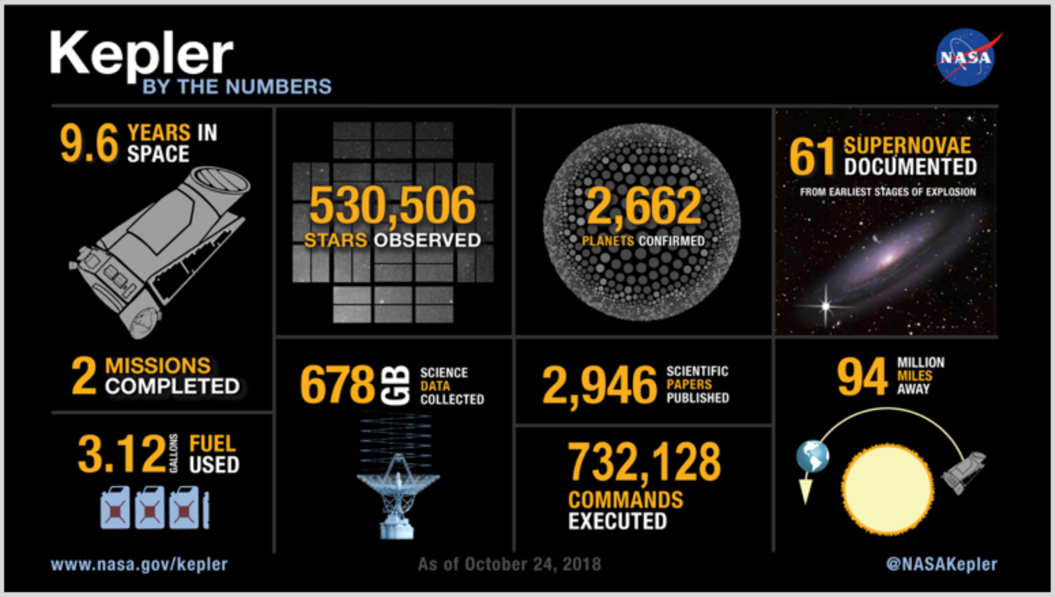
Turn in midterm 2!

Pick up corrected midterm 1 if you weren't here last Thursday

Last week in science…



https://www.nasa.gov/kepler/missionstatistics

Not related to what we're going to talk about today, but important! Kepler retired on Halloween.

30 million miles per gallon! Ha jk. That's not how that works, I know.

Today in science…

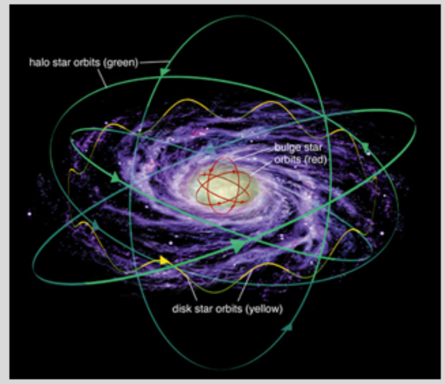
- The end of a galaxy?
  - One of our dwarf satellite galaxies, the Small Magellanic Cloud (SMC), is losing its gas
  - Gotta have gas to make stars… If a galaxy isn't making stars, is it a galaxy?
  - Eventually, SMC will merge with Milky Way

https://www.eurekalert.org/pub_releases/2018-10/anu-aws102918.php?fbclid=IwAR1k3jL0149xDpIF3bLy9DOUOdzW8z_6y6gJ25QM8x1w8b2nUuNtIrCYsG4


The Milky Way
Chapter 19, The Cosmic Perspective

Milky Way's structure

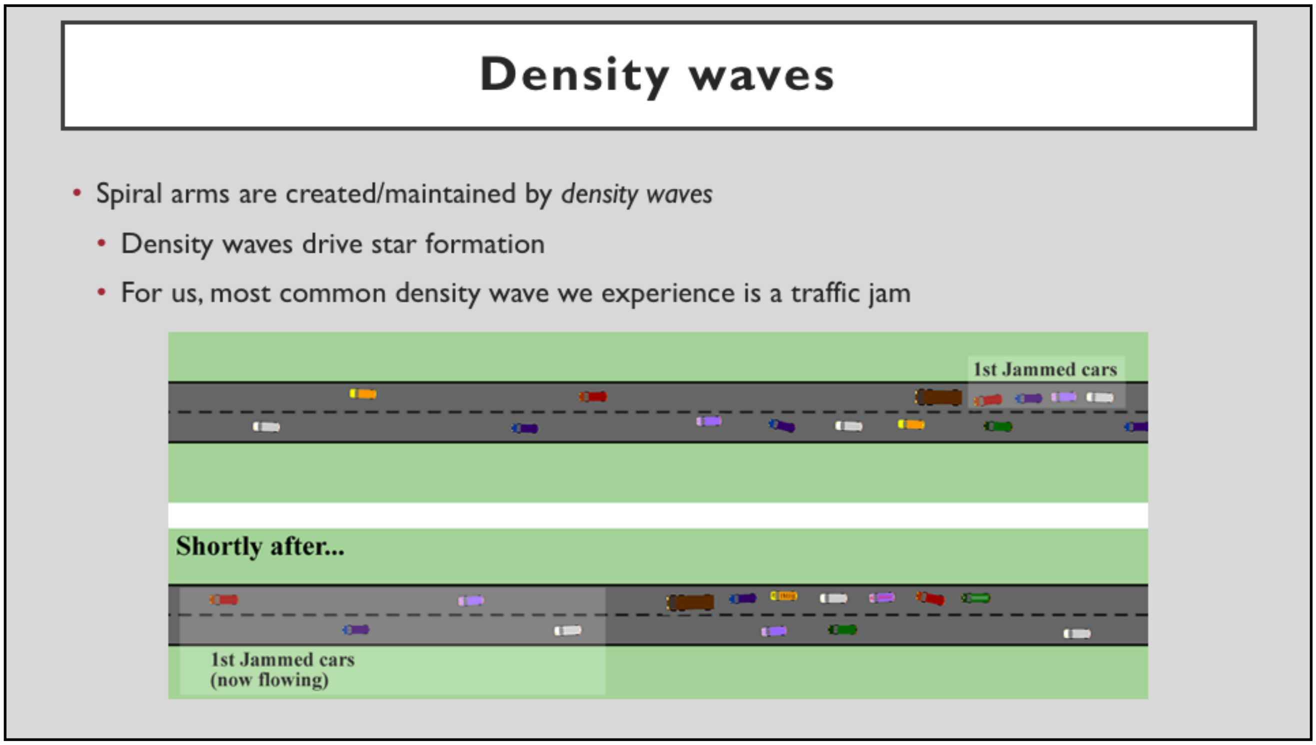
- Disk
  - Younger, more metal-rich stars
  - Mixture of high and low mass stars
  - Open clusters here
  - Molecular clouds in disk; stars can only form in these
- Bulge
  - Mixture of disk and halo stellar orbits, compositions
- Halo
  - Older, more metal-poor stars
  - Low-mass
  - Globular clusters here



We use a number of indicators to understand the structure of our galaxy: stars' orbits, stars' metal content, and where the gas in the galaxy is located

Where do stars form in the galaxy?

Not only are we limited to the disk where molecular clouds are as where star formation happens, but there are distinct locations in the disk where it’s easier to make stars



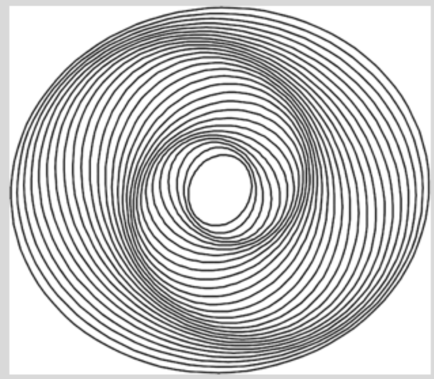
https://briankoberlein.com/2013/09/22/traffic-jam/

Spiral arms are created/maintained by *density waves*

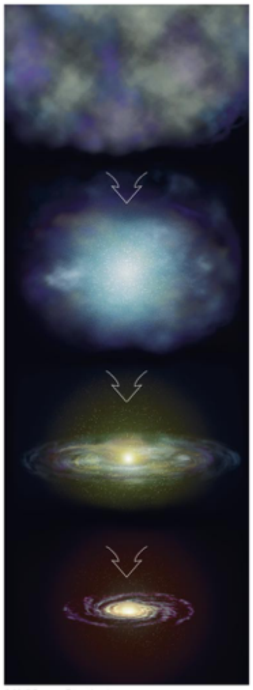
For us, most common density wave is a traffic jam

Density waves

- Stars orbit through spiral arms, slow down a little because more mass in arms = stronger F_g
- Gas becomes compressed in spiral arms, compression triggers star formation



http://rspa.royalsocietypublishing.org/content/465/2111/3425

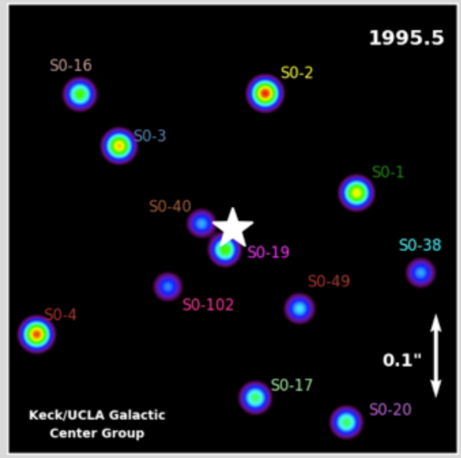


Stellar evolution and galaxy evolution

- Follow parallel physical processes
- Proto-galactic cloud made of hydrogen, helium, collapses
- Halo stars form
- Collapse continues, a disk forms because angular momentum is being conserved
- Billions of years later, a star-gas-star cycle keeps star formation going in the disk as long as there's still gas
- Companion galaxies could impact evolution of a galaxy

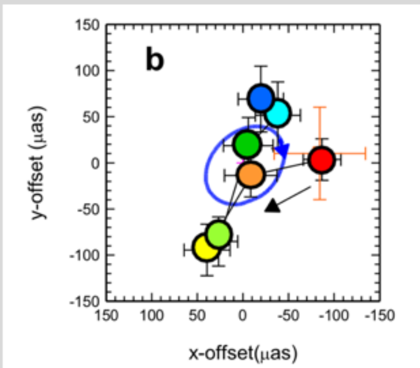
A second 'today in science'...

- We've talked about supermassive black holes at the center of galaxies, and one piece of evidence about our own
  - Andrea Ghez leads a team mapping stellar orbits with interferometry
  - 4 million $M_{\odot}$

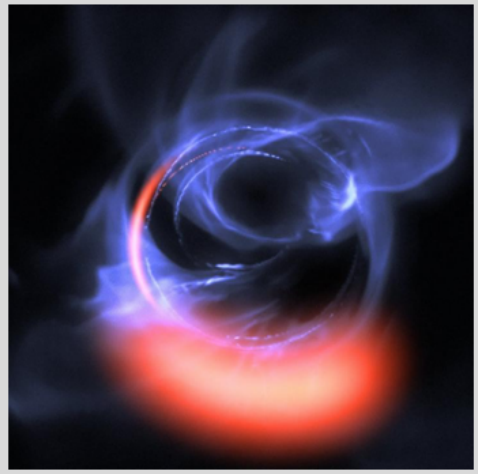


What's our supermassive BH up to?

- Detected hot, flaring gas orbiting ~9x event horizon distance at about 30% the speed of light. NBD.
  - (actual data)



- (artist rendering)

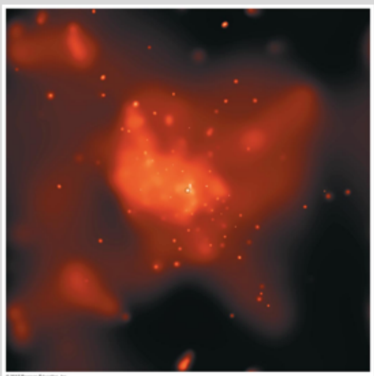


https://www.eurekalert.org/pub_releases/2018-10/e-mdo102918.php?fbclid=IwAR06SPUmbZomaW1EPOukSB-edcyKh7K3jpv6MRAYa5Vrp5WgeJNnzwKDh98

https://www.eso.org/public/archives/releases/sciencepapers/eso1835/eso1835a.pdf

What’s our supermassive BH up to?

- Detected hot, flaring gas orbiting ~9x event horizon distance at about 30% the speed of light. NBD.
  - (other actual data, X-rays)



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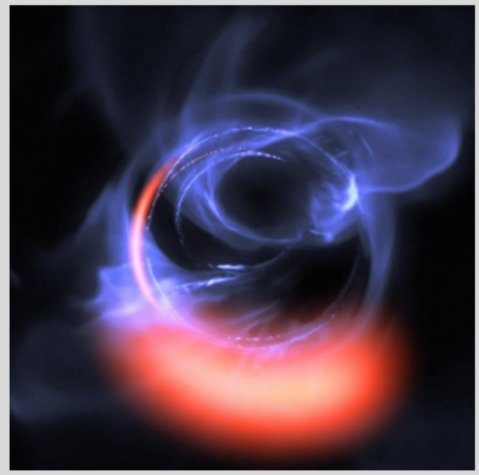
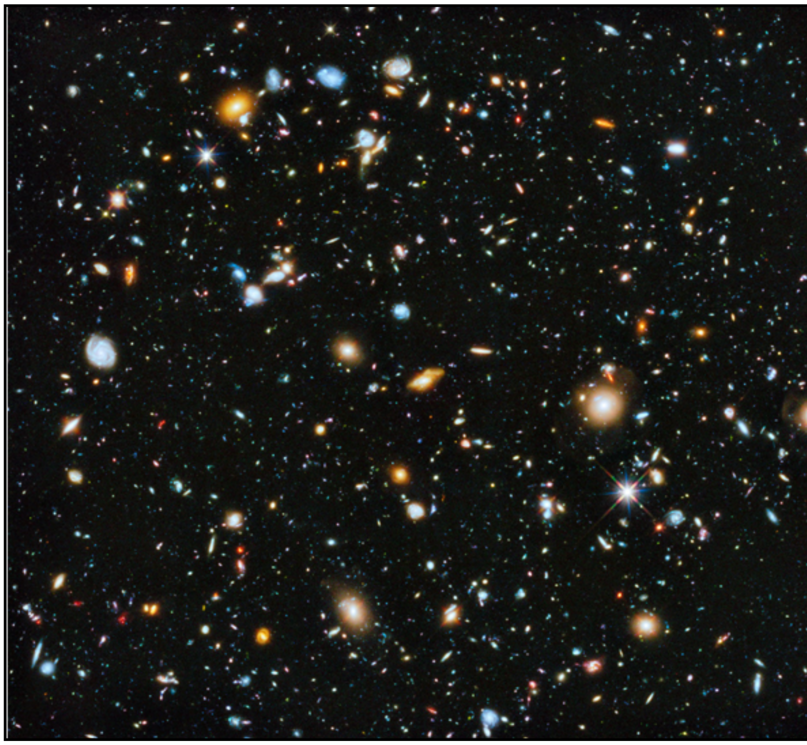


https://www.eurekalert.org/pub_releases/2018-10/e-mdo102918.php?fbclid=IwAR06SPUmbZomaW1EPOukSB-edcyKh7K3jpv6MRAYa5Vrp5WgeJNnzwKDh98

https://www.eso.org/public/archives/releases/sciencepapers/eso1835/eso1835a.pdf

X-ray image is in your book; you can see all the hot gas in the area of the supermassive black hole at the center of our galaxy

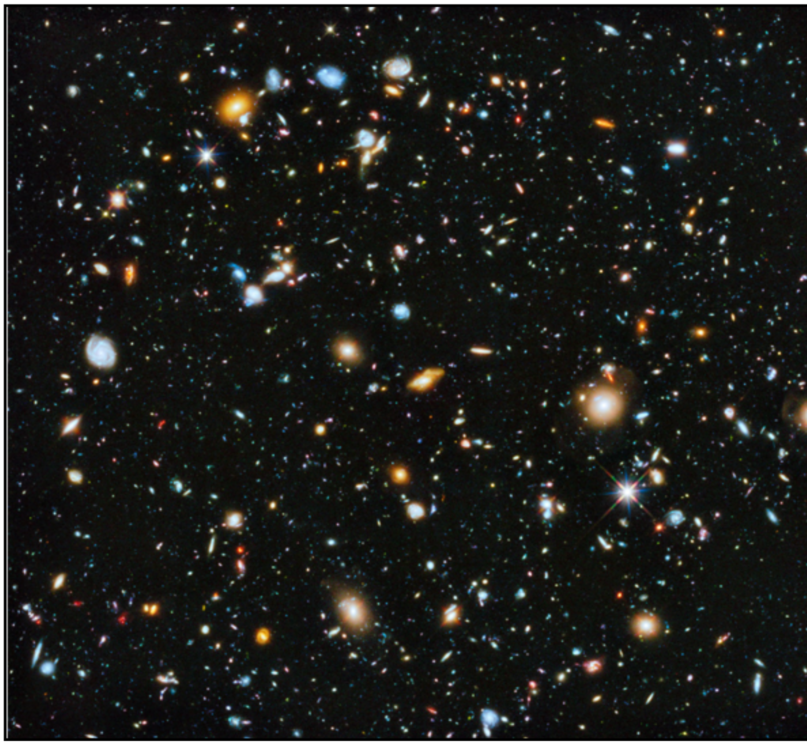
Sometimes x-rays are from material falling in and releasing energy as torn apart by gravitational forces, this time it’s material orbiting that gets heated as it gets closer, cools when farther.



Galaxies and modern cosmology

Chapter 20. The Cosmic Perspective

https://en.wikipedia.org/wiki/Hubble_Ultra-Deep_Field#Hubble_eXtreme_Deep_Field



Galaxies and modern cosmology

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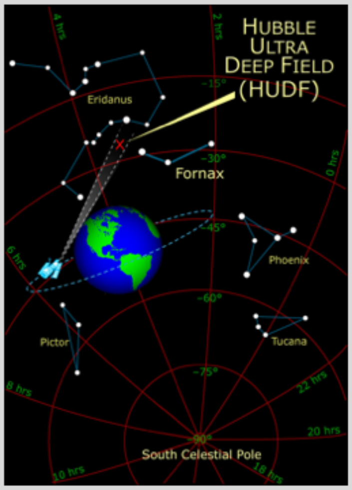
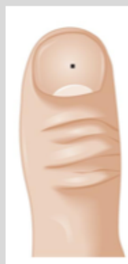
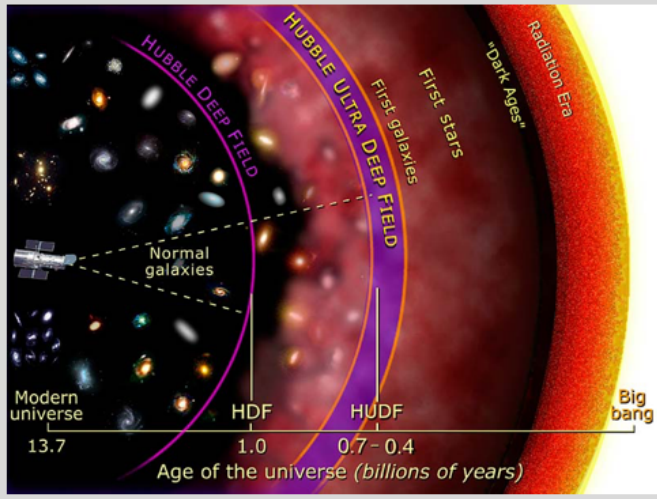
There are ~100 billion stars in the milky way, and about 100 billion galaxies in the universe

Looking back in time







Surveying galaxies

- Bin them into different types depending on how they appear:
  - Spiral galaxies

We see a wide variety of colors and shapes of galaxies, as well as variation in how we see galaxies (at what inclination angle we're viewing them)

https://www.eso.org/public/images/eso9845d/

https://www.spacetelescope.org/images/opo9925a/

Spirals have disk, bulge, halo that we mostly can't see.

The word 'galaxy' comes from the Greek for milky way, 'milky one,' describing our own galaxy in the night sky.

https://en.wikipedia.org/wiki/Galaxy#Etymology

Surveying galaxies

- Bin them into different types depending on how they appear:
  - Spiral galaxies
    - Lenticular galaxies (lens-shaped) → kind of spirals without spiral arms

http://hubblesite.org/image/1415/news_release/2003-28

http://www.rochesterastronomy.org/snimages/sn1994d.html

Lenticular galaxies have disk and halo components, but no clear spiral arm structures. They're somewhere in between spiral and elliptical galaxies in how they look.

Surveying galaxies

- Bin them into different types depending on how they appear:
  - Spiral galaxies
  - Elliptical galaxies

https://www.spacetelescope.org/images/heic1812a/

https://apod.nasa.gov/apod/ap040616.html

Have very little dust or cool gas, not forming stars at a high rate. Look red or yellow, they don’t have the young, high-mass, blue stars around

Surveying galaxies

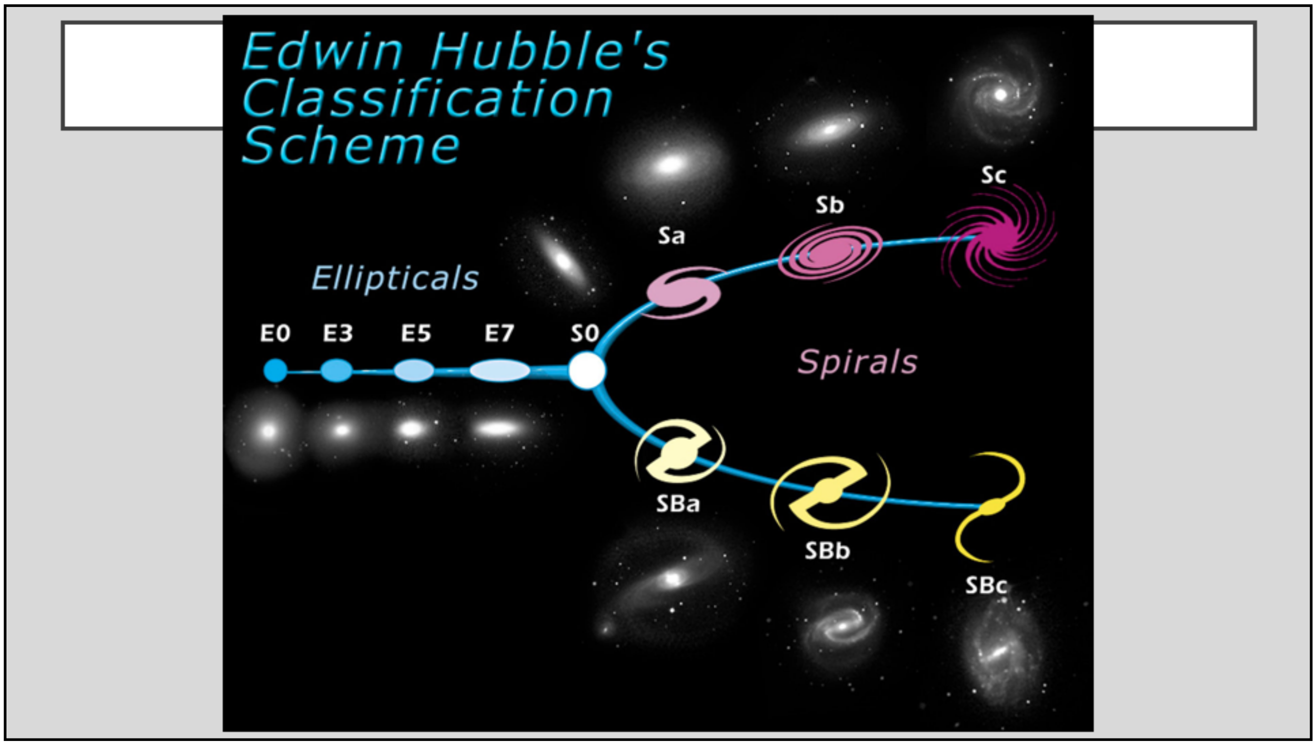
- Bin them into different types depending on how they appear:
  - Spiral galaxies
  - Elliptical galaxies
  - Irregular galaxies

HubbleSite/NASA, ESA and the Hubble Heritage Team

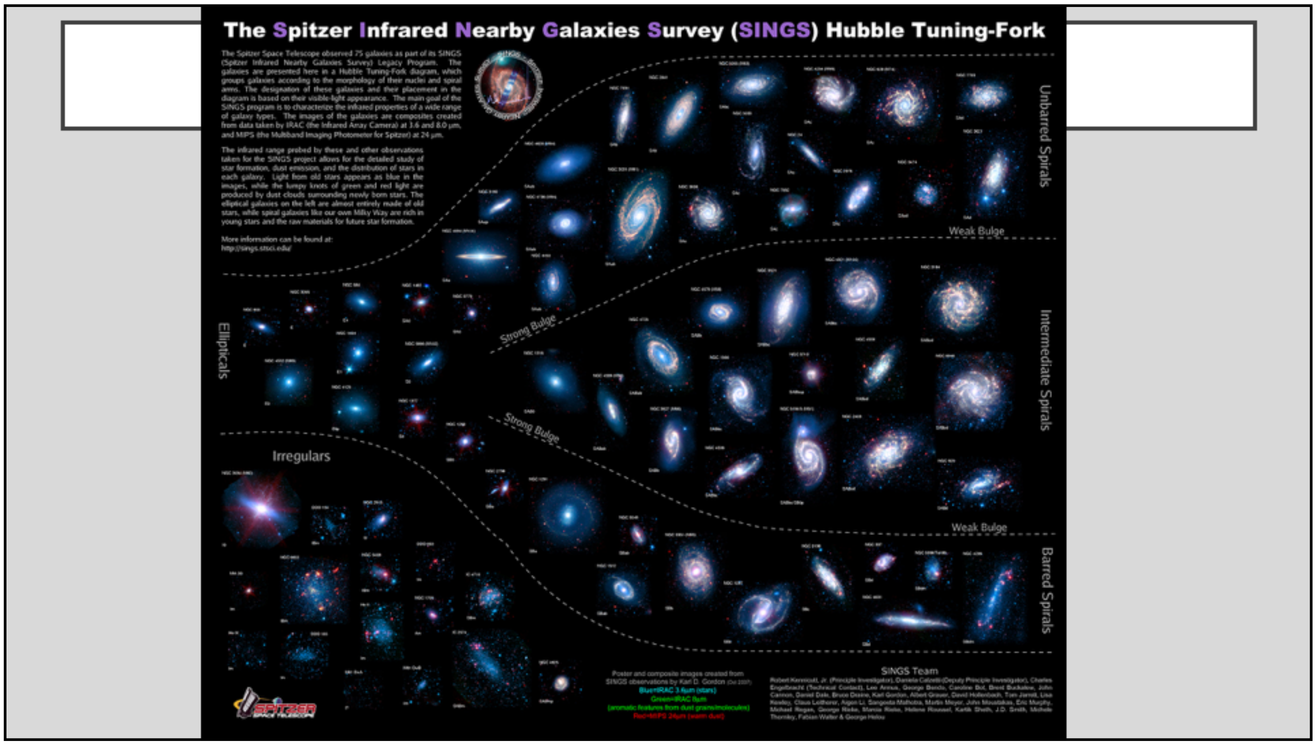
https://www.nasa.gov/feature/goddard/2017/messier-82-the-cigar-galaxy

Small magellanic cloud (from second ‘today in science’ link)

Irregular galaxies are the everything else – galaxies that aren’t spirals, aren’t lenticular, aren’t elliptical. They tend to be bluer, indicating more star formation is ongoing. They’re relatively rare now, but we see more as we look at the universe at younger and younger ages.



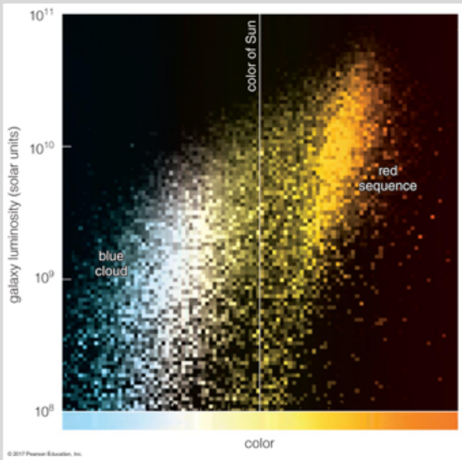
https://www.spacetelescope.org/images/heic9902o/



Can make this kind of classifying as complicated as you wish…

http://www.spitzer.caltech.edu/uploaded_files/images/0008/1211/sig07-025_Med.jpg

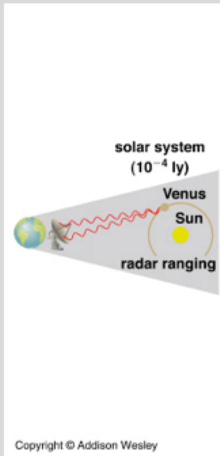
Galaxy colors, luminosity



- Red sequence:
  - Older stars
  - Most elliptical
- Blue cloud:
  - Actively forming stars
    - Groups of young stars' light dominated by bluest (hottest), most luminous stars
  - Tend to be spiral or irregular galaxies

Distance scales in the universe

- We were just talking about galaxy luminosities, so we must know distances to these galaxies somehow…



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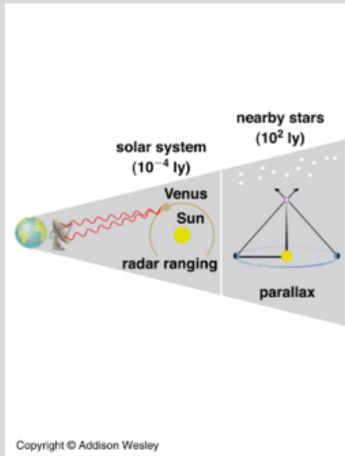

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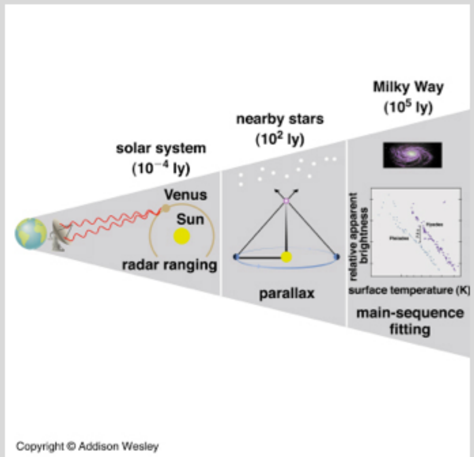

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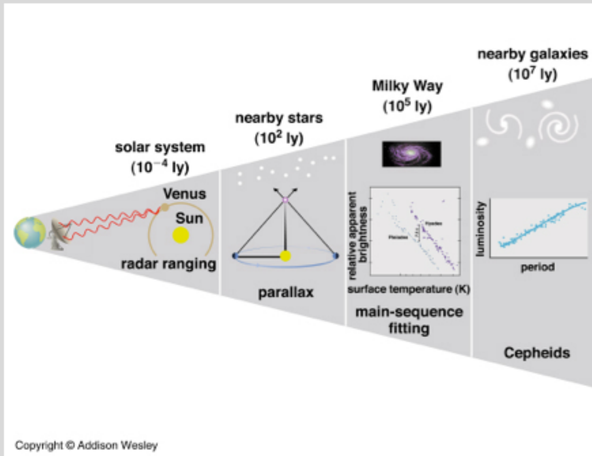
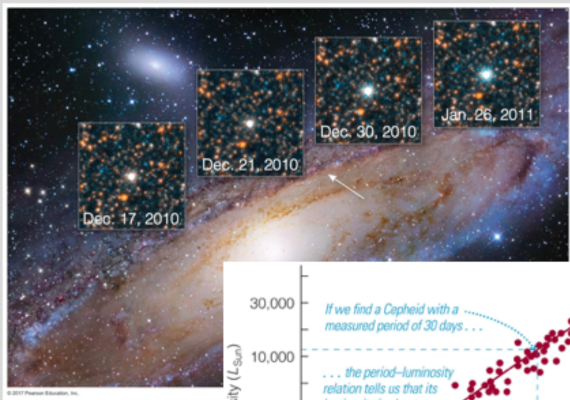
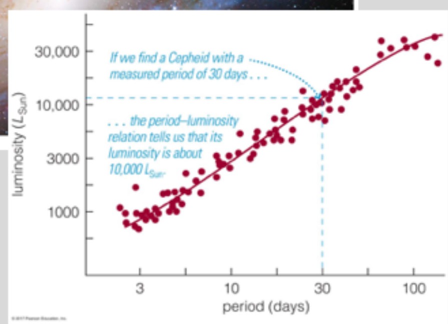


"Standard candles"

- Because the object is so well-known to us from examples in our Milky Way, we already know what their luminosities should be
- Use our apparent brightness/luminosity relationship…
  - $apparent\ brightness = \frac{luminosity}{4\pi d^2}$
  - Rearrange it to solve for distance…
  - $distance = \sqrt{\frac{luminosity}{4\pi\ apparent\ brightness}}$

Standard candles: Cepheid variables





- Each rung of the distance ladder is calibrated where the ranges applicable overlap
- Period-luminosity relationship calibrated by Cepheid variables nearby enough to measure their parallax

https://en.wikipedia.org/wiki/Henrietta_Swan_Leavitt

Distance scales in the universe

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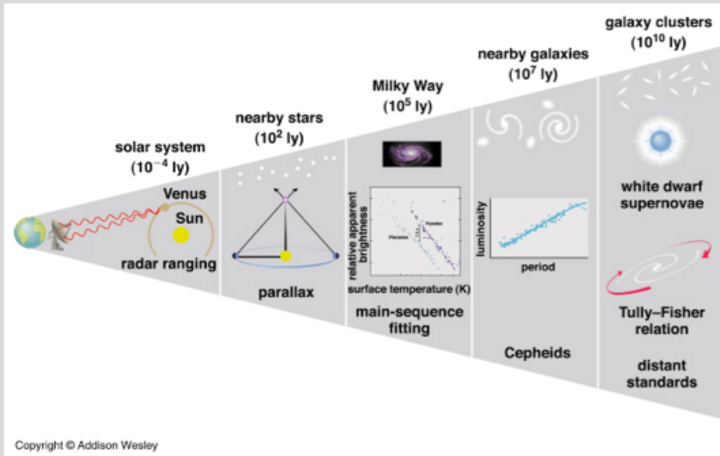


Standard candles: supernovae

- When white dwarfs go supernovae
  - Recall Chandrasekhar mass limit: 1.44Msun
  - When white dwarfs exceed this limit, they go supernova
  - All have nearly same luminosity because *progenitors* are of same mass: energy release is the same

https://phys.org/news/2010-03-super-supernova-white-dwarf-star.html

This one pictured is thought to have been two white dwarfs merging

Historical note

vs.

- In the early 1900s, we didn't know whether galaxies were within our Milky Way, or beyond!
- In 1920, two astronomers debated. Harlow Shapley vs Heber Curtis
- Neither really convinced anyone- there wasn't evidence of the distances to the "nebulae" and no one knew yet what a supernova was
  - Shapley thought supernova in Andromeda was a nova
  - Curtis didn't have solid distance evidence

Here's where some of our favorite characters from earlier in the course reappear..
With one new guy

Remember Shapley? He was the "I'm going to major in the first thing I can pronounce" guy (archaeology was not in his lexicon)

Historical note

- Around that same time, some guy named Edwin finished grad school and went to work at the Mount Wilson Observatory
  - (founded by A235 favorite George Hale)

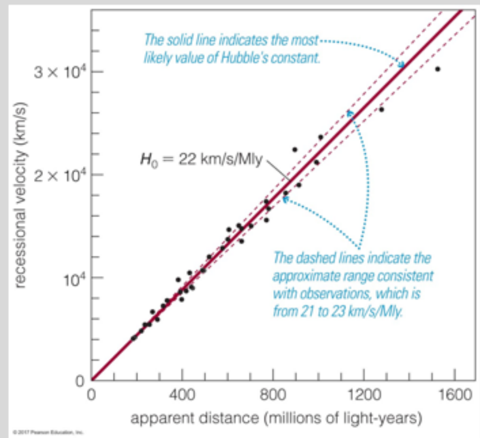
Galaxy! Found it! Nobel, pls

Even farther than supernovae

- Hubble observed Cepheid variables in Andromeda, and used Leavitt's period-luminosity relationship to estimate their distances
- Found them way beyond distances known within Milky Way to that point
- He and assistants found more in other galaxies, kept making measurements

Expansion of the universe

- It was already known that spectra of distant galaxies showed redshifted spectral lines
- Hubble combined velocities measured from the redshifts with distances, found farthest galaxies are moving the fastest



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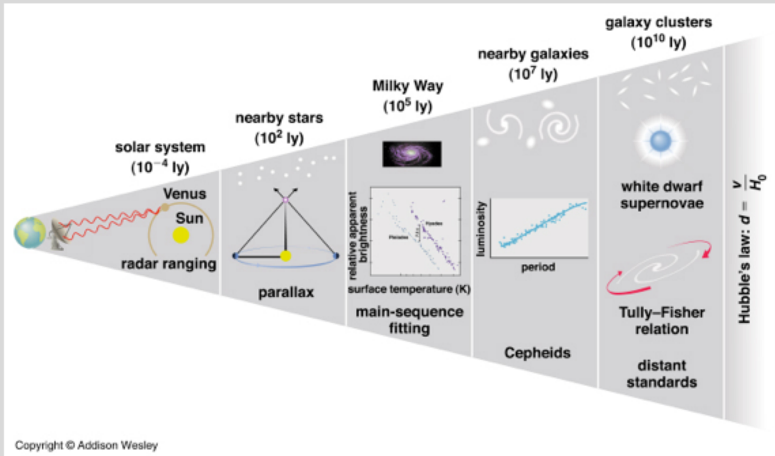
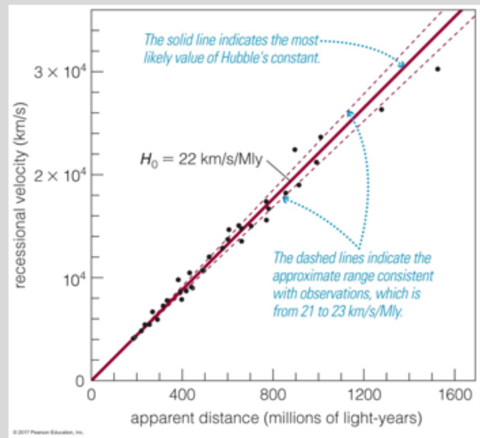


So, for the farthest rung of the distance ladder, we use Hubble's law. Measure the speed of the galaxy and you can figure out its distance.

Expansion of the universe

- It was already known that spectra of distant galaxies showed redshifted spectral lines
- Hubble combined velocities measured from the redshifts with distances, found farthest galaxies are moving the fastest

- So... If they're moving away from us now…
  - Were closer together at some point in the past
  - Forget the raisin cake, try points on a balloon!



Expansion of the universe