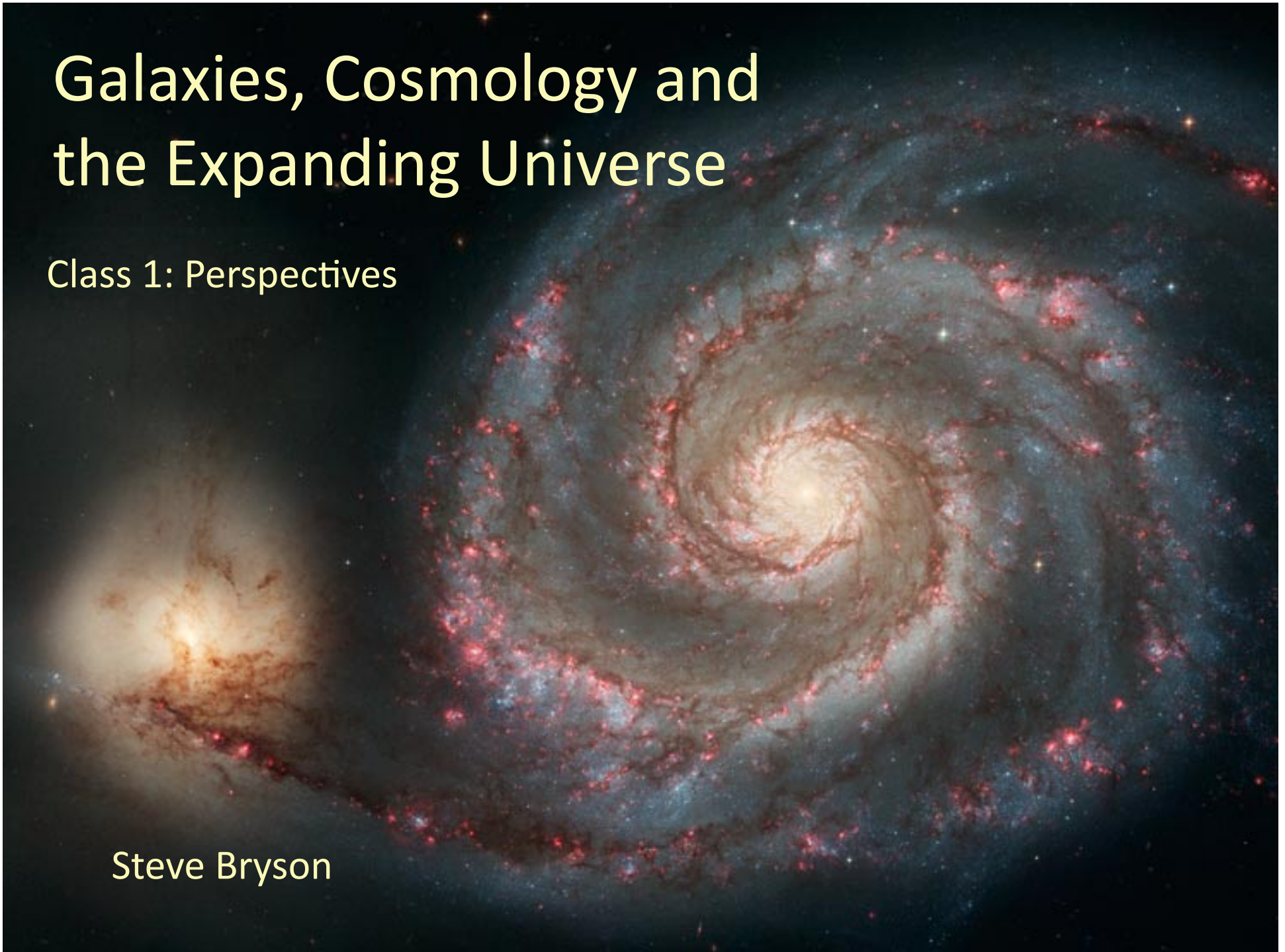


Galaxies, Cosmology and the Expanding Universe

Class 1: Perspectives

Steve Bryson



Class Mechanics



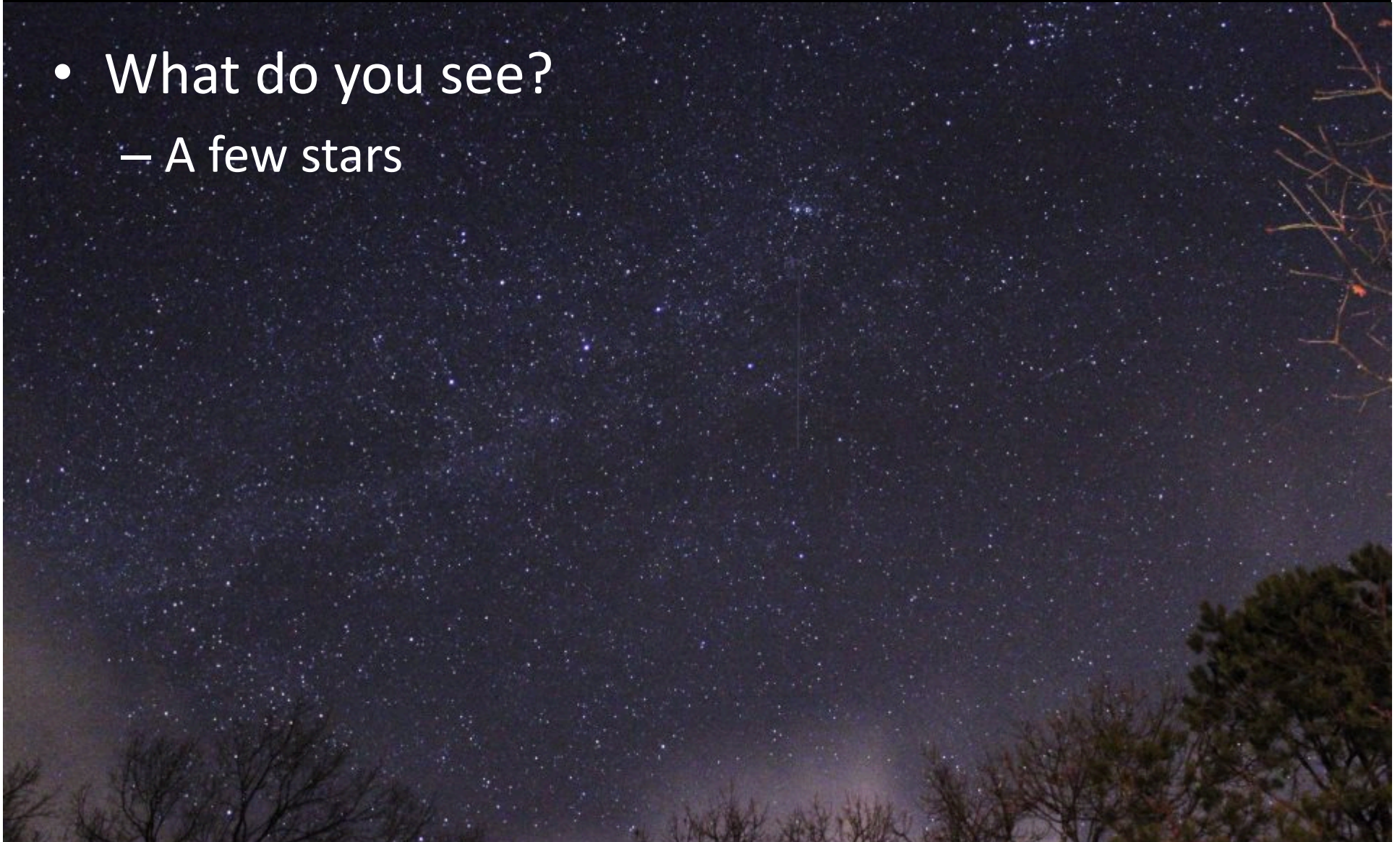
Look Up on a Clear Night

- What do you see?



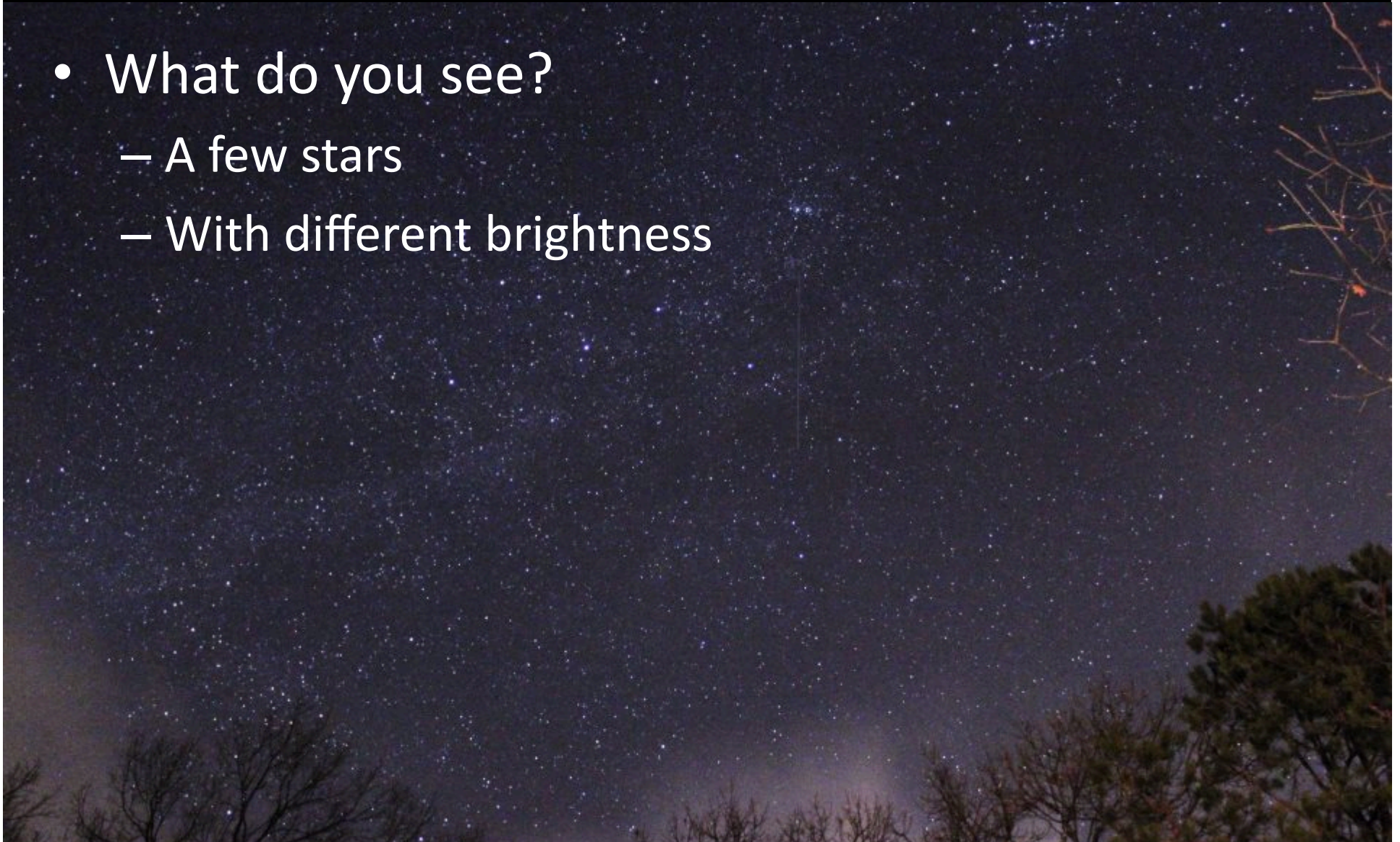
Look Up on a Clear Night

- What do you see?
 - A few stars



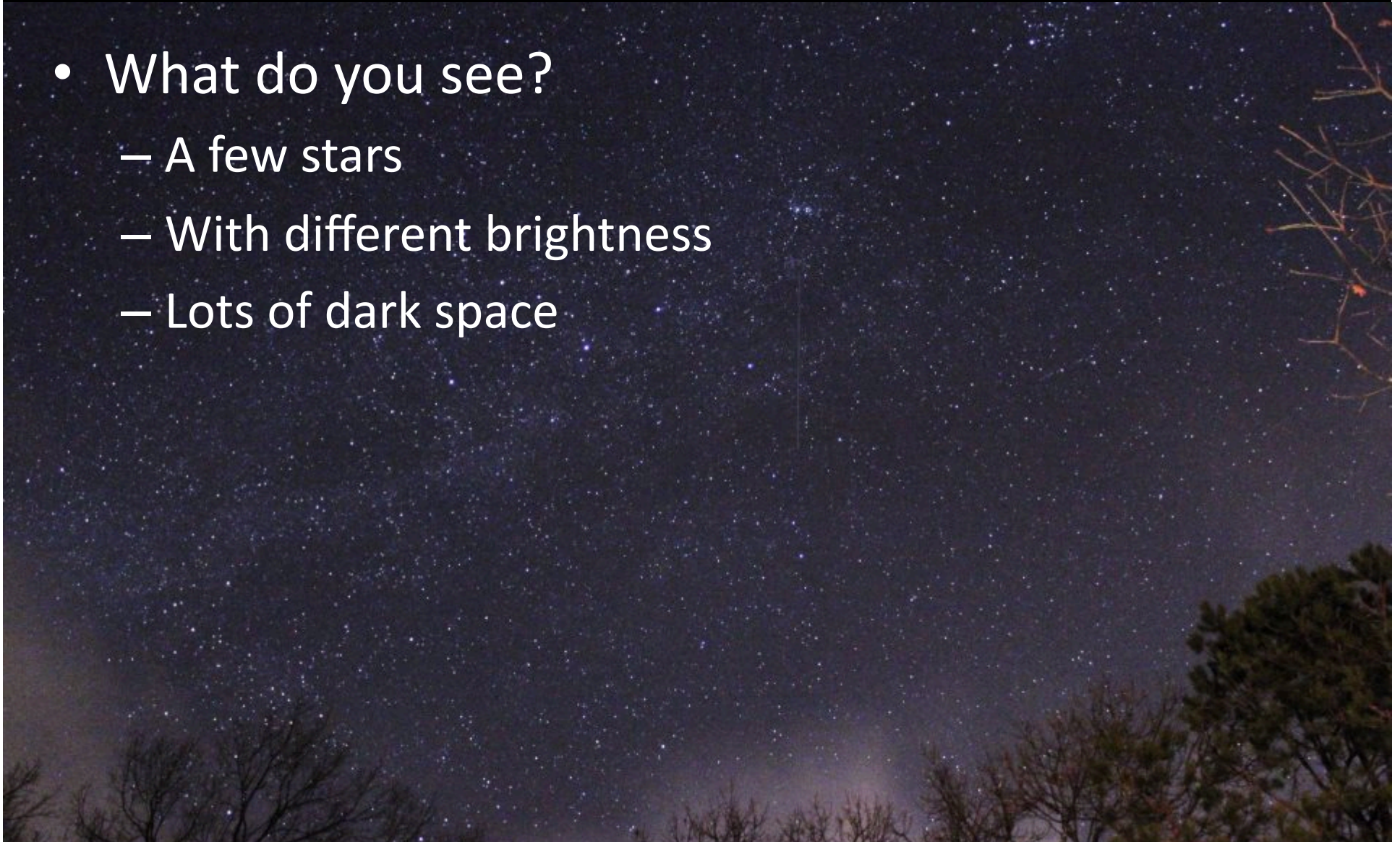
Look Up on a Clear Night

- What do you see?
 - A few stars
 - With different brightness



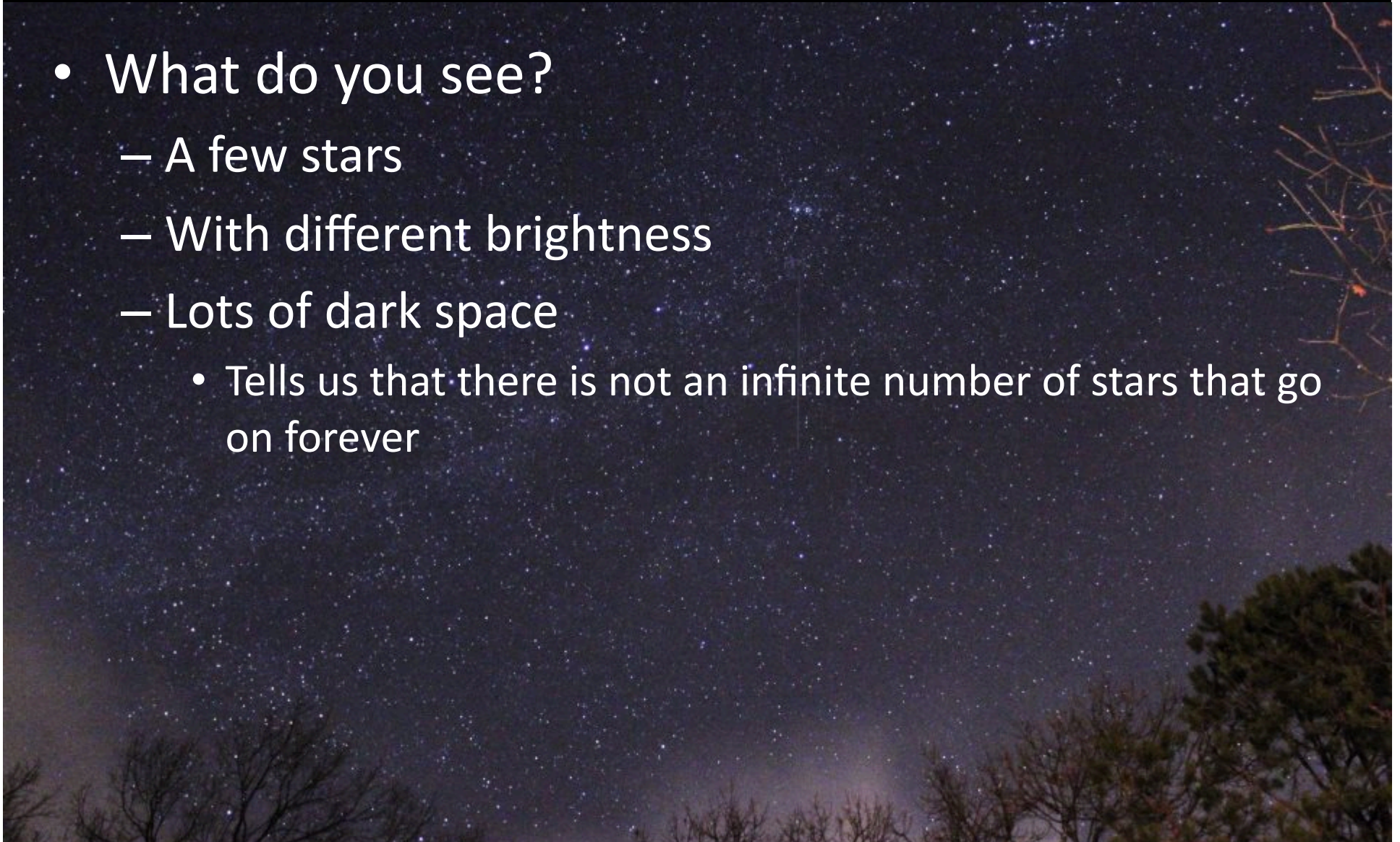
Look Up on a Clear Night

- What do you see?
 - A few stars
 - With different brightness
 - Lots of dark space



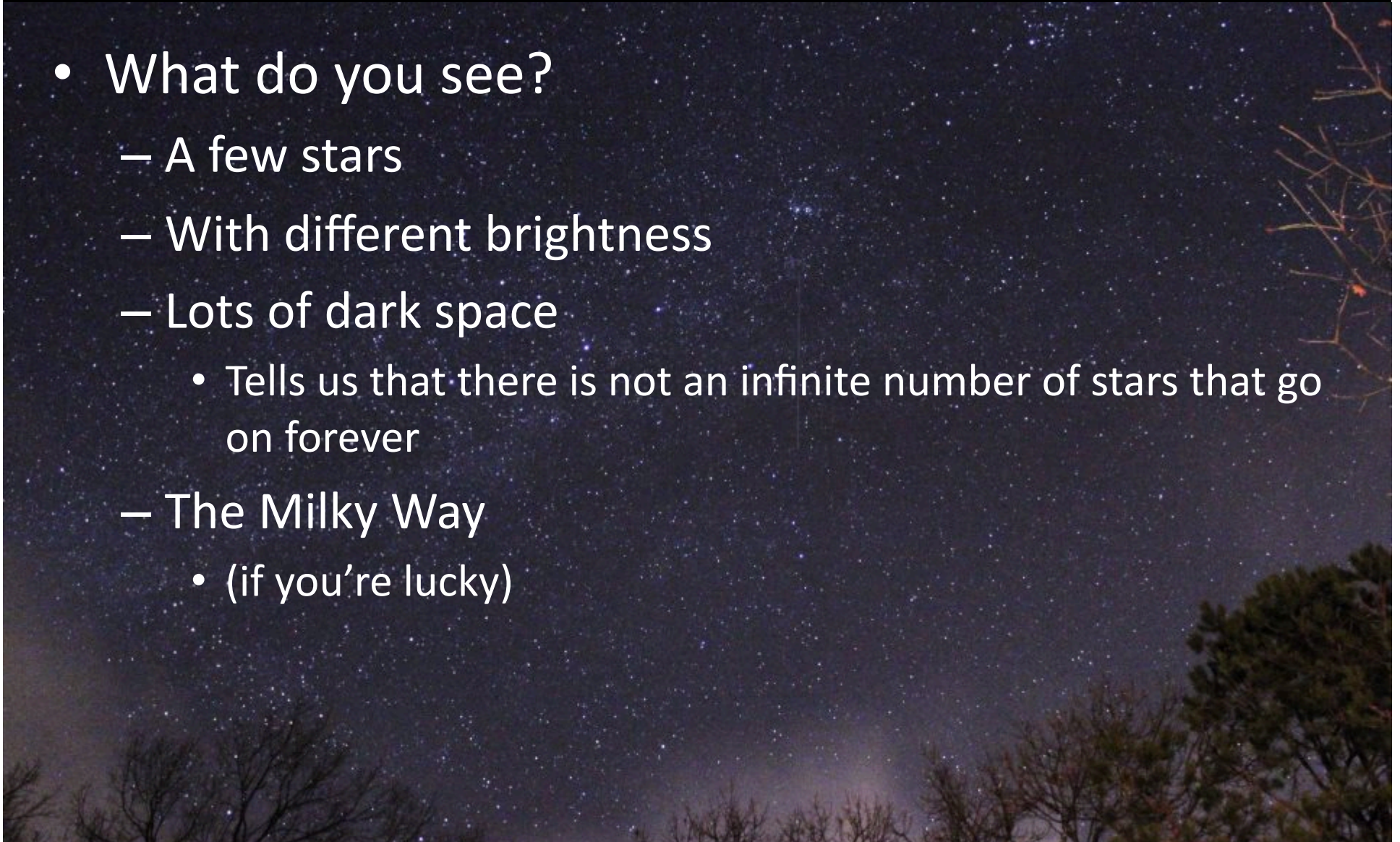
Look Up on a Clear Night

- What do you see?
 - A few stars
 - With different brightness
 - Lots of dark space
 - Tells us that there is not an infinite number of stars that go on forever



Look Up on a Clear Night

- What do you see?
 - A few stars
 - With different brightness
 - Lots of dark space
 - Tells us that there is not an infinite number of stars that go on forever
 - The Milky Way
 - (if you're lucky)



By Collecting More Light We See More



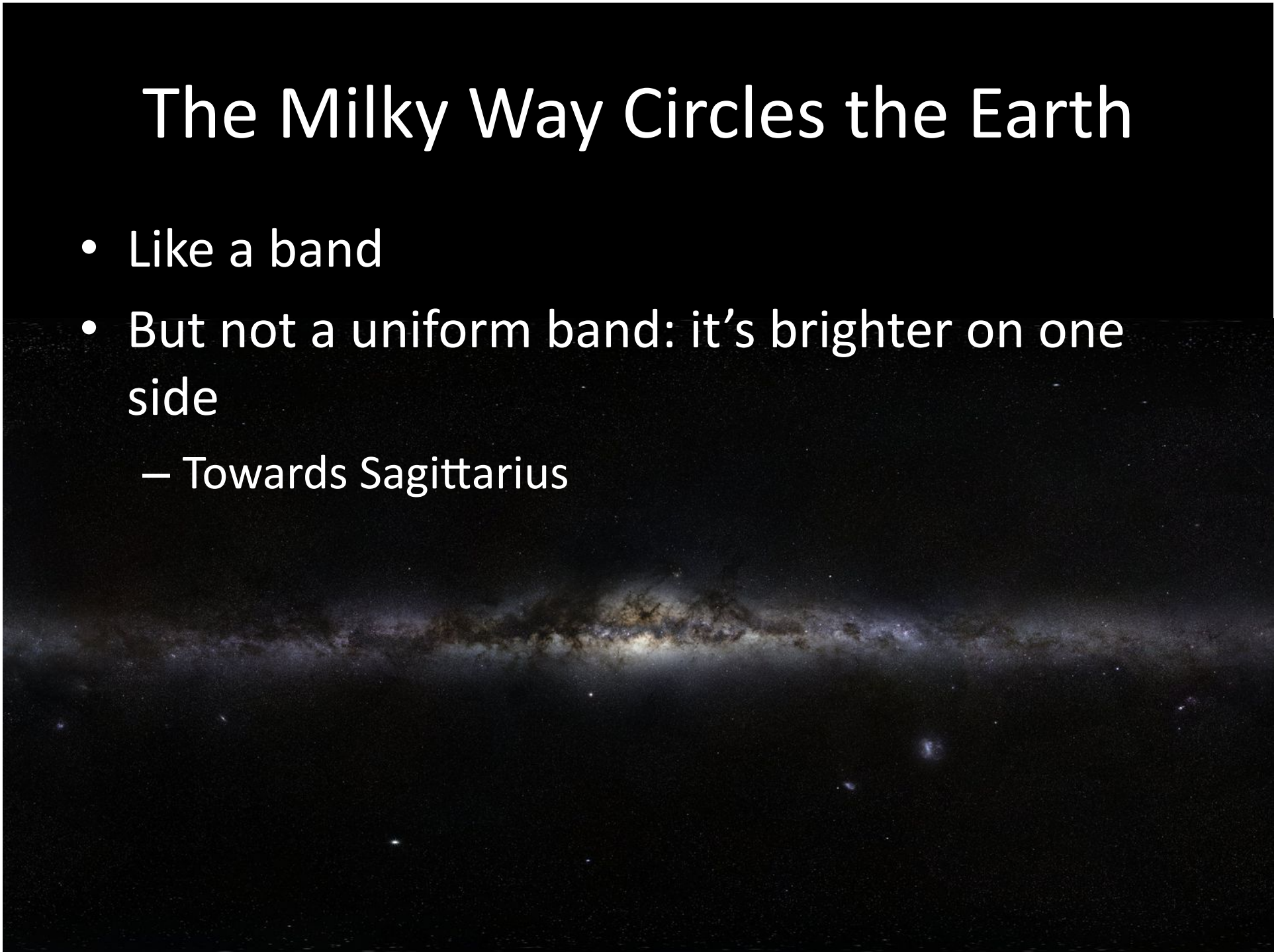
By Collecting More Light We See More

- Stars are different colors
- Bright clouds of gas
- Dark voids

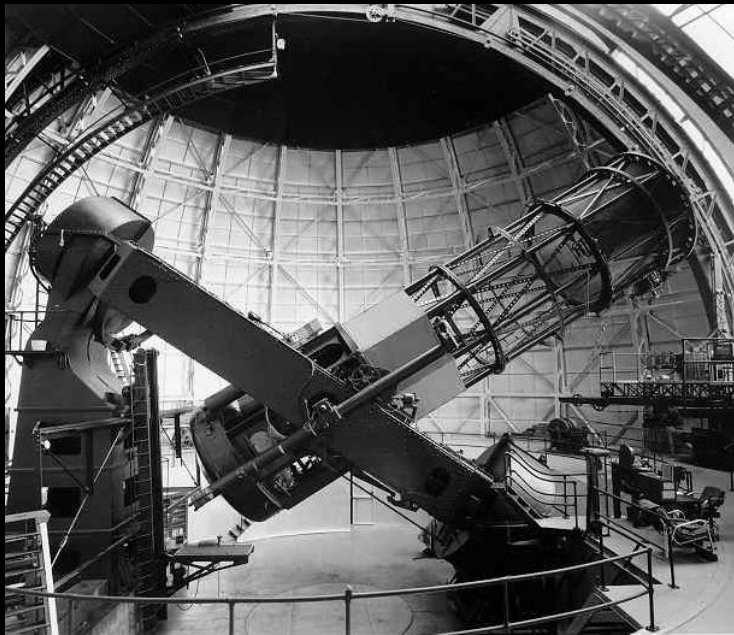


The Milky Way Circles the Earth

- Like a band
- But not a uniform band: it's brighter on one side
 - Towards Sagittarius

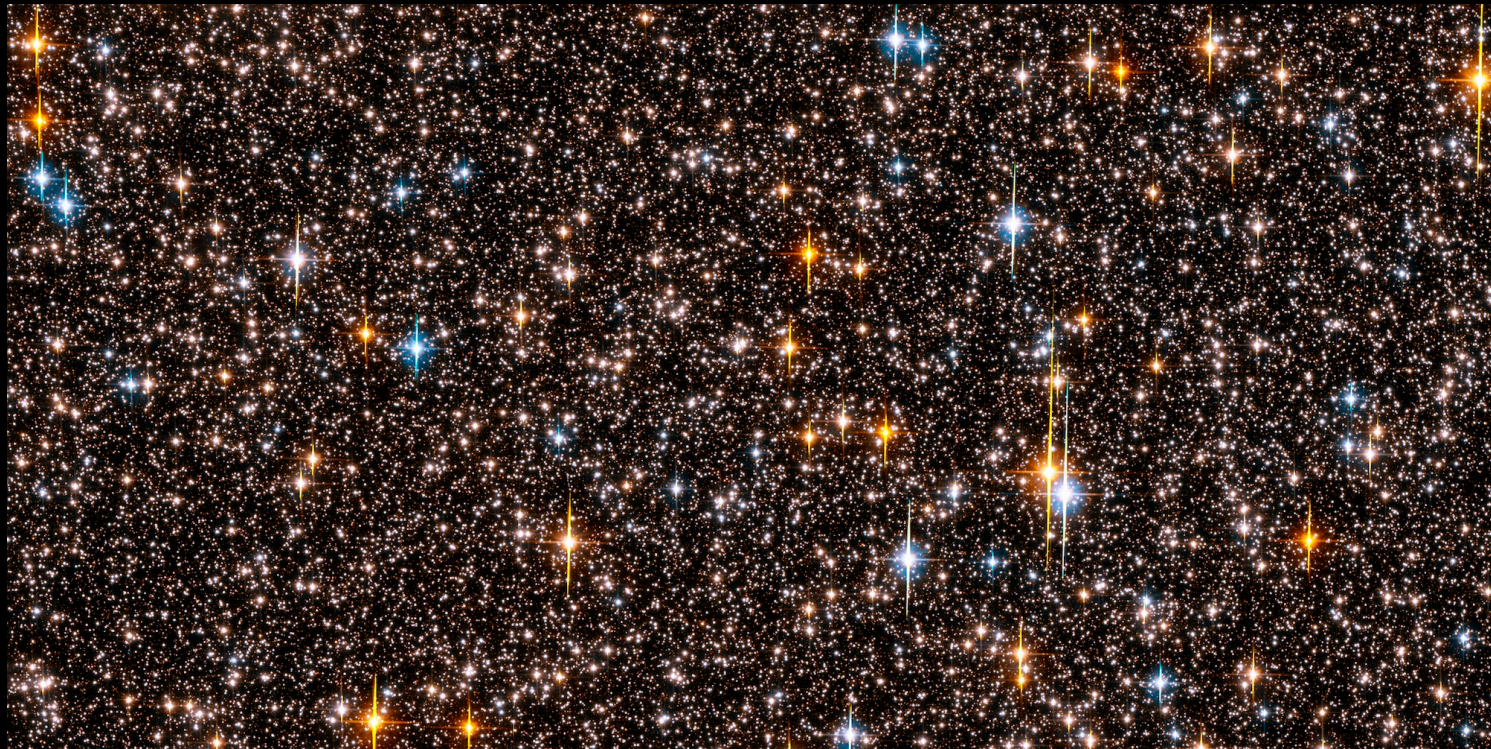


With Telescopes We See Details



The Milky Way is Just Lots More Stars

- First discovered by Galileo
- They must be really far away
 - (compared to the bright stars)



Clusters of Stars

- Open Clusters



- Globular Clusters



Three Kinds of Bright Cloudy Things

- Extended amorphous clouds



- Small roundish clouds



- Spiral clouds

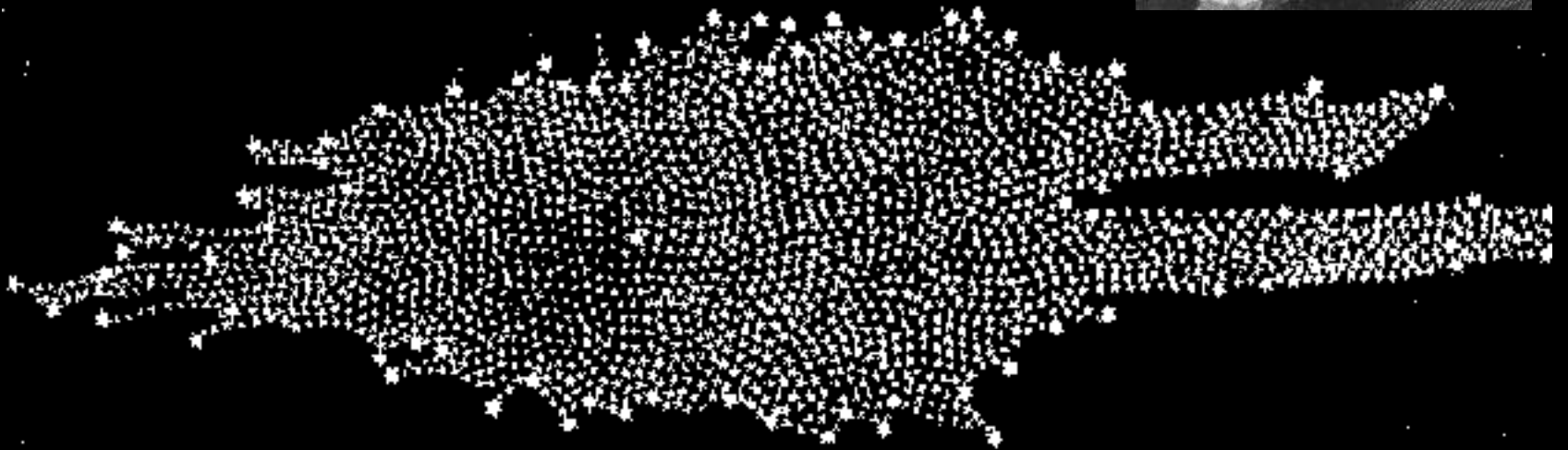


What Does This All Mean?

- How do these different things relate to each other?
 - Stars
 - Clusters
 - Clouds (of three types)
 - The Milky Way
- Very difficult to answer when we don't know the distances to any of these things

In 1783 William Herschel Tried

- Based on counting stars, Herschel decides we live in a disk of stars, near the center

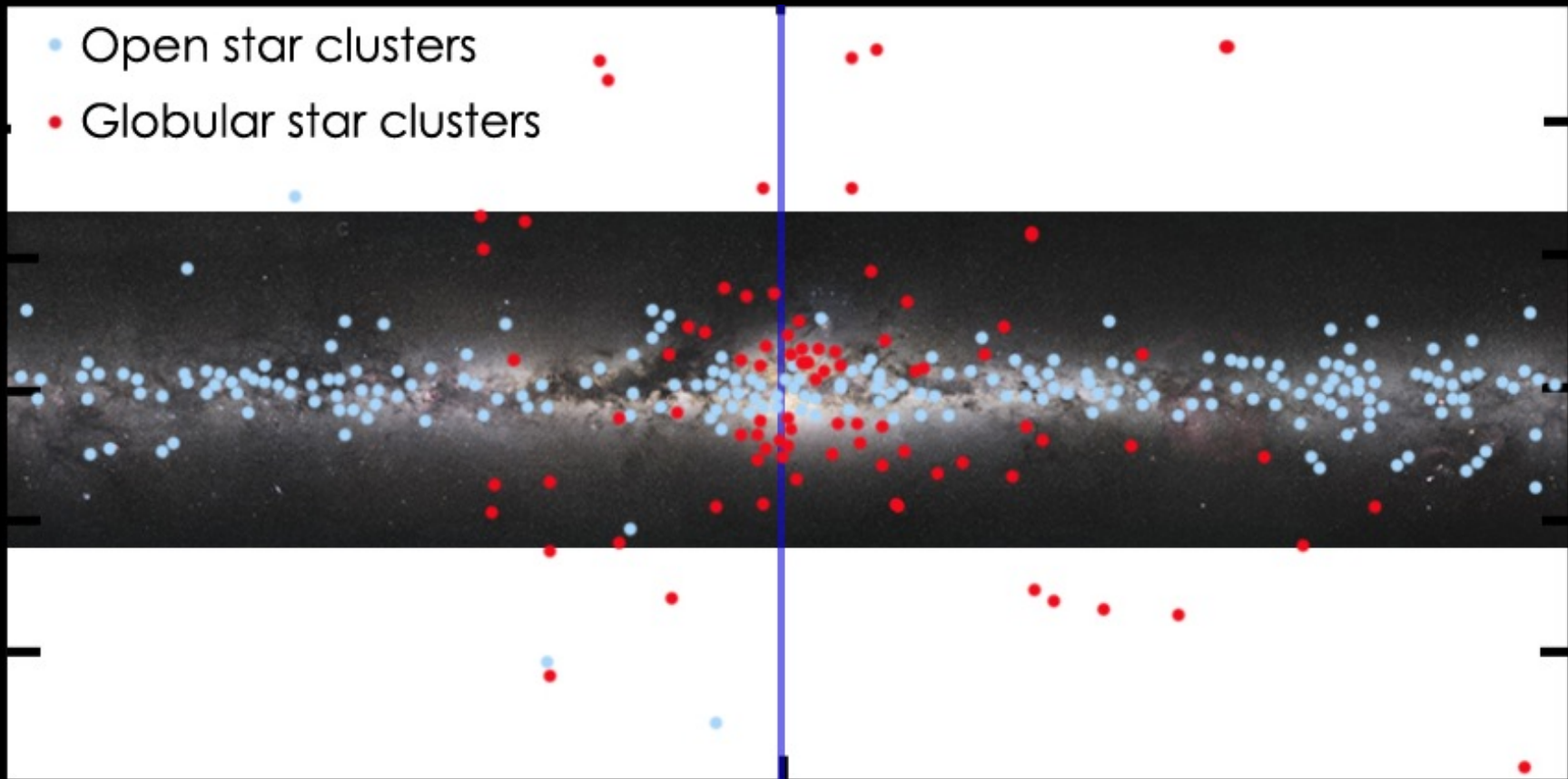


A Hint

- Stars, amorphous and round clouds, and open star clusters tend to be close to the Milky Way
- Globular Clusters are mostly off in one direction
- Spiral clouds are all over the sky



Star Cluster Distribution



Another Hint

- Spiral clouds seem to form flat disks
 - Different ones are seen at different angles



So What Are the Spiral Clouds?

- Nearby forming planetary systems?
 - Theories of planet formation said the planets form from a disk-like cloud of gas
 - LaPlace 1796 to today
- Other Milky Ways?
 - Called, at the time, “island universes”
- Big debate from 1800 to 1926
 - Most astronomers believed they are planetary systems in formation, inside the Milky Way

Other Clouds

- In the Southern Hemisphere there are what appear to be two disconnected pieces of the Milky Way: the Magellanic Clouds



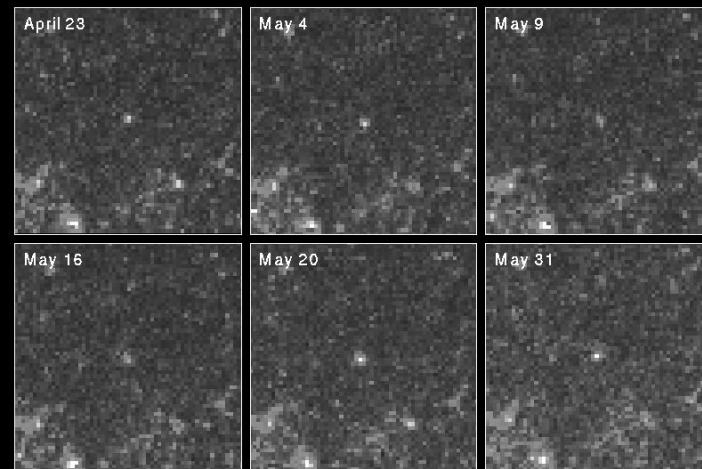
The Magellanic Clouds

- Close enough to pick out individual stars with telescopes around 1910



Breakthrough!

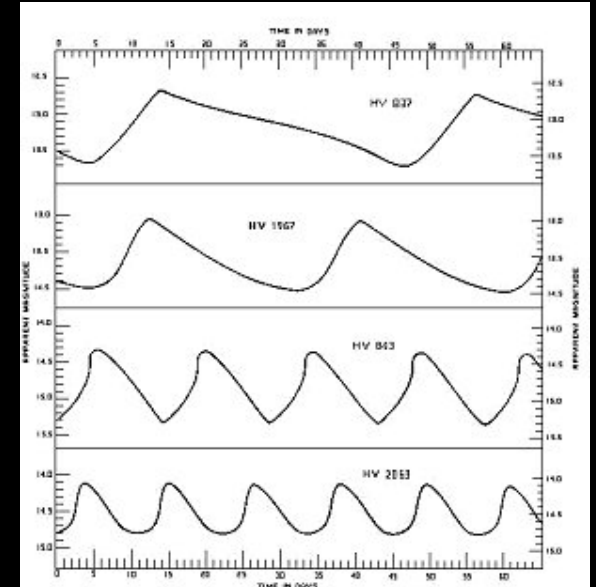
- Henrietta Levitt finds variable stars in the Magellanic Clouds
 - Stars the vary in brightness with a regular period



- She notices that the variable star's brightness depends on the period (1908)

Period-Luminosity Relation

- Levitt found:
 - Stars of the same period were the same brightness
 - Stars of shorter period were dimmer
 - Stars of longer period were brighter
 - From the period she could predict the brightness
- If all the variable stars in the Magellanic Clouds are about the same distance, this means that from the period of a variable we can predict that star's intrinsic brightness

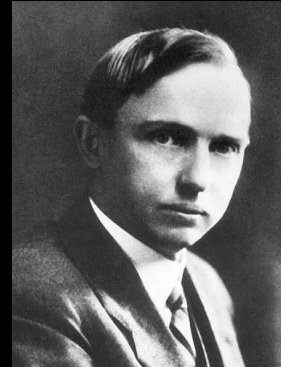


Now We Can Measure Distances!

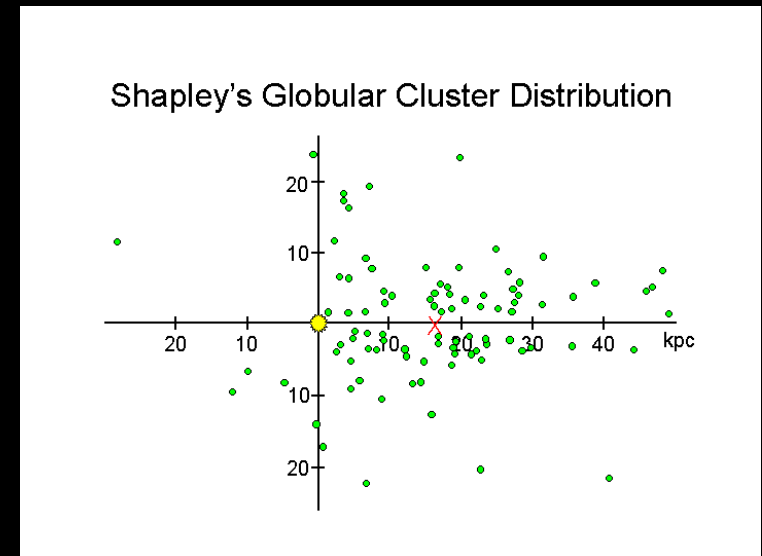
- Once we've found the actual distance to a variable star
 - We'll find out how next week
- Find a variable star, measure its period, compute its intrinsic brightness, compare with its apparent brightness, compute distance!
 - A star twice as far away will be 4 times dimmer
 - Inverse square law

Distances to Globular Clusters

- Measured by Harlow Shapley (1918)



- He found that globular clusters themselves cluster around a distant point in the Milky Way
 - In the direction where the Milky Way is brightest!



Lessons from Shapley

- If the Milky Way is a disk, we're far from its center
- The Milky Way is really big
 - Light from the center would take 30,000 years to get here
- But we still (in 1918) have a very poor idea of what the Milky Way looks like
 - Except that it's disk-shaped

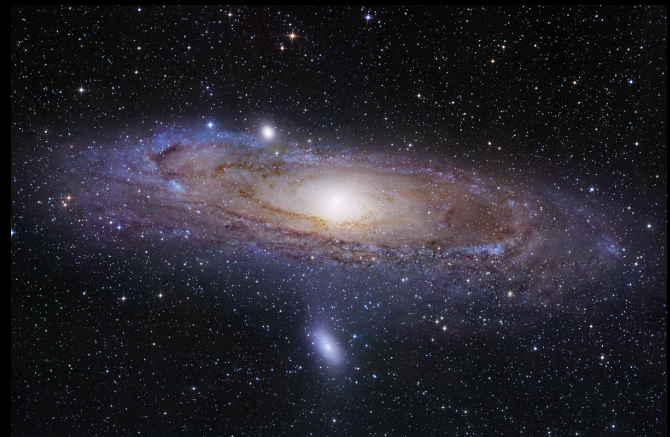
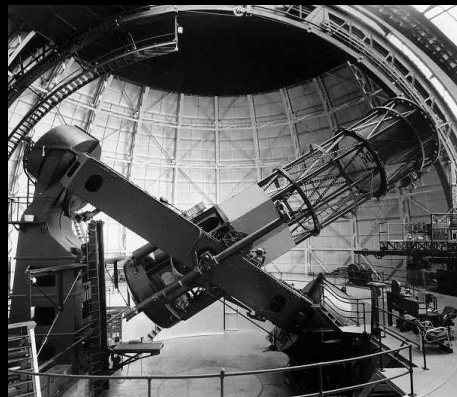
What About the Spiral Clouds?

- In 1918 spiral clouds still looked like clouds in the best telescopes
 - Could not pick out individual stars
- The consensus remained that spiral clouds were probably forming planet systems
 - At least one reputable astronomer claimed to measure the rotation of a spiral cloud, implying that it is small and nearby (he was wrong)
- But it didn't take long...

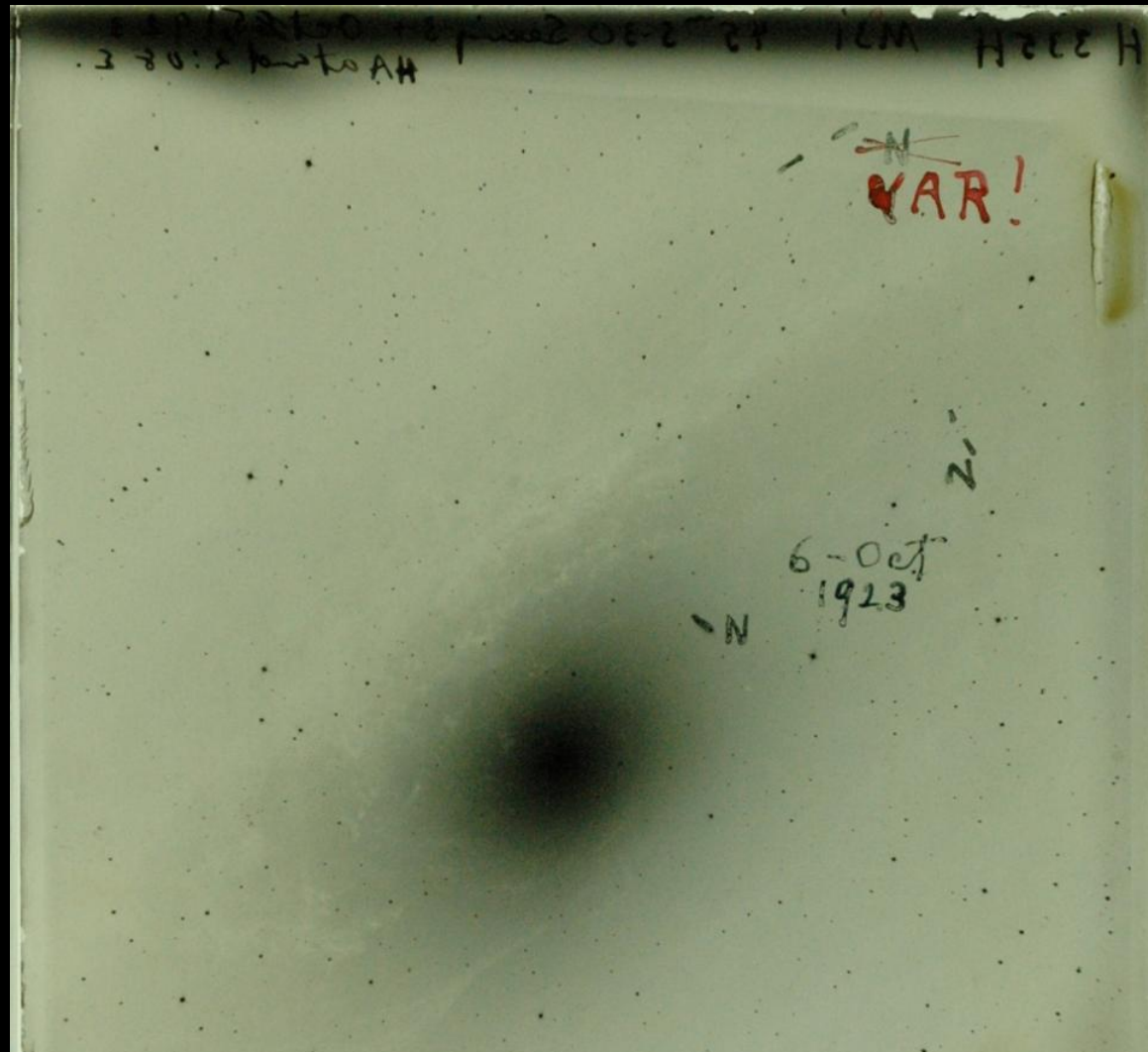


Hubble Measures Distance to a Spiral Cloud

- In 1926, using the new 100 inch Hooker telescope Edwin Hubble measures the distance to the Andromeda spiral cloud
 - And it's really far away: it's light takes 2 million years to get here!



Here's Hubble's Andromeda Variable



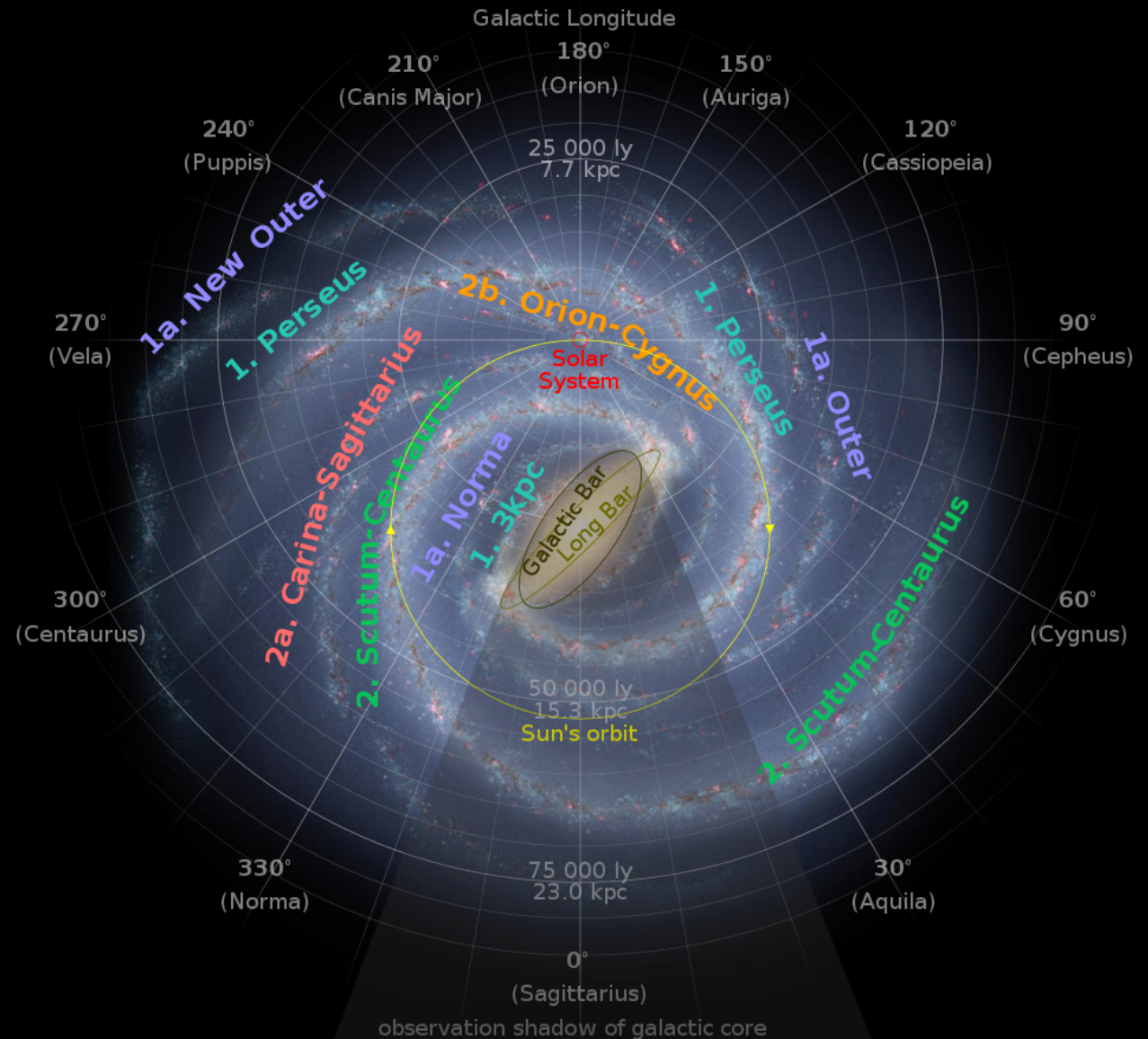
The Distances to Many More Galaxies Quickly Followed

- “Spiral clouds” became “spiral galaxies”
- We can study spiral galaxies to get hints about our Milky Way Galaxy
 - Assume the Milky Way is a spiral galaxy
 - Turns out to be correct



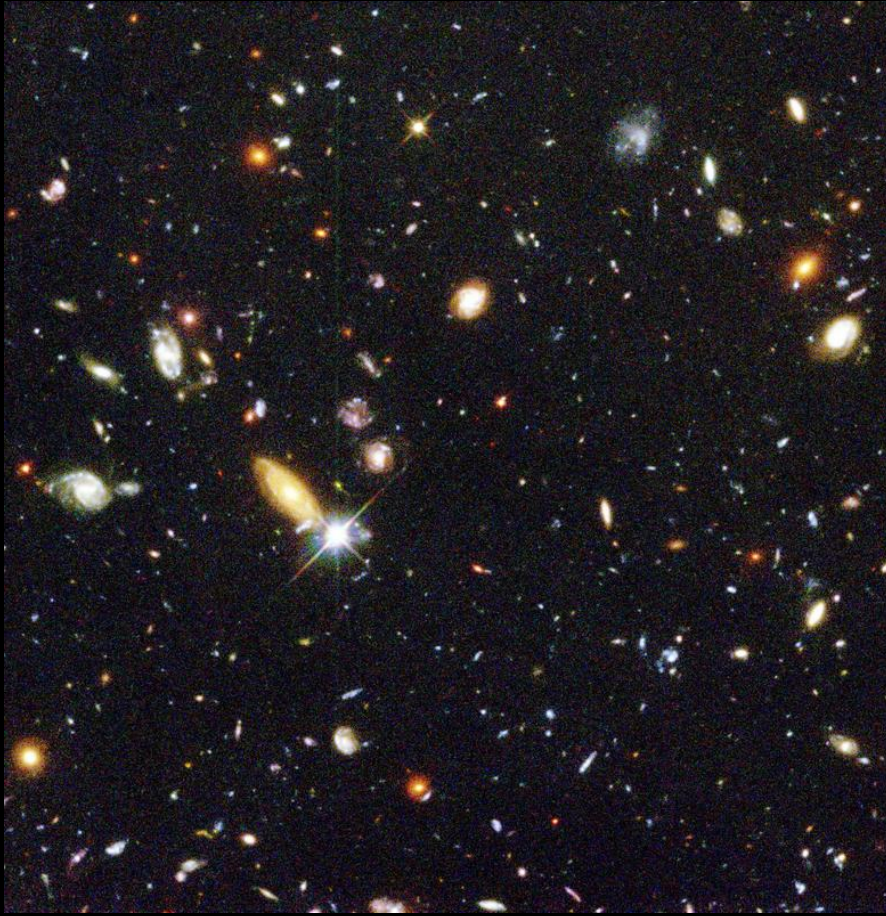
Our Modern View of the Milky Way

- Skipping over almost a century of hard work...



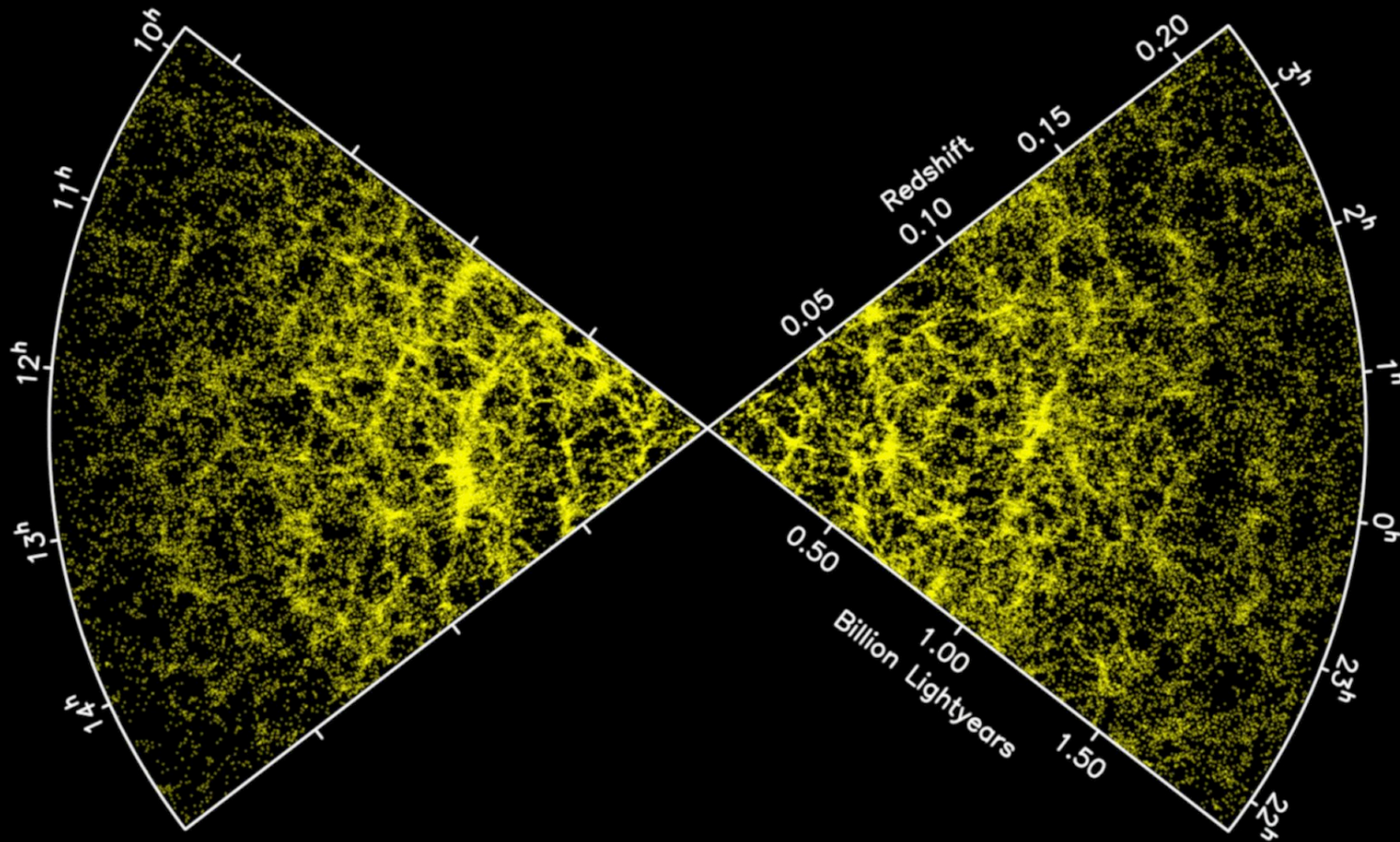
There Are Many Many Galaxies

- Hubble Deep Fields: long exposures where the largest Earth telescopes showed nothing at all



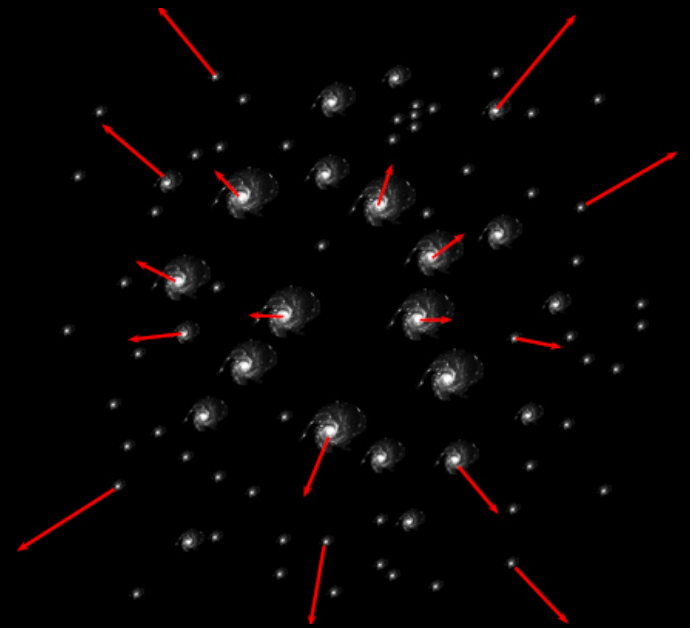
Large-Scale Galaxy Survey

- Each dot is a galaxy



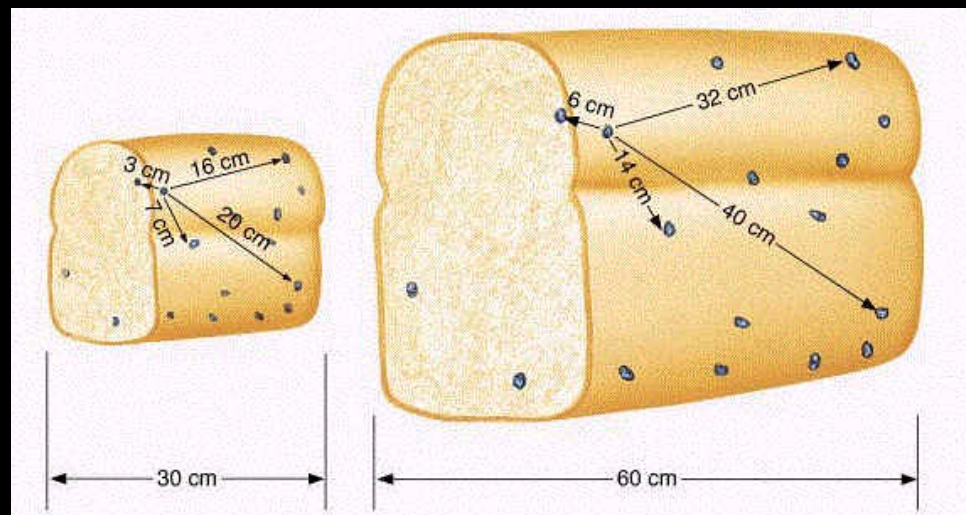
But Wait – There's More!

- We can measure the velocity of stars and galaxies towards us and away from us
 - We'll learn how in a couple weeks
- And the galaxies all seem to be moving away from us
 - The farther the galaxy, the faster it's moving away (1929)
- What's so bad about us that galaxies are trying to get away?



The Expanding Universe of Raisins

- Imagine a loaf of raisin bread, expanding as it cooks
 - The raisins will be moving apart from each other
 - Each raisin will see the other raisins moving away
 - The farther the raisin, the faster it's moving away

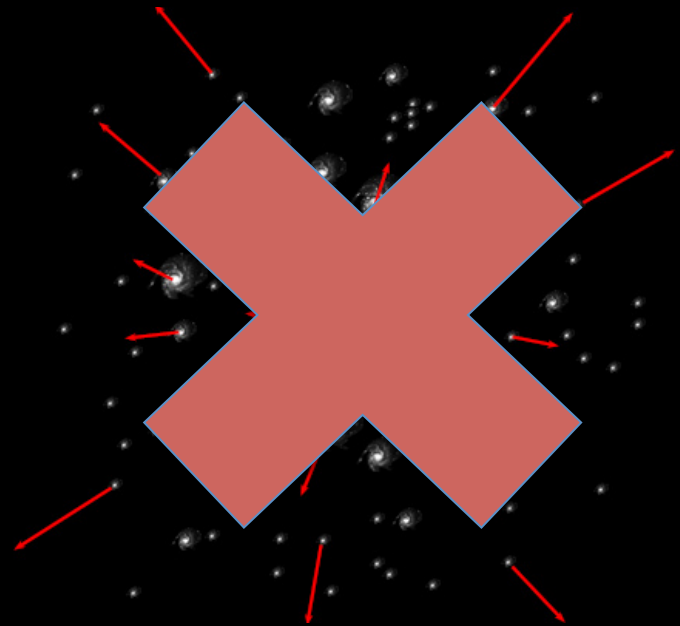


The Expanding Universe

- If the universe is expanding, then distant galaxies will appear to be moving away from us exactly as measured in 1929
- Such expansion was predicted by Einstein's 1915 theory of gravity (General Relativity)
 - But Einstein chickened out and “fixed” his theory so there would be no expansion in 1917
 - He called this his “greatest blunder”, but just wait...
- This means the universe had a history!

What Does it Mean for the Universe to Expand?

- Probably not quite what you think
 - We're going to spend a whole class on this question
- It does not mean that a clump of galaxies are moving into empty space
 - Like an explosion

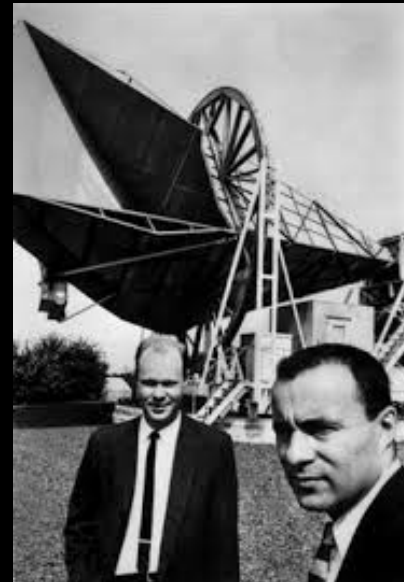


If the Universe is Expanding Now, What Happened in the Past?

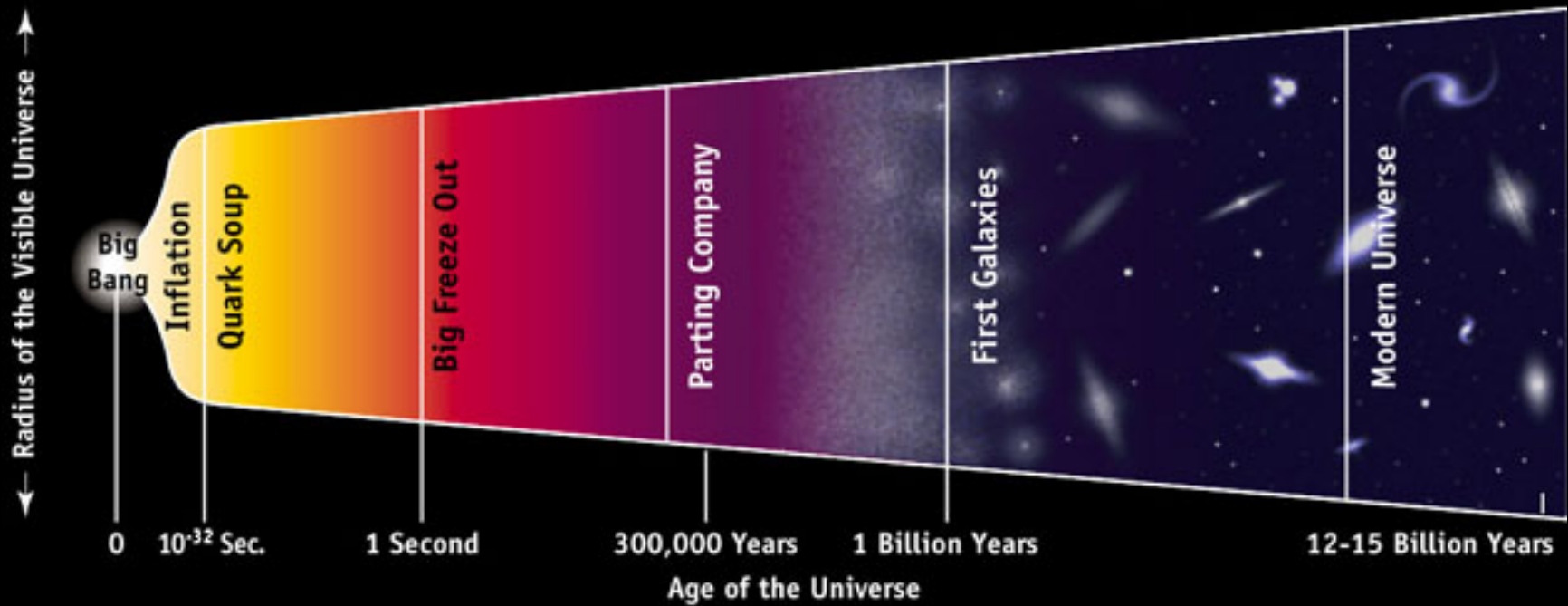
- If we “back up the movie” we find that the galaxies get closer and closer together
- About 13.7 billion years ago they would all be in the same place!!!
- Did this really happen?
 - Astronomers (and physicists) know enough to say that if it did happen, then we should see some consequences today

Cosmic Background Radiation

- And sure enough, we see what is predicted!
- Most dramatically, we see a nearly uniform dim glow in microwaves that exactly matches what we should see if the universe expanded from a hot mass of matter
 - The “Hot Big Bang”
 - Discovered by accident by Penzias and Wilson after being predicted by Gamov and Dicke
 - Penzias and Wilson got the Nobel...



The Hot Big Bang



Much more about this later in the course!

That's Quite a Story

- In the rest of the course we'll cover all this again in more detail
- There are still mysteries
 - There seems to be more gravity than can be accounted for by the matter that we see
 - About ten times more!
 - The expansion of the universe seems to be speeding up
 - Conventional theory says it should be slowing down...