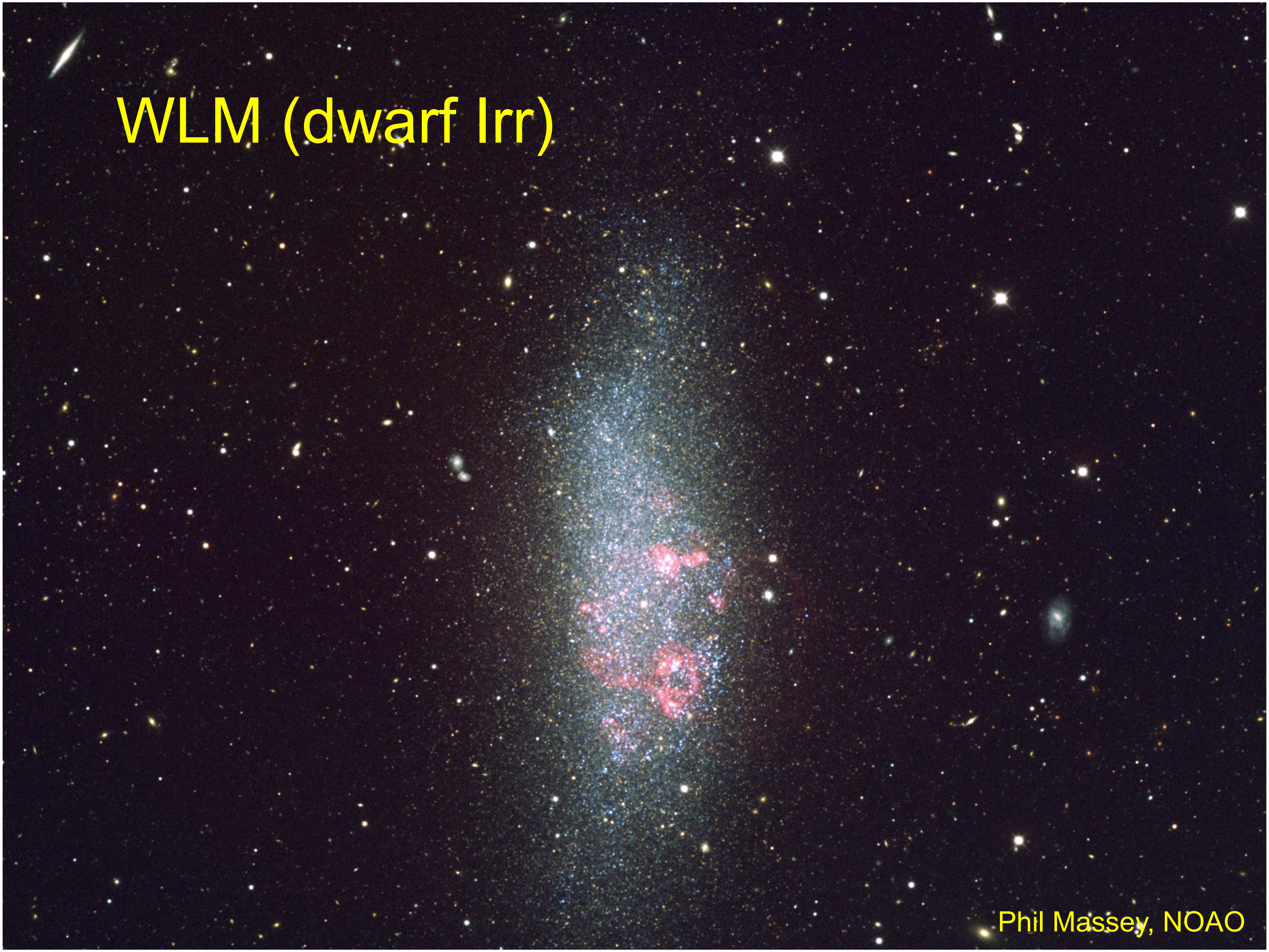
Catch-all class.

Mostly dwarfs.

Irregulars: Large & Small Magellanic Clouds

Amateur photos by Loke Kun Tan, Josch Hambsh & Robert Gendler

WLM (dwarf Irr)



Phil Massey, NOAO

Announcements:

Normal Monday Lab today.

No Tuesday Lab tomorrow! Veteran's Day.

Spiral Galaxies

Properties:

- Stellar Mass: $10^9 - 10^{12}$ M_{sun}
- Diameter: 5 – 50 kpc
- Luminosity: $10^8 - 10^{11}$ L_{sun}

Structure & Dynamics:

- Disk: ordered rotation, gas & dust, star formation, mix of Pop I and Pop II. 10% gas.
- Spheroid: chaotic orbits, little gas/dust, little if any star formation, old population.
- Bar: like a spheroid, but with different orbits
- Supermassive black hole mass proportional to bulge mass.

Elliptical Galaxies

Properties:

- Stellar Mass: $10^5 - 10^{13}$ M_{sun}
- Diameter: 1 – 200 kpc
- Luminosity: $10^6 - 10^{12}$ L_{sun}

Structure & Dynamics:

- All Spheroid: old stars with little gas or dust, all Pop II.
- Star formation ended Gyrs ago.
- All that we can check have supermassive black holes.

Irregular Galaxies

Properties:

- Mass: $10^5 - 10^{11}\ M_{sun}$
- Diameter: 1 – 10 kpc
- Luminosity: $10^6 - 10^{10}\ L_{sun}$

Structure & Dynamics:

- Chaotic structure sometimes, sometimes some disk, sometimes some bar, lots of young blue stars, gas & dust, star formation.
- Mostly Pop I. Many forming first stars now!
- Up to 90% gas! Sometimes very metal-poor.

Dwarfs

Leo I (Dwarf Spheroidal)

Tiny Ellipticals & Irregulars.

Most common type of galaxy by number

There seem to be no dwarf Spirals.

Sloan Digitized Sky Survey

Cosmic Building Blocks

Galaxies of all types are the basic "units" of luminous matter in the Universe.

- Basic units of larger, organized structures
- Sites of star formation from raw gas
- Factories that synthesize heavy elements from Hydrogen & Helium

Differences in the types of galaxies reflect differences in their star formation histories and environments, mergers.

Nearest neighbors, mergers.

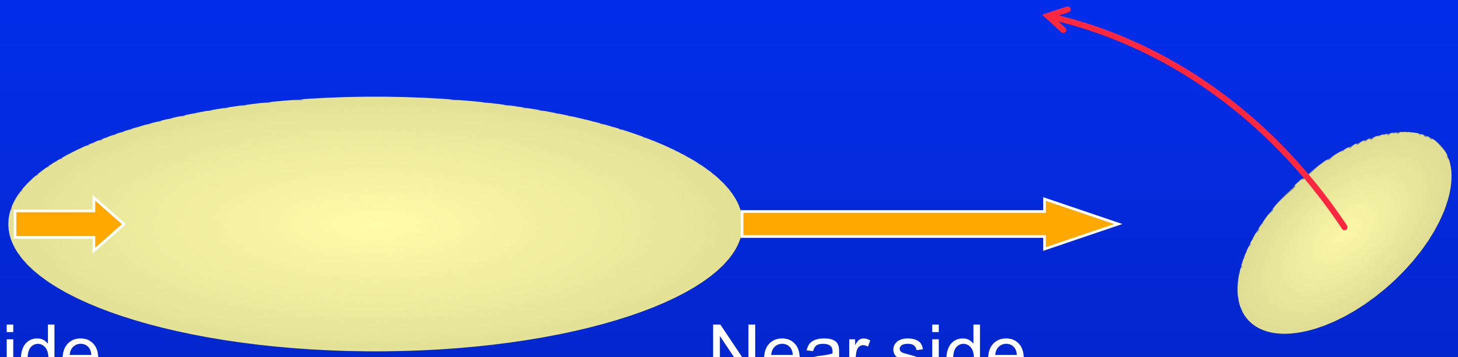
Galaxies are large compared to the distances between them:

- Most galaxies separated by only ~20 times their diameters, ~ 0.5 Mpc. If you are a galaxy, your nearest neighbor is 100 feet away.
- Most stars separated by ~10^8 times their diameters. If you are a star, your nearest neighbor is 50,000 miles away.

Big galaxies are likely to encounter other big galaxies a few times over their histories.

Interact, raise tides. Stars pass through without collisions. Cause starbursts! Fuel black holes, merge.

Raising Tides

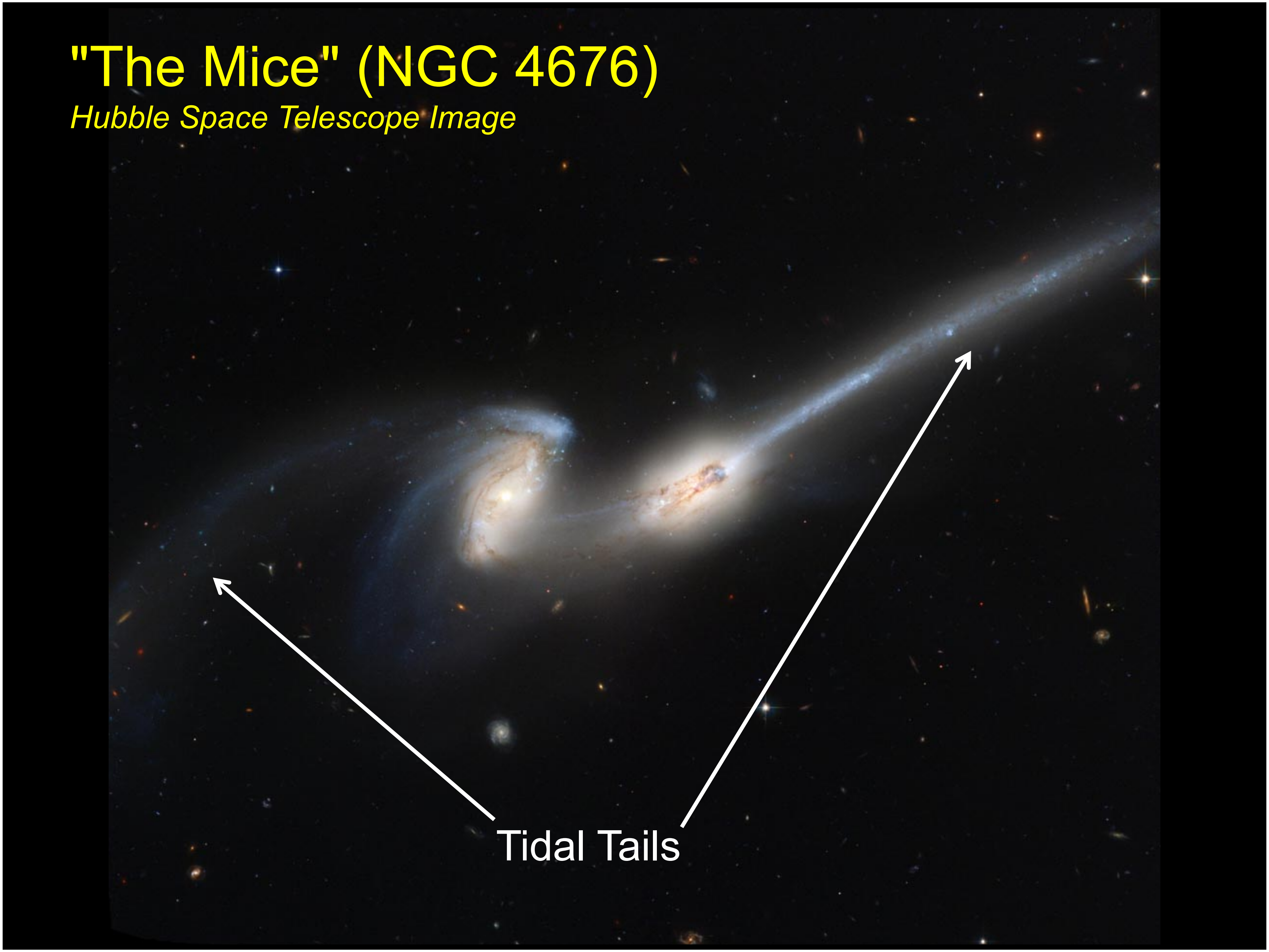


<u>Tidal stretching</u> along the encounter line.

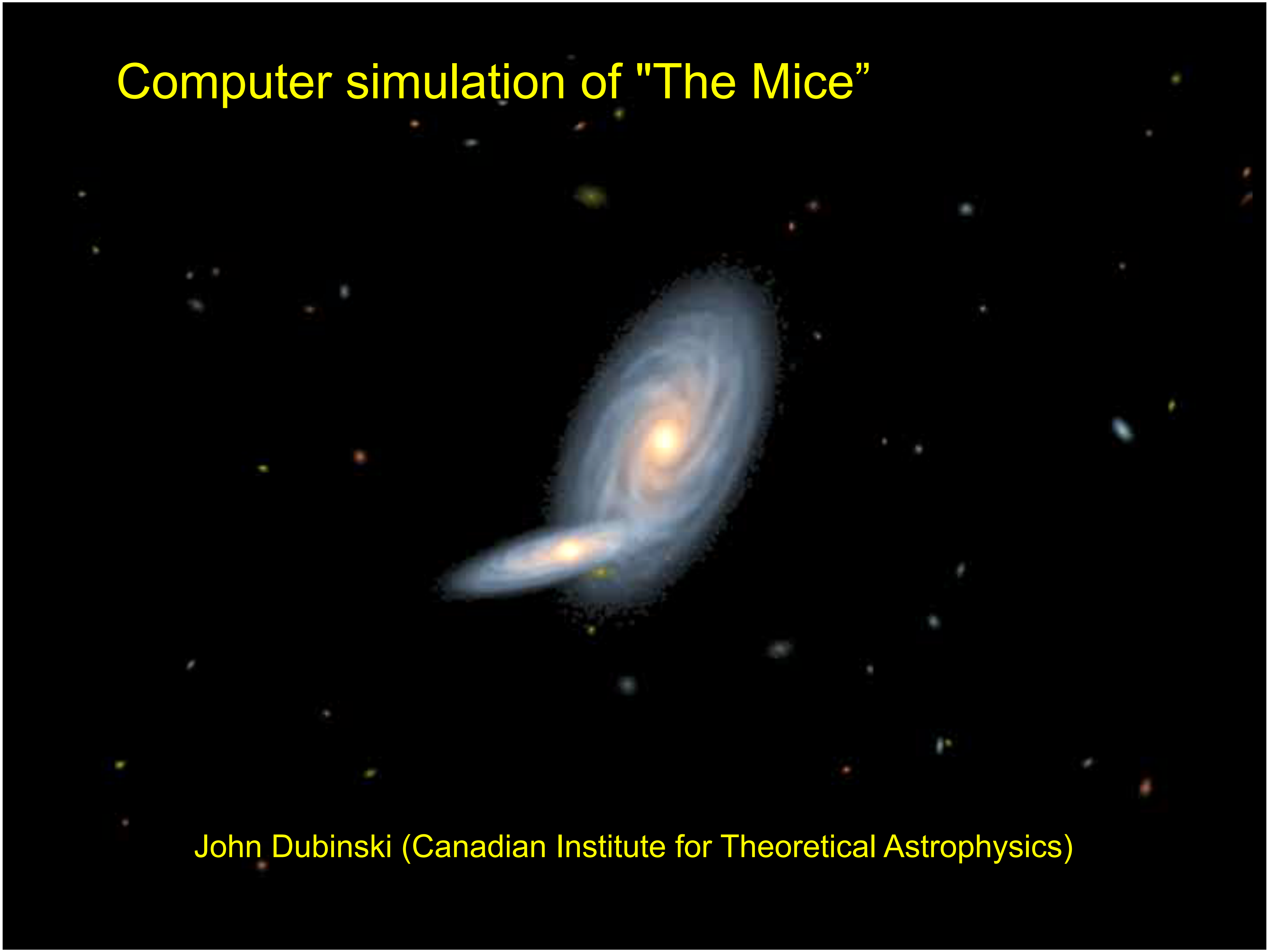
- Near side feels stronger gravitational pull from the companion
- Far side feels weaker gravitational pull and lags behind the near side.

"The Mice" (NGC 4676)

Hubble Space Telescope Image



Computer simulation of "The Mice”



John Dubinski (Canadian Institute for Theoretical Astrophysics)

Starbursts during mergers.

- Shockwaves in gas channel gas to center of galaxy.
- High gas densities imply high star formation rates.
- Millions of massive stars greatly enhance the brightness of the galaxy. Exhaust gas.
- Intense star formation can drive fast “superwinds,” blowing metal-rich gas out of the galaxies.
- The most star-forming galaxies have rates 1000 x larger than the Milky Way (1 star/yr).
- Much more common in the early universe.

The most intense starbursts occur in violently interacting galaxy pairs.

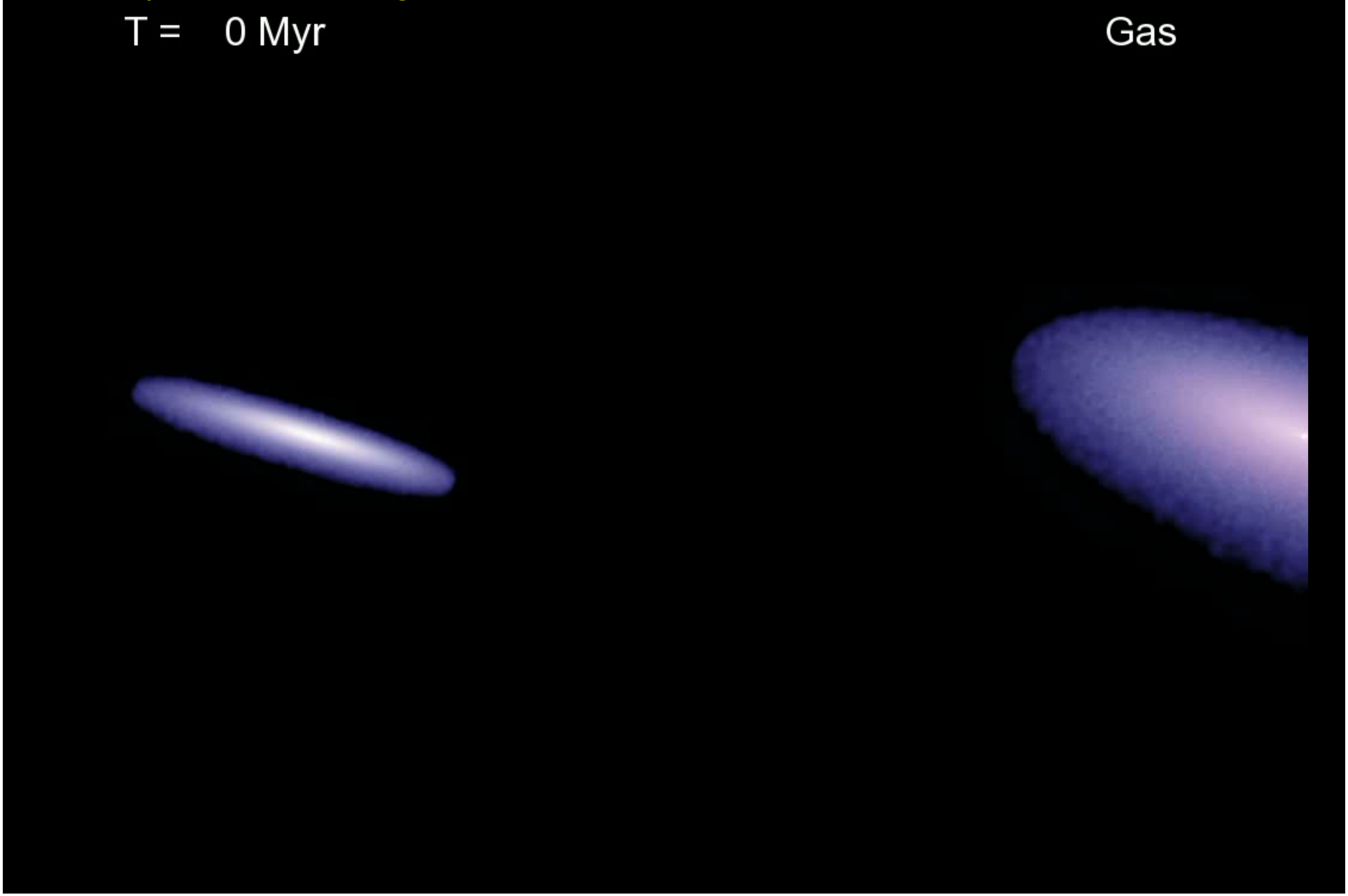
M82

Starburst !!

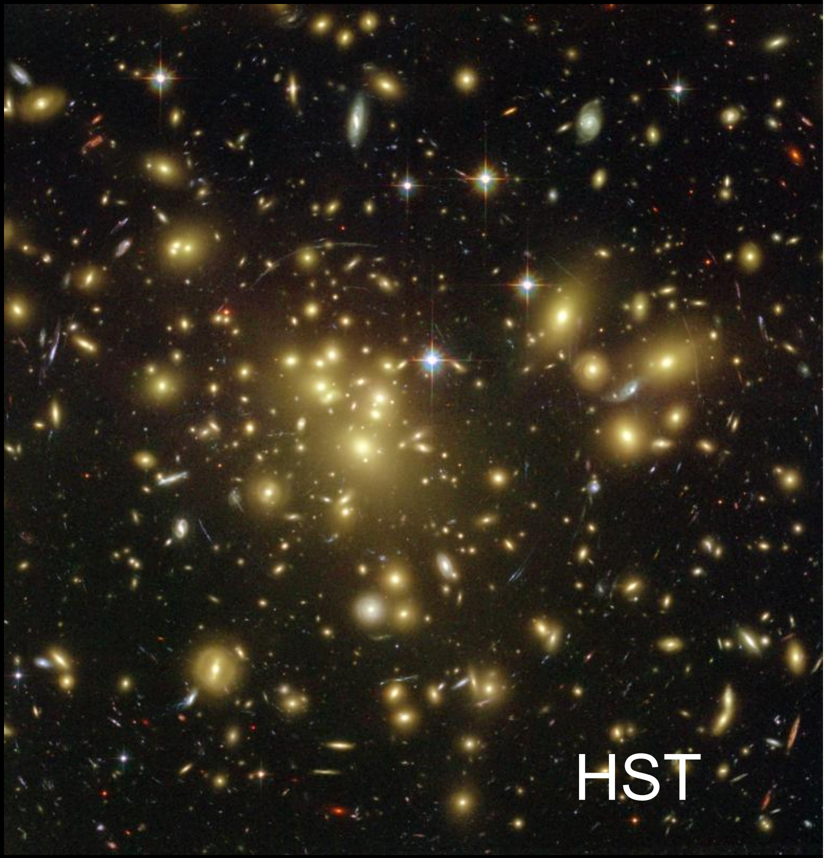
Wind mass loss rate is roughly equal to the star formation rate.

Computer simulation of galaxies colliding & merging.

Gas only. Volker Springel



Simulation of the Formation of a giant cluster Elliptical galaxy by mergers (Dubinski; CITA)



Mergers play a key role in the evolution, transformation, and assembly of galaxies over cosmic time.

Andromeda is heading right at us. In a few Gyr we'll merge, produce elliptical galaxy.

Mergers play a key role in the evolution, transformation, and assembly of galaxies over cosmic time.

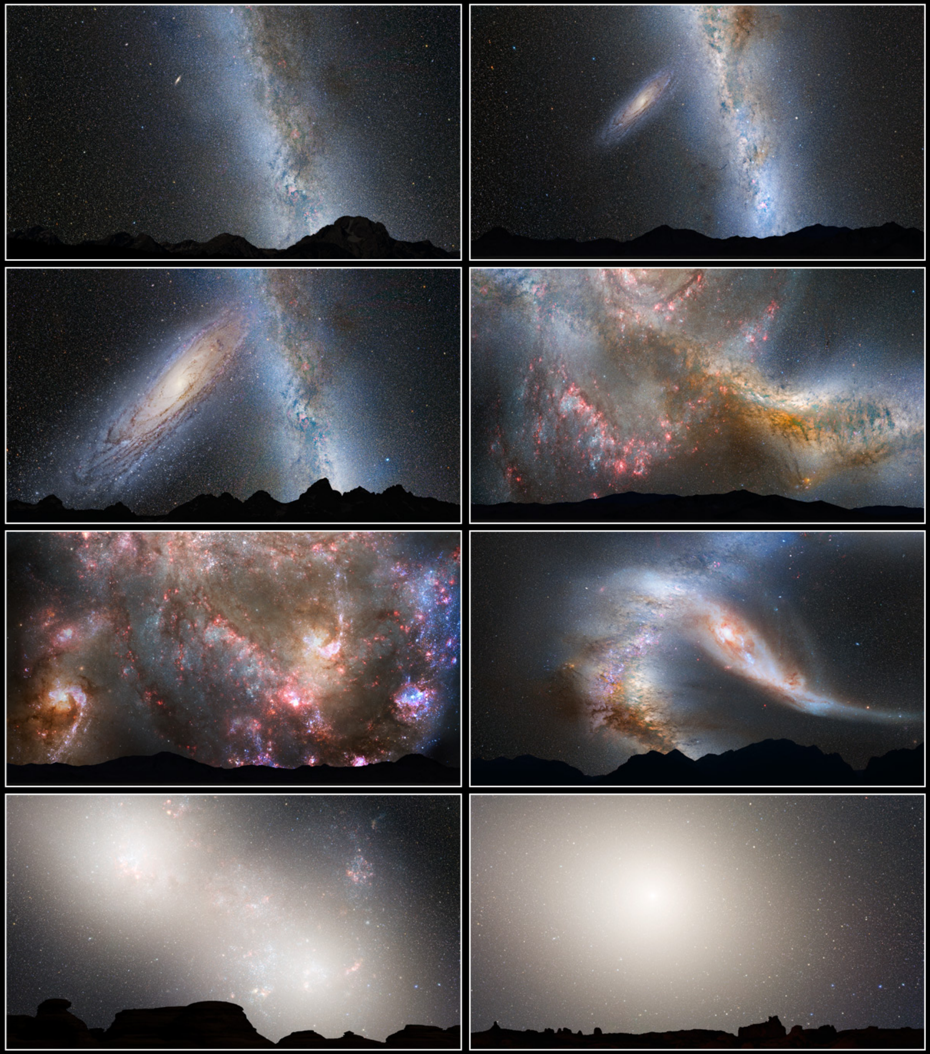


Illustration Sequence of the Milky Way
and Andromeda Galaxy Colliding

NASA, ESA, Z. Levay and R. van der Marel (STScI), T. Hallas, and A. Mellinger ▪ STScI-PRC12-20b

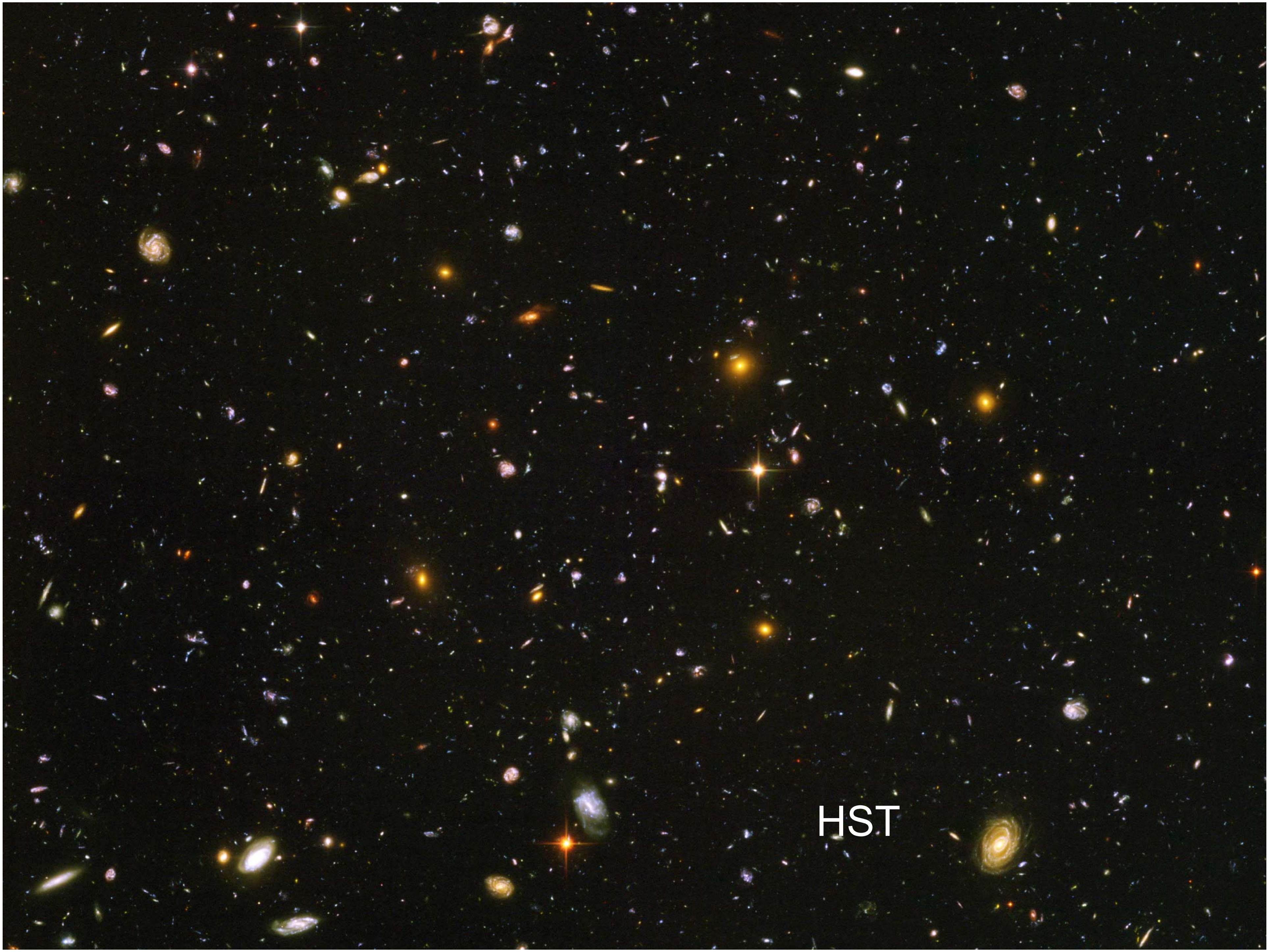
Large scale structure: a structure of structures

Galaxies gather into *Groups & Clusters*

The Milky Way is part of the *Local Group*

Hierarchy of Structure:

- Galaxies are basic building blocks.
- Groups: 3 to 30 bright galaxies
- Clusters: >30 (up to 1000's) of bright galaxies
- Superclusters: Clusters of Clusters
- Voids, Filaments, & Walls


HST

Groups & Clusters of Galaxies

Most galaxies are found in groups & clusters

Basic Properties:

- Groups: 3 to 30 bright galaxies
- Clusters: 30 to 300+ bright galaxies
- Sizes: 1 – 10 Mpc across (MW is ~10kpc across)
- Often contain **many** more dwarf galaxies.

Thousands of clusters have been cataloged.

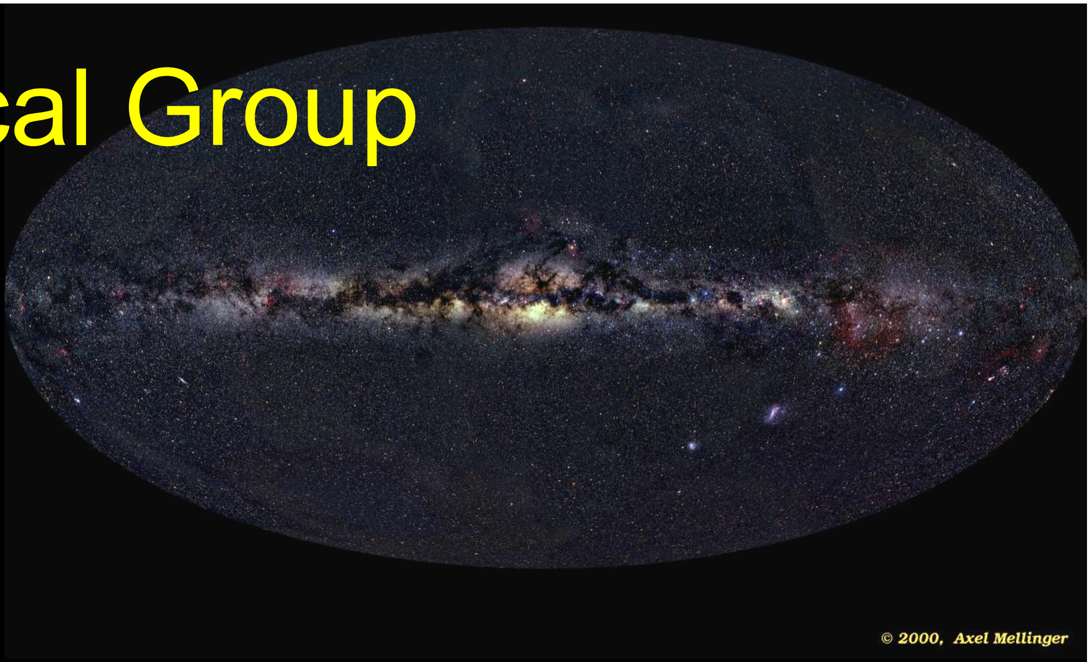
The “*Local Group*”

Group of 39 galaxies including the Milky Way and Andromeda:

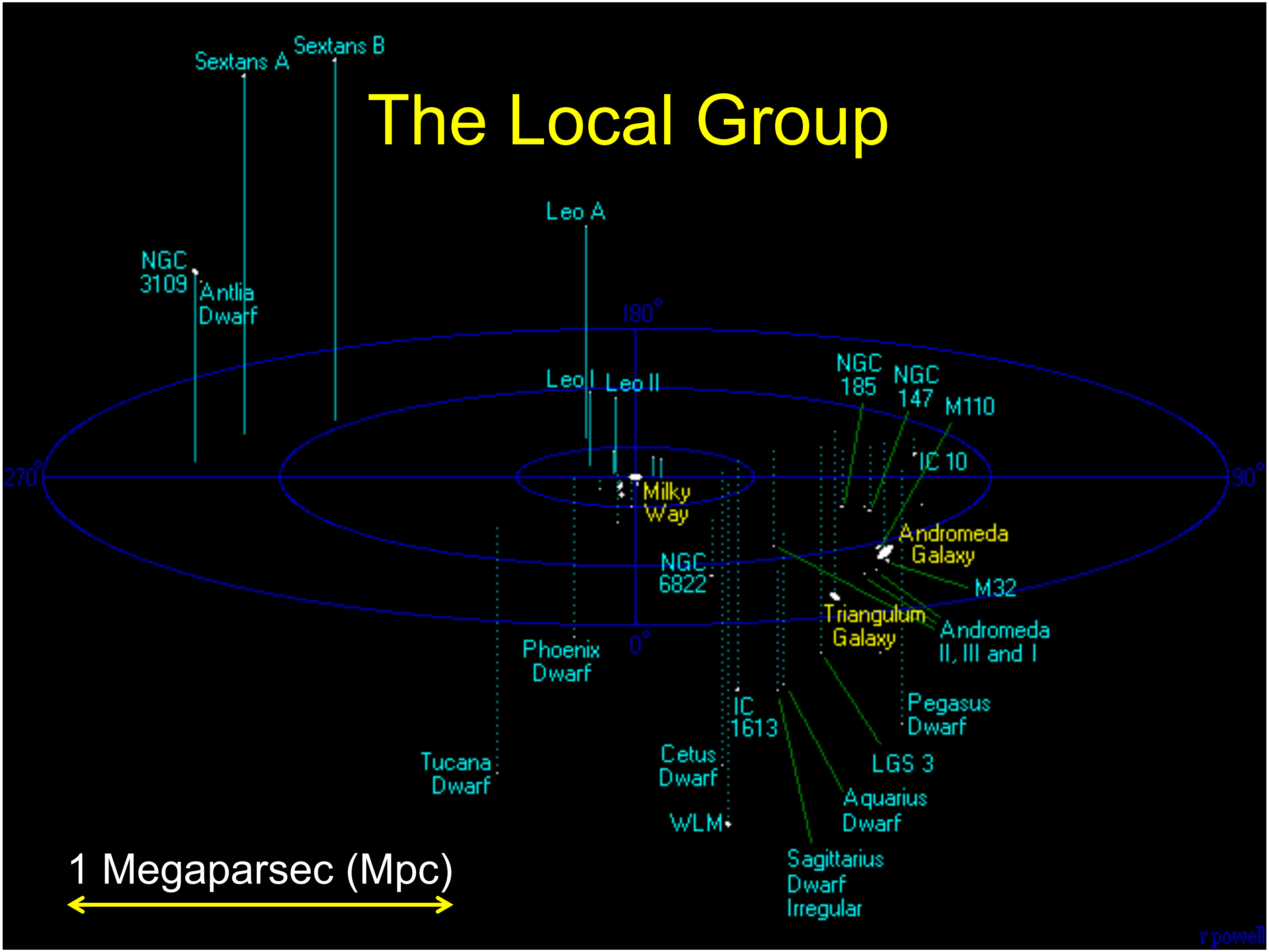
- Size: ~1 Mpc
- 5 bright galaxies (M31, MW, M33, LMC, IC10)
- 3 Spirals (MW, M31, & M33)
- 22 Ellipticals (4 small Es & 18 dEs)
- 14 Irregulars of various sizes

Total Mass ~5×10^{12} M_{sun}

Spirals of the Local Group


© 2000, Axel Mellinger

The Local Group



1 Megaparsec (Mpc)

Virgo Cluster

Nearest cluster to the Local Group

Centered on two bright Ellipticals: M87 & M84

Properties:

- Distance: ~18 Mpc
- Size: ~ 2 Mpc
- 2500 galaxies (mostly dwarfs)
- Mass: ~10^{14} M_{sun}

Rich Clusters

Contain 1000's of bright galaxies:

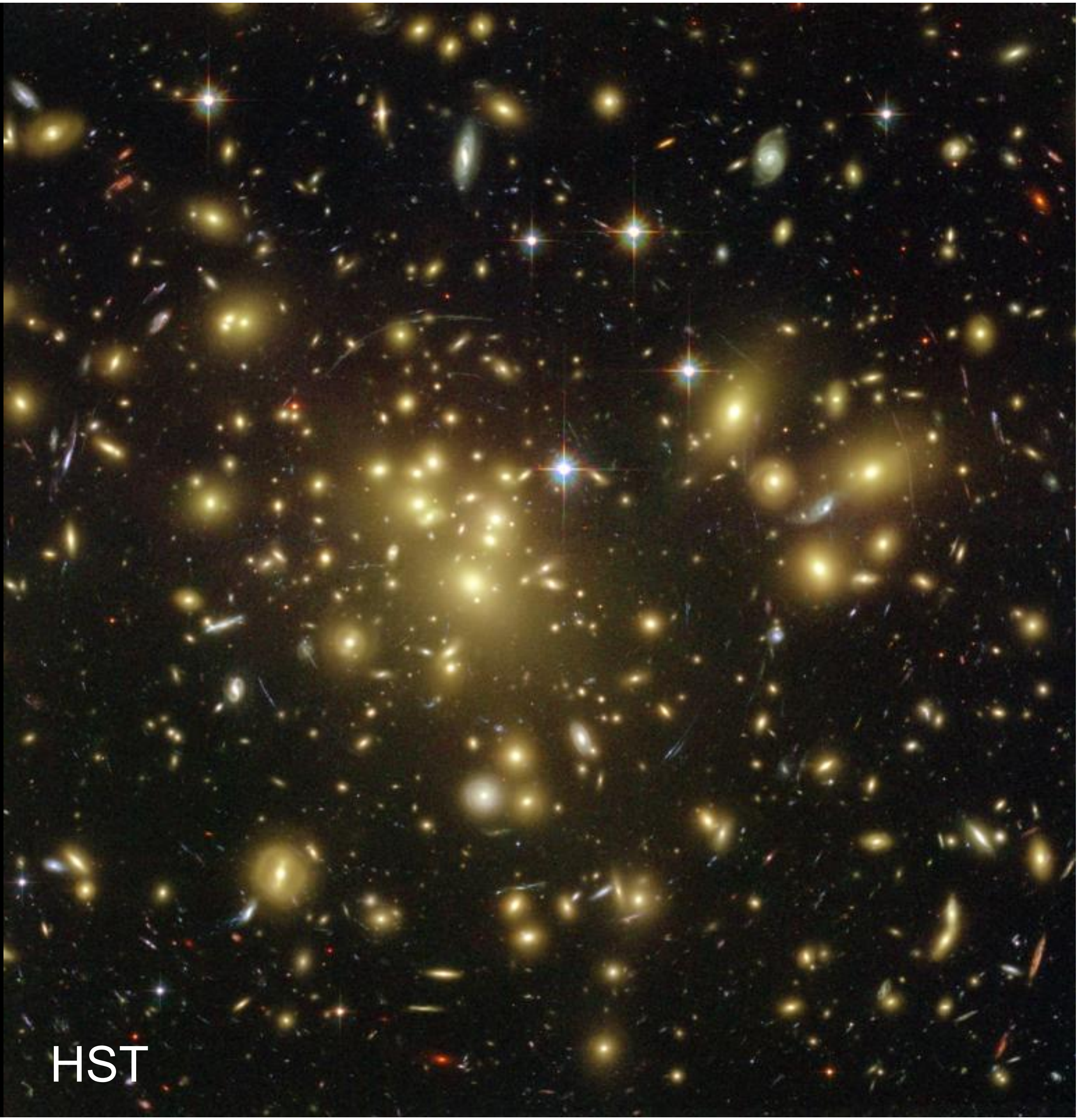
- Extend for 5–10 Mpc
- Masses up to ~10^{15} M_{sun}
- One or more giant Elliptical Galaxies at center
- Ellipticals found near the center (red, dead (no SF))
- Spirals found at the outskirts (actively star-forming)

10–20% of their mass is in the form of a very hot (10^{7-8} K) intracluster gas seen only at X-ray wavelengths.

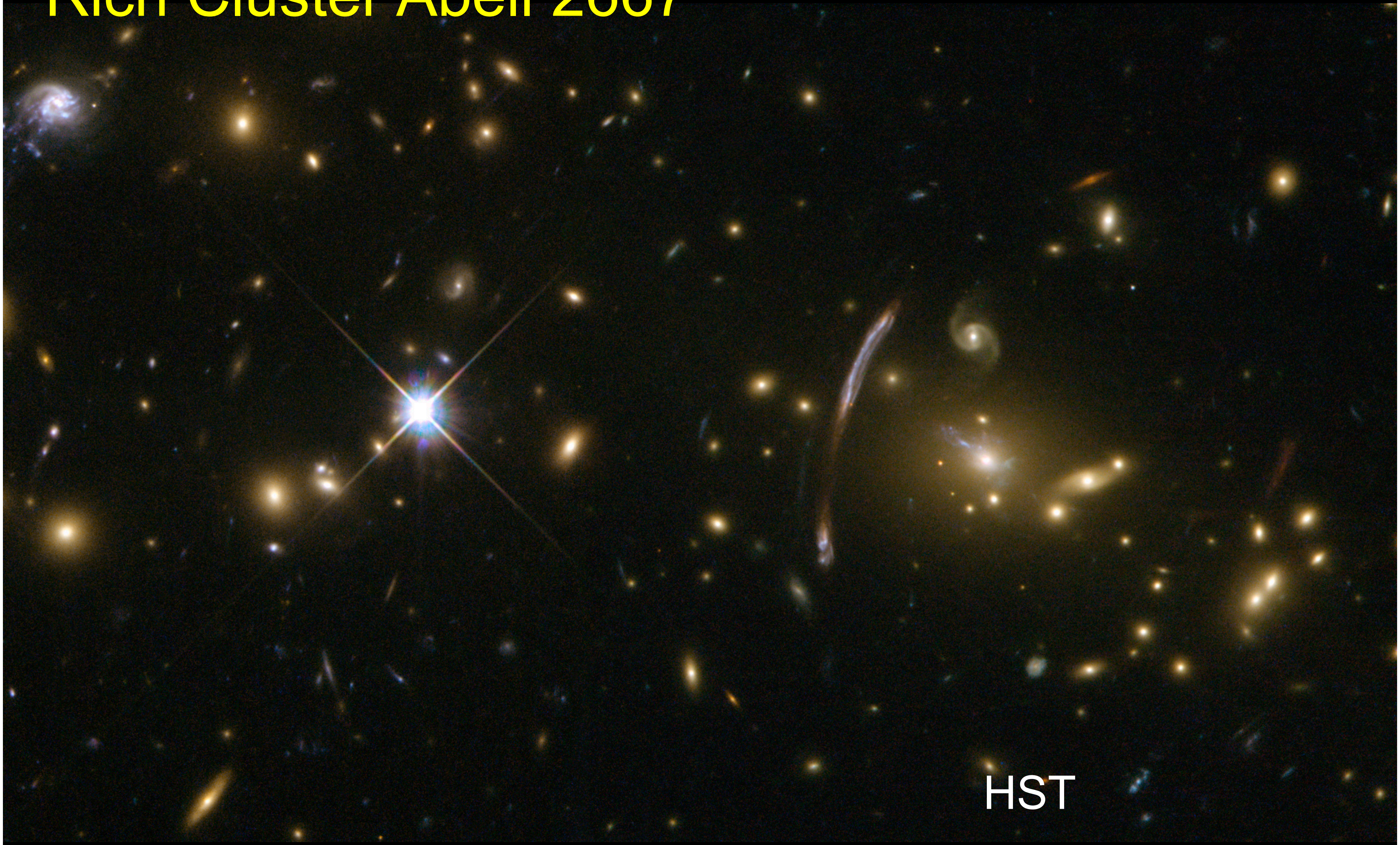
Rich Cluster
Abell 1689

Why more blue galaxies on the outskirts?

As galaxies come in, they merge, are disrupted, undergo bursts of star formation.



Rich Cluster Abell 2667



Superclusters are clusters of clusters.

Properties:

- Sizes up to 50 Mpc
- Masses of 10^{15} to 10^{16} M_{sun}
- Often long and filamentary in shape

Largest coherent structures in the Universe.

The Local Group is located on the outskirts of the Local Supercluster, and falling into the Virgo Cluster.

Voids, Filaments & Walls

The Universe looks foamy on the largest scales

Filaments:

- Vast chains of superclusters
- Occupy ~10% of the Universe

Voids: Empty bubbles

- 25–50 Mpc in diameter
- 5 x fewer galaxies than in superclusters

Sloan Digital
Sky Survey