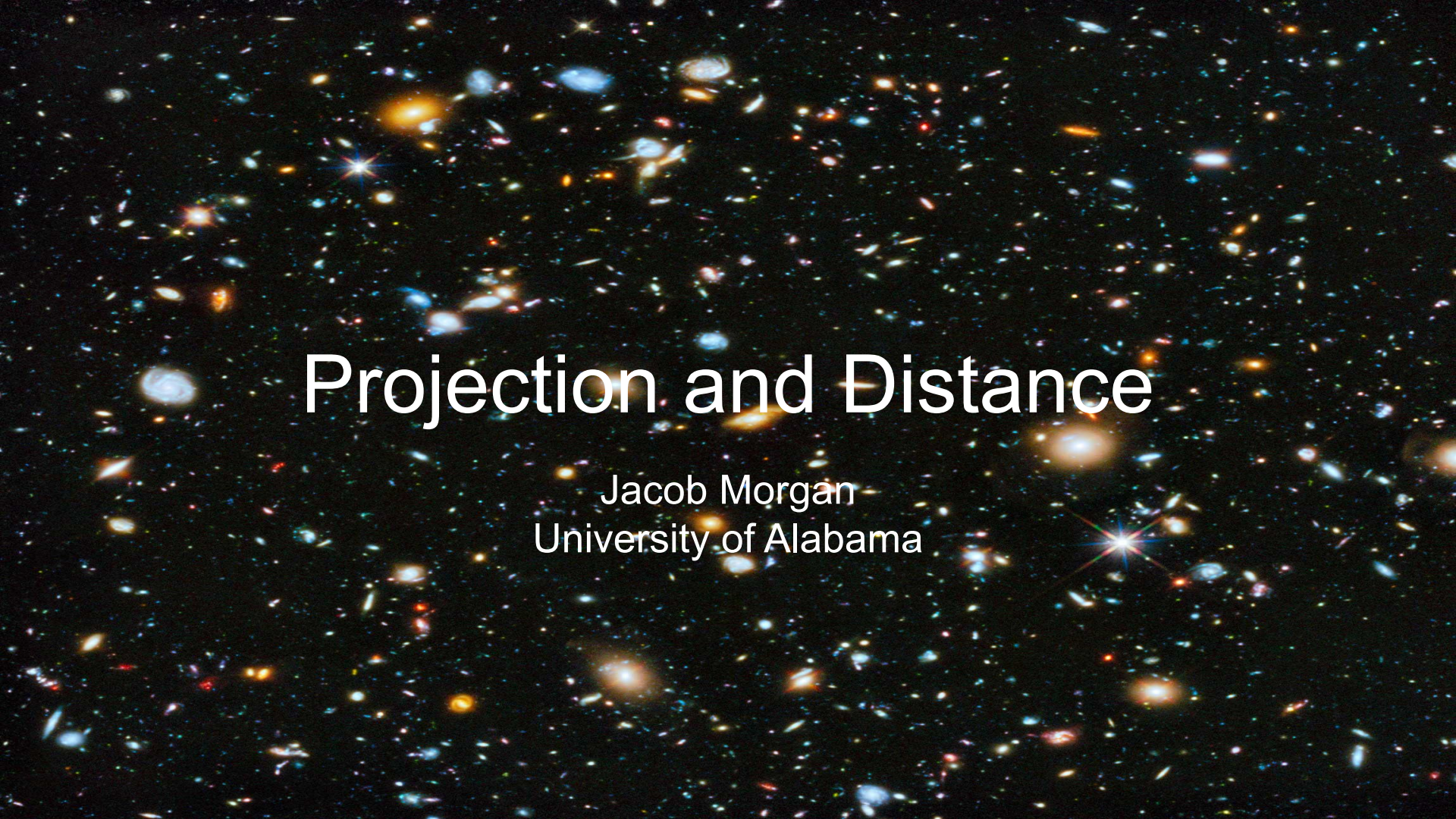
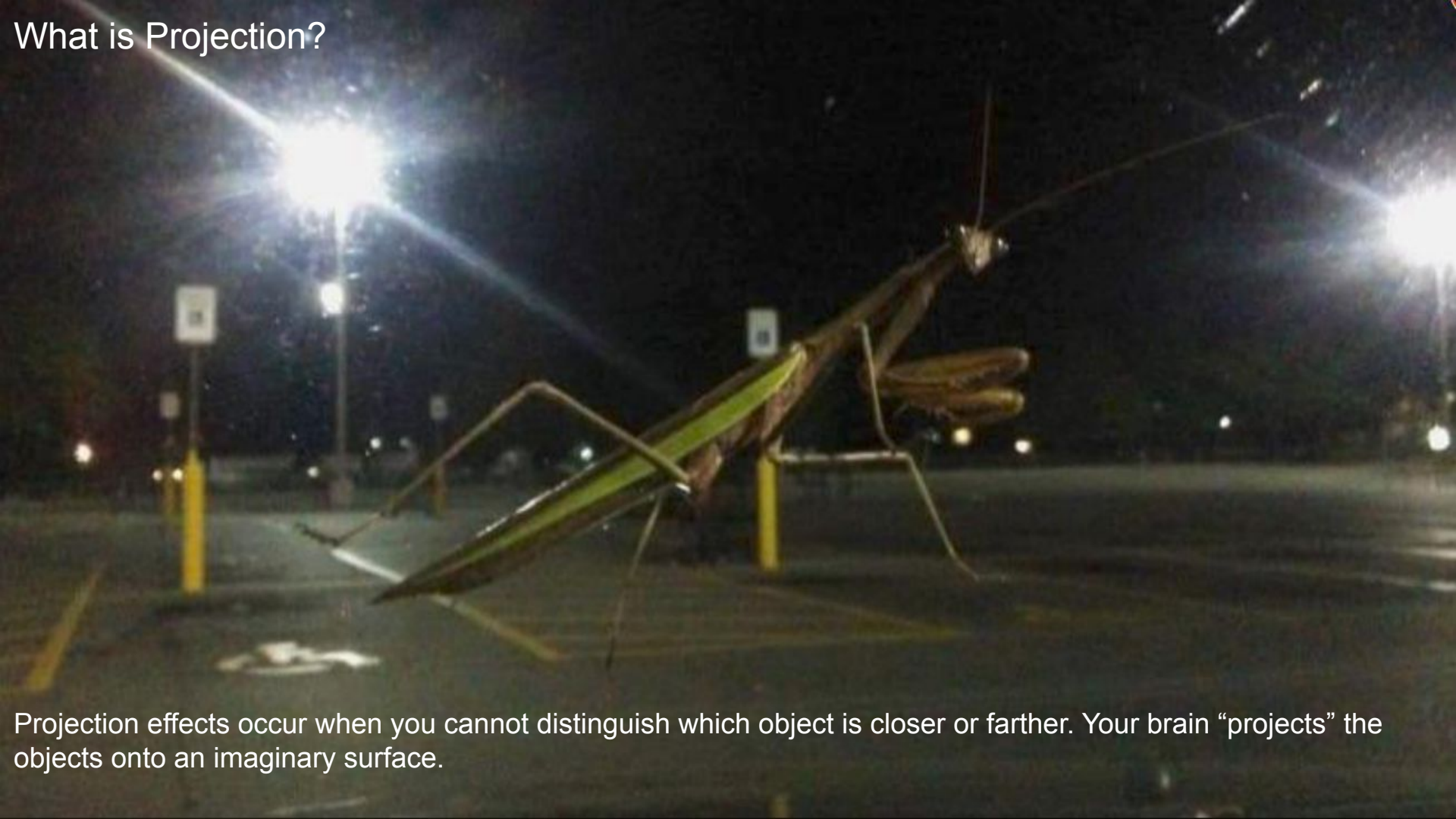


Projection and Distance

Jacob Morgan
University of Alabama

What is Projection?



Projection effects occur when you cannot distinguish which object is closer or farther. Your brain “projects” the objects onto an imaginary surface.

What is Projection?

We aren't fooled by the mantis because our brains automatically use context clues and prior knowledge
But we don't have instincts like that for astronomical objects because size, brightness, and distance are all extremely variable for the same type of object
SIZE: the Milky Way and IC1101 are both galaxies, but IC1101 is 5X larger and 1000X more massive! Likewise, the Milky Way is 1000X more massive than dwarf galaxies! 1000X1000=factor of a million difference in mass!

Milky Way (technically Andromeda)

IC1101

What is Projection?

DISTANCE/BRIGHTNESS: Besides the Sun, the closest star is Proxima Centauri, about 4.2 lightyears away. But it is not visible to the naked eye! The Sun outputs 20,000X more light, but both are main sequence stars burning hydrogen

Betelgeuse is clearly visible in the night sky, but is 100X farther away! Betelgeuse is 65,000X brighter than the Sun and 65,000X20,000=1.3 billion times brighter than Proxima Centauri

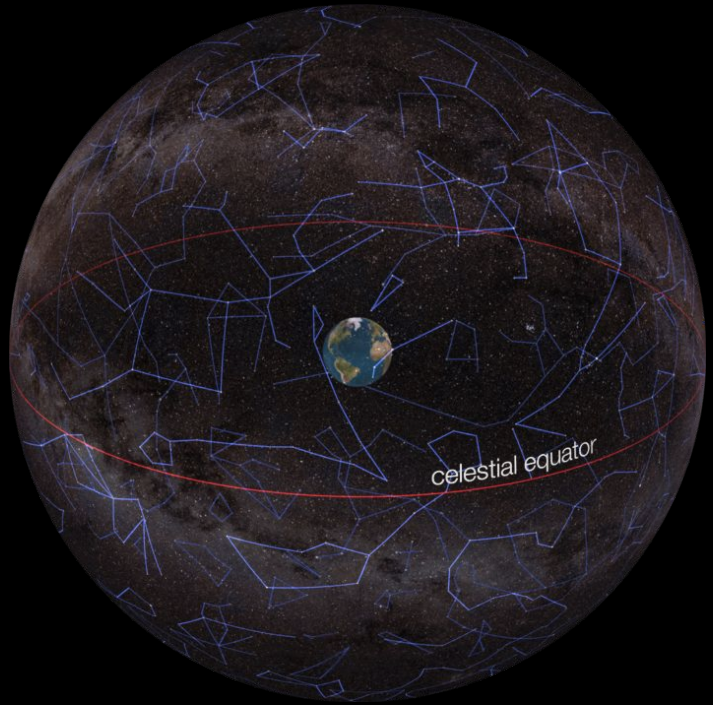
Luminosity: The total amount of light emitted by an object. This is not dependant on distance

The Celestial Sphere

Measuring distance is hard→scientists disagree about the distance to objects all the time! How do you talk about where something is without getting into a “discussion”?

The “Celestial Sphere” is the imaginary surface we project stars onto! A black shell surrounding the Earth, with all of the stars pasted onto it (making the stars the same distance away). This is sort of what the Greeks thought, and it is still useful to pretend it works this way, ie for pointing telescopes

Then scientists go in later and use a variety of techniques to measure distance to each individual object**



**often it is actually a group of objects, like a cluster of stars

Some Consequences of Projection

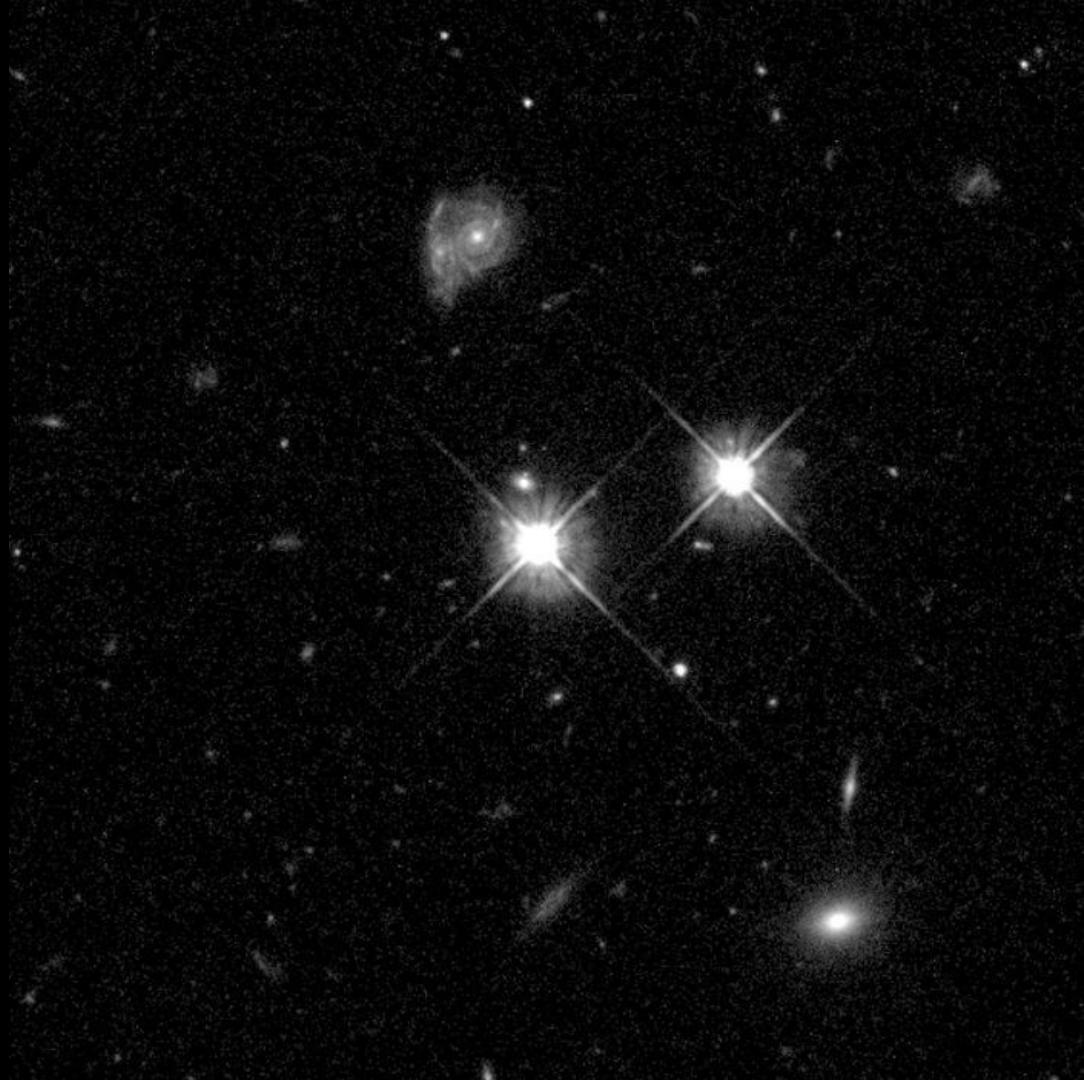
Double stars: objects that appear near each other are often very far apart. The bright objects appear to be associated stars, but are not

Right bright object: Star in our own galaxy, ~500 lightyears away

Left bright object: a quasar 9 billion lightyears away. Quasars are not stars, but massive black holes at the center of galaxies. The luminosity of all the billions of stars in the host galaxy are eclipsed by the black hole

Small Blob above left bright object: an unrelated elliptical galaxy that is 7 billion lightyears away. Closer than the quasar, and consisting of over 2 billion stars, it is not nearly as bright as a single active black hole

To appear the same brightness as the star, the quasar must be 324 trillion times more luminous!



Some Consequences of Projection

Constellations: Most constellations would not exist if not for projection effects!

Orion's Belt and the Orion Nebula are actually associated! The Orion Nebula is forming stars at an extremely high rate, and Orion's Belt consists of some of the brightest stars formed in this region

Alnitak: 3 stars, the largest is a blue supergiant ~22000X brighter than the Sun
Alnilam: this is only one star, ~420,000X brighter than the Sun
Mintaka: 5 stars! A giant and several Sun-like stars, total brightness ~190,000X brighter than Sun

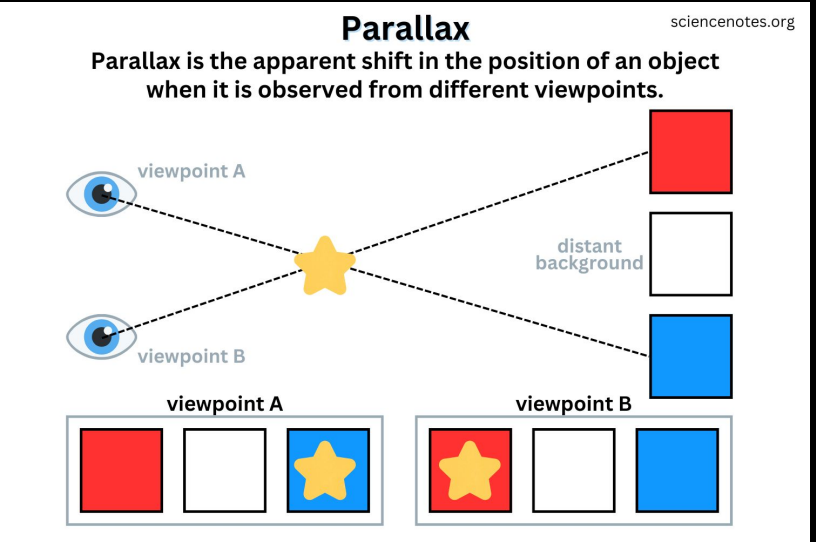
But Betelgeuse, Rigel, Bellatrix, and Saiph are several hundred lightyears away from the others! Betelgeuse is also much older, and near the end of its life

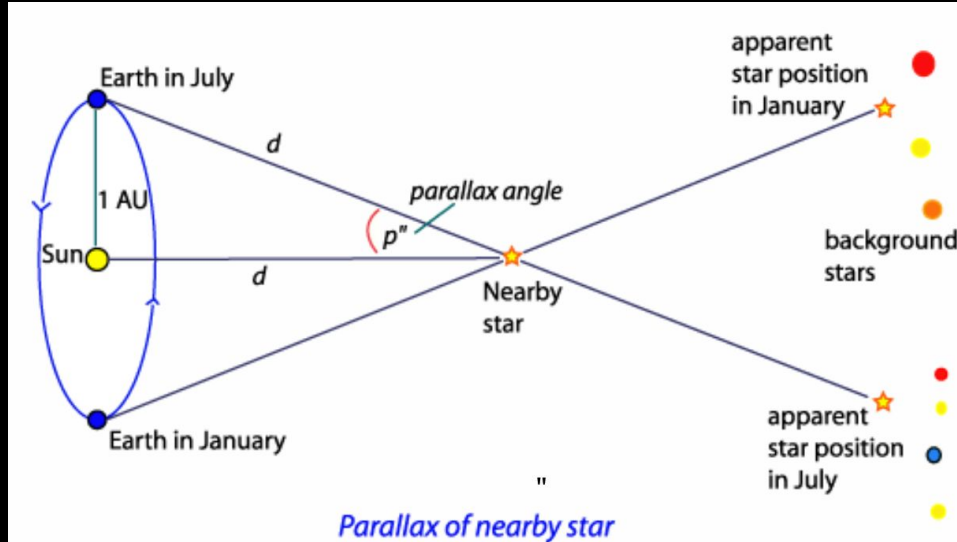
The Distance Ladder I: Parallax

Parallax effects occur when you change the angle you are viewing an object at without changing distance, ie, like looking with one eye and then the other. More distant objects will shift more.

1) Close one eye
2) Place finger in front of face, near nose, so that it covers me
3) Wink with one eye, then the other, to observe parallax! (finger shifts so that I am no longer covered)
4) Now place finger at arms length so that it covers me. Blink one eye, then the other to observe *decreased* parallax (your finger shifts less)

We can do a bunch of math to show that the amount you shift decreases with distance; your brain uses the different viewing angles of your eyes to determine distance *subconsciously*!





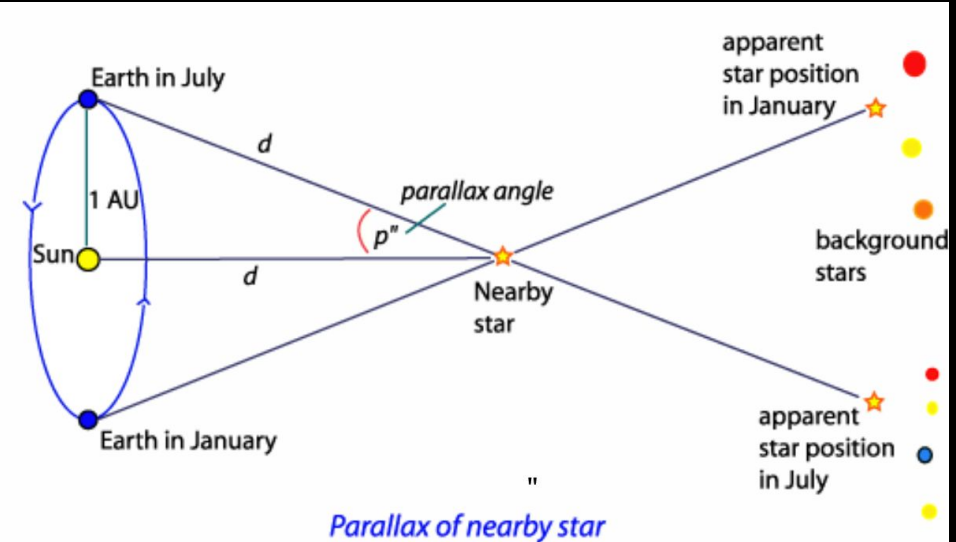
The Distance Ladder I: Parallax

We can do a bunch of math to show that the amount you shift decreases with distance; your brain uses the different viewing angles of your eyes to determine distance *subconsciously*! ←Why does this not work on stars?

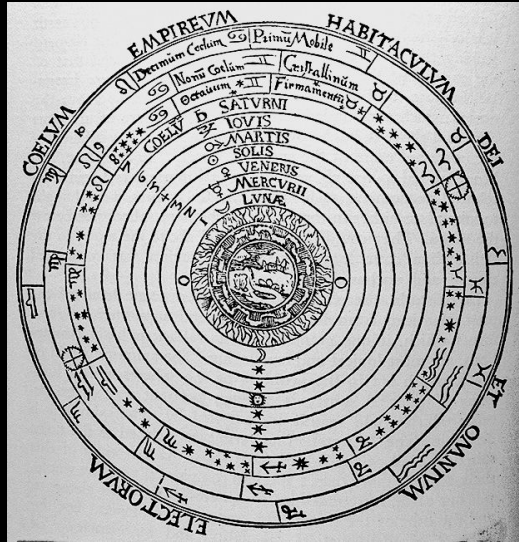
Every star in the Universe is so distant, that their parallax angle is too small to be seen with the human eye!
Proxima Centauri has a parallax angle of 0.0002 degrees!
The Greeks actually knew about this effect– it is one reason they believed in Earth was the center of the Universe!
When the ancient Greeks tried and failed to detect stellar parallax, they concluded (correctly!) that either

The Universe was so large the nearest star was unimaginably far away

Earth is the center of the Universe



Parallax of nearby star



The Distance Ladder II: Cepheid Variables

Cepheid Variables are stars which pulse in brightness at regular intervals.
In 1908, Henrietta Swan-Leavitt was working as a human computer at Harvard Observatory for ~$10.50/hour (in today's dollars). She was tasked with using parallax to calculate the distance to some nearby Cepheids, then using that to find their brightness independent of distance. She discovered the Cepheid period-luminosity relation; Leavitt's Law says brighter Cepheids have longer time between pulses!

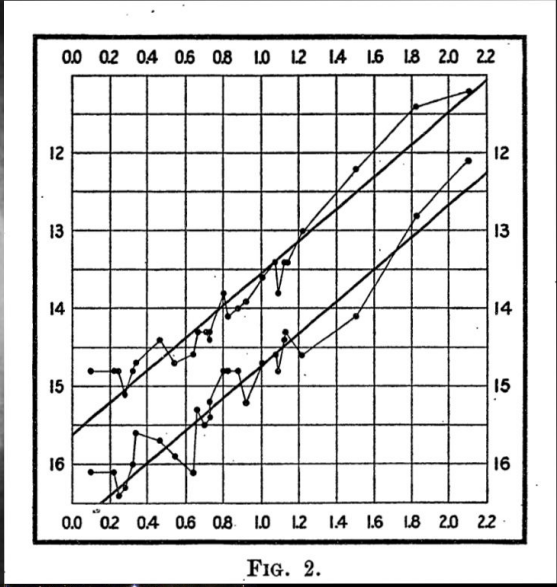
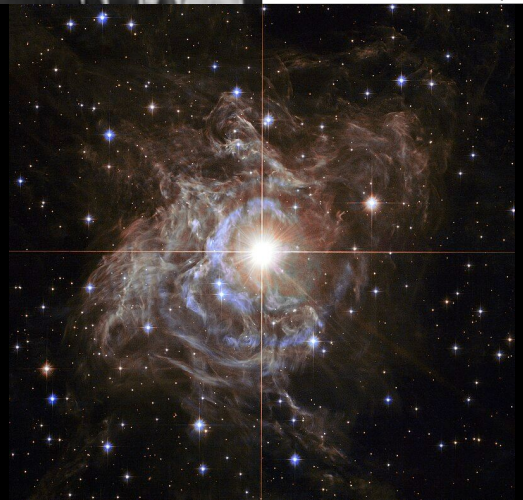


FIG. 2.

Measure time between pulses→get luminosity→compare to detected brightness→solve for distance!

Even with modern telescopes parallax angle is only detectable for very nearby stars. These pulses are much easier to detect, and allow us to calculate the distance to other galaxies!



The Distance Ladder III: The Great Debate and Hubble Flow

Well into the 1900s, it was commonly believed that the entire Universe and the Milky Way were the same thing; the word, “galaxy” did not exist in astronomy.

In 1920 The Great Debate was held between two prominent astronomers.

Heber Curtis argued that Andromeda was an “island universe”, and showed there were more nova happening in Andromeda than elsewhere in the Milky Way. But why would there by more nova in one small part of the galaxy? Curtis also showed these “island universes”/”spiral nebulae” were moving away from us at high speed, implying they were not gravitationally connected.

Harlow Shapley argued that “spiral nebulae” like Andromeda were relatively nearby, smallish collections of heated gas and dust. He emphasized that the Milky Way/Universe was ~300,000 lightyears across, and that if spiral nebulae were NOT small collections of gas and dust, but a similar size to the Milky Way, then the distance between them must be enormous! Too enormous to imagine!

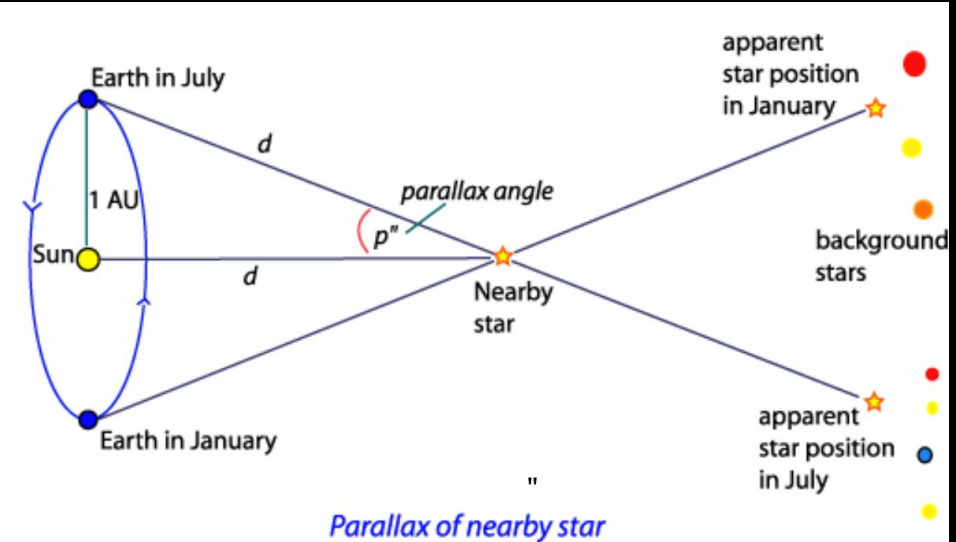
The Distance Ladder I: Parallax

We can do a bunch of math to show that the amount you shift decreases with distance; your brain uses the different viewing angles of your eyes to determine distance *subconsciously*! ←Why does this not work on stars?

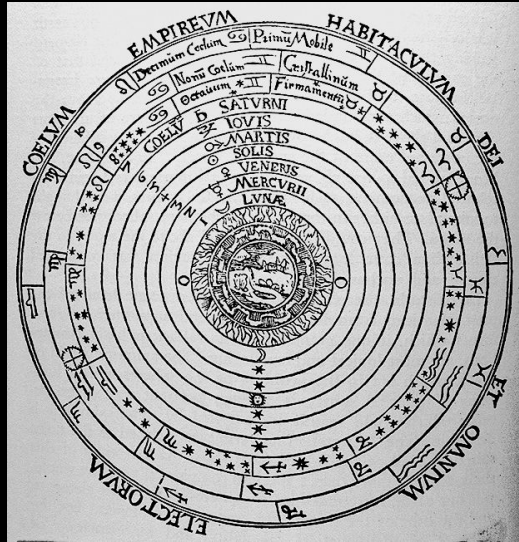
Every star in the Universe is so distant, that their parallax angle is too small to be seen with the human eye!
Proxima centauri has a parallax angle of 0.0002 degrees!
The Greeks actually knew about this effect– it is one reason they believed in Earth was the center of the Universe!
When the ancient Greeks tried and failed to detect stellar parallax, they concluded (correctly!) that either

The Universe was so large the nearest star was unimaginably far away

Earth is the center of the Universe



Parallax of nearby star



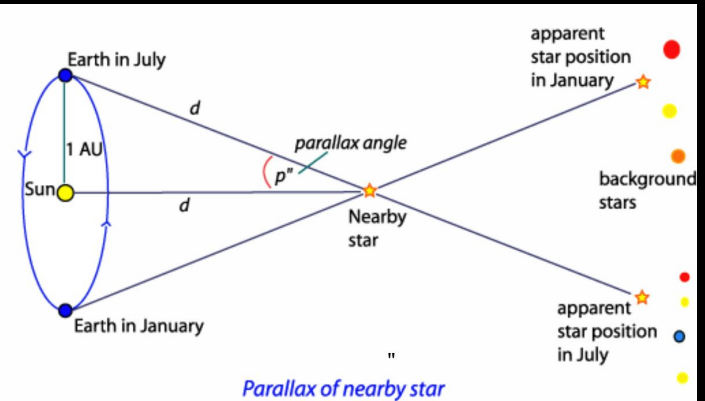
The Distance Ladder III: The Great Debate

Harlow Shapley argued that “spiral nebulae” like Andromeda were relatively nearby, smallish collections of heated gas and dust. He emphasized that the Milky Way/Universe was ~300,000 lightyears across, and that if spiral nebulae were NOT small collections of gas and dust, but a similar size to the Milky Way, then the distance between them must be enormous! Too enormous to imagine!

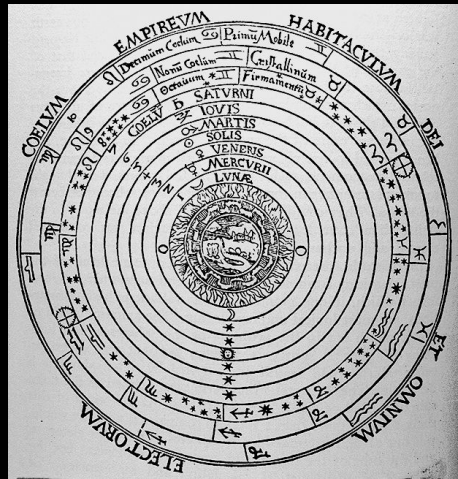
Heber Curtis argued that Andromeda was an “island universe”, and showed there were more supernova happening in Andromeda than elsewhere in the Milky Way. But why would there by more supernova in one small part of the galaxy? Curtis also showed these “island universes”/”spiral nebulae” were moving away from the Earth at high speed, implying they were not gravitationally connected.

The Universe was so large the nearest ~~star~~ galaxy was unimaginably far away

~~Earth~~ Milky Way is the center of the Universe



Parallax of nearby star



The Distance Ladder III: The Hubble Flow

In 1929 it all comes together; Edwin Hubble uses Leavitt's Law on Cepheid variable stars in Andromeda and other "spiral nebulae" to measure the distance to them. He found that the "spiral nebulae" were in fact "island universes" billions of lightyears away, not ~300,000 as Shapley supposed. This meant that many "nebulae" we had been studying were entirely different galaxies!

Hubble discovered something else as well: not only were galaxies more distant than we believed, they were actually moving *farther away*! And more distant galaxies are moving away *faster*! This gives us a relationship between distance and speed; Hubble's Law

distance=velocity/75 (if you use the right units!)

Measuring speed is much easier than measuring distance! Hubble's Law is used for the most distant objects, and actually works **better** as distance increases!

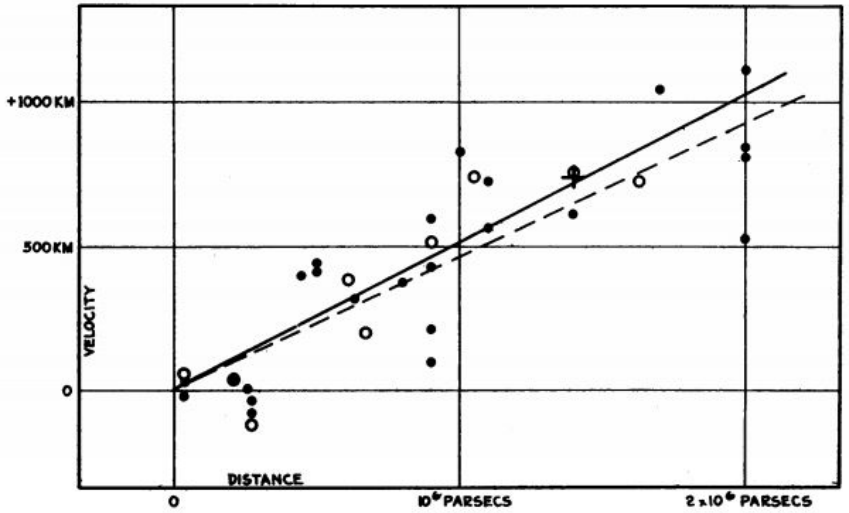


FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

Hubble Flow and the Expansion of the Universe

The Cosmological Principle is the idea that Earth (and the Milky Way!) cannot be in a special area of the Universe; instead, the Universe must be similar everywhere. In other words:

If every galaxy is moving away from the Milky Way, then every galaxy must be moving away from every other galaxy!

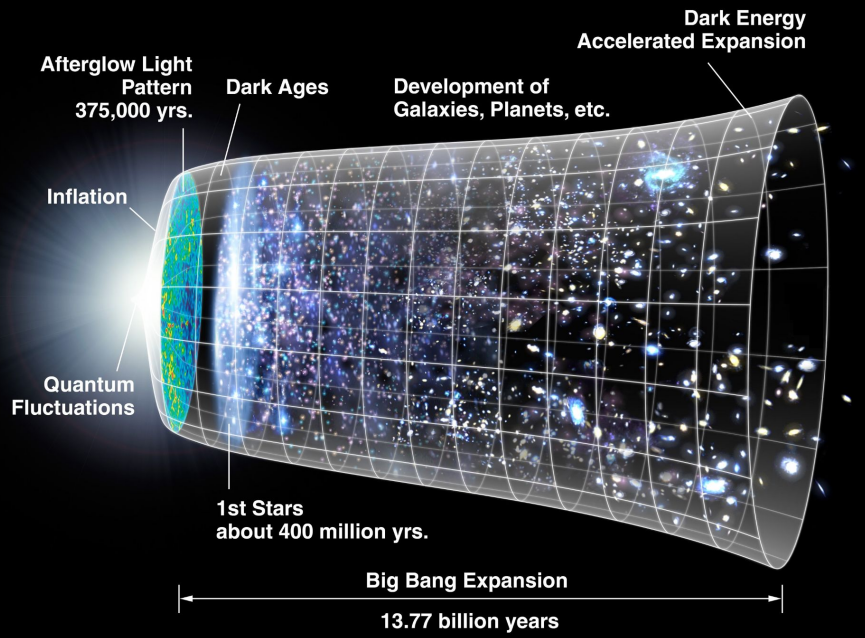
The only way for this to happen is for the whole Universe to expand;

In the future, the Universe will always be bigger

So

In the past, the Universe has always been smaller?

We just wanted to know how far away stars are, and now we discovered the Big Bang…..

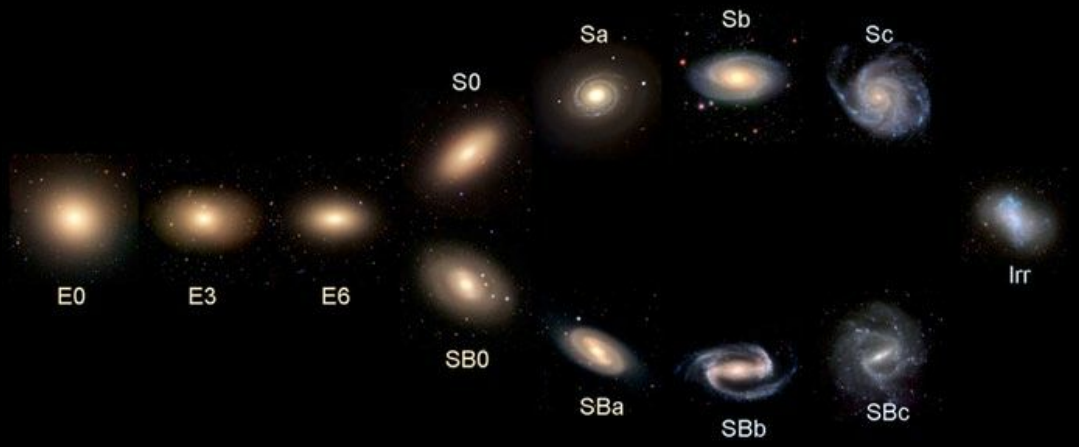


Distance and Time Travel

What is a lightyear? The distance light travels in one year.

The Milky Way is ~100,000 lightyears across, so it takes 100,000 years for light to cross it; we observe the other side of the Milky Way 100,000 years in the past! This is not an issue: it takes ~200 million years to orbit around the Milky Way, so not much changes in “only” 100,000 years.

But Hubble proved that many galaxies are millions, or even billions of lightyears away! This means we are viewing these galaxies billions of years in the past! This is why astronomers looooooove telescopes; the James Webb Space Telescope allows us to see almost 14 billion years into the past, only shortly after the Big Bang.



This is necessary to understand how galaxies change over time. If light did not take time to travel, we couldn’t know anything about our past