We reside inside the Milky Way Galaxy.

Understanding it is difficult given our perspective.

To us it is a faint band of stars across the sky with a dark lane in the middle.

We know much of what we do about the galaxy because of studies of other galaxies.

Understanding objects within the galaxy is easier since we are close to them.

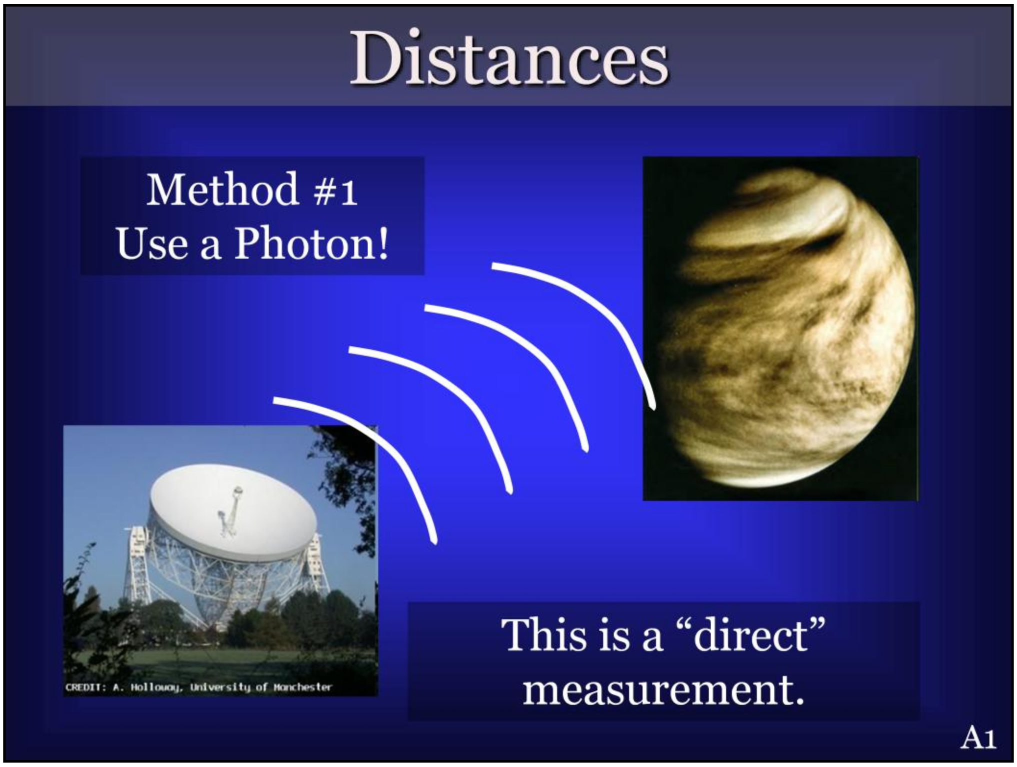
Overview

A. Distance
  1. What are three ways that we know distance?
  2. How are the three measures related?
  3. What is the difference between a direct and an indirect measure?
  4. What is a standard candle? What are some examples?
  5. For what distance scale does each measurement work best?

B. The Shape of the Universe
  1. What was different between Herschel's Kapteyn's stellar distance measurements?
  2. What was Kapteyn/Shapley debate about?
  3. Who was the "most" correct?
  4. What did they *both* get wrong?

Overview

C. The Milky Way
1. What are the main components?
2. What is the composition of each component?
3. How do we determine the age of a population of stars?
4. What is the overall motion of each population?
5. How does orbital velocity change with mass?
6. What is a rotation curve?
7. What does the rotation curve imply about our galaxy?



We know the speed of light… and we know that it can be reflected back to us.

So- we bounce some light off of a distant object and time how long it takes to get back to us.

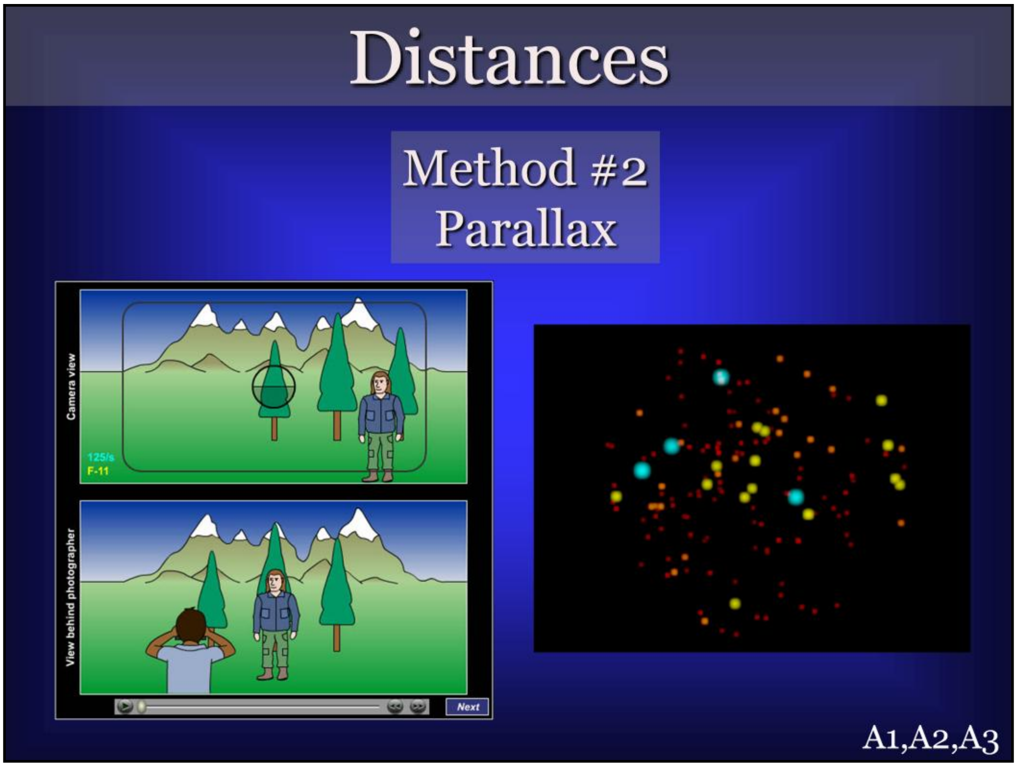
Given the speed and the distance, we can get the time.

We bounce radar signals off of Venus to measure our precise distance from it.

Kepler gave us the relative distances of all the planets from the Sun, so we now can solve for 1 AU.

This measurement is "direct" since it does not depend on detailed knowledge of physics or other inferences.

It depends only on knowing the speed of light accurately.



Parallax is the apparent motion of foreground objects against a distant background.

You can see it if you hold your finger out and close one eye and then the other.

The apparent position of your finger against a distant object will change.

The Greeks reasoned that we should be able to see parallax of nearby stars against distant ones. They couldn't.

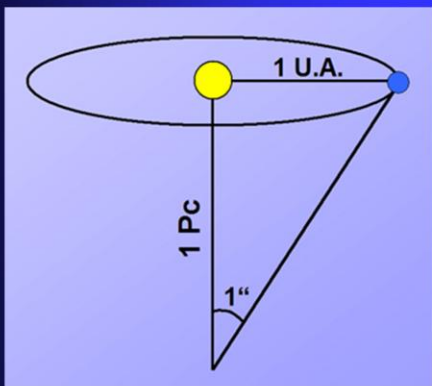
That's why (one of the reasons) they concluded that the Earth isn't moving.

But! stars are crazy far away, so their parallax is VERY hard to measure.

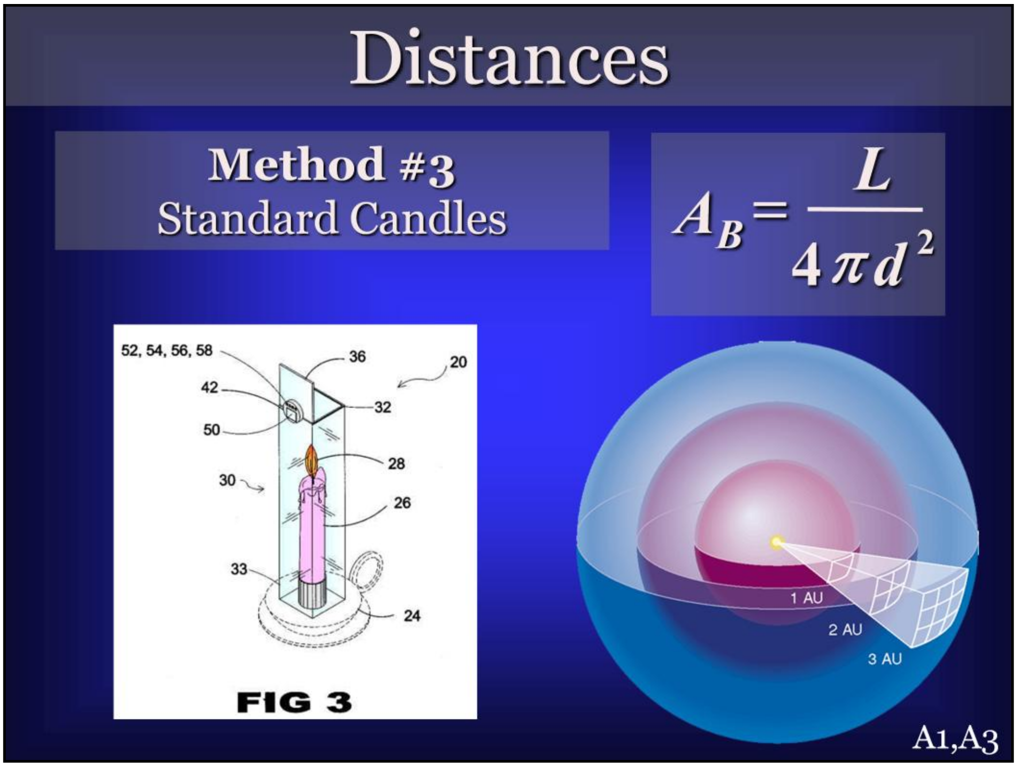
Today, we are able to detect the parallax of stars within a few hundred light years from the Sun.

The Parsec

1 **AU** object subtends an angle of
1 **arcsecond** at a distance of
1 **parsec**



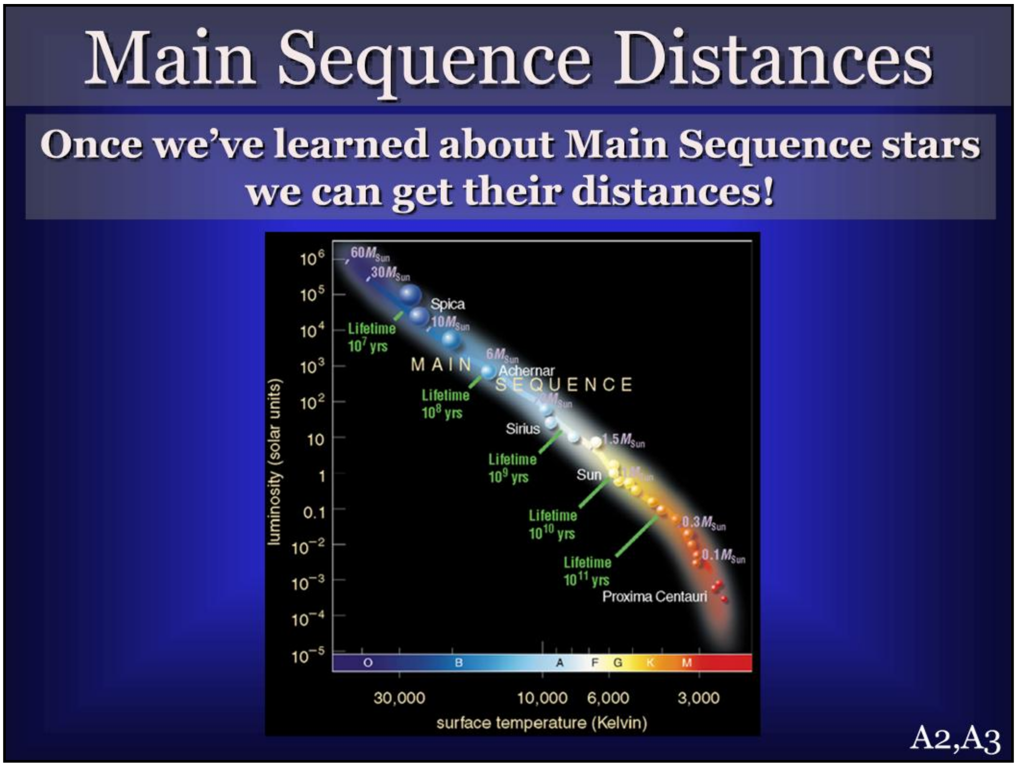
1 parsec = 3.26 lyr



The apparent brightness of an object gets decreases as the square of the distance.
A fixed amount of power that gets spread over increasingly larger surface areas.

So IF we know the LUMINOSITY of an object, we can calculate its distance.
A STANDARD CANDLE is an object for which we know the LUMINOSITY.

Using a standard candle is an INDIRECT measure because it depends on detailed knowledge of the object under consideration.



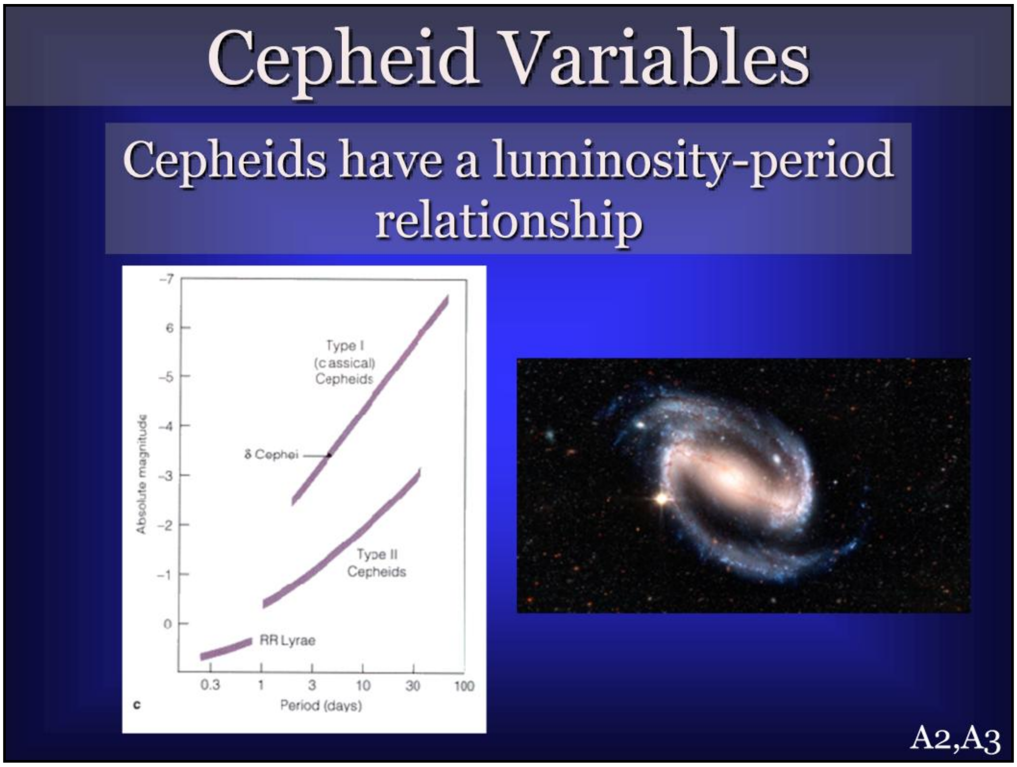
Main sequence stars can be used as standard candles

Using parallax, we sampled enough stars to discover the Main Sequence.

We've also used our large sample of stars to understand how they work and verify our physical models.

if we know a star's temperature and we know that it's a main sequence star, we can use the main sequence temperature/luminosity relationship to get it's LUMINOSITY and thus its distance.

This is an indirect method. It depends on knowledge of the inner workings of stars.



Another standard candle

Cepheid variables are massive stars that are near the end of their lifetimes.
They are REALLY bright- visible to millions of light years.
They are unstable and pulsate with a very regular period.

A period luminosity relationship was discovered in Cepheids.
If we spot one, we can measure its PERIOD and get its luminosity

Oops… There appears to be more than one kind.
So- we have to know if it's a type I or at type 2

If the real speed of light was slightly faster than we think

A) our distances derived from Cepheids would be too small.
B) our distances derived from Cepheids would be too large.
C) only our Earth-Venus distance would be effected.
D) No distances would be effected.

Besides radar measurements and parallax, how do we generally measure large distances?

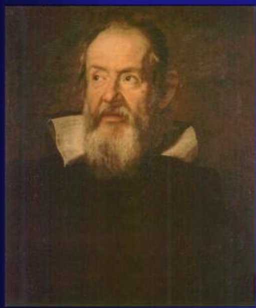
A) There are no other ways of knowing distance

B) By knowing the temperature of <u>any</u> distant stars.

C) By knowing the physical size of distant stars.

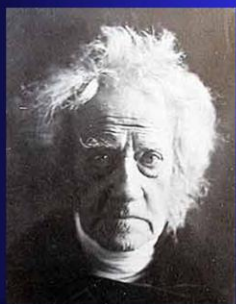
D) By knowing the intrinsic brightness of <u>any</u> distant star

The Shape of the Universe



Gallileo

The Milky Way is composed of innumerable stars

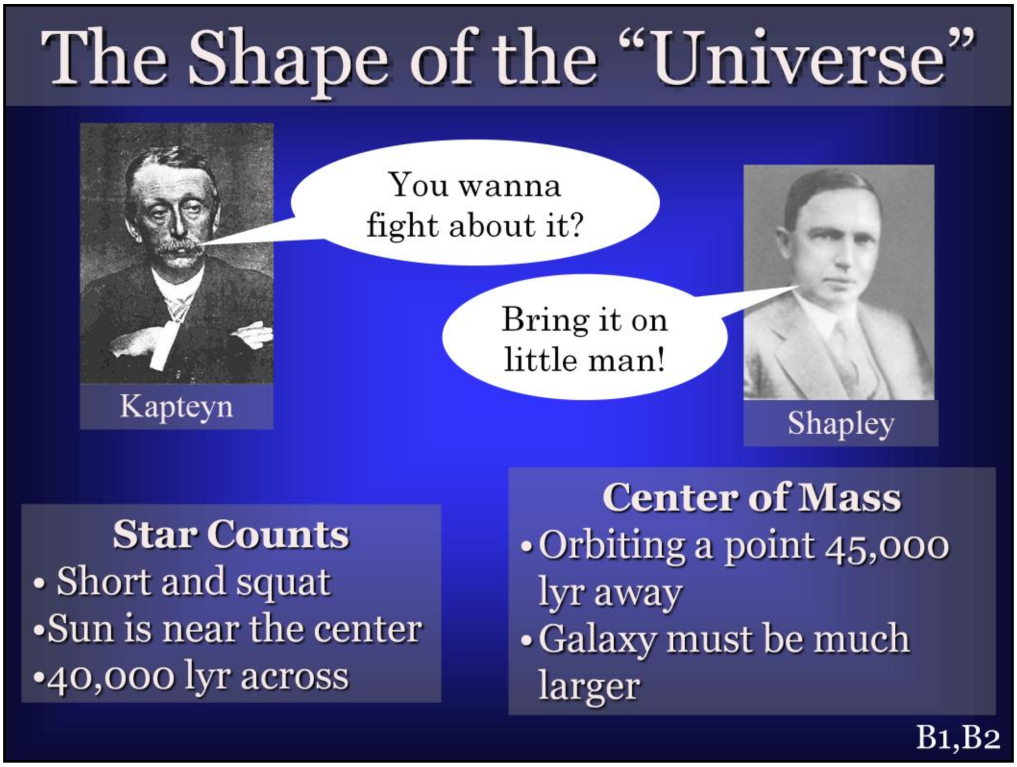


William Herschel

Assumed that all stars have the same intrinsic brightness

The Galaxy is a flat disk 5 times wider than thick

B1



Kapteyn measured the distance to stars in many different directions using main sequence stars as standard candles.

Using Newton's laws, Shapley measured the orbits of globular clusters to find the center of mass of the galaxy.

Kapteyn underestimated the obscuring effects of interstellar dust.

He imagined a lens shaped galaxy.

Who's Correct?

Kapteyn's distances were too large because:

A) The stars appeared brighter than they should.

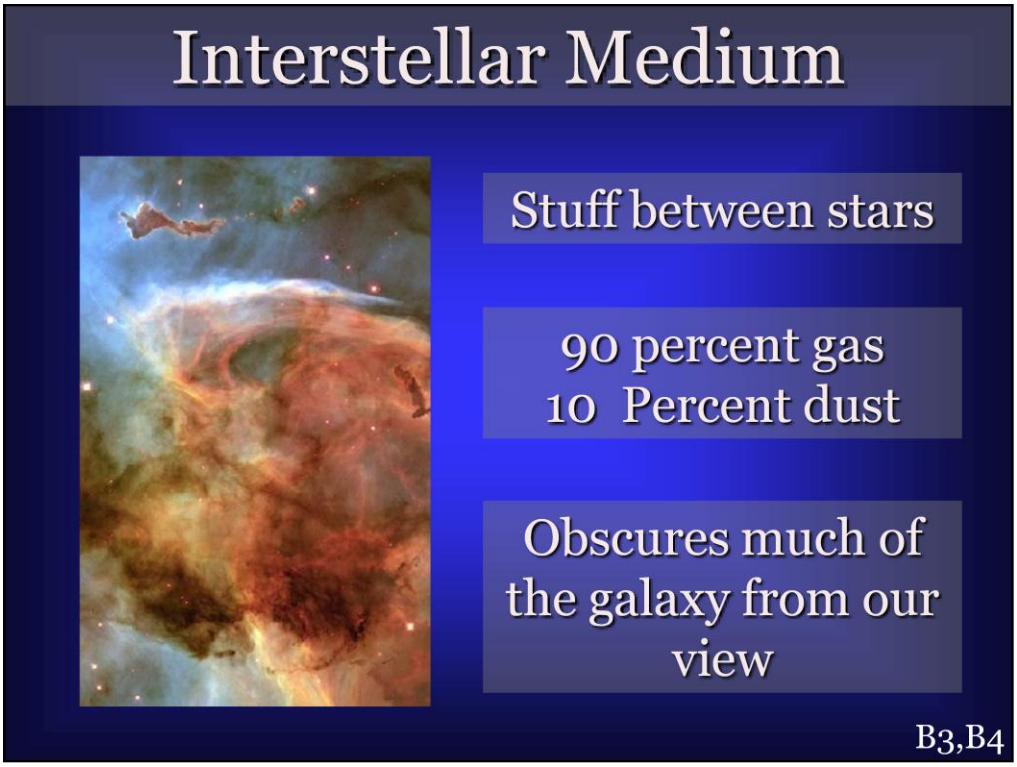
B) The stars appeared dimmer than they should.

C) His distances were correct.

D) The stars are in motion.

B) Dimmer stars look farther away than they really are.

B3,B4



Neither Kapteyn nor Shapley knew about the dust.

Dust has a dimming effect on stars making them look farther away than they really are.

Both Kapteyn and Shapley overestimated their distances.

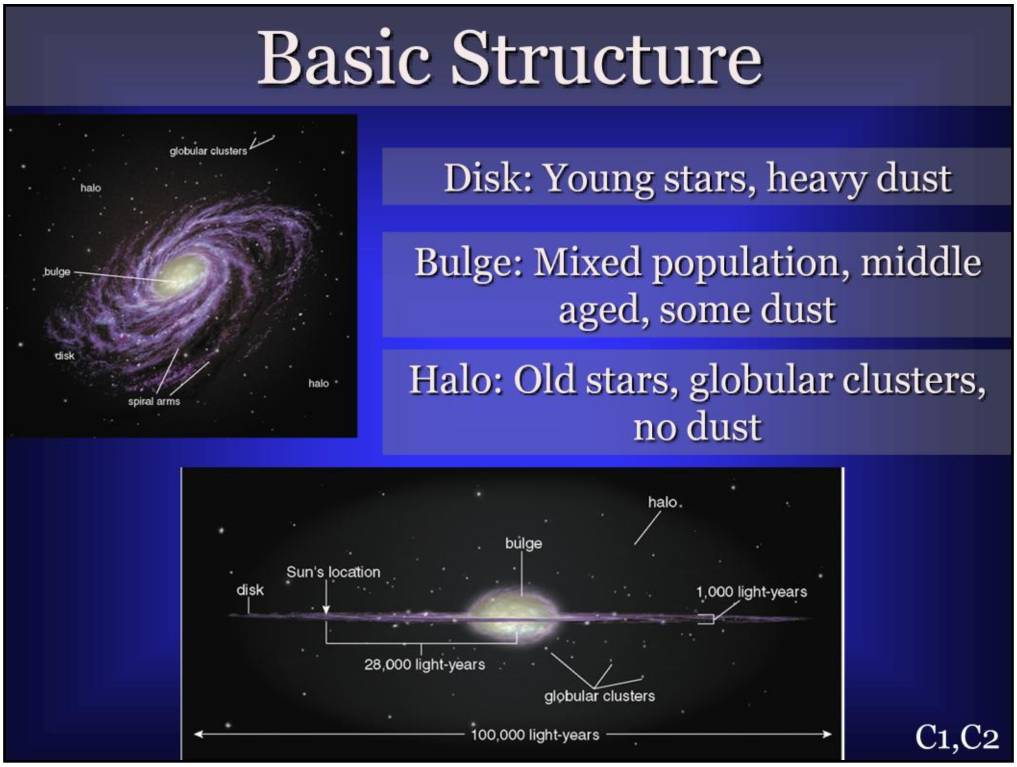
The ISM is the stuff between the stars

Composed of gas and dust

- 90% gas
- 10% dust

The ISM absorbs and/or scatters visible light.
 it obscures much of the Milky Way Galaxy from us

Radio & infrared light does pass through the ISM.
 we can study otherwise invisible regions of the Milk Way Galaxy using these wavelengths



Disk

- A flat disk with a thickness that is 1/100th the length of the disk
- Most of the younger stars lie in the disk
- Composed of stars, gas, and dust
- Spiral arms are in the disk

Bulge

- Central region of the galaxy
- Contains a mixture of old and new stars
- More tightly packed; higher densities

Halo

- A sphere that surrounds the disk and bulge of the galaxy
- Contains older stars
  - Globular clusters
- No gas and no dust, just stars
- No star formation going on in the halo

The glactic center is reddish.
The spiral arms are blue. The pink is glowing hydrogen.

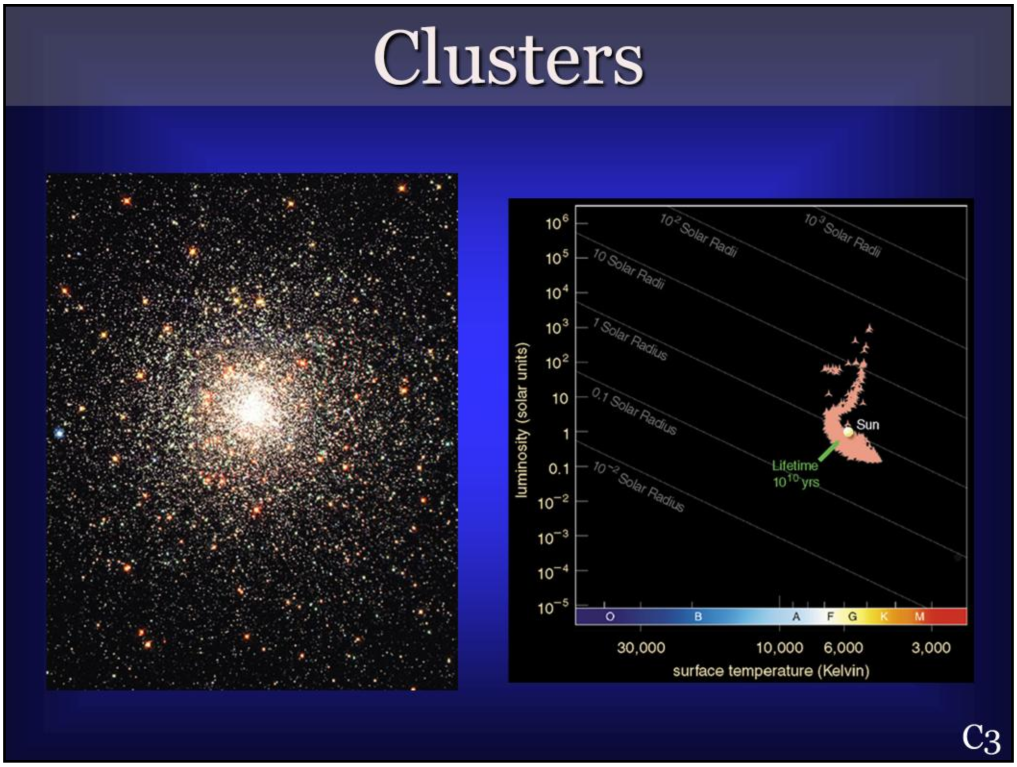
The arms have a young population of stars hot blue stars.
The hot blue stars ionize the hydrogen causing it to glow.

The globular cluster on the right is typical of what is found in the galactic halo.
There is NO dust here and thus NO star formation.

Blue stars are MUCH more luminous than red stars.
They are also short lived.

A young population will have a few blue stars that dominate the output.
These stars die first, leaving behind the cooler red stars.

So young populations tend to appear blue while old populations appear red.



We can get the AGE of glubular clusters by looking at the Main Sequence Turn-off.

Assume that all stars in the cluster have approximately the same birth day.

High mass stars evolve more quickly than low mass stars.

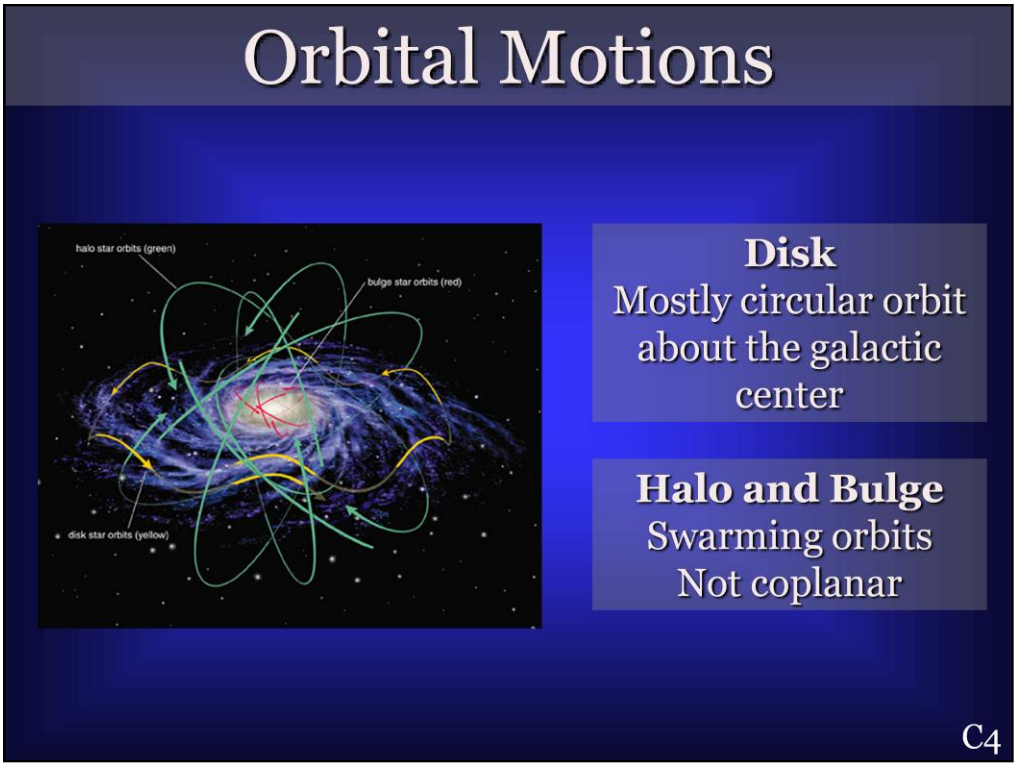
So… The highest mass star STILL ON the main sequence determines the age of the cluster

Because, higher mass stars that WOULD appear just above it are no longer on the main sequence.

Globular cluster orbits.

Stars don't interact… meaning there's no friction between them (star star collisions are very rare)

So.. The orbits never flatten to a disk or circularize.



Orbits in the disk are similar to planetary orbits. They are coplanar and mostly circular

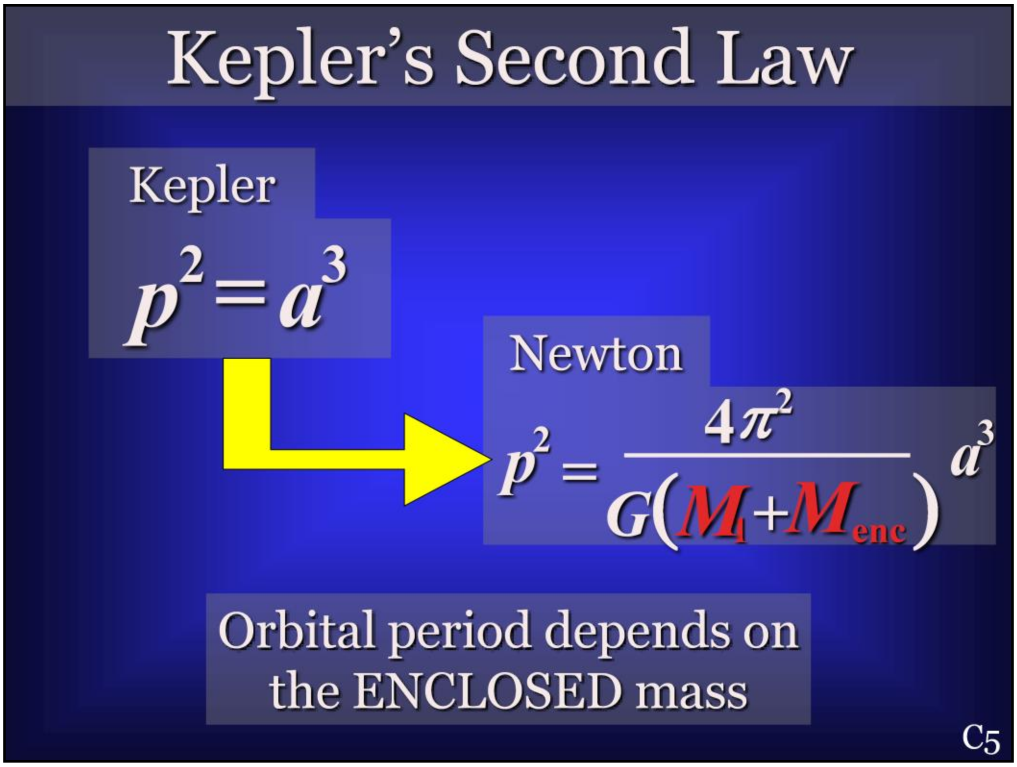
Disk orbits do bob above and below the disk.

If a star is too low, the gravitational force of the disk pulls it back up, but there isn't enough friction in the disk to stop it from going all the way through.

So… it just oscillates. Add to the oscillating motion the fact that the star is ALSO in orbit around the center.

It looks a bit like the star is riding a circular roller coaster.

Halo and bulge stars are on erratic orbits like a swarm of bees.

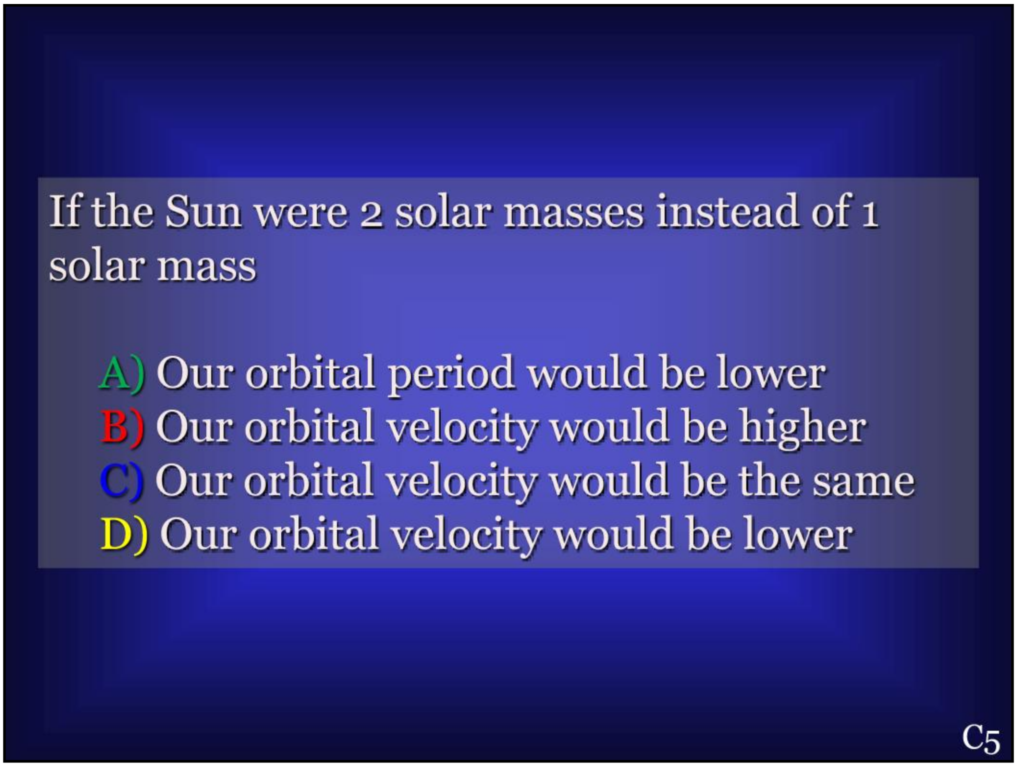


Don't mind the exact form of the equation…

The point is that orbital period is dependant on BOTH the mass of the body AND the mass enclosed by the orbit.

Kepler's third law only works in the solar system.

If we make the Sun more massive, all of the planetary orbital velocities would go up!



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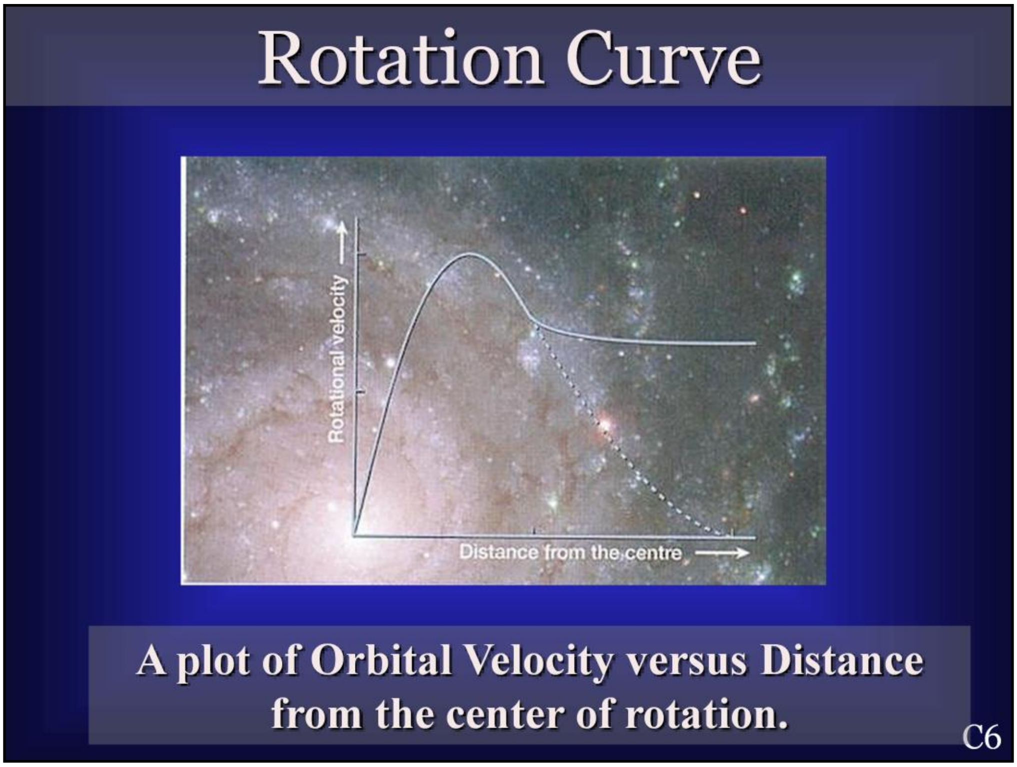


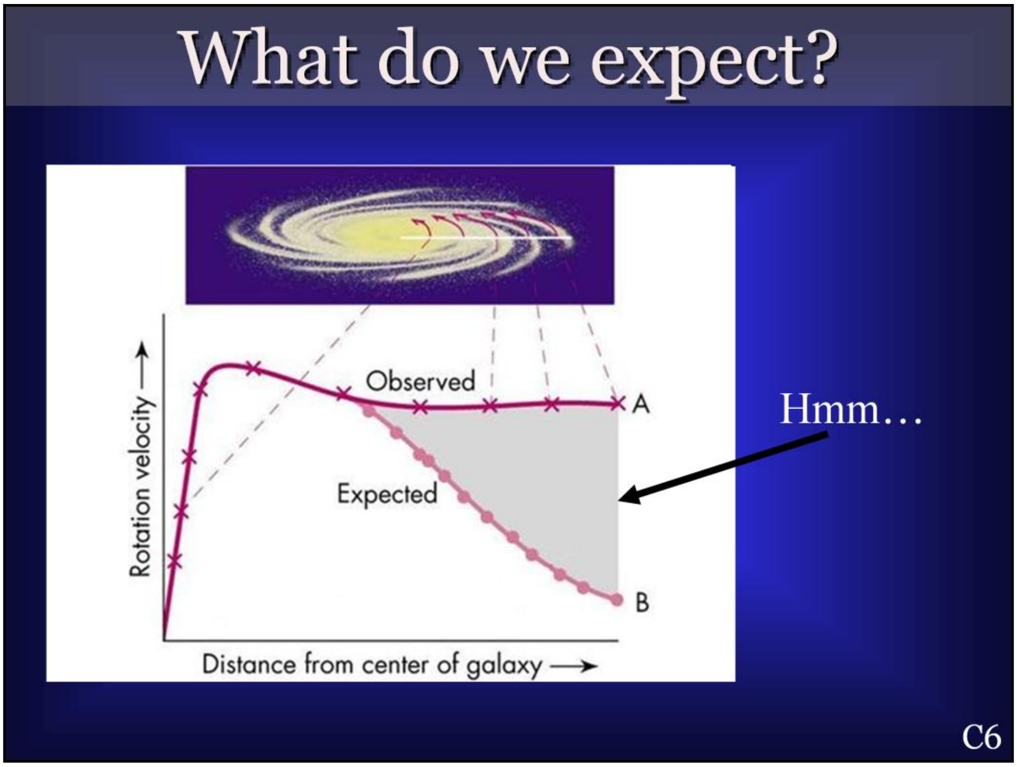
In rigid bodies, the velocity is directly proportional to the radius… faster rotation further from the center.

Planetary orbits follow Kepler's third law, and go slower as you get further from the center.

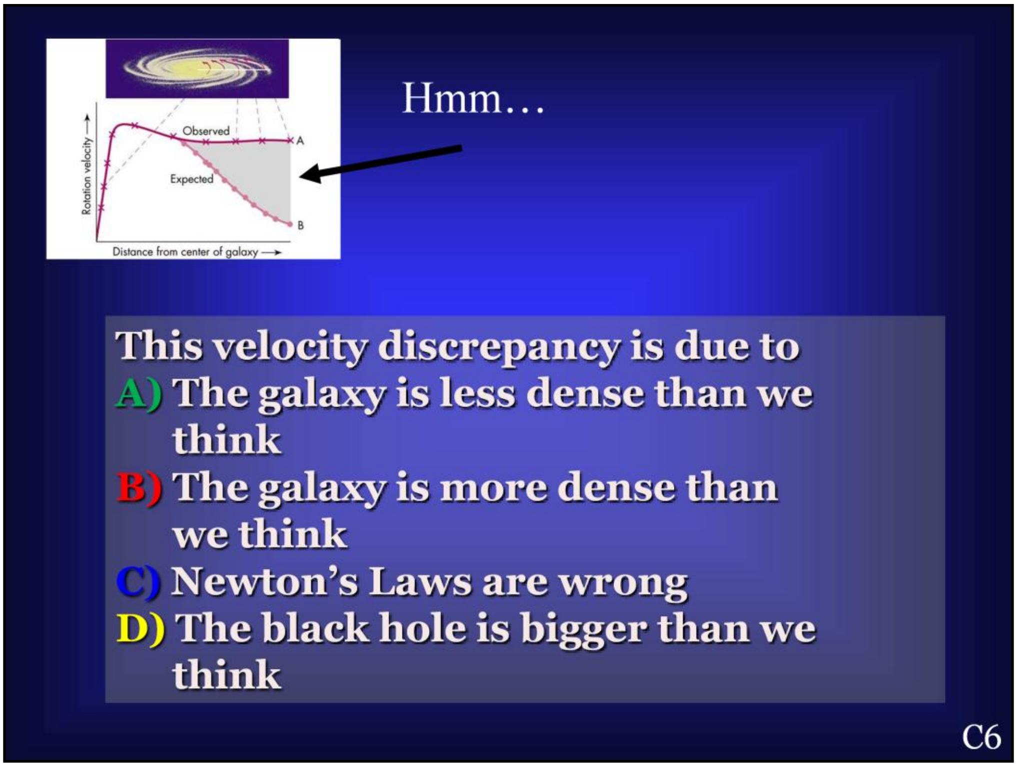
Galaxies have a rigid section in the middle followed by a flat rotation curve. The velocity doesn't change as you go out from the center.

We can't account for all of the mass by considering all of the stars and all of the gas and dust.

Evidence for mass that we can't see… Dark Matter.



So we measure the mass that we can see (due to the starlight) and predict orbital velocities using Newton's version of



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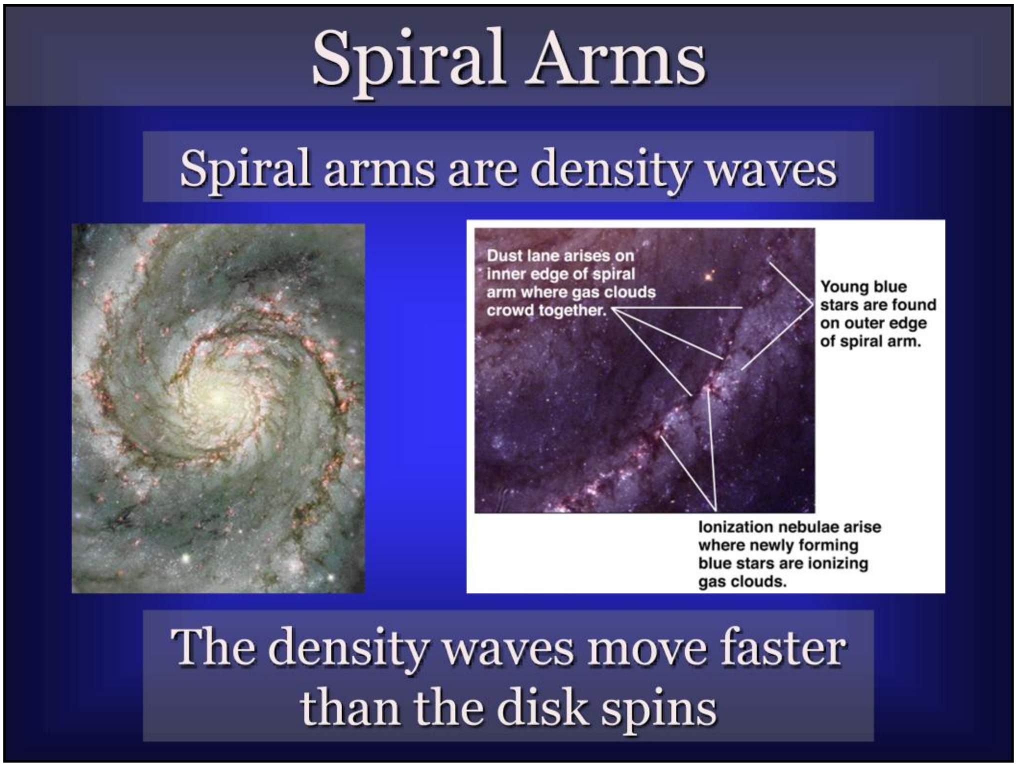


Star formation happens in the spiral arms.

Gas and dust piles up just in the wave.

The density wave compresses the ISM triggering star formation.

Hot young stars dominate the area just behind the density wave making the arms blue and bright.

The spiral arms appear much bluer than the bulge, which contains an older population of stars.

The big O and B stars cause ionized nebula to glow in the region of the arms.

The big stars die quickly, long before another wave comes by.

Lower mass stars (the Sun) pass through several density waves in their lifetimes.

History of Matter

The Galaxy's metal content

A) has been decreasing since its formation

B) has not changed since its formation

C) has been increasing since its formation

D) is not something we can measure

Cold molecular clouds collapse and form stars

Stars fuse and make heavy elements.

Big stars explode and enrich the interstellar medium

Smaller stars puff their stuff out in planetary nebula and enrich the interstellar medium

Each new generation of stars contain more ‘metals’ than previous generations.

So, as a galaxy ages, more and more of its material gets processed and the fraction of heavy elements increases.

Halo Stars?

We would expect halo stars to have
A) Higher metal content than the disk stars
B) Lower metal content than the disk stars
C) The same metal content than disk stars
D) There is no way to know.

When a super nova goes off… the velocities of the particles is WAAAAY above the escape velocity of the galaxy.

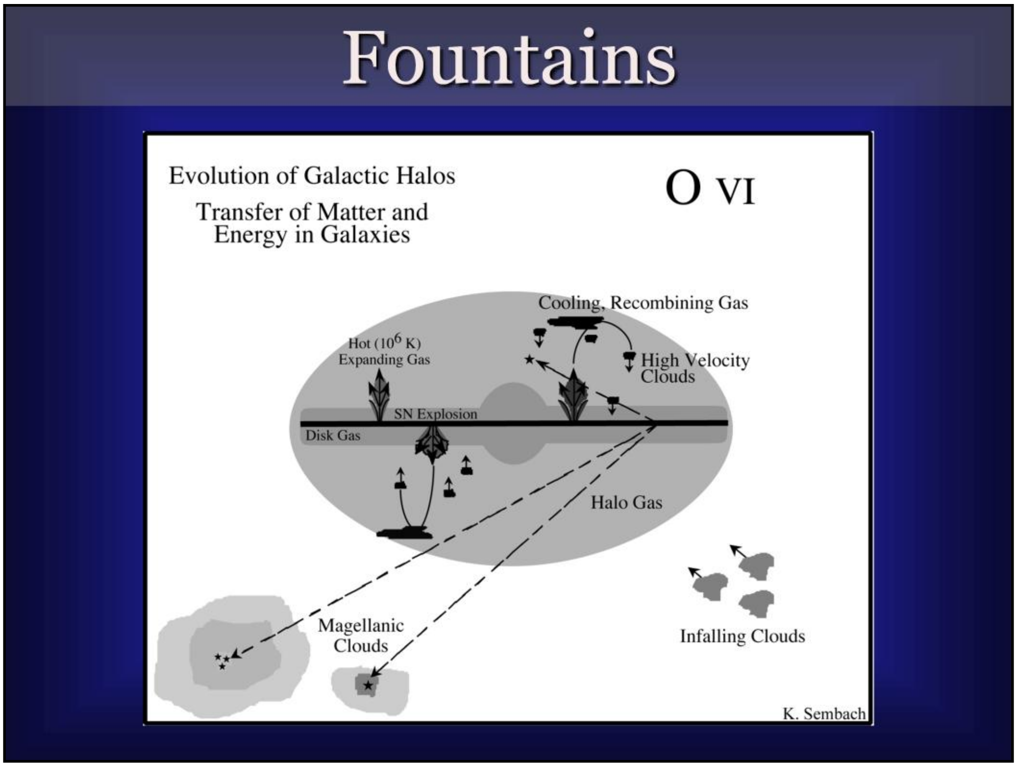
Stars tend to form in clusters containing some high mass stars and some low mass stars.

When the massive stars explode, the push some of the ISM away.

When a lot of them explode, they blow big bubbles

The Sun resides in a bubble.

Sometimes the bubbles break out of the plane and a chimney forms. The gas then rains back down onto the disk.



Sometimes… a LOT of SN go off very close in time to one another.

This can keep blowing the bubble bigger and bigger until the galaxy has a blowout.

W3