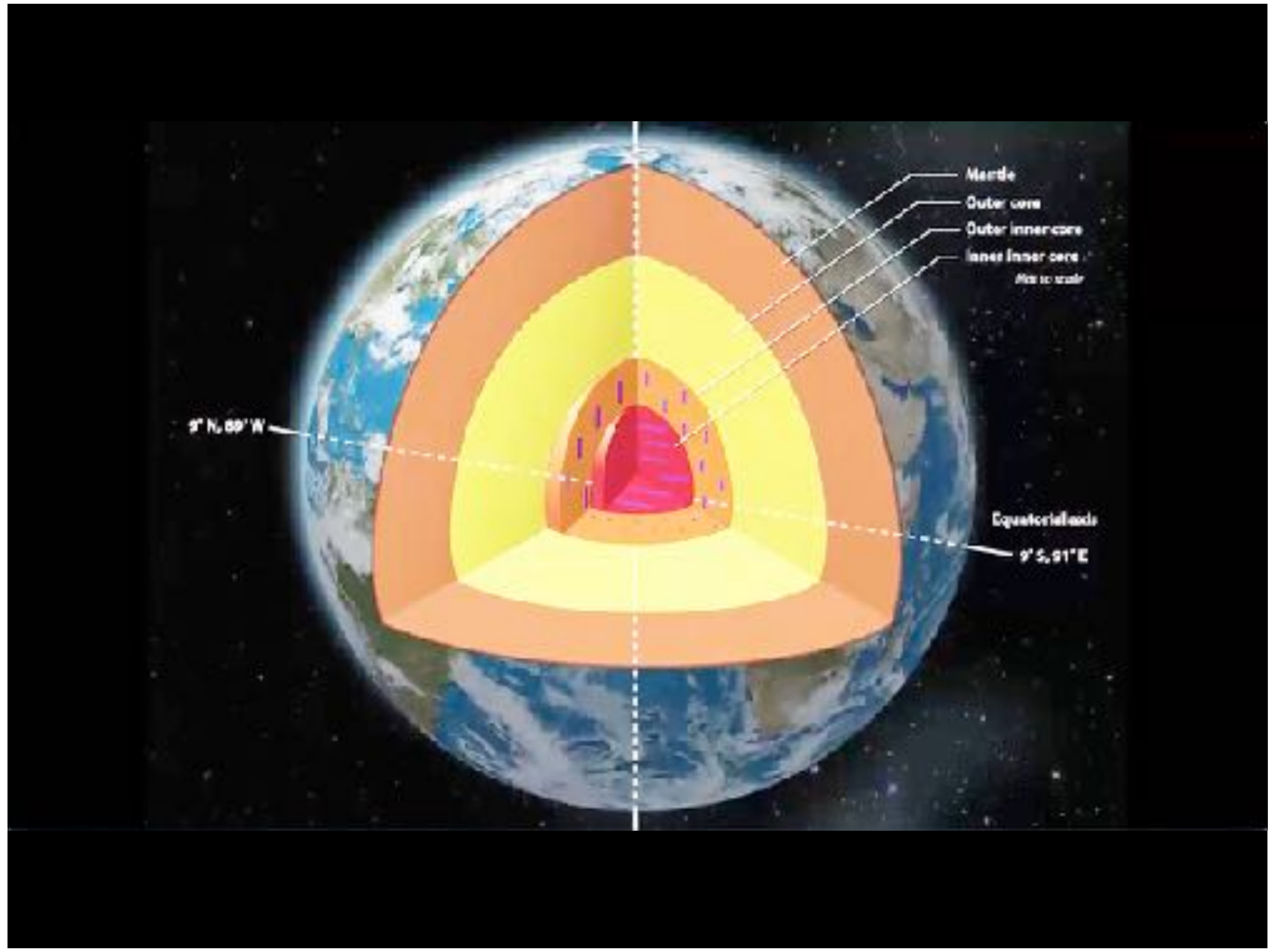

AN EXPLORATION OF ASTRONOMY AND EARTH SCIENCE
ACT VI: ORIGINS OF THE UNIVERSE

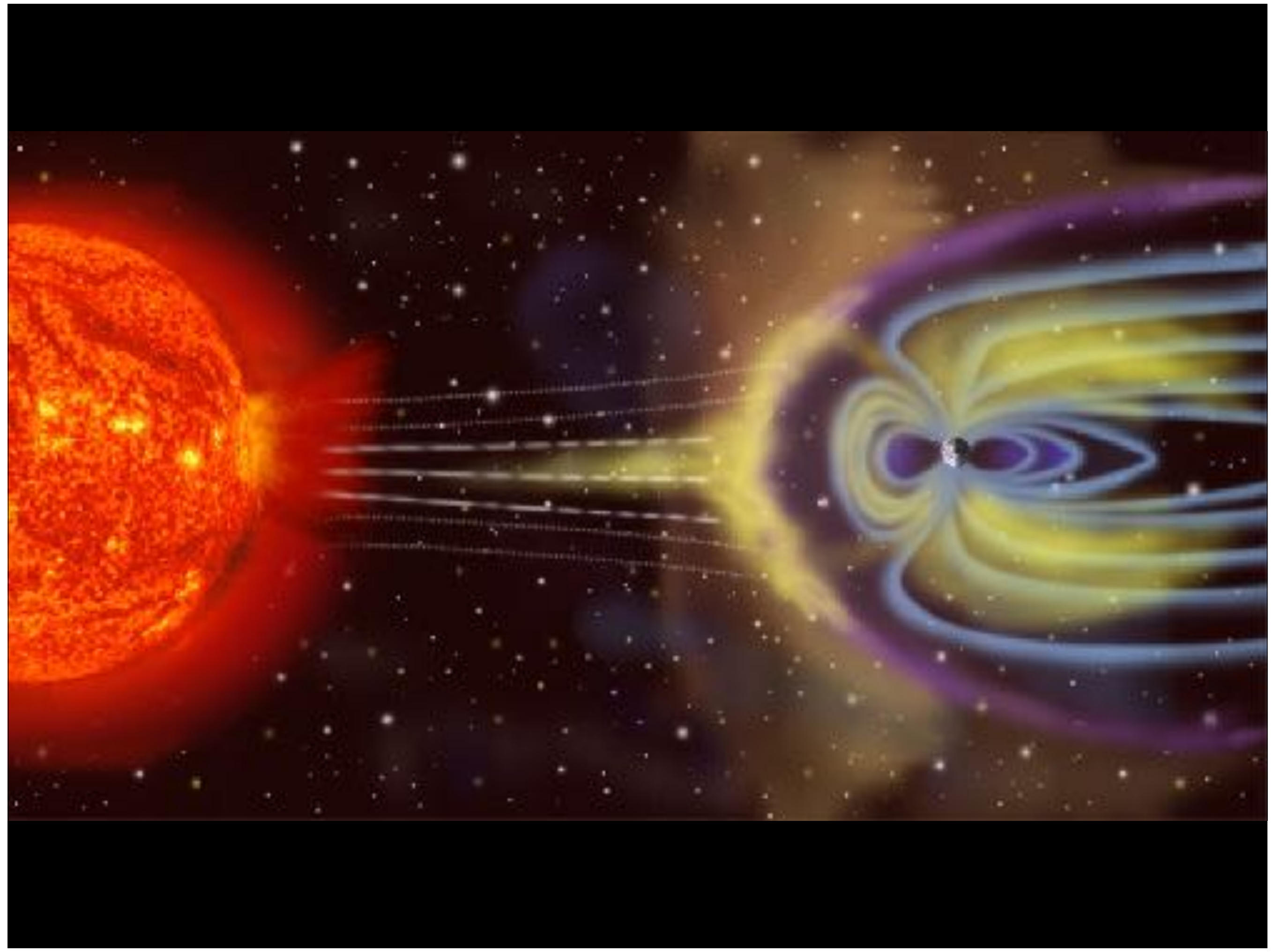

HOW TO OBSERVE A UNIVERSE
SCENE I: STARGAZING

# WHAT IS ASTRONOMY?

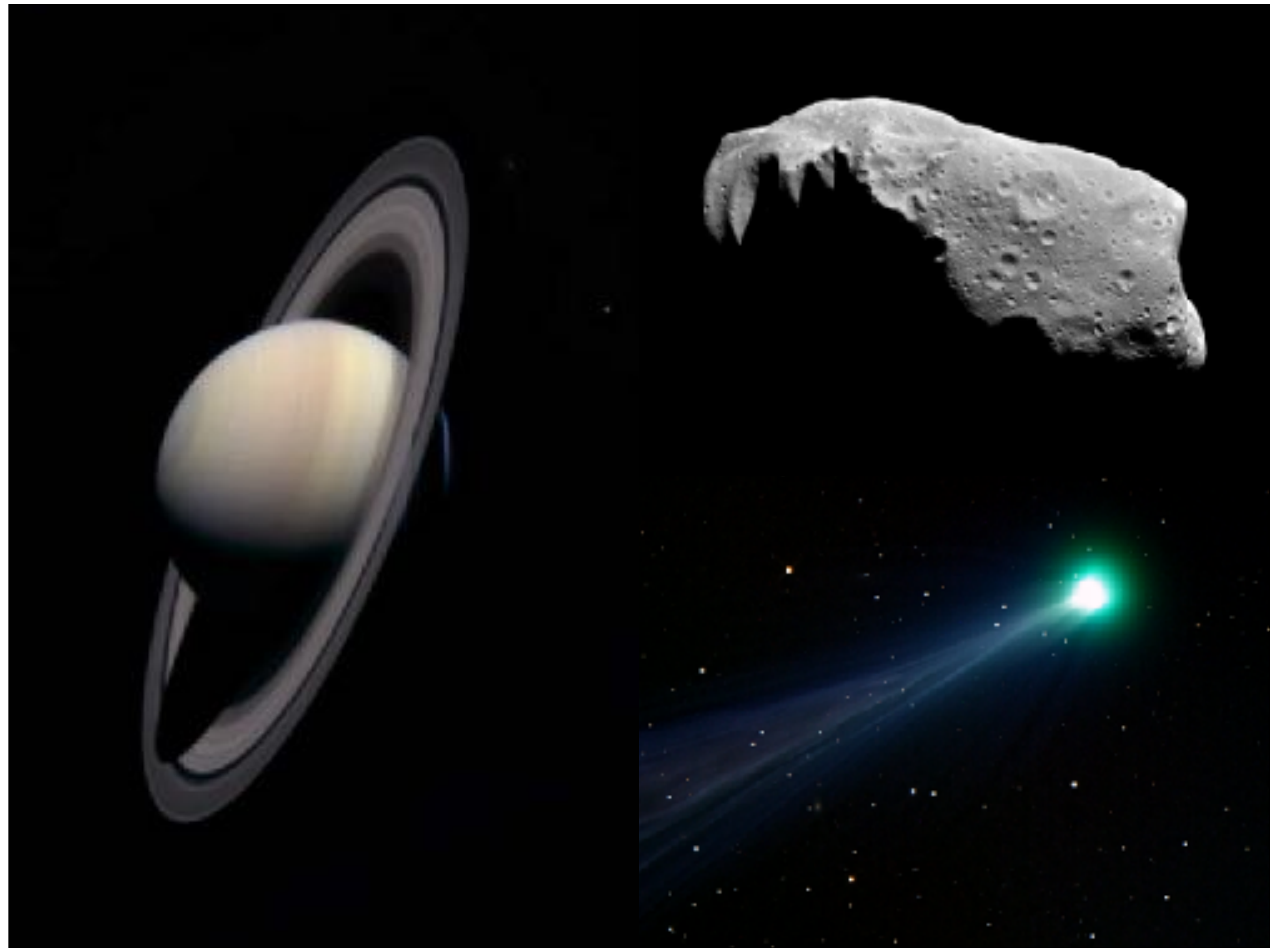
Astronomy puts you in your place. Because of astronomy, we know…



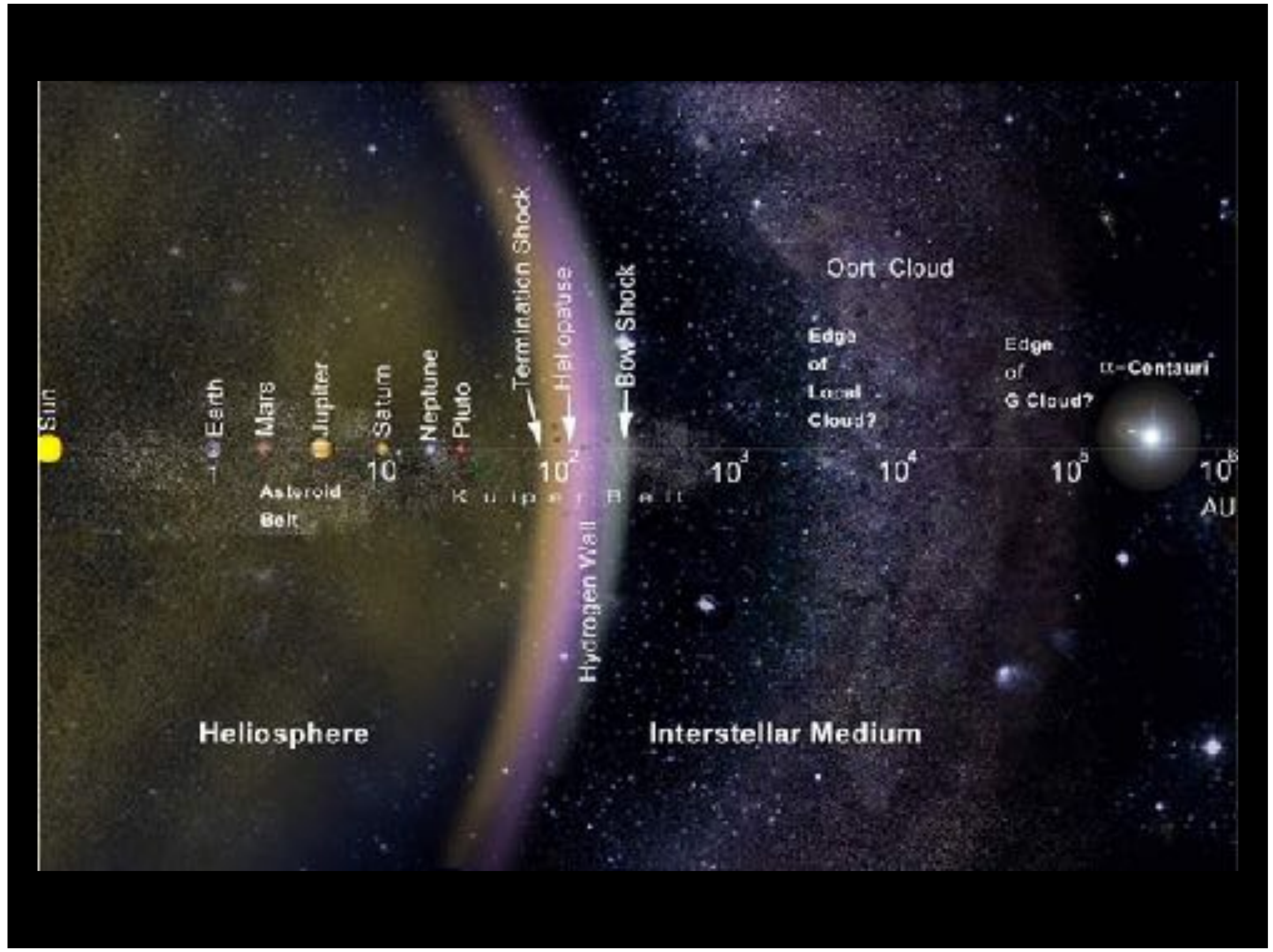

we are on a sphere of mostly molten rock and metal 13,000 km across with a fuzzy atmosphere about 100 km high



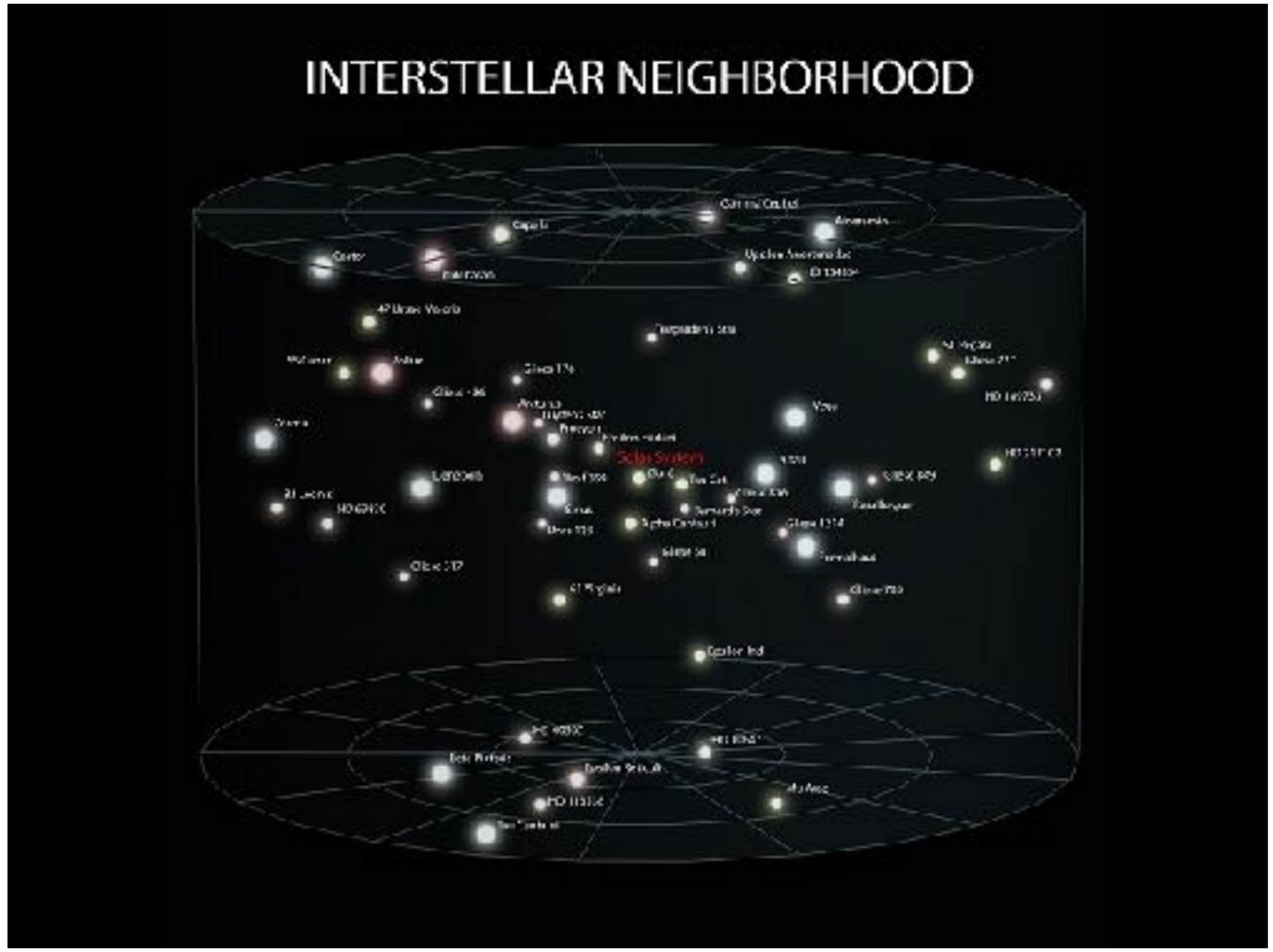
surrounded by a magnetic field that protects us from the onslaught of subatomic particles from the Sun 150 million km away,



which is also flooding space with light that reaches across space to illuminate the planets, asteroids, dust, and comets




racing out past the Kuiper Belt, through the Oort Cloud, into interstellar space




past the nearest stars, which orbit along with gas clouds and dust lanes

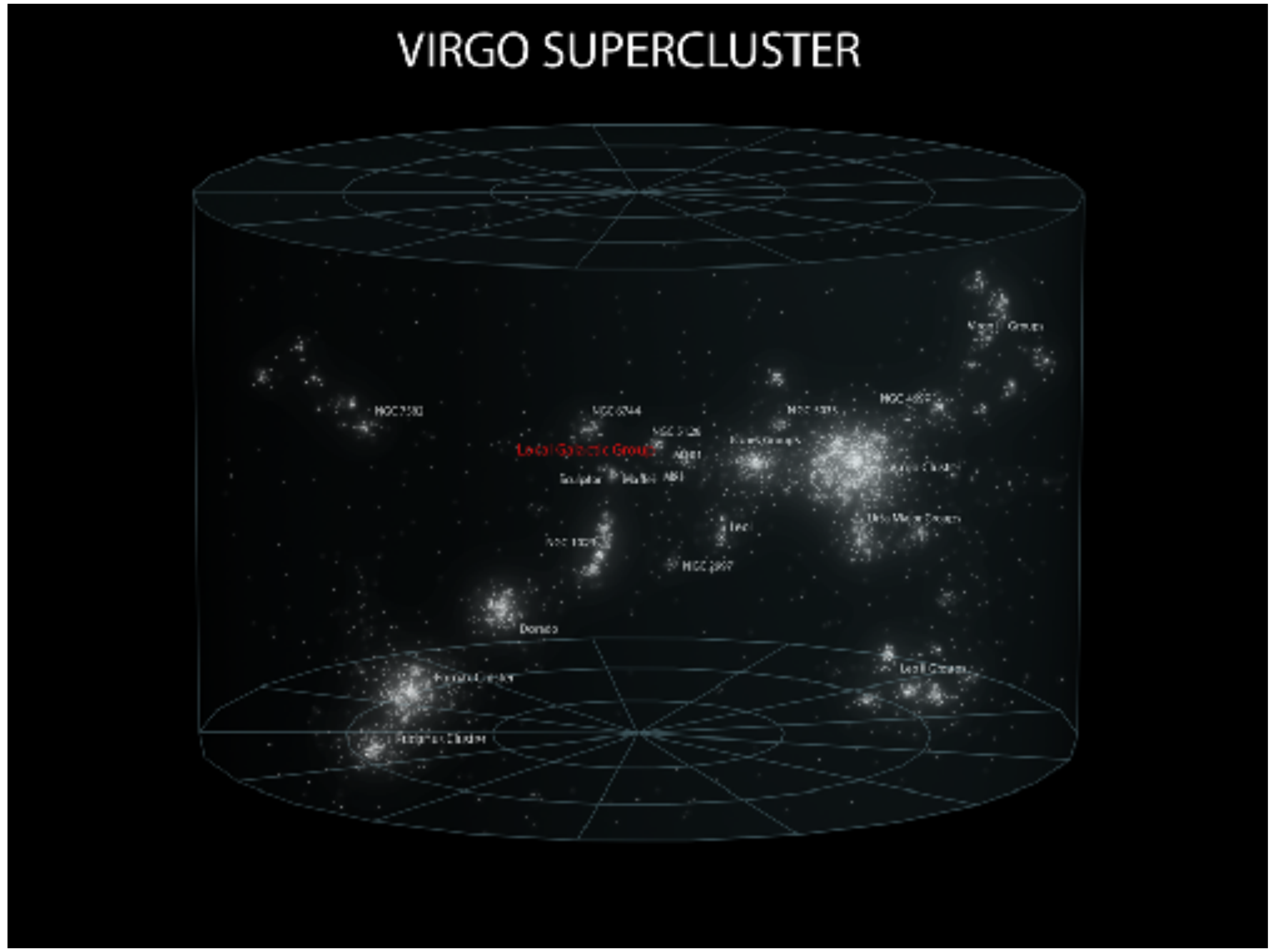
in a gigantic spiral galaxy we call the “Milky Way”

that has a supermassive black hole at its center

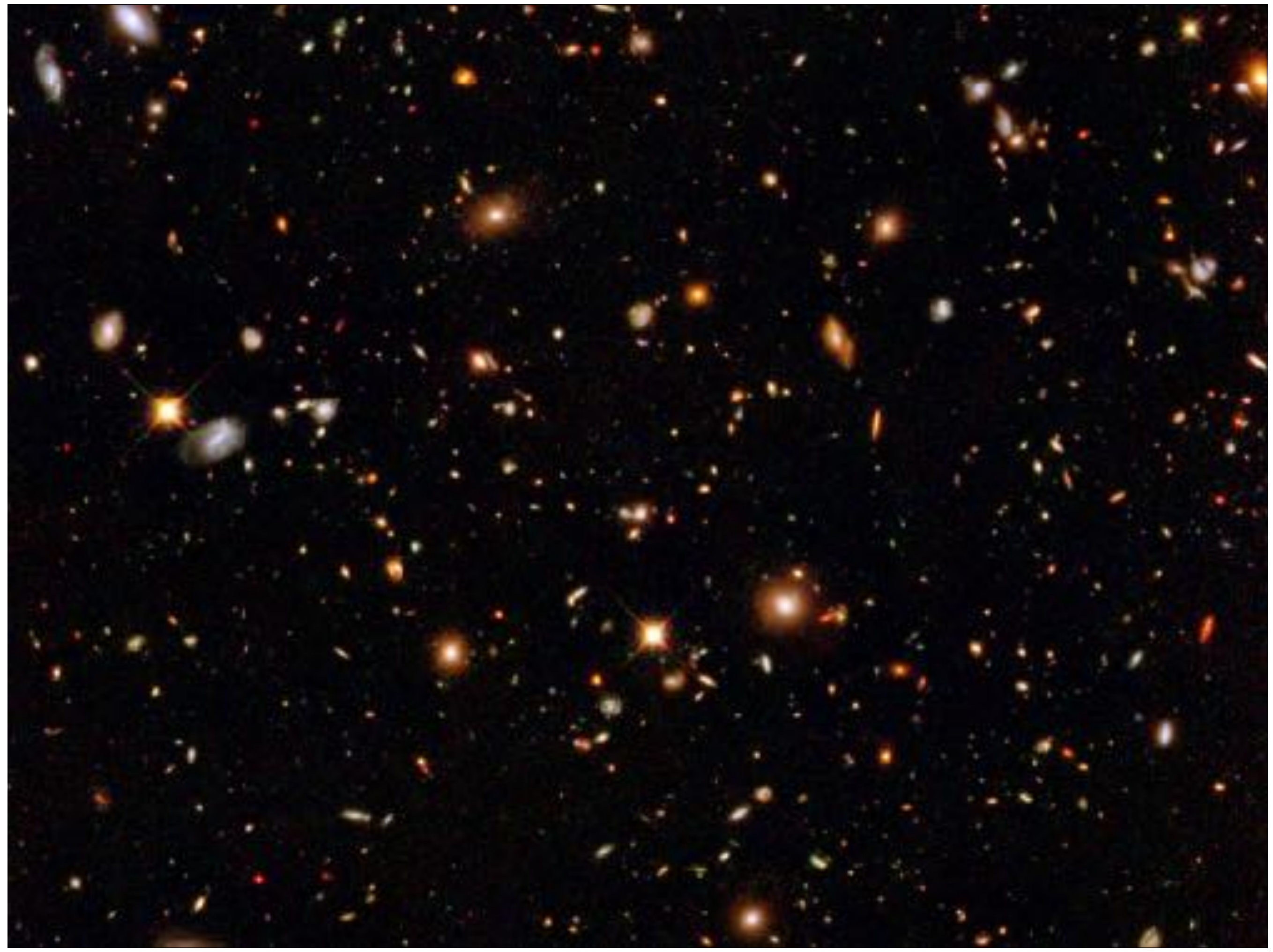
and is surrounded by 150 globular clusters and a halo of dark matter and dwarf galaxies, some of which it’s eating

all of which can be seen by other galaxies in our local group, like Andromeda and Triangulum

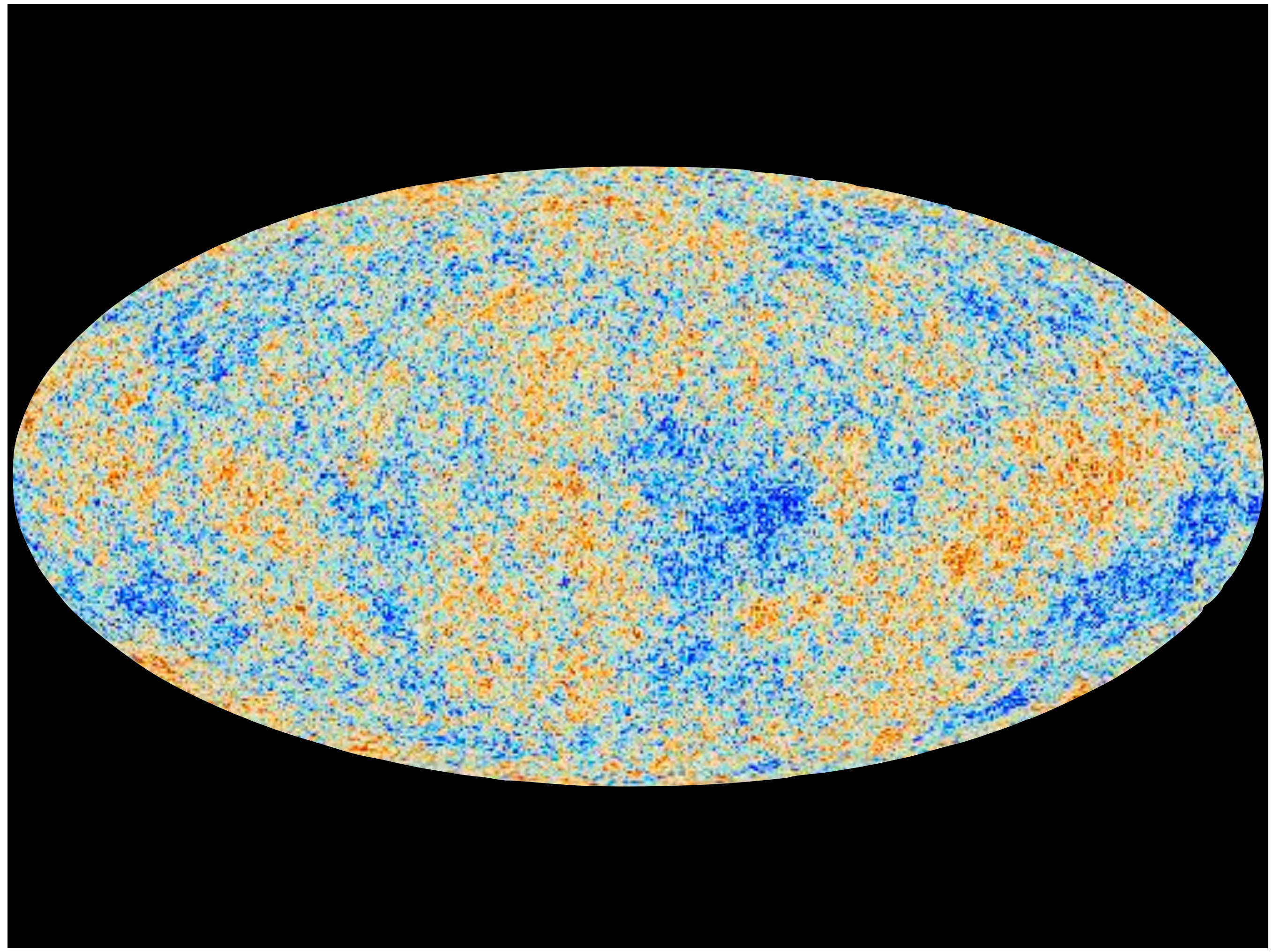
and our group is on the outskirts of the Virgo Galaxy Cluster



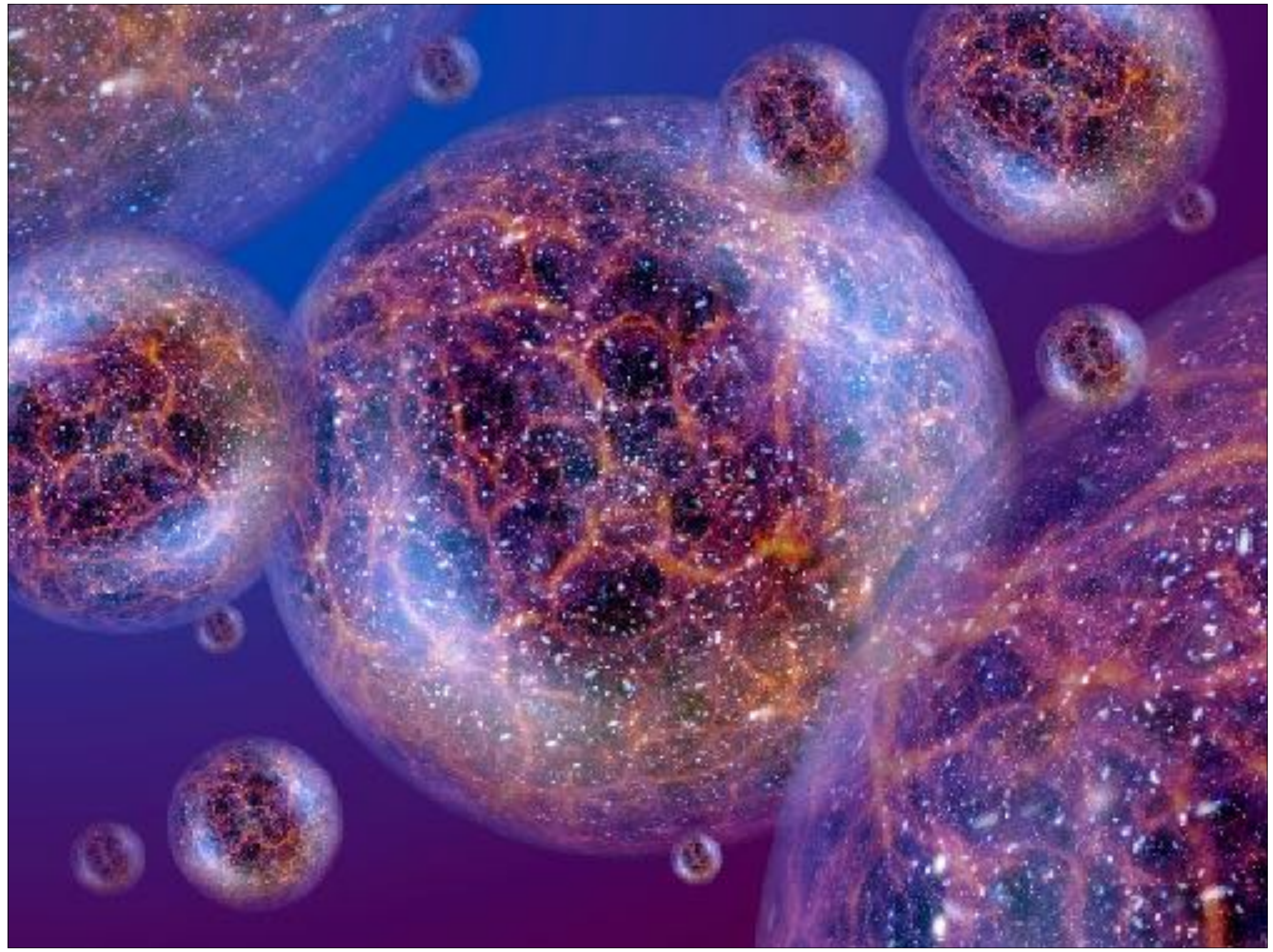

which is part of the Virgo Supercluster



which is just one of many other gigantic structures which stretch most of the way across the Visible Universe

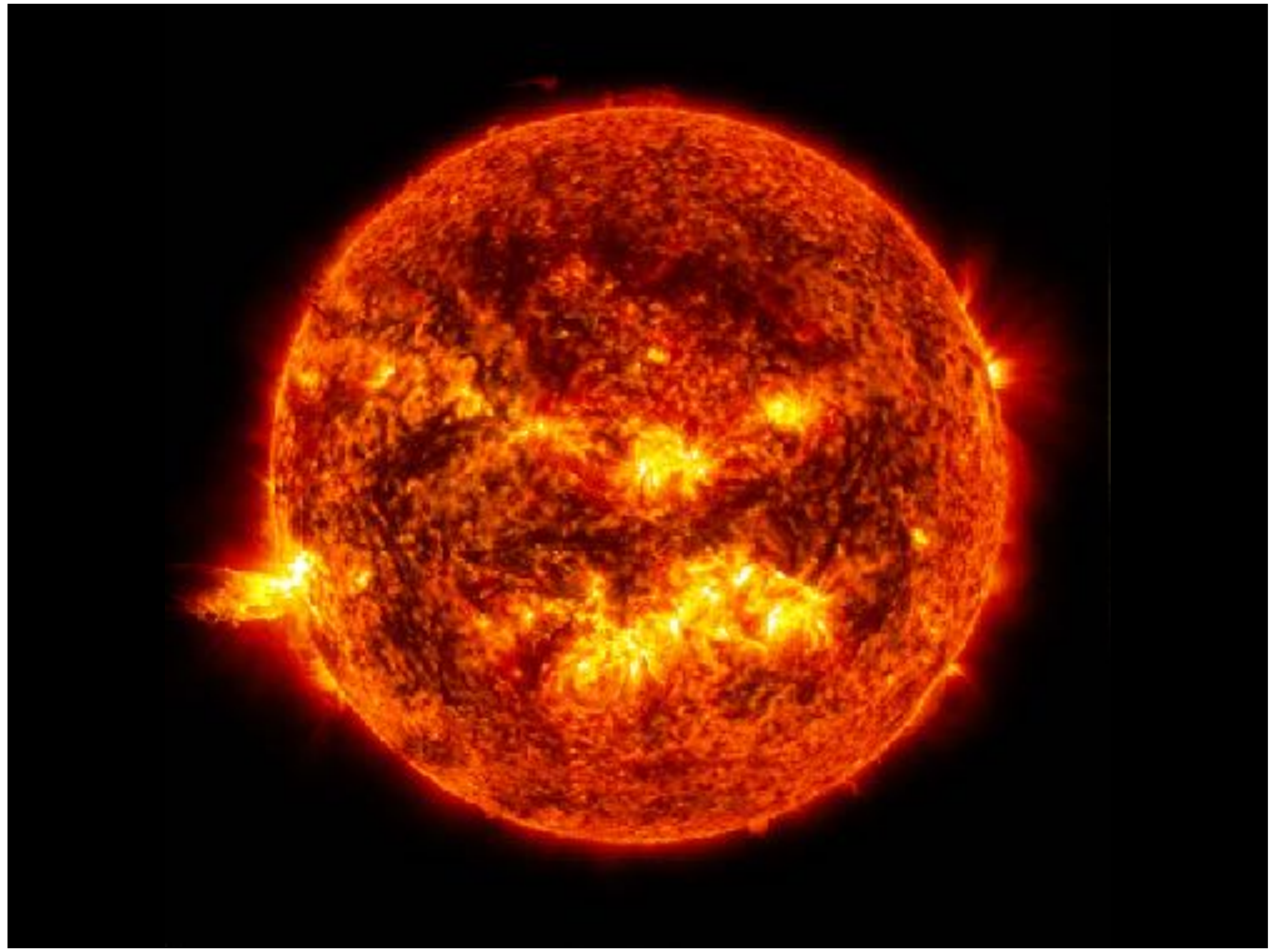


which is 90 billion light years across and expanding everyday, even faster today than yesterday, due to mysterious “dark energy”



and even that might be part of an infinitely larger Multiverse that extends forever in both time and space

*Humans have been looking up at the sky for as long as we've been humans*



Certainly, the ancients noticed the big, glowy ball in the sky and how it lit everything up when it was around, but it got dark when it was gone

The other, fainter glowy thing tried but wasn’t as good at lighting up the night

They probably also noticed that when certain stars appeared in the sky, the weather started getting warm and days longer, and when other stars were seen, the weather would get colder and the days shorter

Once humans settled down, discovered agriculture, and started farming, noticing those patterns in the sky would have an even greater impact. It told them when to plant seeds and when to harvest

The cycles in the sky became pretty important. So important, it wasn’t hard to imagine gods up there looking down us weak and ridiculous humans, interfering with our lives. Surely if the stars tell us when to plant and control the weather, seasons, and the length of the day, they control our very lives, too


Thus, astrology was born

# ASTRONOMY

"LAW OR CULTURE OF THE STARS"

Which is too bad, because it's honestly a better name for the field than "astronomy." But whatever


But a millennia ago, astrology was as close to science as you got. It had some of the flavors of science

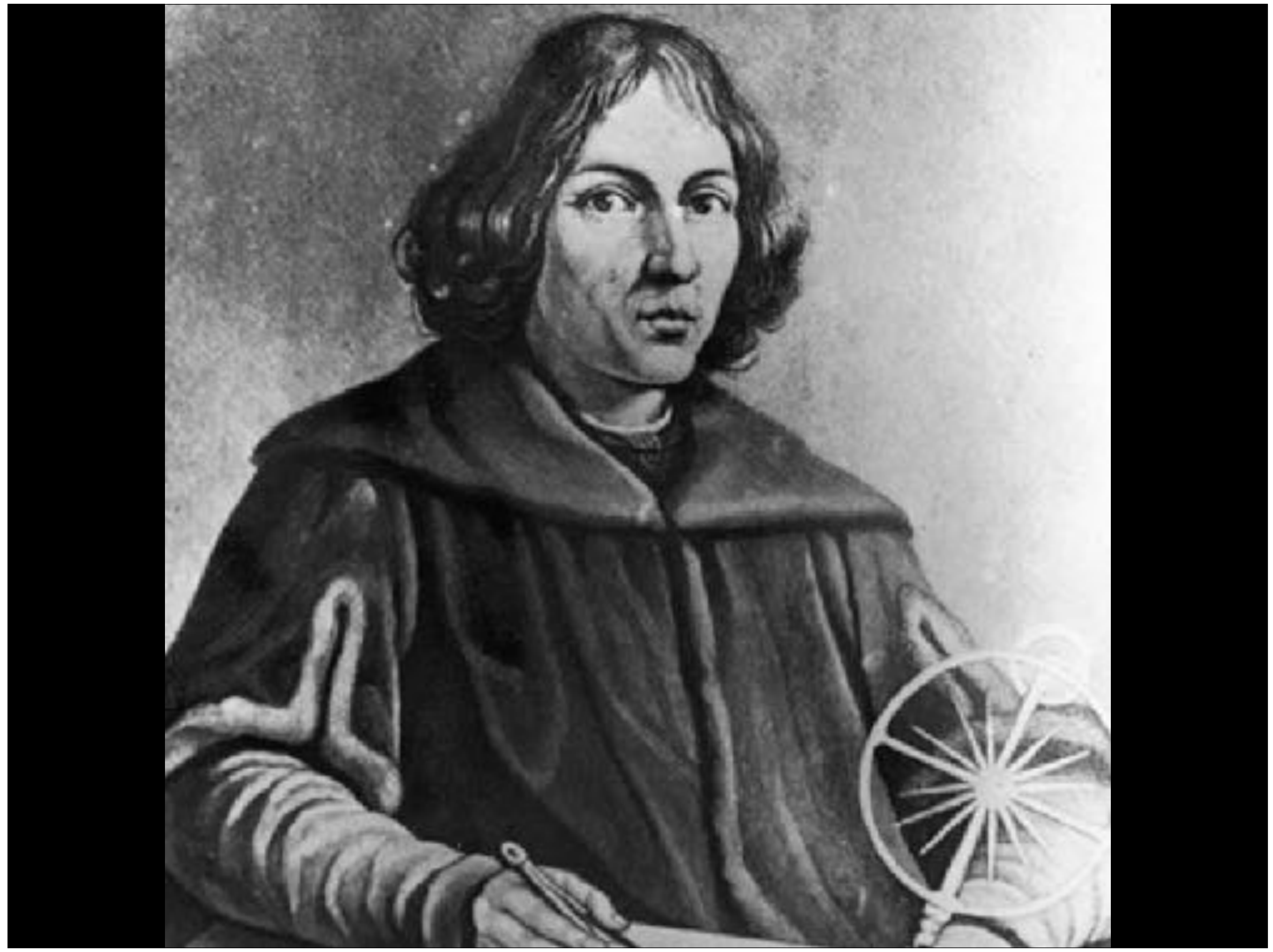
## ASTROLOGERS...

- observed the skies
- and made prediction about how it would effect people
  - then those people would provide evidence for it by swearing it worked

The thing is, it doesn't work, but that's our fault, not the stars. People tend to remember the hits and not the misses (the same logic keeps casinos in business). But astrology did lead people to really study the sky and find the patterns there, which in turn led to a more rigorous understanding of what's going on out there

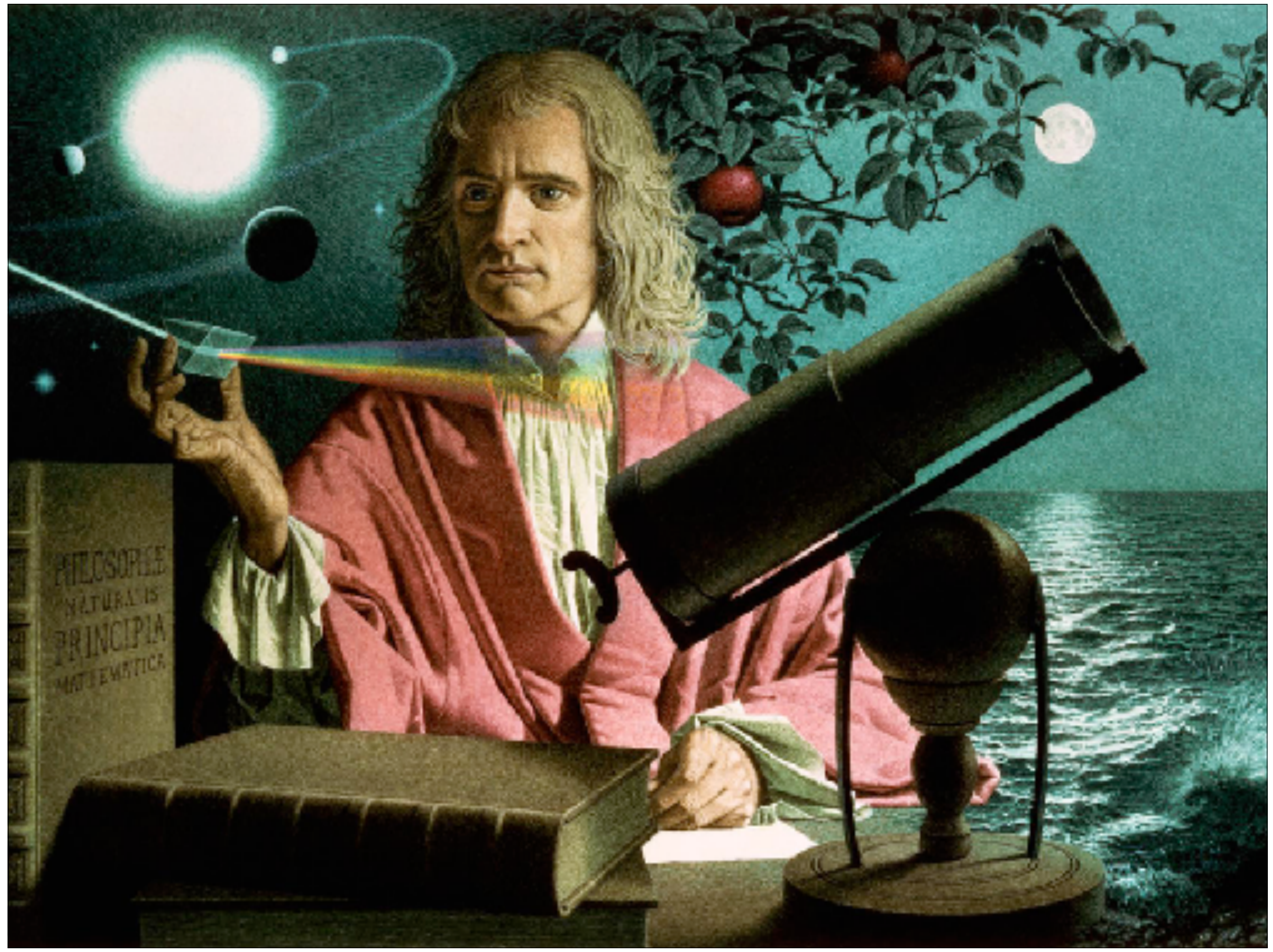
# FIRST MAJOR TURNING POINT:

The geocentric model of the solar system seemed obvious to our ancestors and was endorsed by Ptolemy, Plato, Aristotle, and the major religions at the time

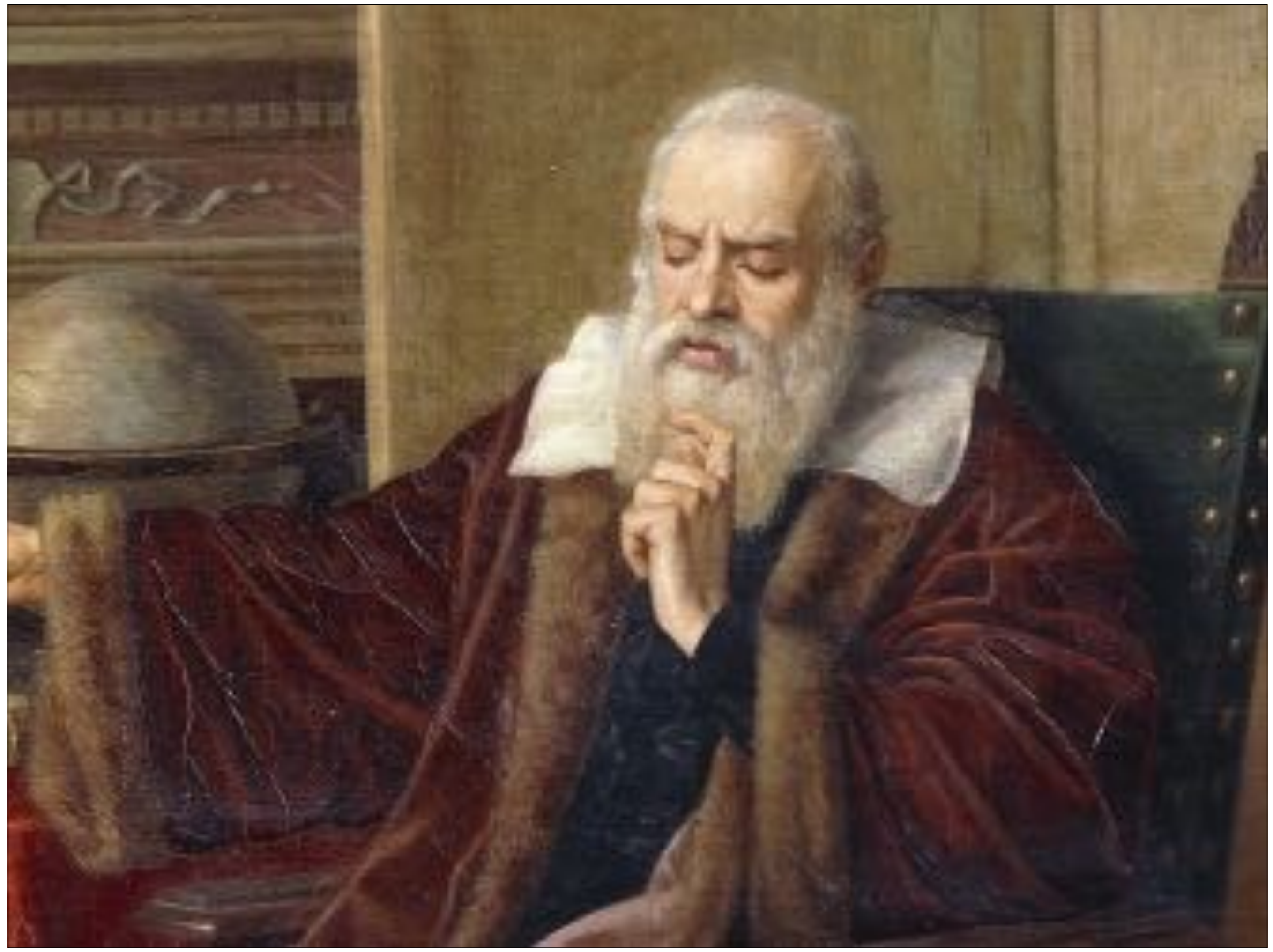


Things changed when Copernicus came up with the idea that the Sun was the center of the solar system, not the Earth

Tycho Brahe and Johannes Kepler improved on that model

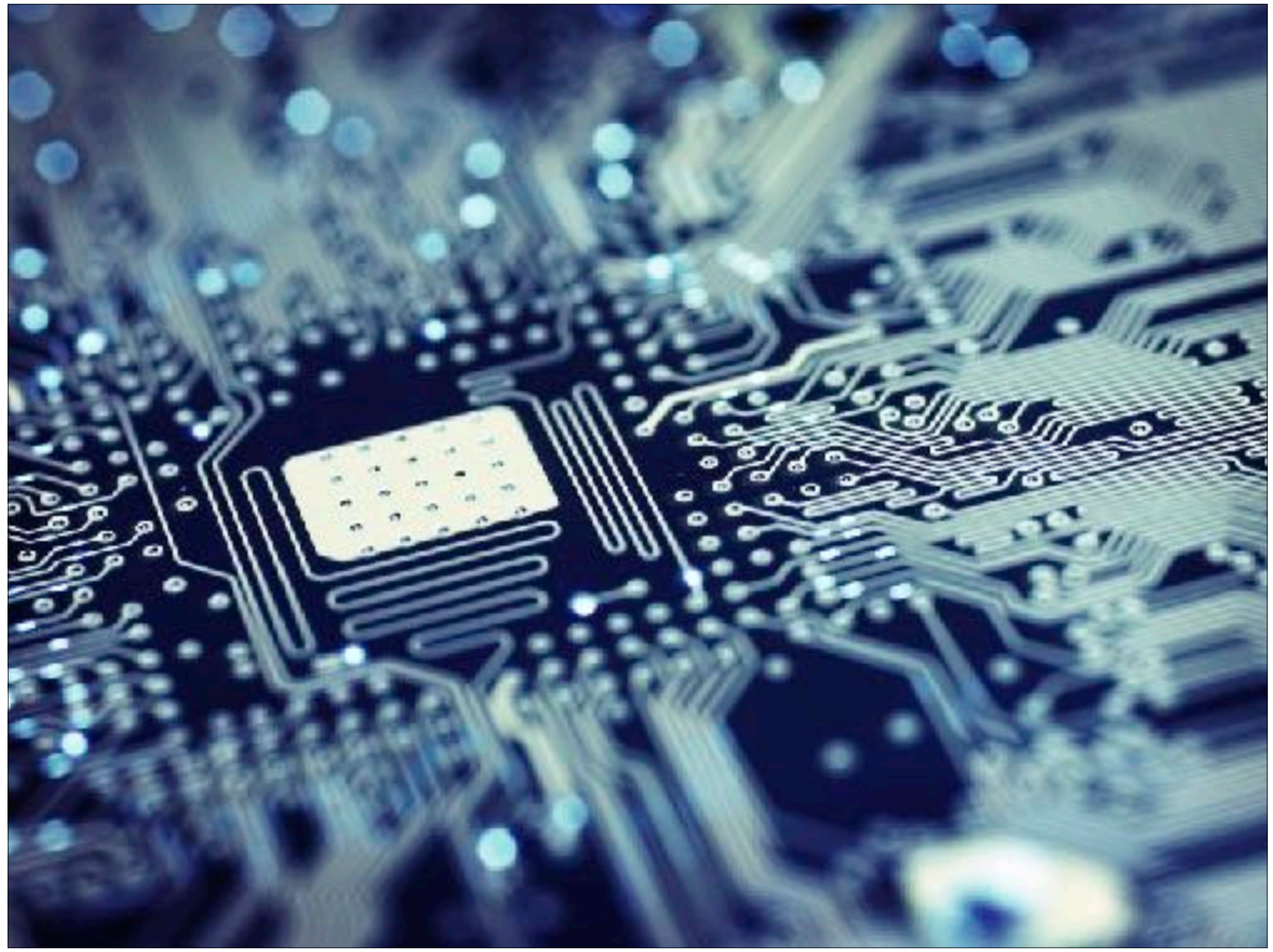



Thanks in large to Isaac Newton, our physics got better, our math got better, and applied mathematics became a revolution in astronomy



Galileo didn’t invent the telescope, but he did make them better. Newton made them even better than that. We’ve run with the idea ever since

Then, about a century ago, came another revolution: photography. We could capture much fainter objects on glass plates sprayed with light-sensitive chemicals, which revealed stars otherwise invisible to us, details in galaxies, beautiful clouds of gas and dust in space



Then, in the later half of the last century, digital detectors were invented, which were even more sensitive than film. We could use computers to directly analyze those observations

Once we attached those instruments to telescopes and launched those telescopes into space (where there’s no atmosphere to blur out observations), we began yet another revolution in astronomy

# WHERE ARE WE NOW?

Well, think on this: the lights in the sky are stars. There are other worlds, and we take the idea of looking for alien life on those worlds seriously, spending billions of dollars to do so. Our galaxy is one of a hundred billion others. We can only directly see ~4% of the Universe. Stars explode, and in doing so create all the elements needed for life. The most common type of stars are too faint to see without a telescope. There is so much out there, and we’ve only just scratched the surface


The earliest astronomy was done based on what we could see with the unaided eye, without telescopes, and that’s how we did astronomy for thousands of years

# NAKED EYE OBSERVATIONS

1. There are a *lot* of a stars
2. They're not all the same brightness
3. 
4. 
5. 
6. 

- Looking at the night sky (on a clear night, far from city lights), what do you notice?
- People with normal vision can see a few thousand stars at any given time. There are about 6-10 thousand stars bright enough to detect by eye alone
- The faintest stars you can see are by far the most abundant. Two reasons for that:
    1. Not all stars are the same intrinsic, physical brightness
    2. The further away a star is, the fainter it appears
  - Fun fact: of the two dozen or so brightest stars in the sky, half are bright because they're close to Earth and half are much farther away but incredibly luminous

Running theme in science: *Some effects you see have more than one cause*

# HIPPARCHUS

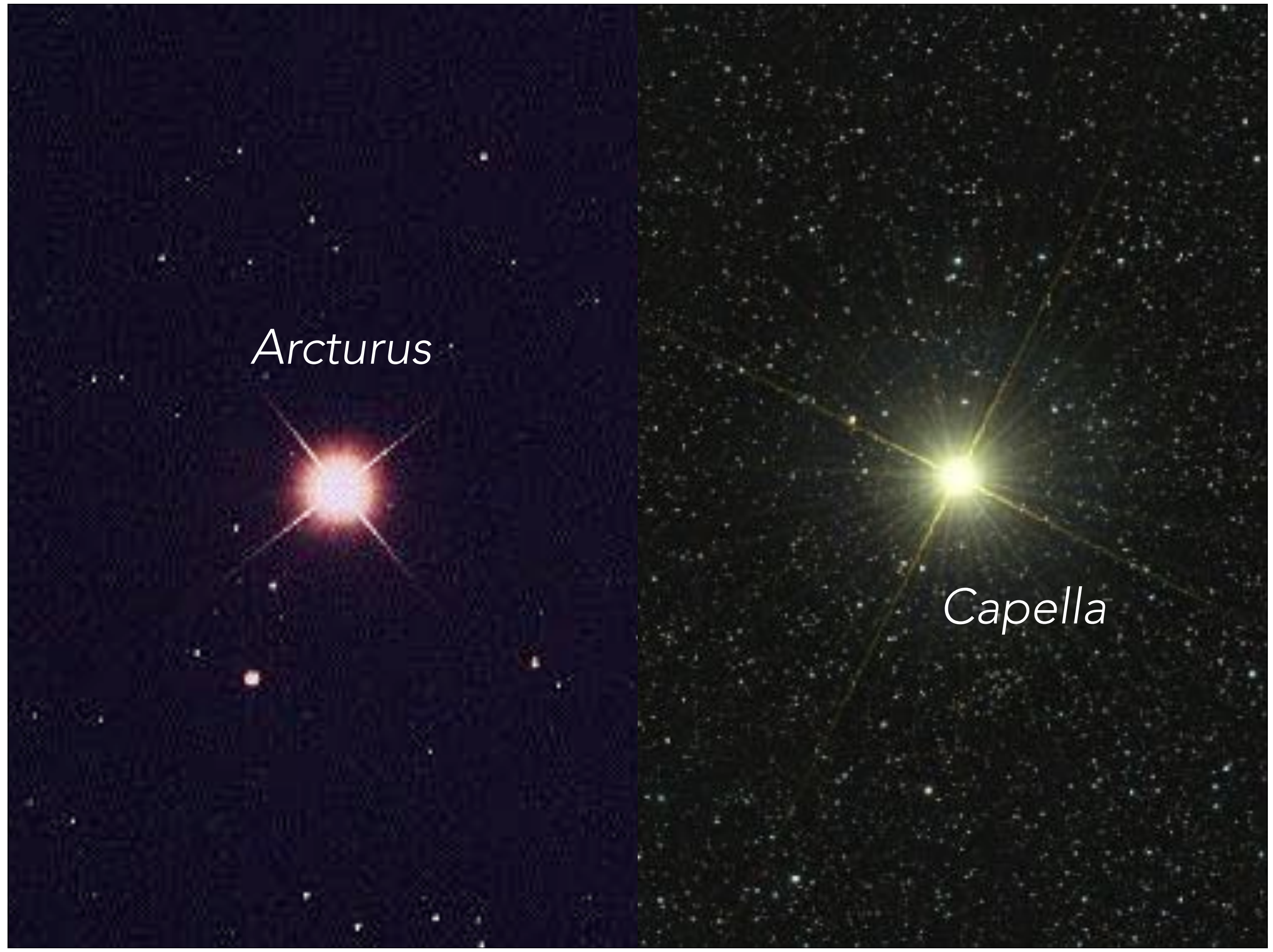
- Greek astronomer who created the first catalogue of stars, ranking them by brightness
- Came up with a system called ***magnitudes***
  - Brightest stars are first magnitude; higher magnitude = fainter stars

We still use a variation of this system today. The faintest stars ever seen, using Hubble Space Telescope, are magnitude 31. The faintest stars you can see with your eyes are about 10 billion times brighter


The brightest star in the night sky, Sirius, the Dog Star, is about 1,000 times brighter than the faintest star you can see


Take a closer look at some of those bright stars. Here’s Vega. Notice anything? It’s blue!


Betelgeuse is red




- Arcturus is orange and Capella is yellow
- Those stars really are those colors. By eye, only the brightest stars seem to have color, while the fainter ones just look white, but that's because the cones in your eyes (which detect color) only activate under bright light

# NAKED EYE OBSERVATIONS

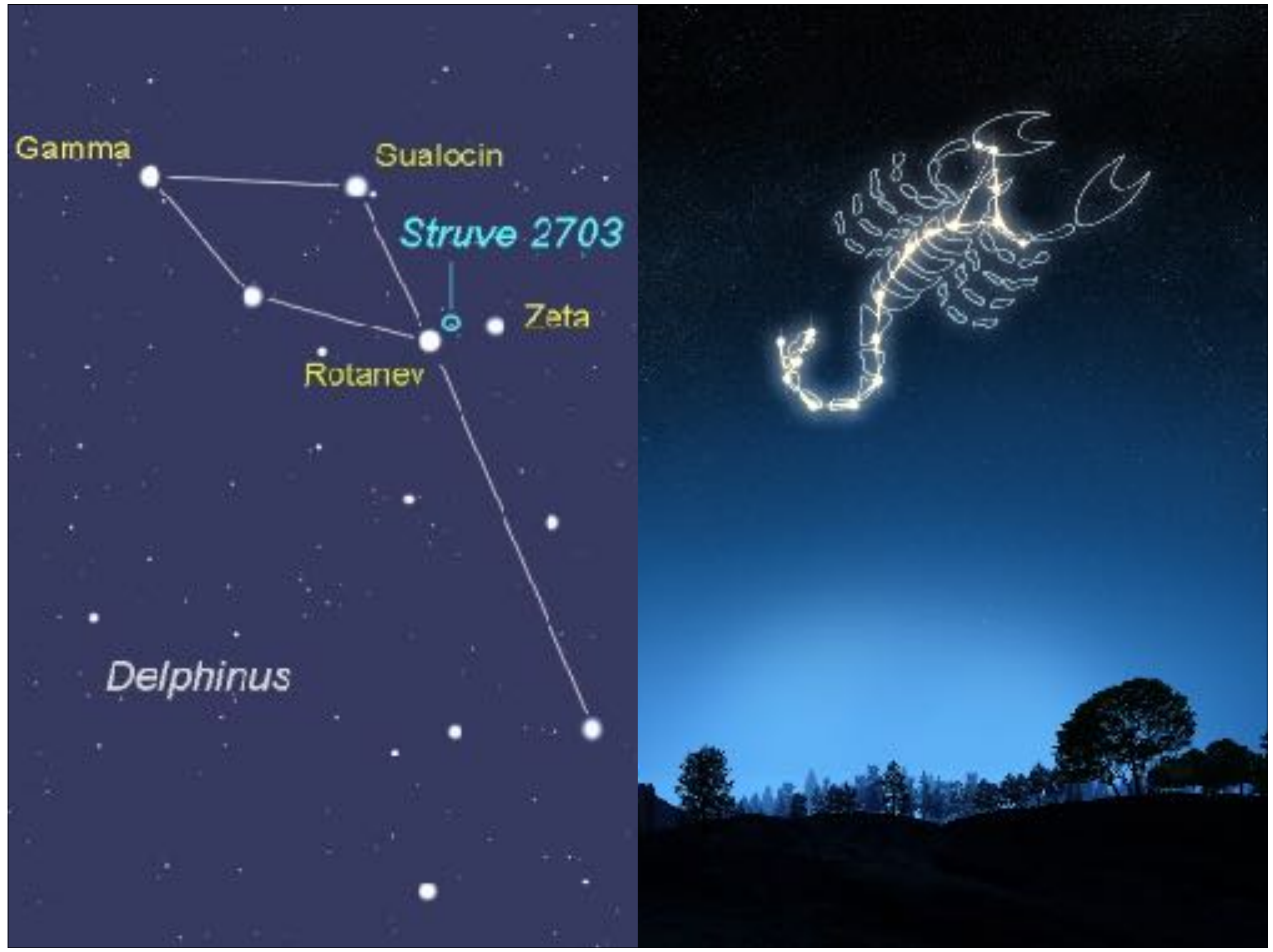
1. There are a *lot* of a stars
2. They're not all the same brightness
3. They're different colors
4. They aren't scattered evenly across the sky
5. 
6. 

Stars form patterns — shapes across the sky. This is mostly coincidence, but we humans sure do love patterns. Thus, ancient astronomers divided the skies up into constellations (lit. "sets or groups of stars") and named them after familiar objects

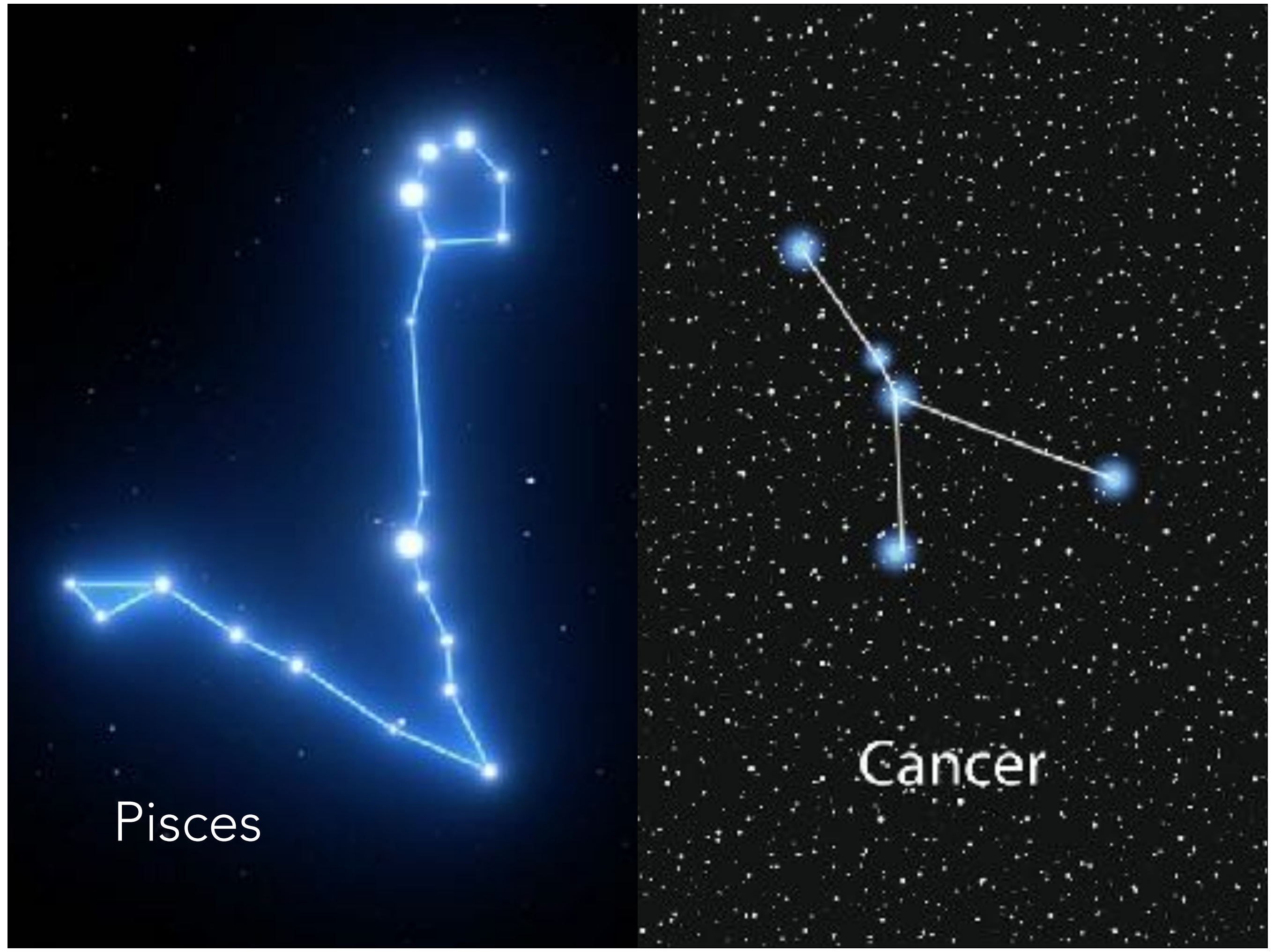
THE HUNTER

# ORION

Orion is probably the most famous constellation. It’s pretty easy to see as a person, arms raised up, and most civilizations saw it that way

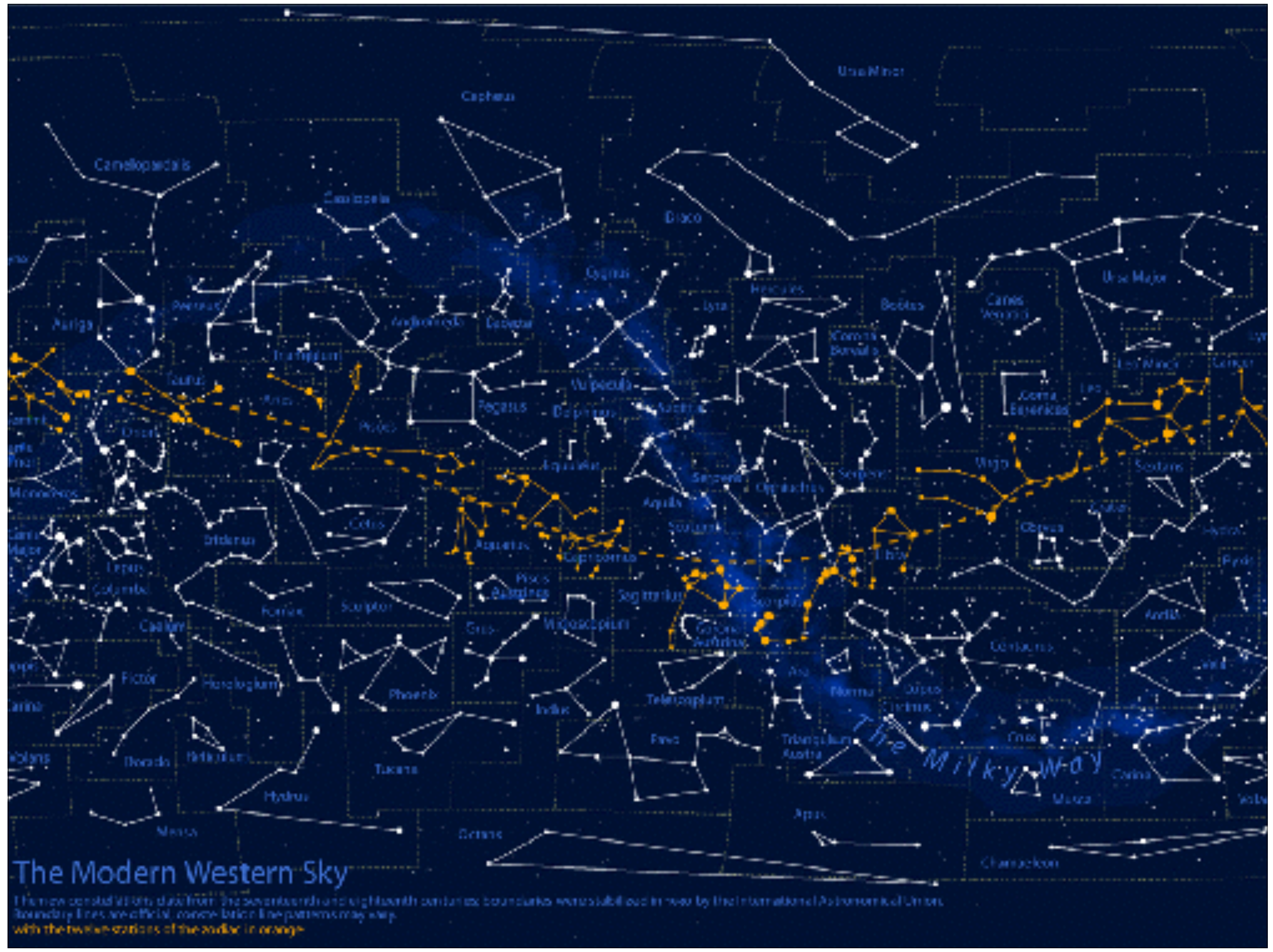



Tiny Delphinus isn’t hard to see as a dolphin leaping from the water, and it’s not a stretch to see Scorpius as a scorpion




Apparently Pisces is a fish and Cancer is a crab, but I don’t buy it

Today, we recognize 88 official constellations, and their boundaries are carefully delineated on the sky




Astronomers use constellations to identify different regions in the sky. It’s a lot like dividing a country up into states. The boundaries are decided upon by mutual agreement, and just like how identifying what state a city is in helps locate that city, identifying which constellation a star is around help locate that star

## ABD AL-RAHMAN AL-SUFI

- Translated ancient Greek astronomy texts into Arabic, and the names he gave to the stars have stuck with us ever since

Most of the brightest stars have proper names, mostly Arabic.

# STAR NAMES

- Stars in constellations are assigned Greek letters based on their brightness
  - E.g. α-Orionis is the brightest star in Orion, β-Orionis is the second brightest, etc.
- Most stars in general, however, are simply assigned a number

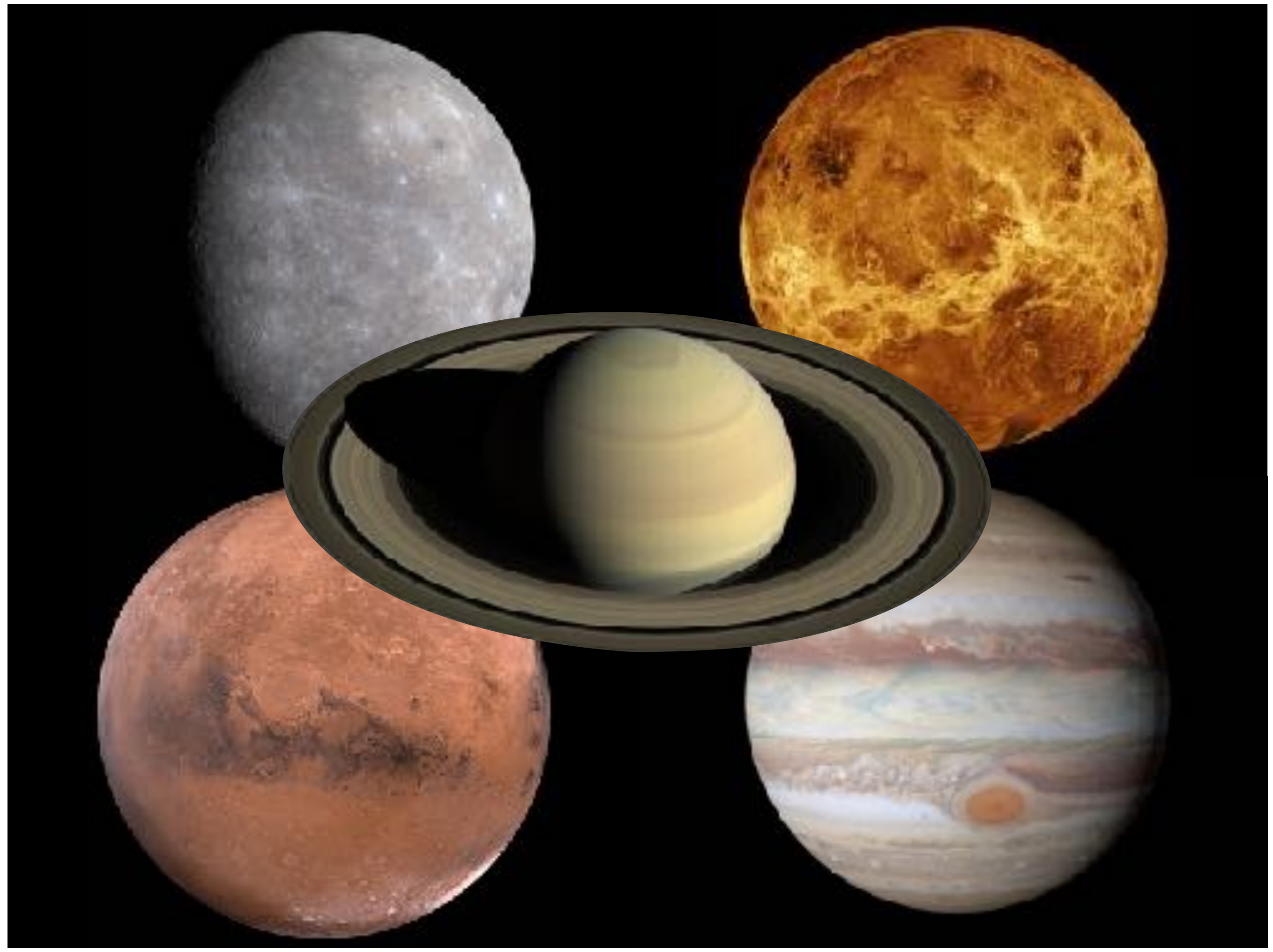
# NAKED EYE OBSERVATIONS

1. There are a *lot* of a stars
2. They're not all the same brightness
3. They're different colors
4. They aren't scattered evenly across the sky
5. Not all "stars" twinkle
6.

Looking at the night sky, you might notice that a couple of the brightest "stars" don't twinkle. That's because they aren't stars — they're planets

Twinkling happens because the air over our heads is turbulent, and as it blows past, it distorts the incoming light from stars, making them appear to slightly shift position and brightness several times per second

But the planets are much closer, they appear bigger, and the distortion doesn’t affect them as much



There are 5 naked eye planets, not counting Earth: Mercury, Venus, Mars, Jupiter, and Saturn. Uranus is *just* too far away to see. Venus is actually the third brightest thing in the sky, after the Sun and Moon

# NAKED EYE OBSERVATIONS

1. There are a *lot* of a stars
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3. They're different colors
4. They aren't scattered evenly across the sky
5. Not all "stars" twinkle
6. The stars appear to move over time

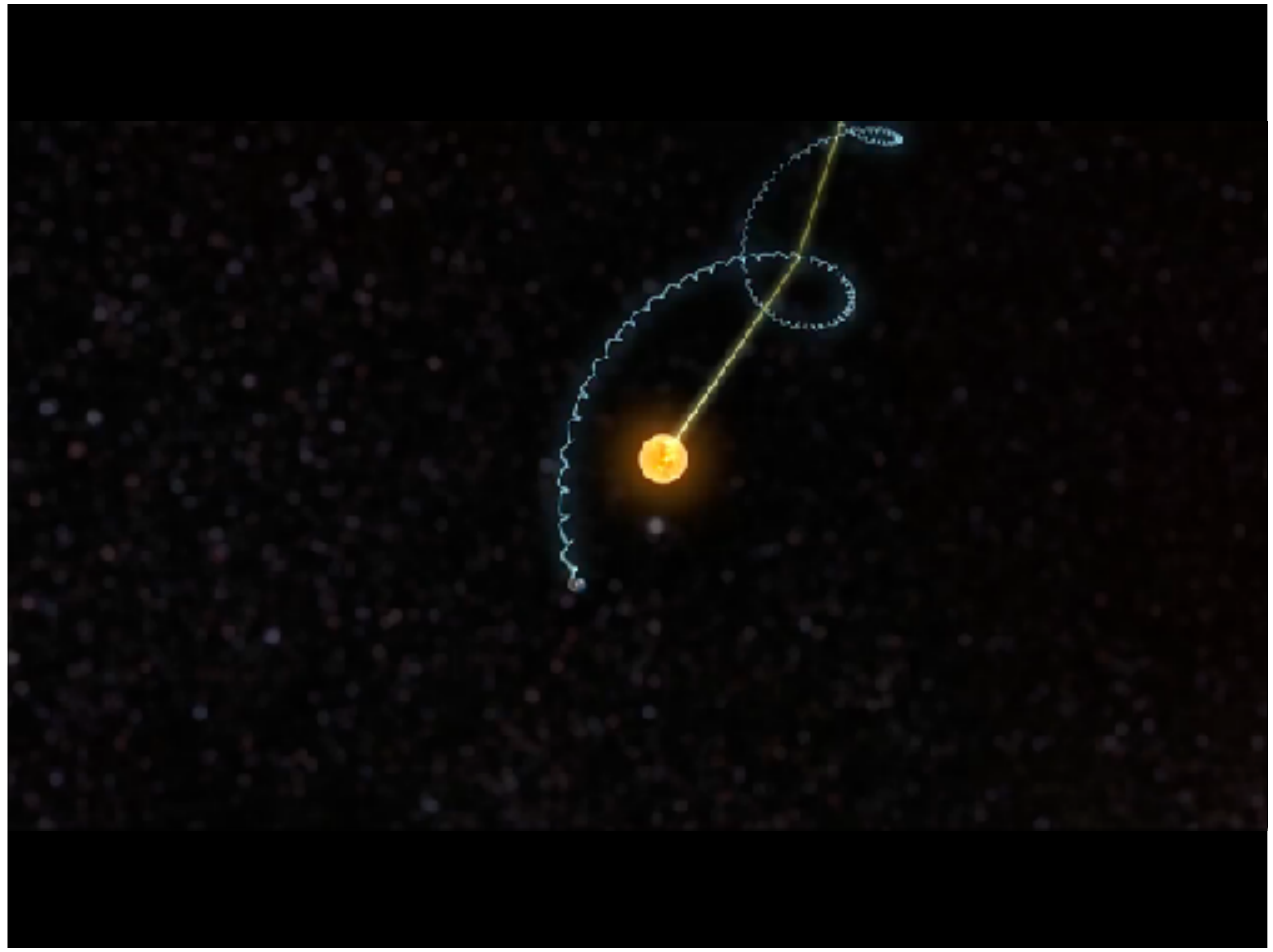
- If you stay outside for an hour or two, you'll probably notice that the stars move, like the sky is a gigantic sphere wheeling around you over the course of the night
- Pay closer attention, and you'll notice that stars rise in the East, set in the West, and take about 24 hours before returning to their original positions, making a big circle over the course of the night and (presumably) day


- This apparent movement is really just a reflection of Earth spinning. The Earth rotates once per day, and we're stuck to it, so it looks like the sky is spinning around us in the opposite direction
- Everyday, you make a circle around Earth's axis of rotation. The closer you are to the equator, the larger that circle. Stand on the North or South Pole, however, and you don't make a circle at all — you just spin in place
- it's the same with the sky. As the sky spins over us, it has two poles and an equator. Stars near the celestial equator appears to make a big circle across the sky, while a star on a pole wouldn't appear to move at all

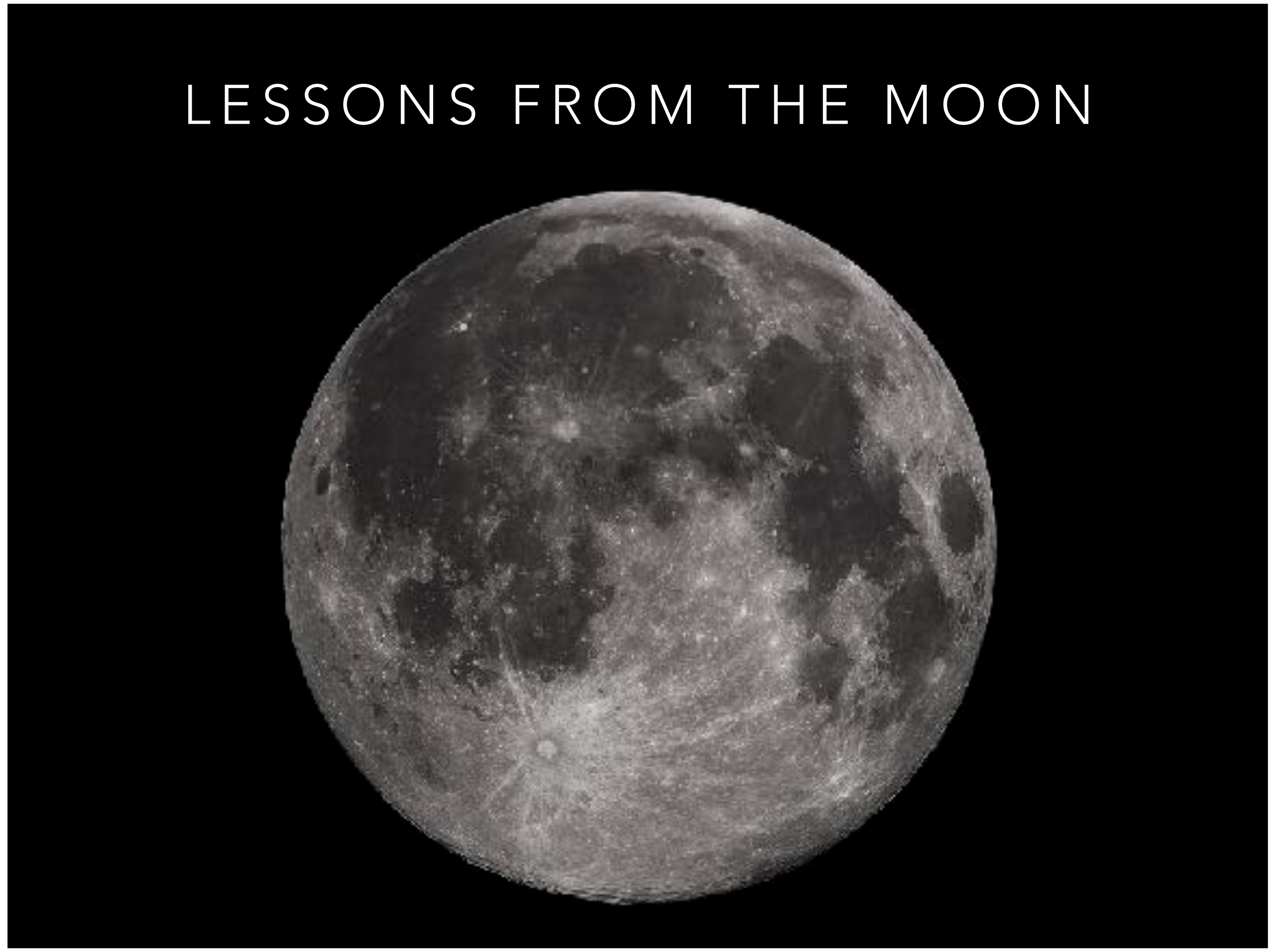
Photographic time exposures show it best. Stars in the photo look like streaks. The longer the exposure, the longer the streak as the stars rise and set making their circular arcs in the sky. You can see stars near the celestial equator making their big circles, and by coincidence, there happens to be a fairly bright star almost perfectly on the north celestial pole: Polaris, the North Star. It’s just coincidence. There is no South Star

Remember, the sky's motion is a reflection of the Earth's motion

- If you stand on the North Pole, Polaris will directly overhead, and stars on the celestial equator would appear to circle the horizon once per day
- That also means that stars south of the celestial equator can't be seen from Earth's North Pole; they're always below the horizon
    - From Antarctica, Polaris is forever hidden from view, but stand on the Equator and eventual you'll see every star in the sky



*How Earth Moves* (20 min) — VSauce
https://www.youtube.com/watch?v=IJhgZBn-LHg




Each student gets a Styrofoam ball on a stick to represent the Moon. A desk lamp at the front of the class represents the Sun. The student's head will represent Earth

## PHASES OF THE MOON

1. Stand facing the Sun (lamp) at “noon” with the Moon between the Earth (you) and the Sun. What do you see?

New Moon


NEW MOON

## PHASES OF THE MOON

2. Stand at “midnight” with the Moon on the on the far side of the Sun. Raise the Moon above your head. What do you see now?

Full Moon


FULL MOON

## PHASES OF THE MOON

3. Face noon and this time move the Moon a bit to the left. What do you see?

    - On what side of the Moon is the crescent?

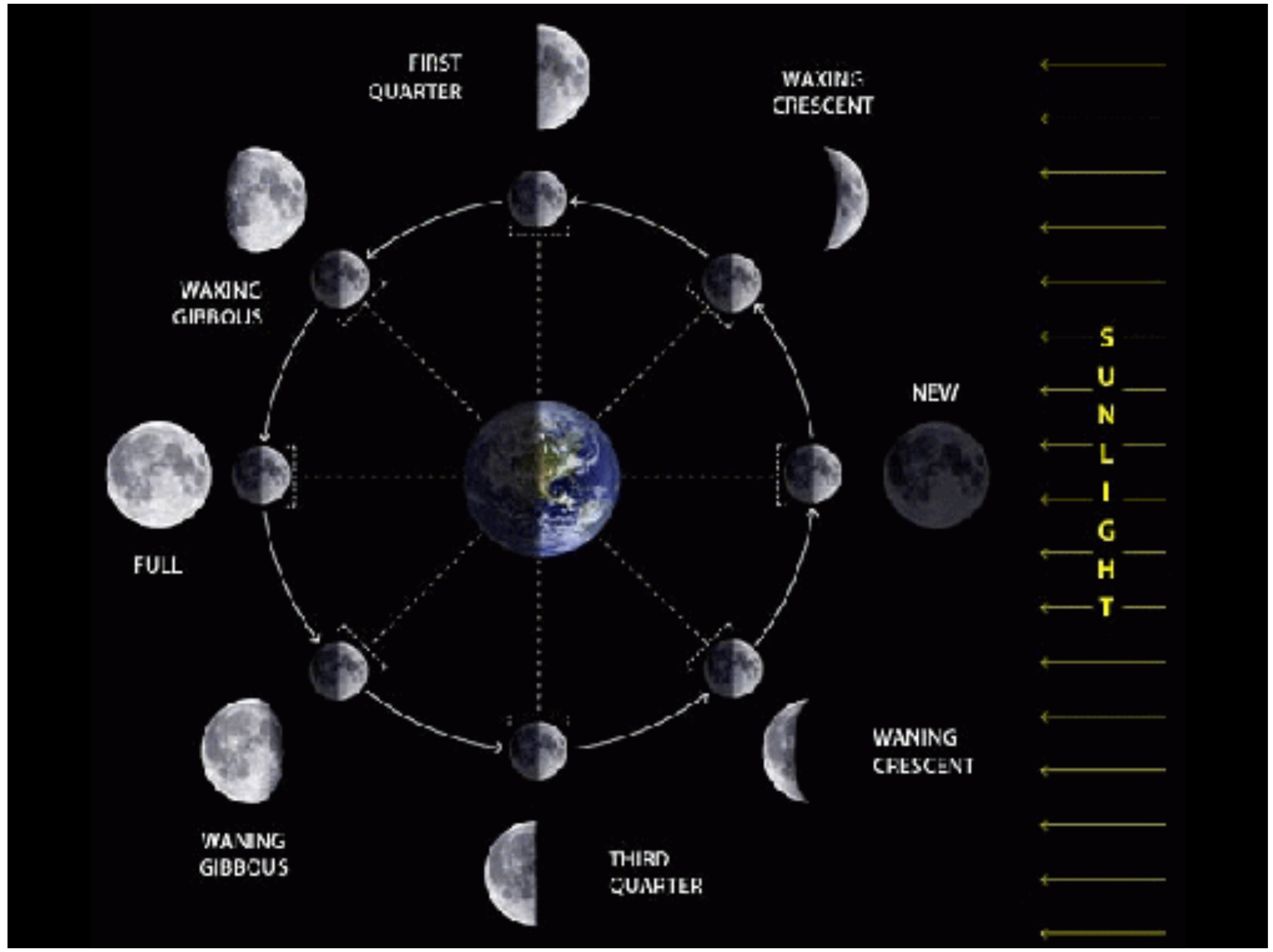
Waxing Crescent Moon; right side


WAXING
CRESCENT
MOON

## PHASES OF THE MOON

4. Continue moving the Moon leftward to first quarter, waxing gibbous, full, waning gibbous, third quarter, and back to new. What's the difference between waxing and waning? What's the difference between first and third quarter?

Waxing = getting bigger, waning = getting smaller; waxing crescent, first quarter, and waxing gibbous are all lit on the right side of the Moon, while waning gibbous, third quarter, and waning crescent and lit on the left (either way, whichever side points toward the Sun is lit)


FIRST QUARTER
WAXING CRESCENT
WAXING GIBBOUS
NEW
FULL
SUNLIGHT
WANING CRESCENT
WANING GIBBOUS
THIRD QUARTER

## PHASES OF THE MOON

5. Roughly what time of day does the New Moon rise? Full Moon?

Sunrise and sunset, respectively

## PHASES OF THE MOON

6. Roughly what time of day do First and Third Quarter Moons rise?

Noon and midnight, respectively

## PHASES OF THE MOON

7. What percentage of the time is the Moon up during the day?

50%

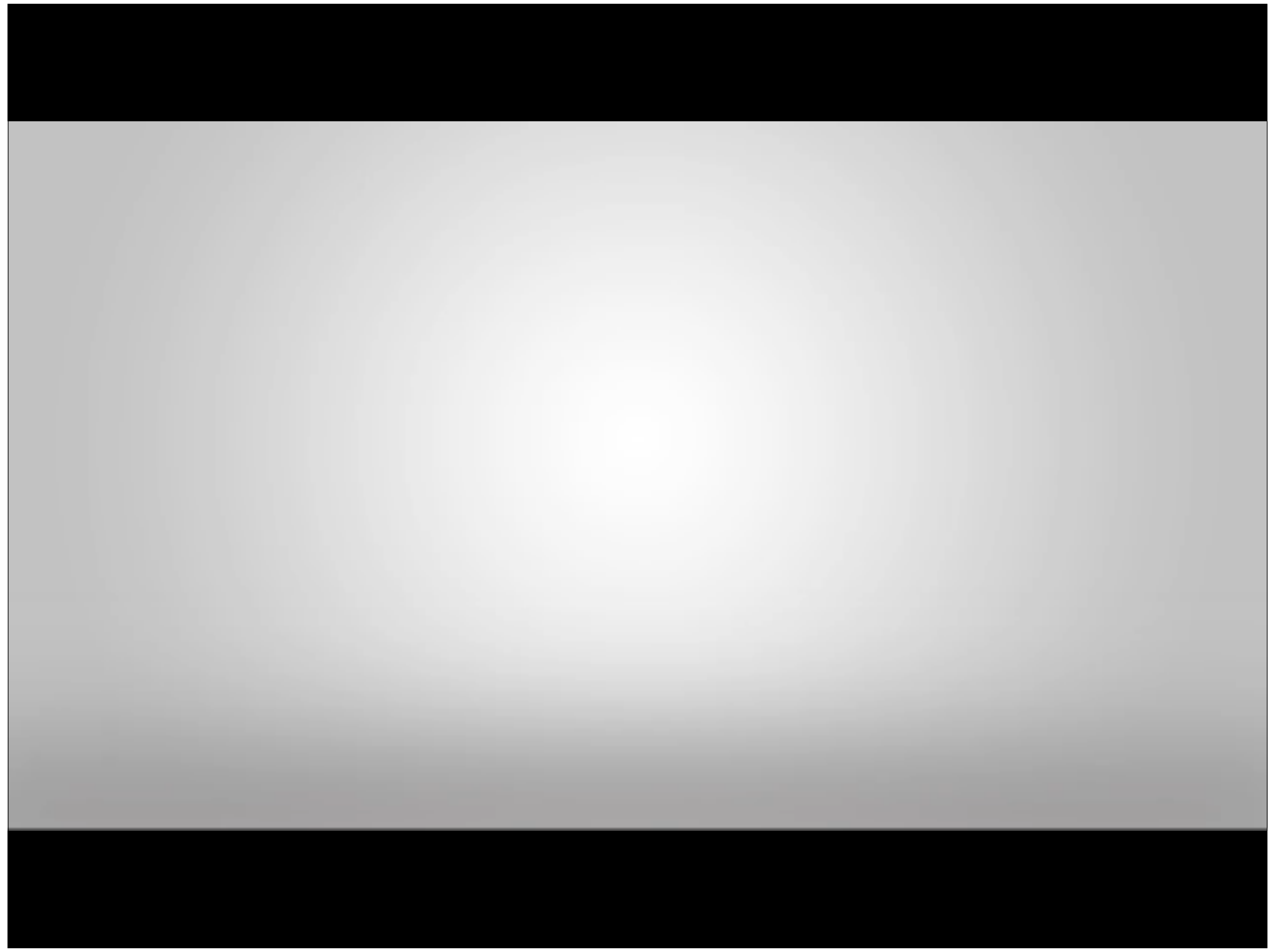
| DAY OF CYCLE | PHASE | RISE (APPROX.) | HIGH IN THE SKY (APPROX.) | SET (APPROX.) |
|---|---|---|---|---|
| 0 | New Moon | sunrise | noon | sunset |
| 3.7 | Waxing Crescent | ~9 AM | ~3 PM | ~9 PM |
| 7.4 | First Quarter | noon | sunset | midnight |
| 11 | Waxing Gibbous | ~3 PM | ~9 PM | ~3 AM |
| 14.7 | Full Moon | sunset | midnight | sunrise |
| 18.4 | Waning Gibbous | ~9 PM | ~3 AM | ~9 AM |
| 22 | Third Quarter | midnight | sunrise | noon |
| 25.7 | Waning Crescent | ~3 AM | ~9 AM | ~ 3 PM |
| 29.5 | New Moon | sunrise | noon | sunset |

## PHASES OF THE MOON

8. Do all people on Earth see the same phase of the Moon on any given day?
9. Do the people in the southern hemisphere see the same phase of the Moon as in the northern hemisphere?

Yes; yes, but upside-down


Northern Hemisphere
Southern Hemisphere



Eclipses: Crash Course Astronomy (10 min)
https://www.youtube.com/watch?v=PRgua7xceDA&t=302s

# ECLIPSES

1. What phase is the Moon in during a solar eclipse? During a lunar eclipse?

2. How many people on Earth can see a total solar eclipse? How many can see a total lunar eclipse?

3. Why don’t we have solar and lunar eclipses every month?

The following pictures were taken by my friend during our trip to see the 2017 Great American Eclipse

*Almost* totality

Totality

Bailey’s Beads

The Diamond Ring

# TELESCOPES

*The purpose of a telescope is to make things easier to see: to make the invisible visible, and to make things already visible visible more clearly*

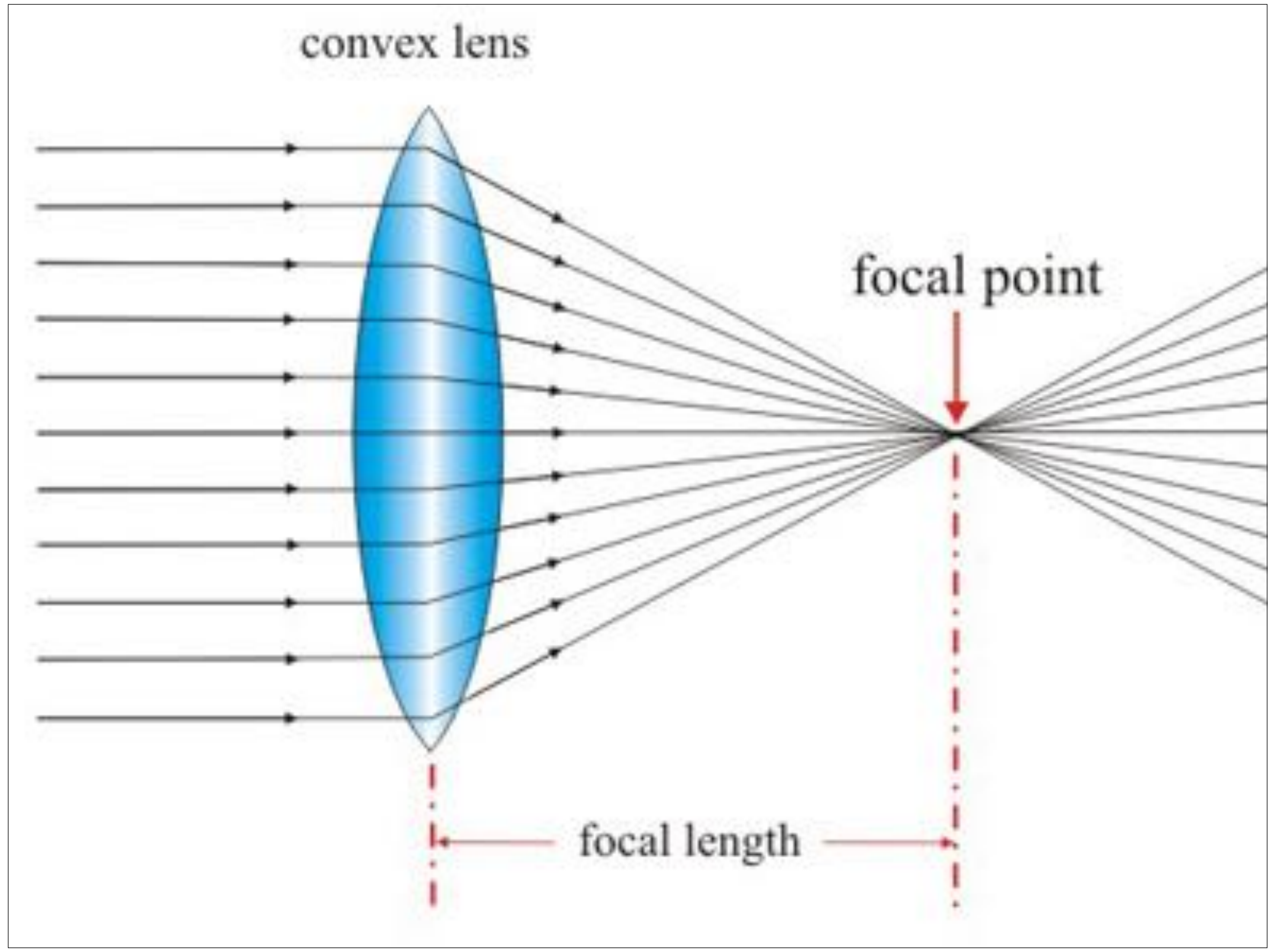
- While Galileo didn’t invent the telescope, he was an early adopter and made many of his most famous observations using them. When he built one in 1609, he could, for the first time, see craters on the Moon and that the Milky Way is made of stars
- Telescopes are marketed as devices for magnifying small or distant objects, and while that’s true, the definition above is true more generally

A telescope works by gathering light. Think of it like a bucket in the rain. The bigger the bucket, the more water you collect. Get a big enough bucket, and you'll collect plenty of water even if it's only sprinkling out

*Objective* — lens or mirror used by a telescope for collecting light

In the case of a telescope, the “bucket” is a lens or mirror for collecting light, called the “objective.” The bigger the objective, the more light it collects. The more light we can collect from an object, the better we can see it

Your eyes are also “light buckets” but they only collect light through your pupils which, at best, are less than a centimeter across




A telescope acts like a light bucket with a funnel at the bottom. All that light collected, concentrated, and focused into your eye

The amount of light a telescope collects depends on the area of the objective

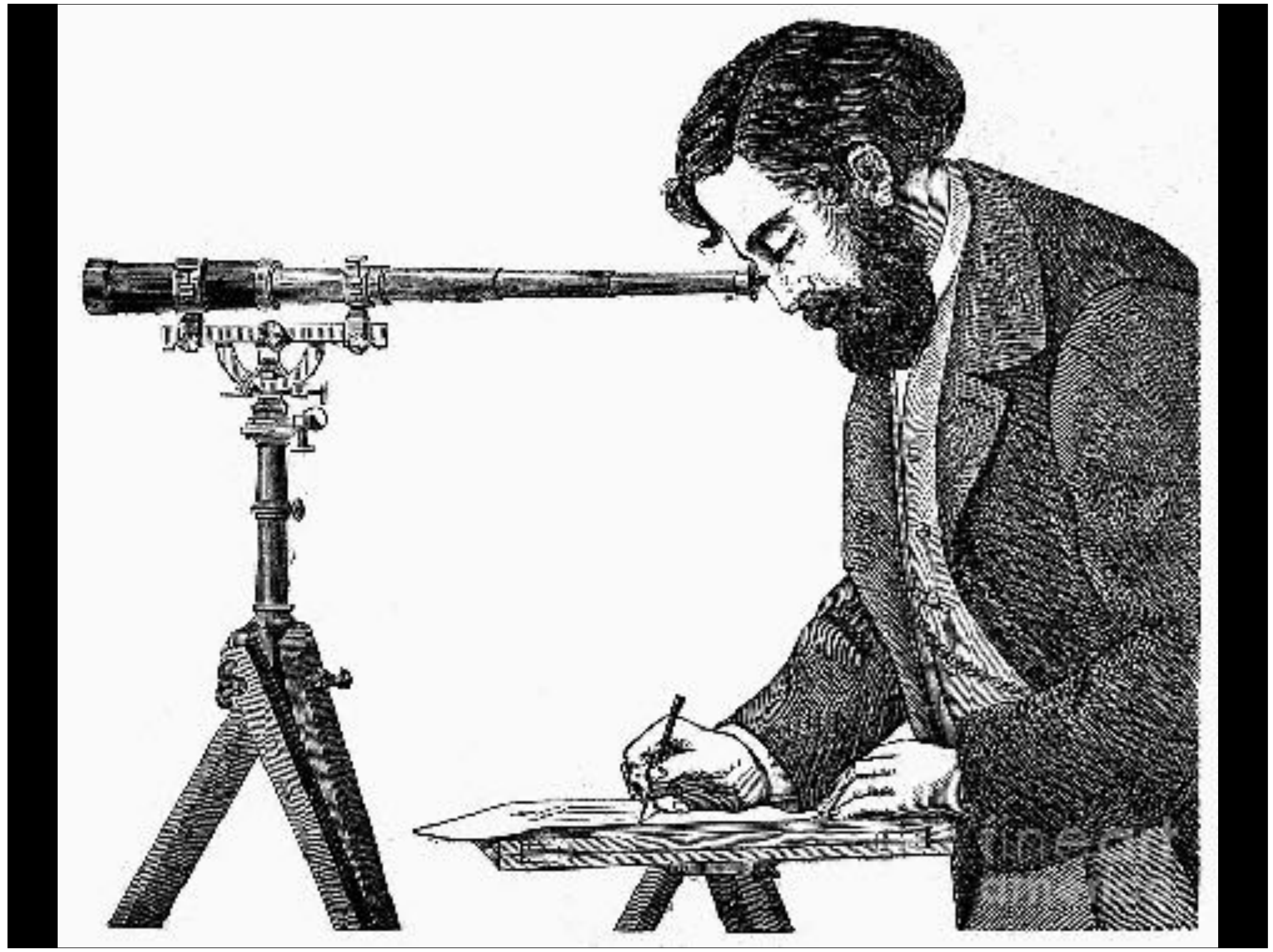
Double the diameter of the collector and you collect 4x as much light. Make it 10x bigger, you collect 100x the light, etc. So a telescope with a lens even just a few centimeters across can easily reveal stars invisible with the naked eye

Telescopes work primarily by changing the direction of light

When you look at a star, you can see it because light from that star is sent into your eye. But most of the light misses your eye, falling to the ground all around you. The telescope collects that, bounces it around, and channels it into your eye

# REFRACTION

One way to change the direction of light is through refraction



A lens bends light in a cone shape, like a light funnel. There’s a couple interesting consequences of this…

Light from the top of distant objects gets bent down and light from the bottom gets bent up, so the the image looks upside-down. Left and right are also flipped

The lens can also magnify the image

# ADVANTAGES

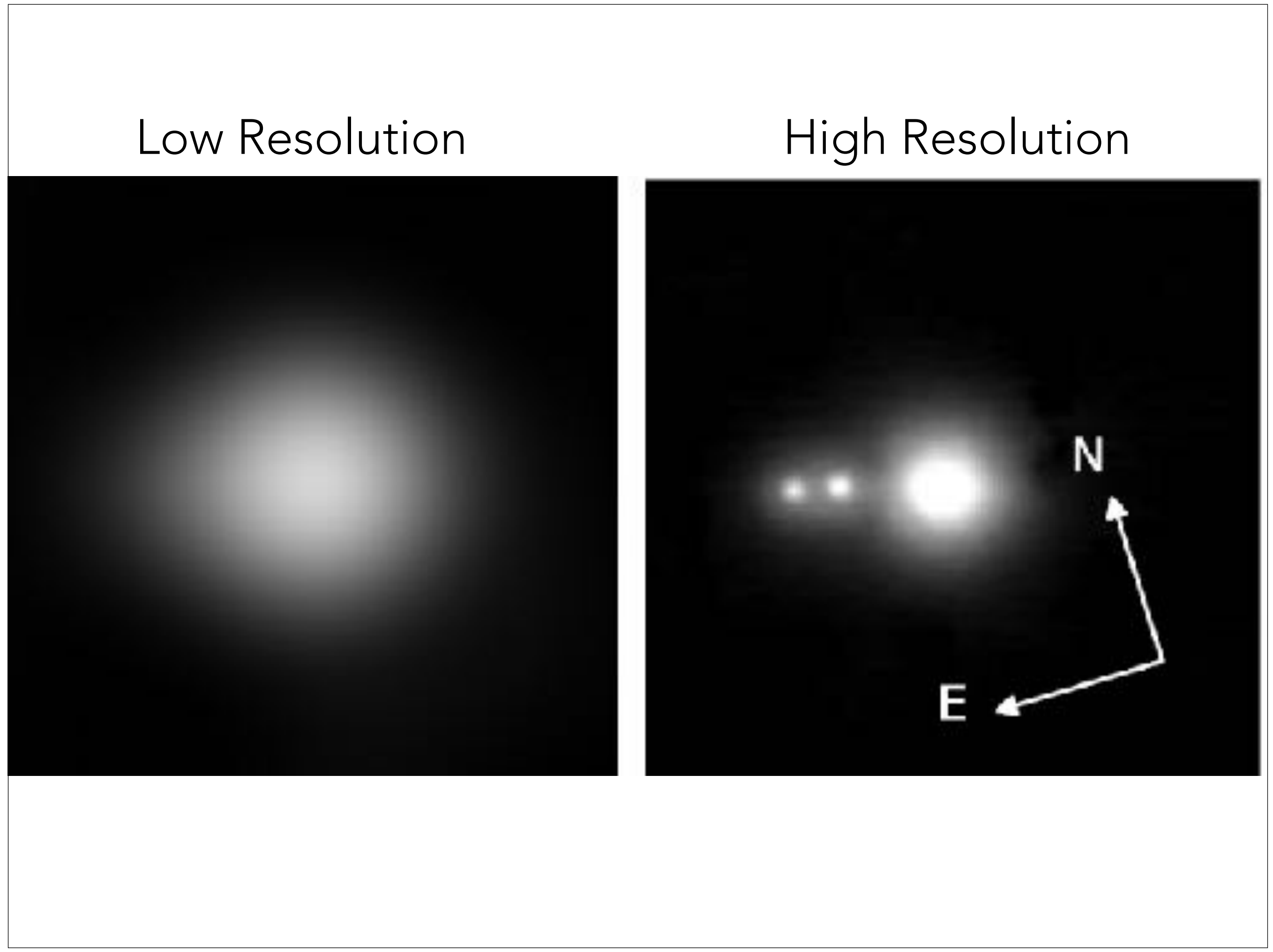
- Objects that look like just a dot from a distance now look bigger and details can be seen


All the sudden we could craters on the Moon, moons around Jupiter, the phases of Venus, the rings of Saturn, and much more

*Resolution* — the ability to distinguish objects or details that are very close together

When astronomers talk about using telescopes to make details more clear, they use a term called *resolution*

When driving on a road at light, a distant car heading toward you appears as a single light. As it gets closer, the light separates out — *resolves* — into two headlights




A telescope increases resolution, making it easier to distinguish two stars that are close together or make out the bands of color around Jupiter


- Bigger objective = better resolution
- There's a limit to how well you can resolve and image but not a limit on how much you can magnify it. But a poorly-resolved image, no matter how well magnified, just looks like mush

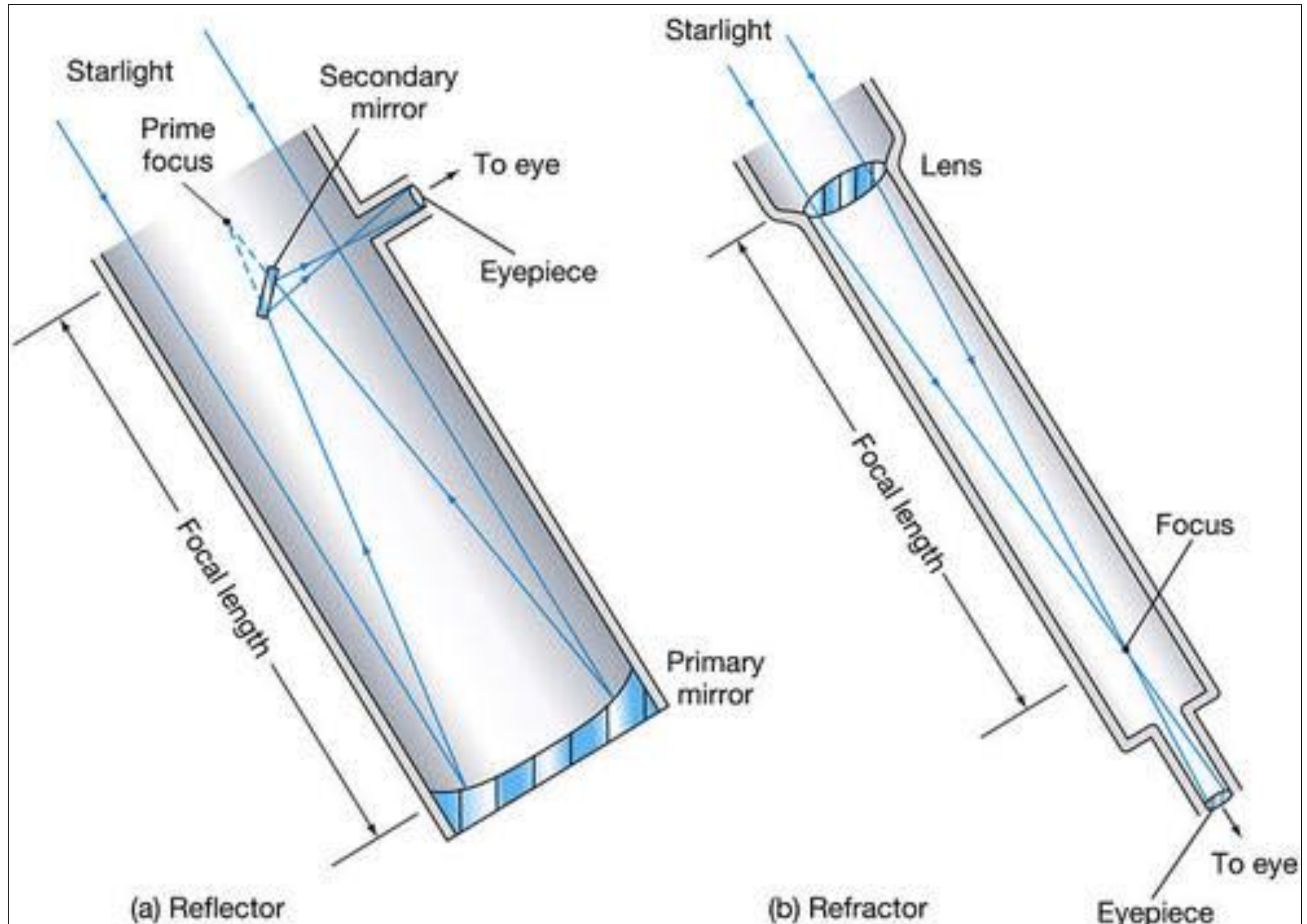
# DISADVANTAGES OF REFRACTING TELESCOPES

1. Big lenses are hard to make and break easily
2. Lenses bend different frequencies of light by different amounts

1. They break because they get thin near the edges
2. Even if you get, say, a red star to resolve, the blue star next to it will still look fuzzy

# Solution: *Use mirrors!*

Mirrors also change the direction of light. Isaac Newton realized he could use a curved mirror instead of a lens to funnel light, focusing it to a point





Refracting vs. Reflecting Telescopes

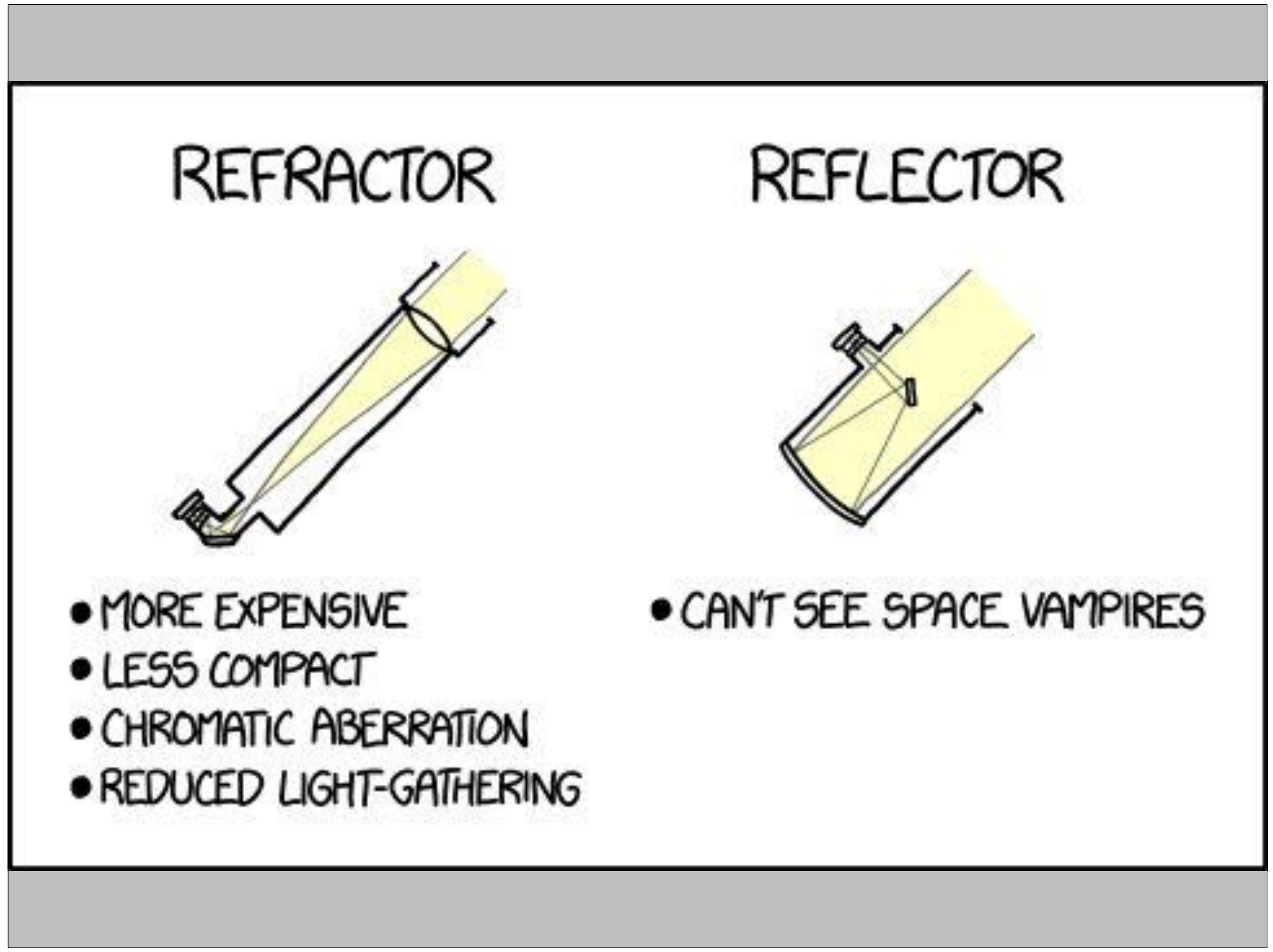
## ADVANTAGES OF REFLECTING TELESCOPES

1. You only have to polish one side of a mirror

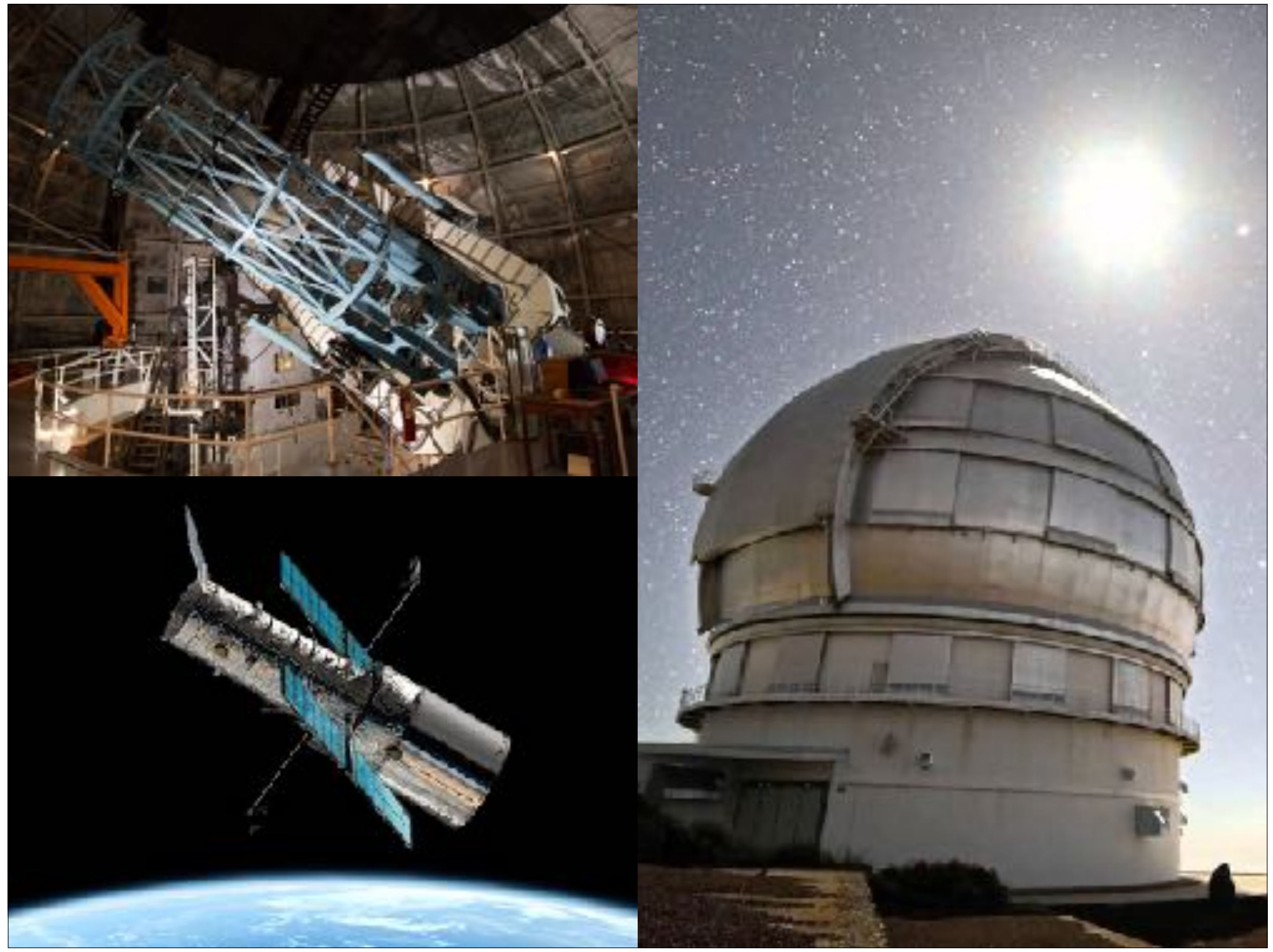
2. Mirrors can be supported from the back

1. Lens have two sides to polish
2. They can be manufactured larger, more easily, and for less money

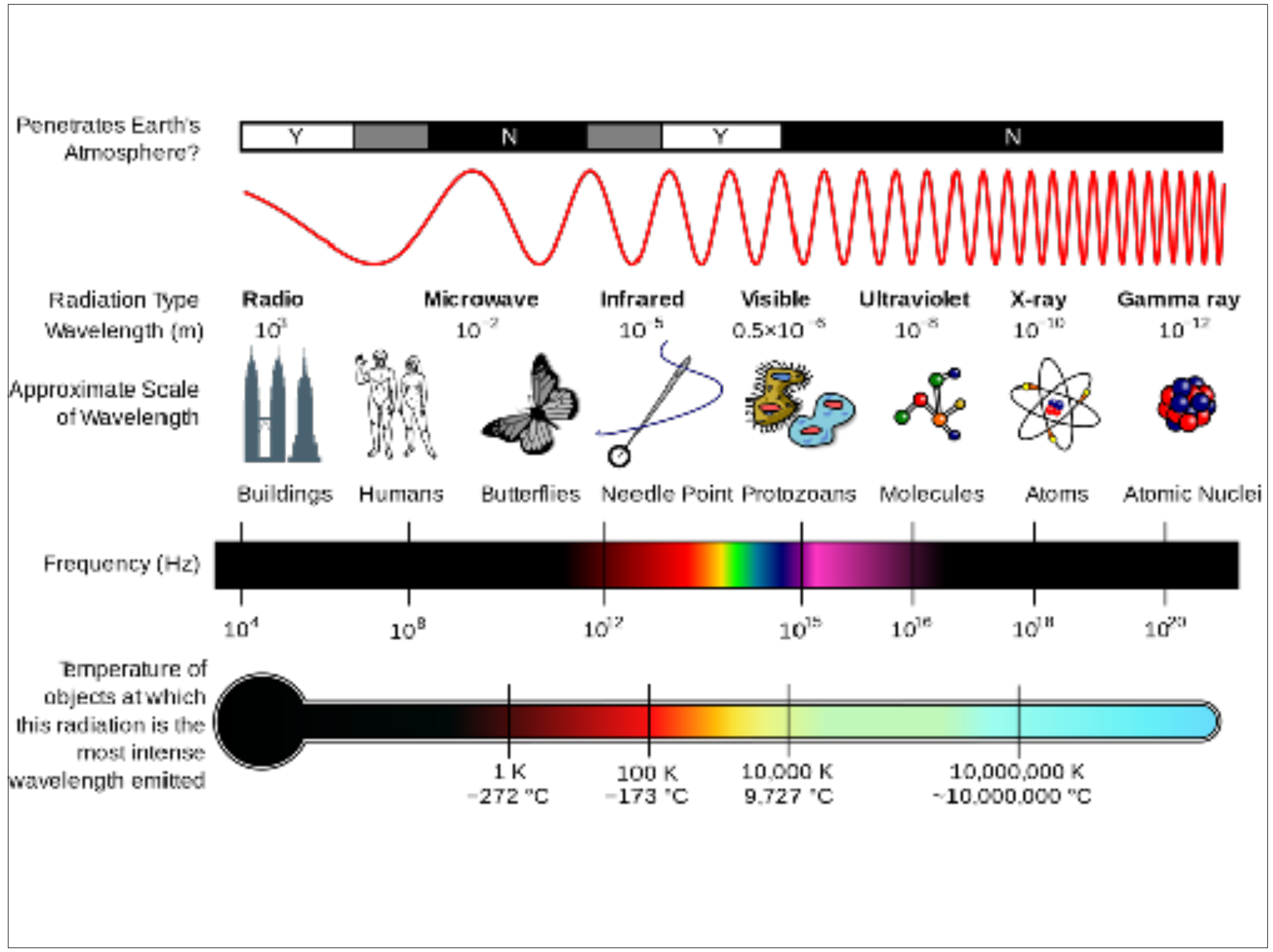
- Although there have been many improvements over the centuries, most modern telescopes, at their heart, are based on this design


REFRACTOR
REFLECTOR
• MORE EXPENSIVE
• LESS COMPACT
• CHROMATIC ABERRATION
• REDUCED LIGHT-GATHERING
• CAN'T SEE SPACE VAMPIRES

Credit: xkcd

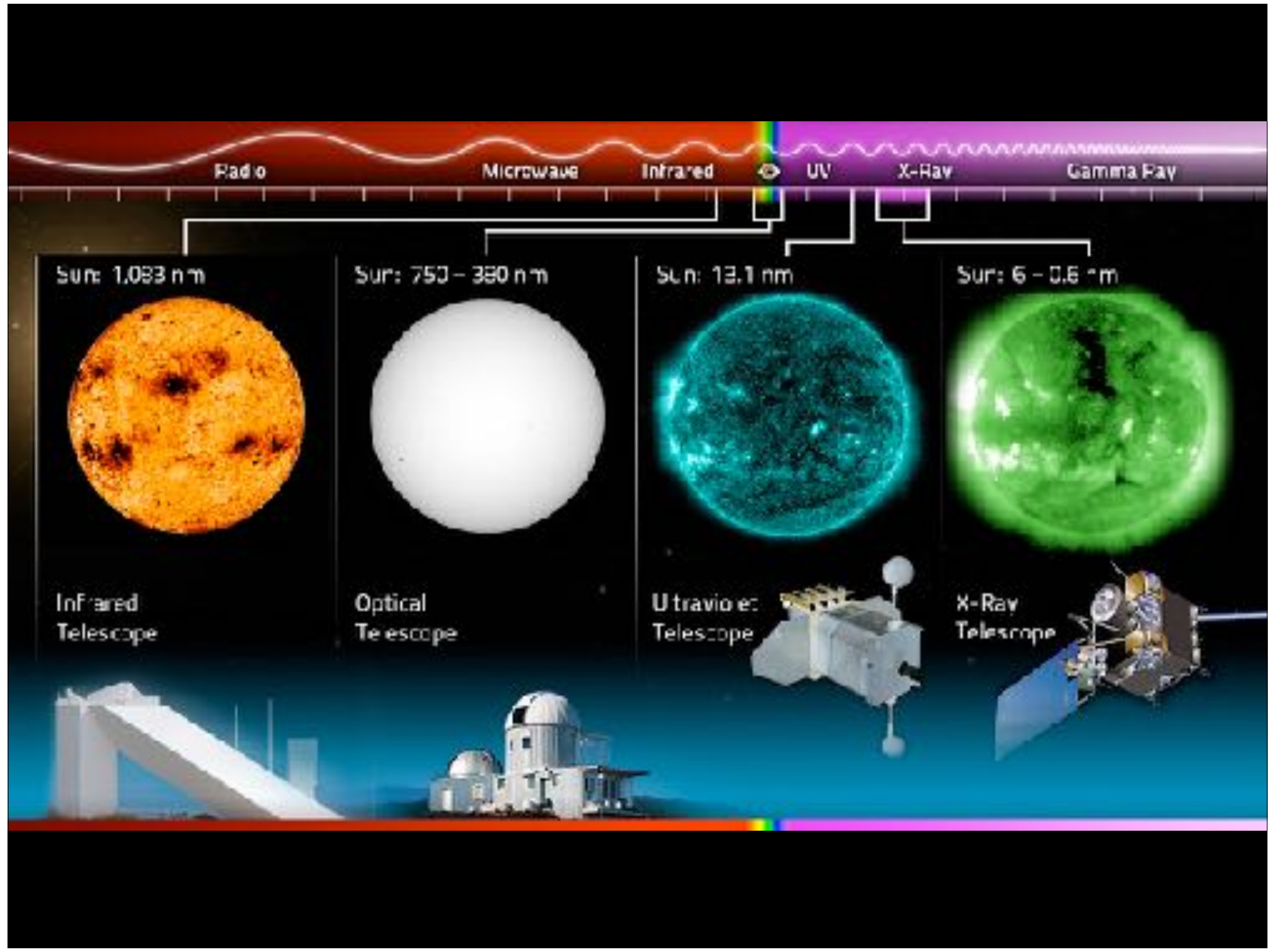


- Mt. Wilson's largest telescope has mirror objective 100 inches across
- The Hubble Space Telescope uses a 2.4 m (~95 in.) objective
- The largest optical reflecting telescope, El Gran Telescopio Canarias in the Canary Islands, Spain, has a 10.4 m (409 in.) objective




There is much more light out there than we can see. Astronomical objects can be observed in all these flavors of light if we have the right detectors. Radio waves pass right over normal optical telescopes, and gamma and X-rays pass through them like they're not even there

However, big metal dishes can reflect radio waves just like mirrors reflect visible light, so we can detect radio waves using a pretty similar concept. At this point, we've developed detectors for every flavor of light across the electromagnetic spectrum




Four images of the Sun taken in infrared, optical, ultraviolet, and X-ray.
Remember! the coloration is artificial. The bright areas represent high levels of radiation, the dark areas represent low levels

# WE HAVE A PROBLEM

- Earth's atmosphere acts as a shield against many forms of light
  - Water vapor can prevent gamma rays, X-rays, and most infrared and ultraviolet rays from reaching Earth's surface

Ground-based telescopes used to study these forms of radiation work best at high elevations, where air is dry. But they only way to study many forms of radiation is from space

# HUBBLE SPACE TELESCOPE

- Year launched:
  - 1990
- Types of light
  - Visible, UV, near-IR
- Primary target:
  - Deep space objects


The granddaddy of space telescopes, Hubble has been observing from Earth orbit for almost three decades. Hubble, the first of NASA's Great Observatories, has revolutionized astronomy, providing stunning images of countless cosmic objects and giving astronomers their most distant views of the universe with the Hubble Deep Field and Ultra Deep Field. Hubble has shed light on the scale of the universe, the life cycle of stars, black holes, and the formation of the first galaxies. Currently receiving its fifth and final makeover, Hubble is expected to last at least another five years, hopefully overlapping with its successor, the James Webb Space Telescope.

Hubble Deep Field

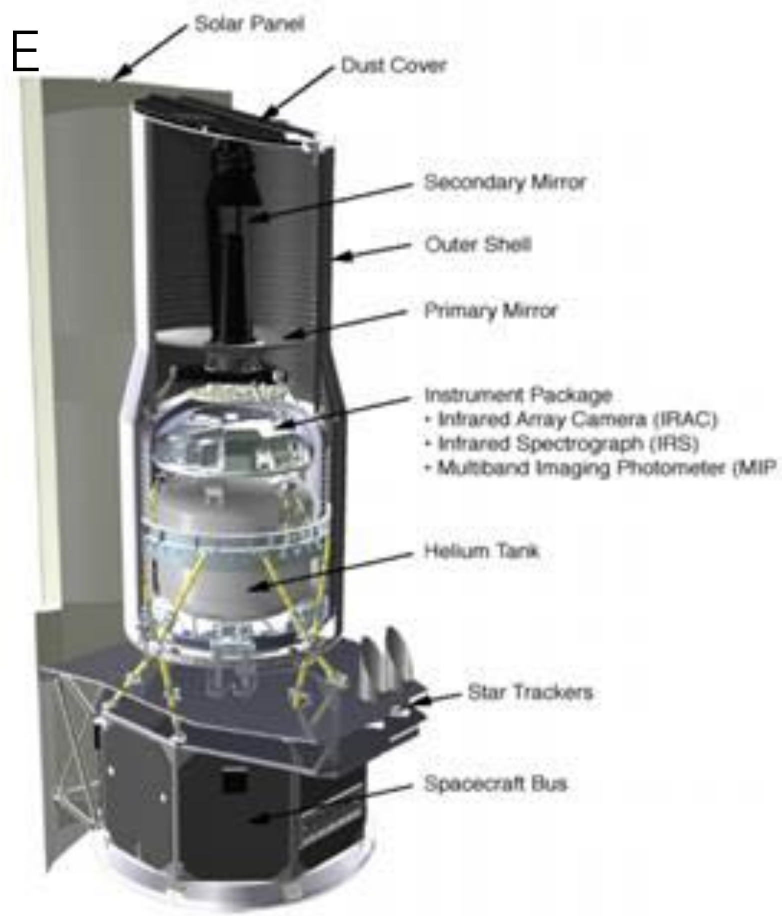
# CHANDRA X-RAY OBSERVATORY

- Year launched:
  - 1999
- Types of light
  - X-ray
- Primary target:
  - Various


The third of NASA's four Great Observatories, Chandra is the world's most powerful X-ray telescope. Chandra, named for Indian-American physicist Subrahmanyan Chandrasekhar, examines the X-rays emitted by some of the universe's strangest objects, including quasars, immense clouds of gas and dust and particles sucked into black holes. X-rays are produced when matter is heated to millions of degrees. Chandra has teamed up several times with other telescopes, including Hubble, to take composite images of galaxies and other denizens of the cosmos. It has found previously hidden black holes, provided observations of the Milky Way's own supermassive black hole, Sagittarius A*, and even taken the first X-ray images of Mars.

# SPITZER SPACE TELESCOPE

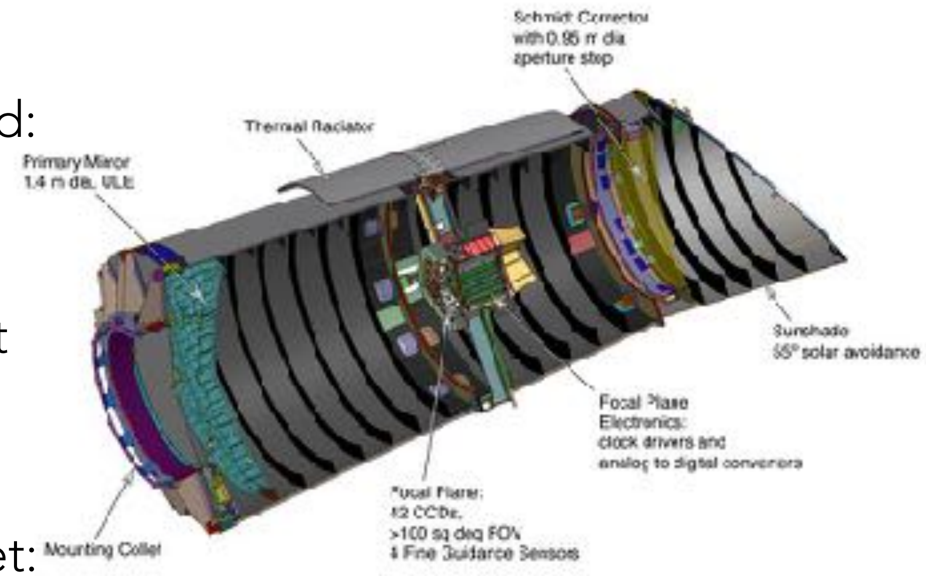
- Year launched:
  - 2003
- Types of light
  - IR
- Primary target:
  - Distant and nearby objects




Spitzer was the last of the Great Observatories to be launched and gathers the infrared radiation emanating from cosmic objects, including faraway galaxies, black holes and even comets in our own solar system. (Infrared radiation is hard to observe from the ground because it is largely absorbed by the Earth's atmosphere.) Spitzer was the first telescope to see light from an exoplanet, which it was not originally designed to see; it took the temperatures of so-called "hot Jupiters" and found that not all of them are really hot. Spitzer is about to use the last of the liquid helium coolant that has kept its instruments chilled for the past 5.5 years. Spitzer's instruments will be able to keep going for another two years, meanwhile, the European Space Agency's Herschel telescope is designed to pick up where Spitzer left off.

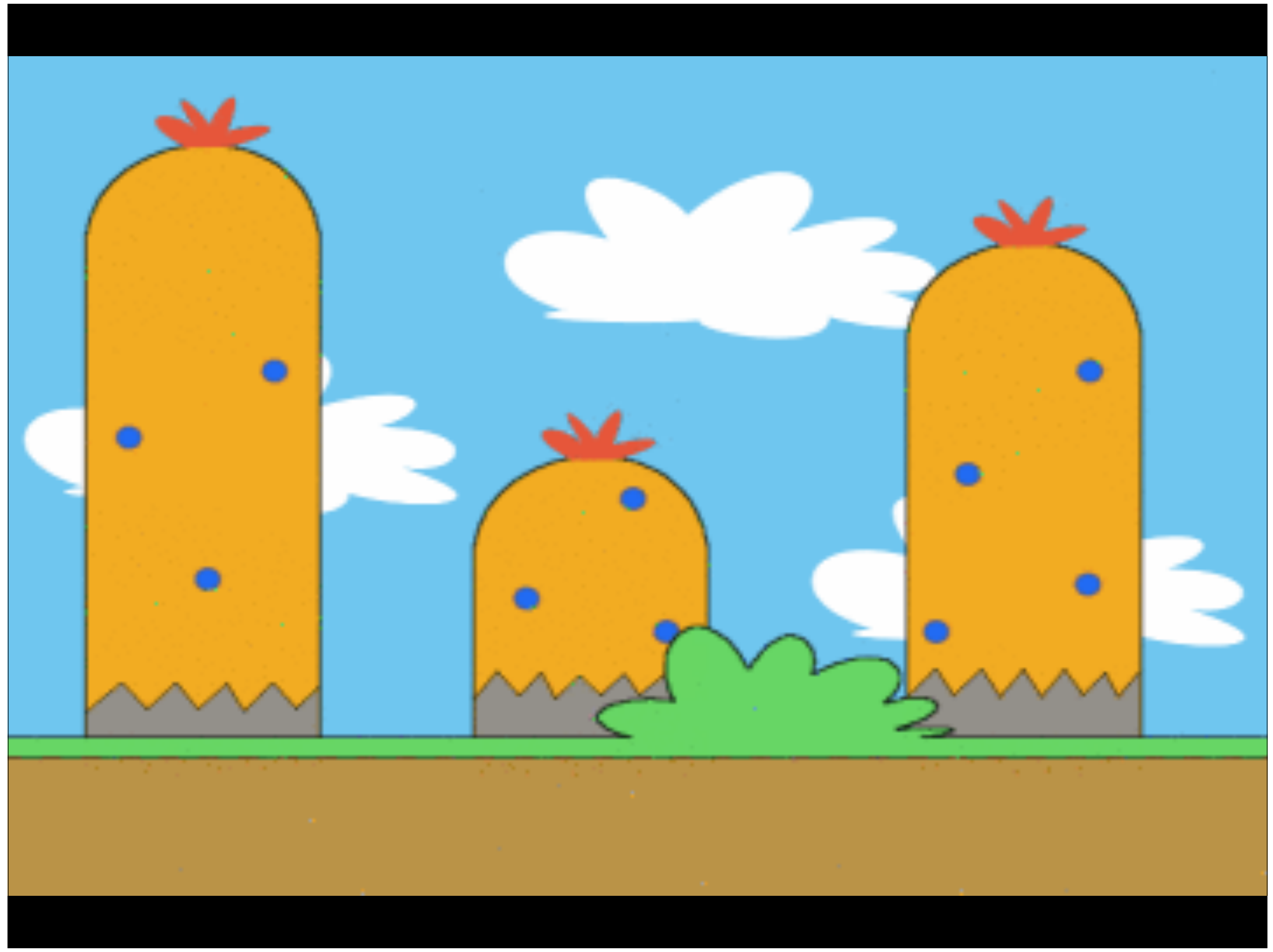
# KEPLER MISSION

- Year launched:
  - 2009
- Types of light
  - Visible
- Primary target:
  - Extrasolar planets




Also new to the space scene is Kepler, NASA's new planet-hunting telescope that will specifically be searching for other Earth-like planets in the galaxy. Kepler will be looking for characteristic variations in the light from a pre-selected target group of 100,000 stars. Dips in the light from the stars can indicate a planet passing in front of the star (from Earth's perspective). Astronomers are hoping that Kepler fill find planets in the stars' habitable zones, where temperatures are just right for liquid water to exist. After getting settled into its new orbital home, Kepler officially began its search in May. First light from the telescope came on April 16.


How do you measure huge distances, especially through space? It’s not like you can use a tape measurer



Picture yourself in a car driving up an open stretch of road. The bushes near the side of the road zip past you, but the distant mountains seem to gently scroll across the horizon. Keep that in mind as we try to work out the problem of measuring distance

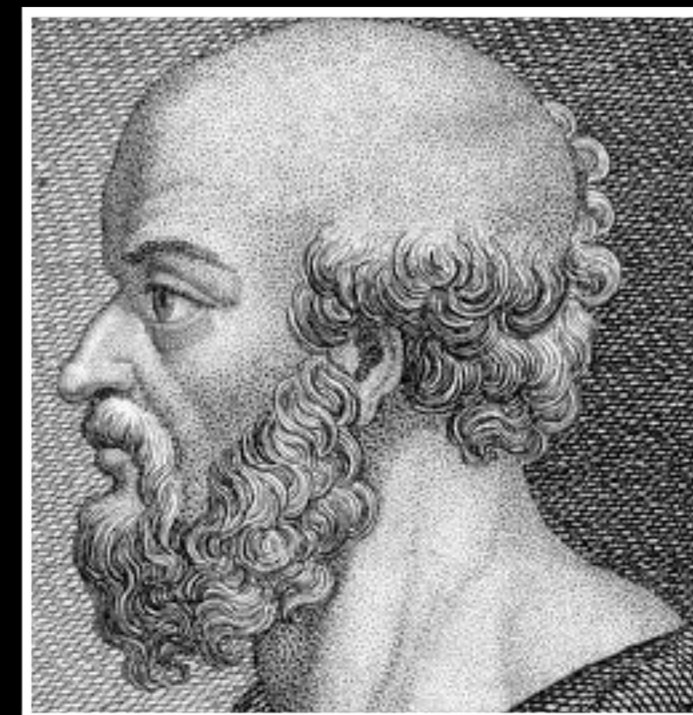
# HOW BIG IS THE EARTH?

People have known the Earth is round for thousands of years. But how big is it?

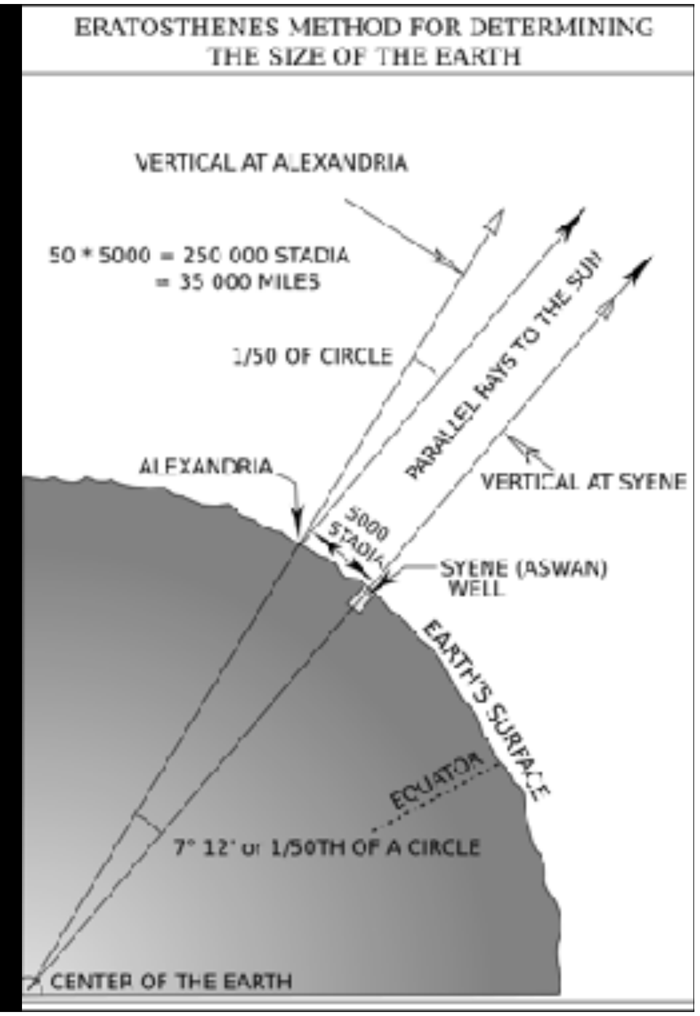
# ERATOSTHENES

ca. 276 BC - 194 BC

- Greek mathematician, geographer, poet, astronomer, and music theorist
- First to measure the circumference of the Earth



- Syene lies on the Tropic of Cancer
    - Noon on the Summer Solstice, the Sun is directly overhead
- At the that same time, measured the Sun’s angle of elevation in Alexandria
    - 7° 12′ (or 1/50th of a circle)
    - Calculated circumference: 46,620km (err. 16.3%)



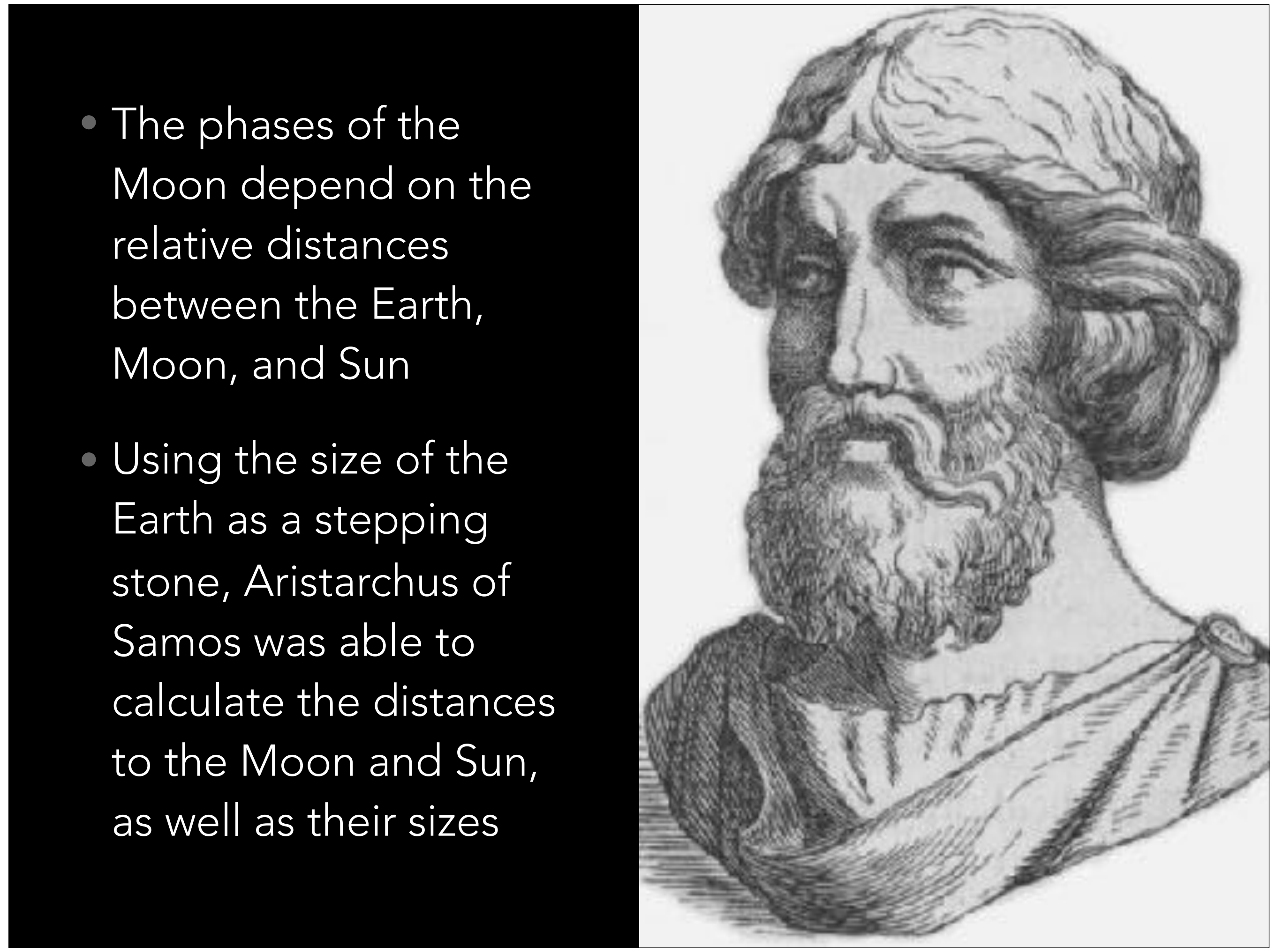

Eratosthenes knew that on the Summer Solstice, the Sun shown directly down a well in Syene at noon. He also knew that at the same time, it was *not* shining straight down in Alexandria. By measuring the angle to the Sun in Alexandria and the distance between the two cities, he could use simple geometry to calculate the circumference of the Earth

FOR THE VERY FIRST TIME, HUMANS HAD DETERMINED A SCALE TO THE UNIVERSE

This was the first step in a much, much longer journey. Once you know how big the Earth is, other distances can be found

# TO THE MOON AND BACK

- During a lunar eclipse, the shadow of the Earth is cast on the Moon
  - By tracking the movement of Earth's shadow, and knowing the size of Earth, you can calculate the distance to the Moon

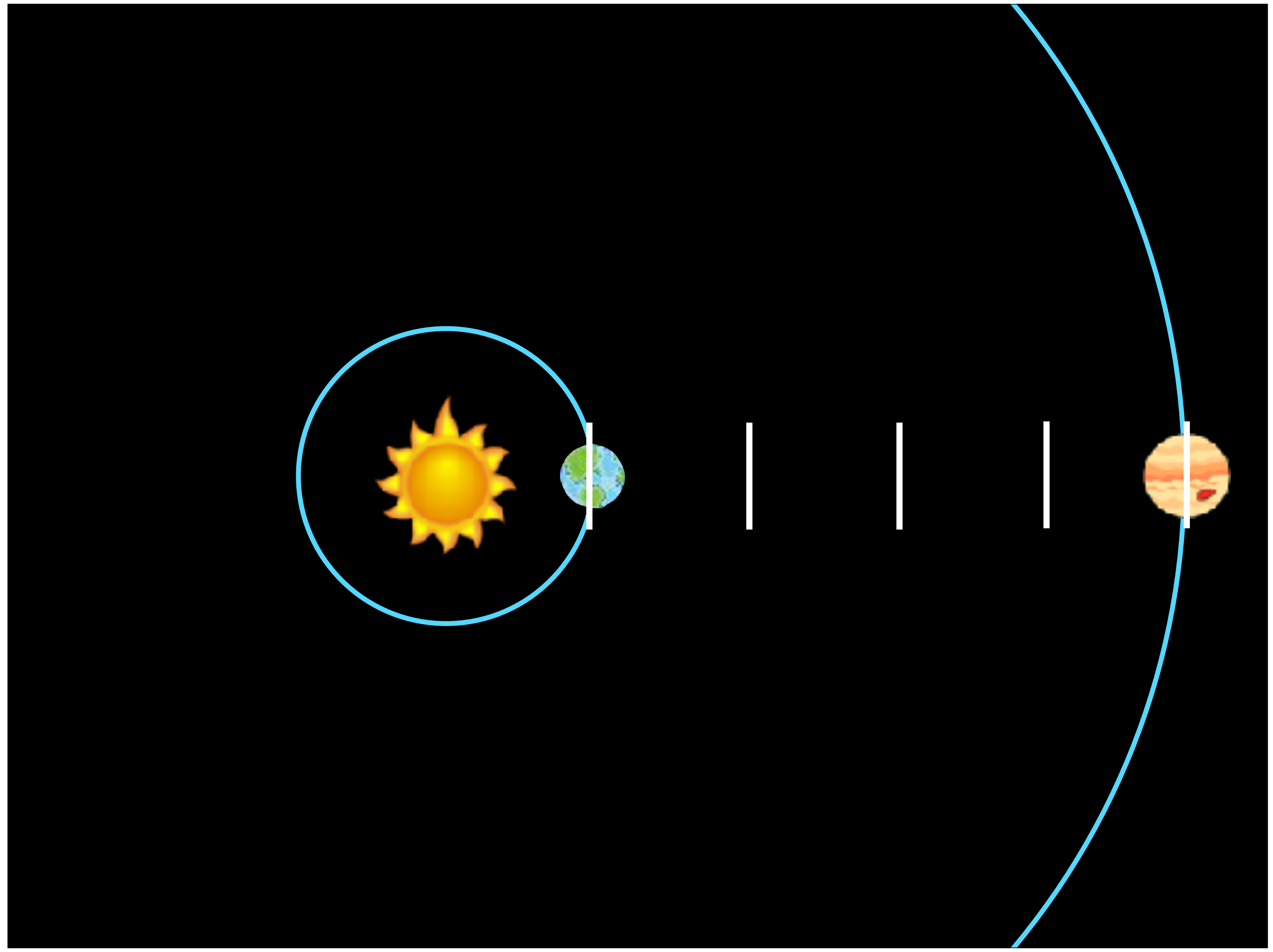



ca. ~200 B.C.
After this, things got a lot more difficult. For example, the planets are pretty far away and look like dots in the sky, so our pervious methods failed in trying to figure out how far they are

"The **orbital period** of a planet **squared** is *proportional* to its **average distance** from the Sun **cubed**"

–KEPLER'S 3RD LAW

In the 17th Century, Kepler and Newton laid the mathematical groundwork of planetary orbits, which made it possible, in theory, to figure out distances by comparing orbital periods

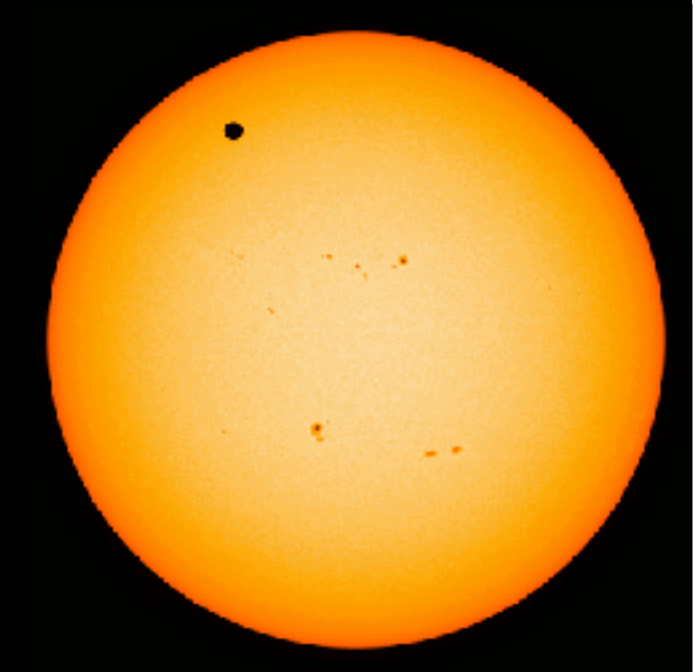


The catch, however, is that to get the distance to the other planets, you first have to know the distance between the Earth and Sun accurately. So, for example, Kepler's 3rd Law could tell you that Jupiter is 5x further from the Sun than Earth, but that doesn't give a distance in kilometers. We had a rough idea of the distance to the Sun thanks to the ancient Greeks, but to truly understand the solar system we'd need a much more accurate value for it

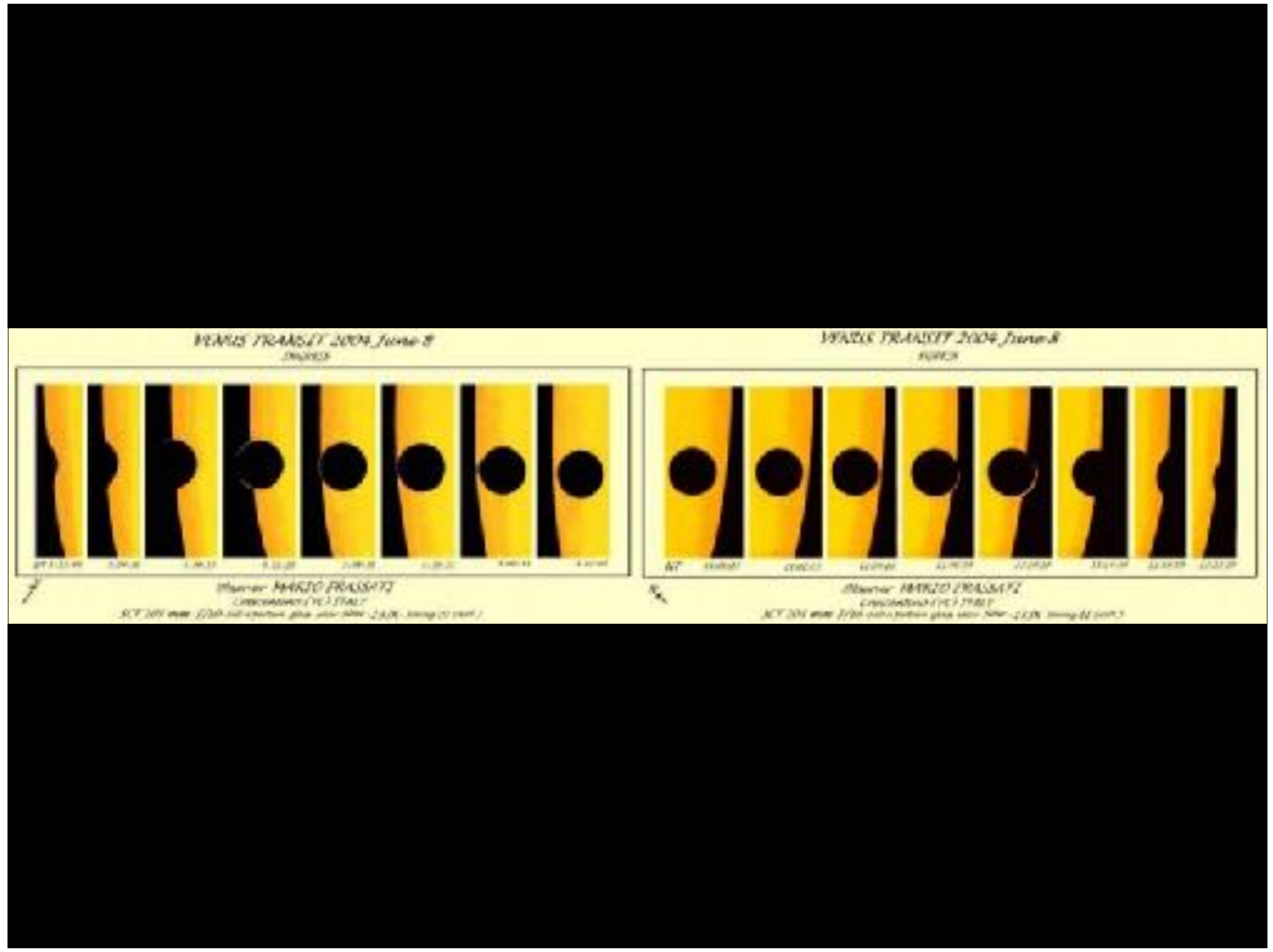
*The Astronomical Unit* (*AU*) — the average distance between the Earth and Sun

Knowing the distance between the Earth and Sun is so important to understanding everything else that scientists give it its own name

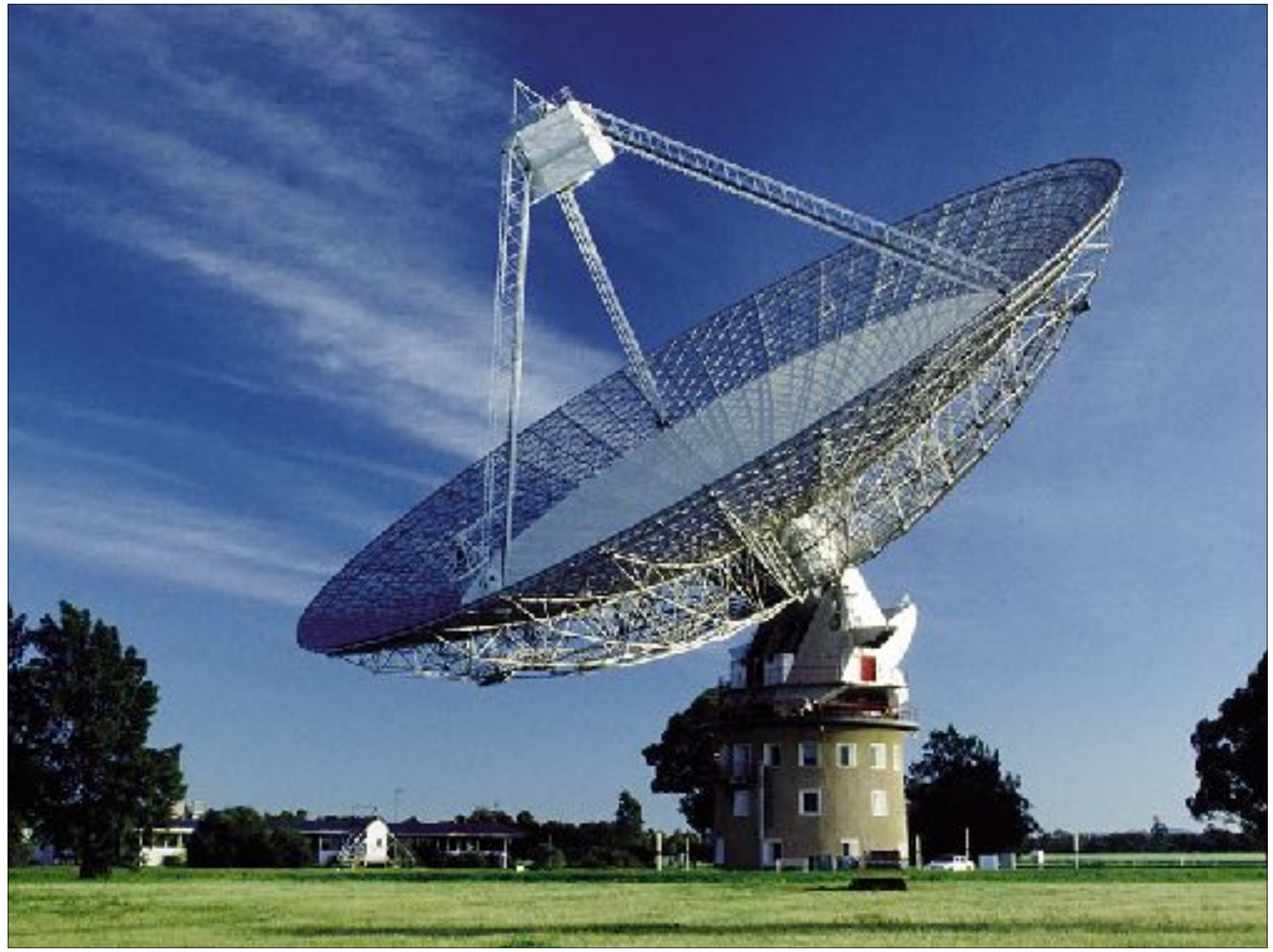
- Sometimes Mercury and Venus transit, or cross the face of the Sun
- The timing of these events can be used to calculate the value of 1 AU



Expeditions were sent around the globe to measure the transits




Our atmosphere blurs the images of the planets, putting pretty big error bars on the measurements. The best they could do was to say the AU was 148,510,000 km ± 800,000 km



Finally, in the 1960s, astronomers used radio telescopes to bounce radar pulses off Venus. Because we know the speed of light with amazing precision, we can use the time it takes for the radar pulse to reflect back to the Earth to get an extremely accurate value for the AU

1 AU = 149,597,870.7 km

The orbits the Sun on an ellipse, so that’s the average distance from Earth to the Sun

The AU is the fundamental meterstick of astronomy, the scale we use to measure everything

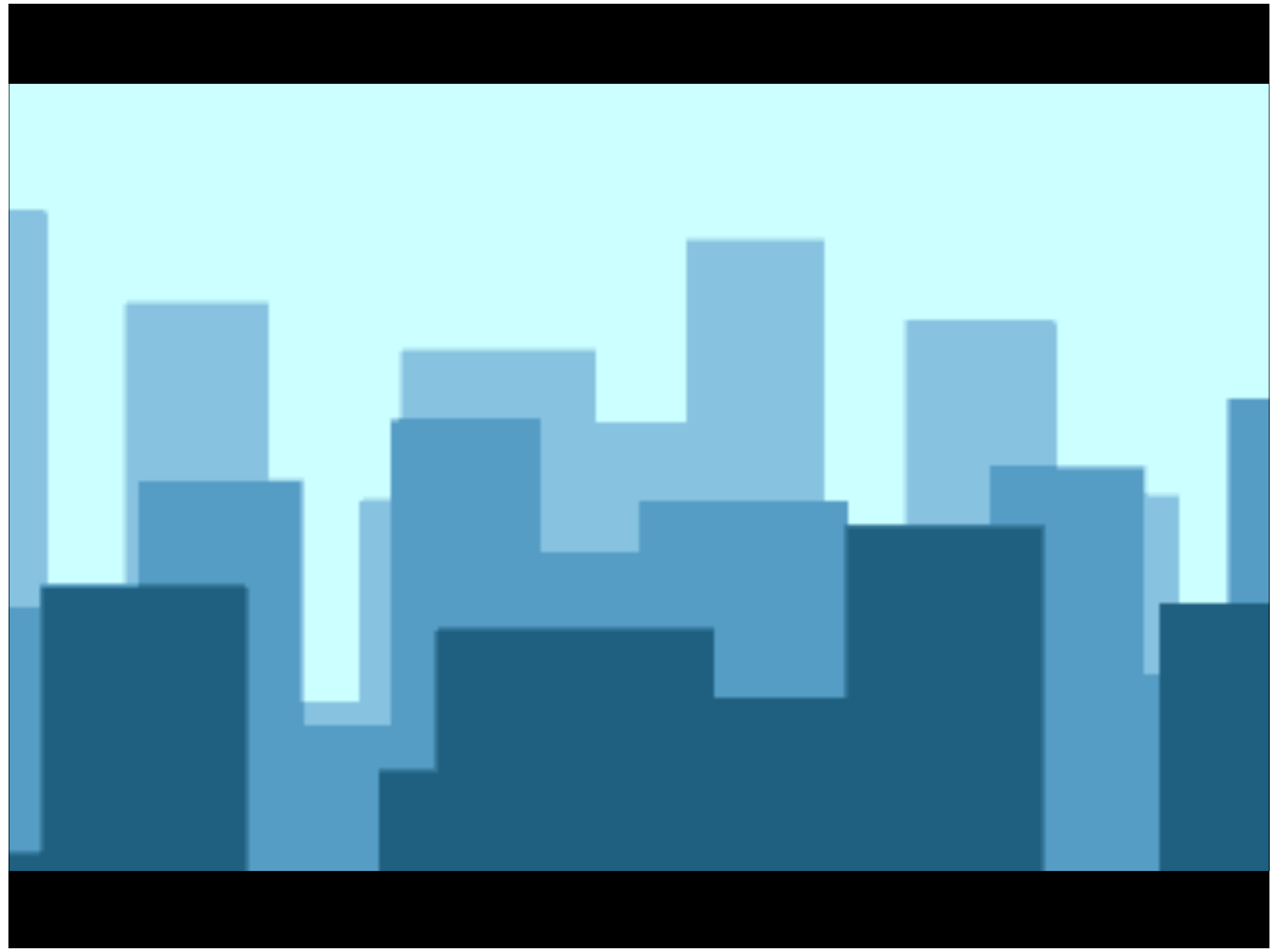
## NOW WE CAN…

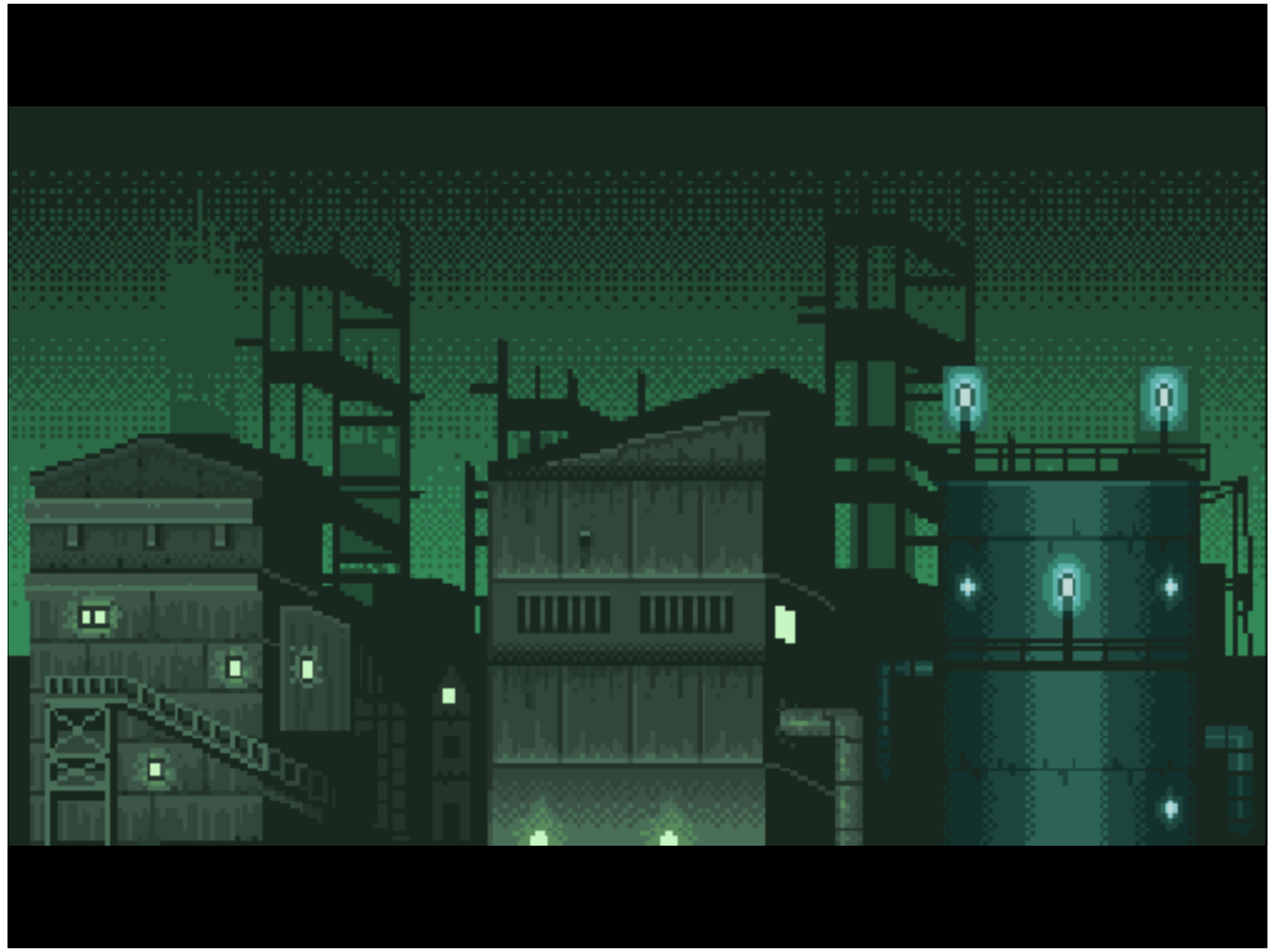
- predict the motion of the planets, moons, comets, and asteroids,
- launch our probes into space, and
- access the information held by the stars

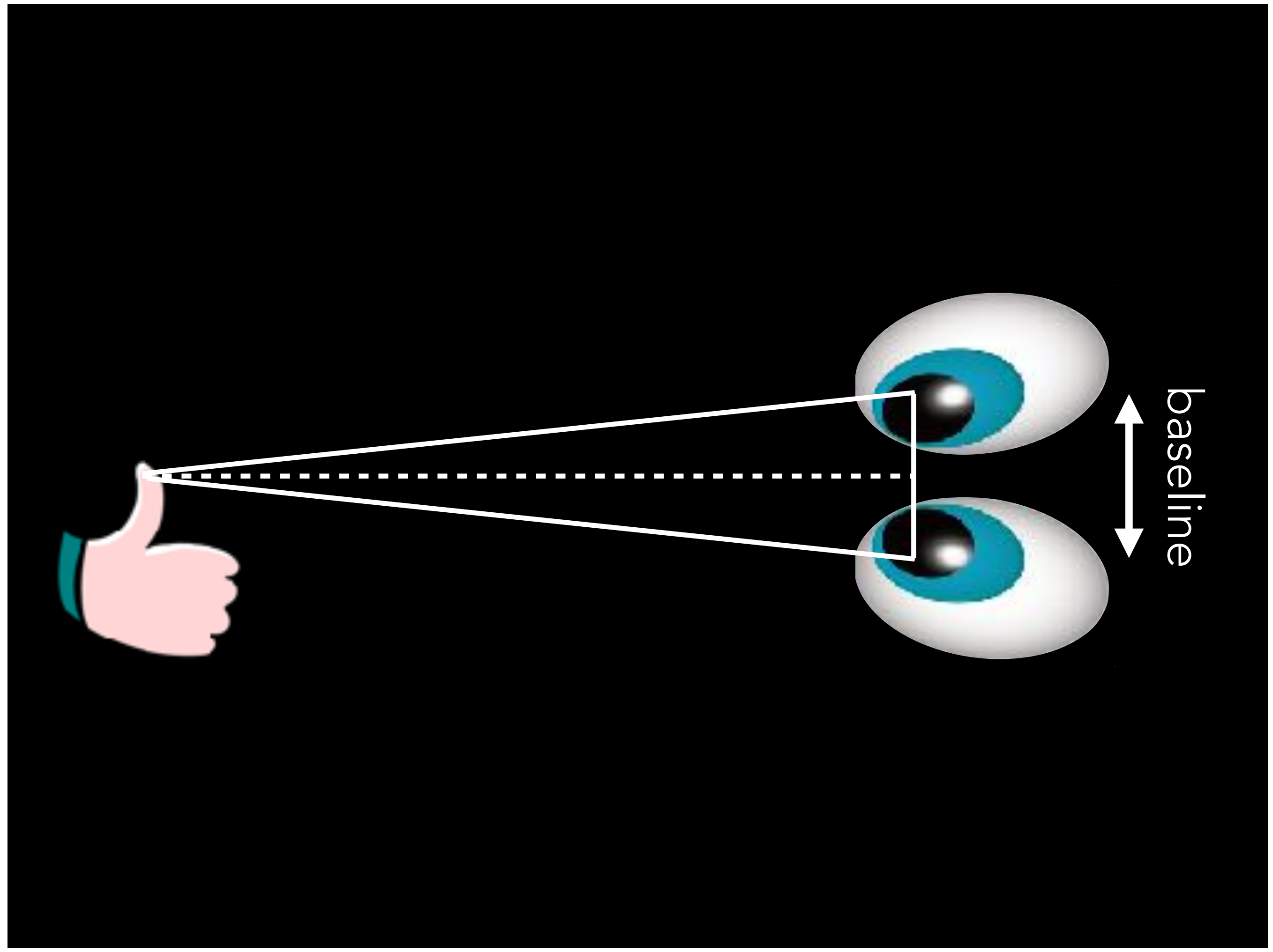
You have two eyes, and when you look at an object, each eye sees that object at a slightly different angle. Your brain puts these two images together, compares them, does the geometry, and gives you a sense of distance to that object — we call that depth perception

*Parallax* — the apparent difference in position of an object when viewed from different positions

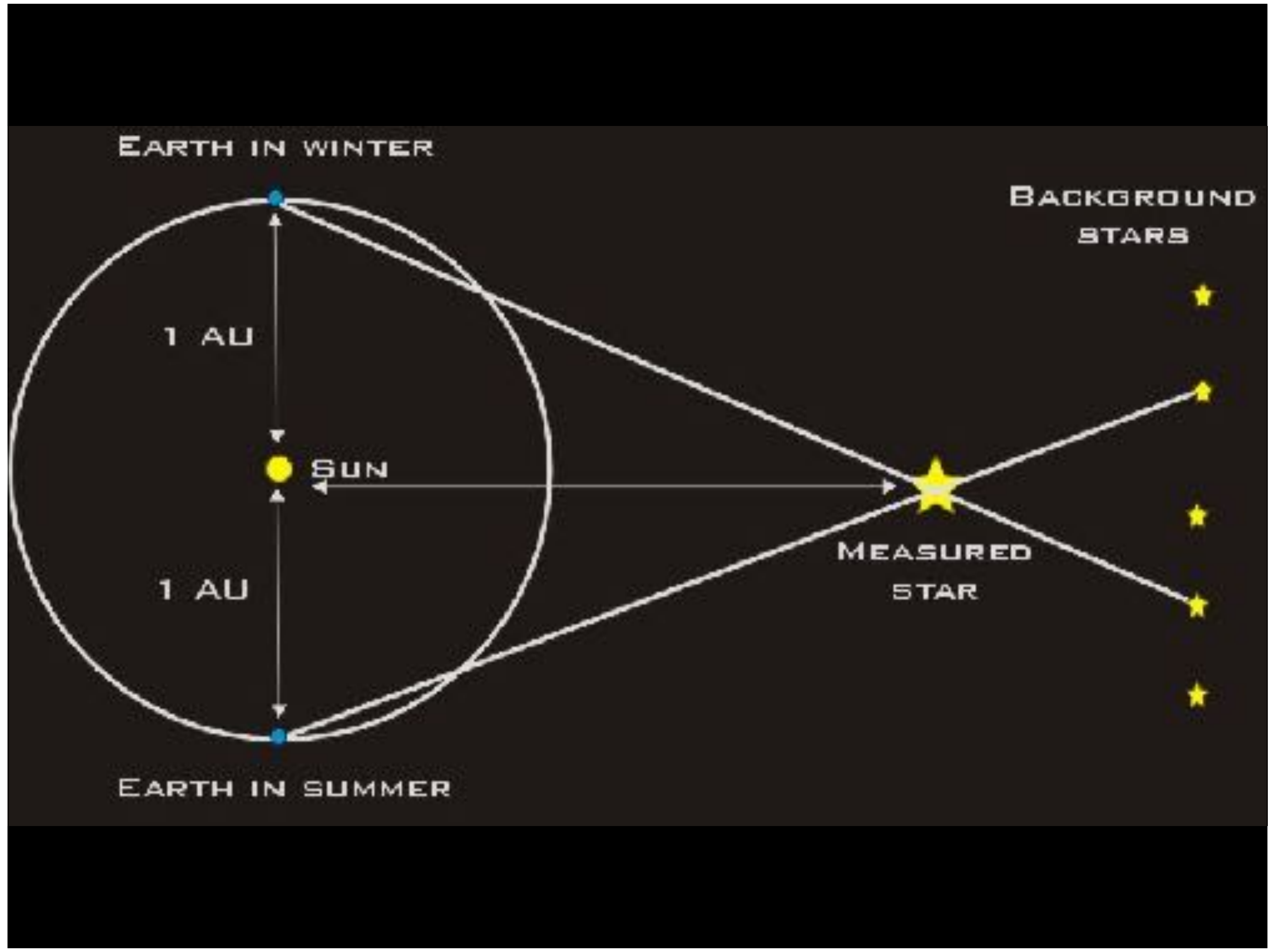
Hold out your thumb and look at it first with one eye and then the other. Your thumb will appear to shift against the background. How much it shifts depends on how far away your thumb is and how far apart your eyes are








If you know the distance between your eyes, a distance called the *baseline*, then you can use some trigonometry to determine how far away the object is. If the object's nearby, it shifts a lot; if it's far away, it shifts less. The further away something is, the bigger baseline you need to determine its distance




The Earth’s orbit acts like a huge baseline. If you observe a star then wait 6 months until the Earth is on the opposite side of the Sun to observe it again, you can determine the distance to that star (assuming you know the size of Earth’s orbit)

# 61 CYGNI

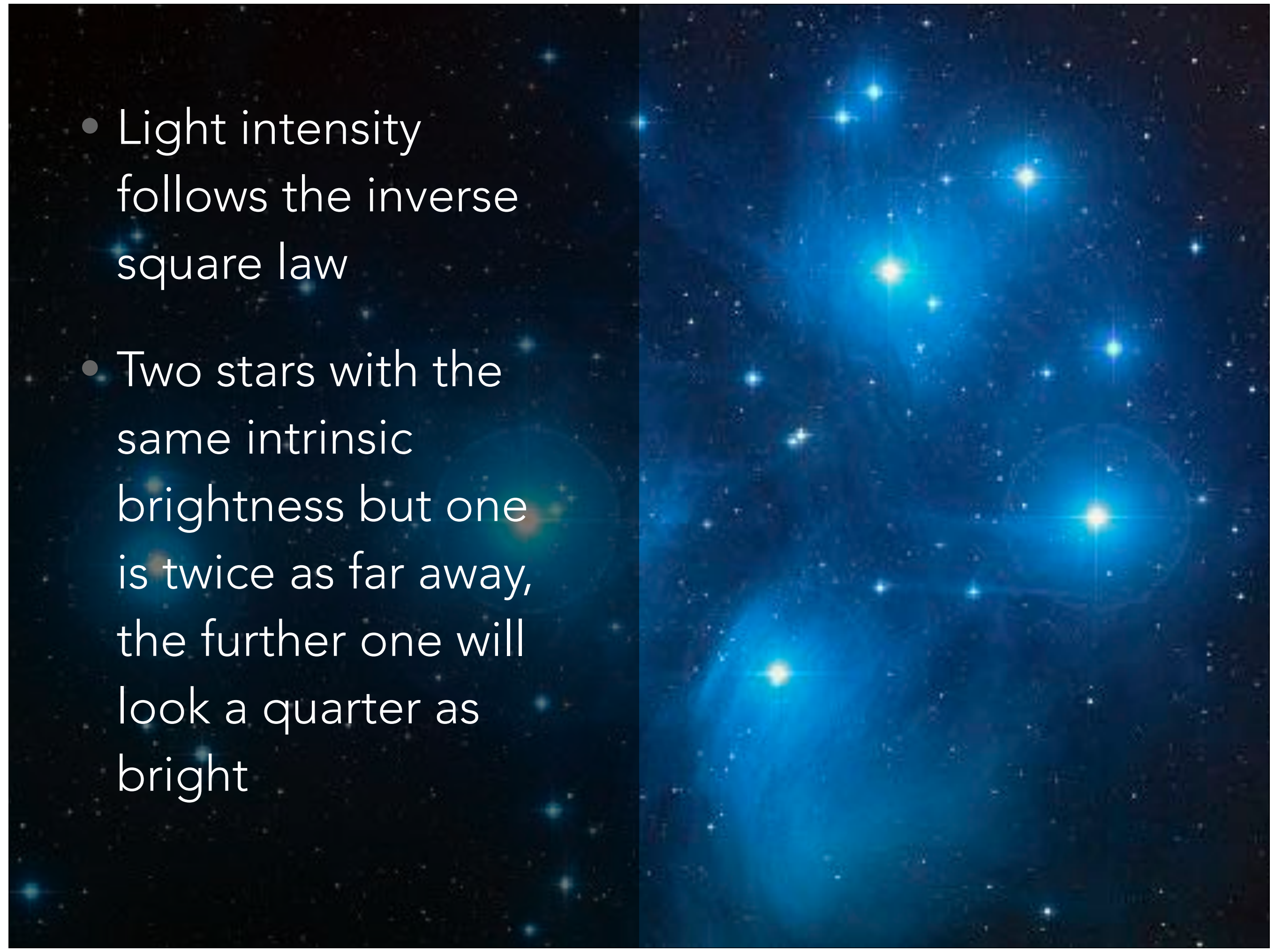
- In 1838, astronomers successfully measured the parallax of 61 Cygni
- 61 Cygni is about 720,000 AU away
  - that's well over 100 trillion km
  - or, more palatably, 11.4 light-years

# PARSEC

- A parsec is another unit of distance used by astronomers, one based on the angle a star shift over the course of a year
- A star 1 parsec away will have a shift of 1 arcsecond (1/3600th of a degree)
- 1 parsec = 3.26 light-years

As a unit of distance, it’s great for astronomers

Not great if you’re doing the Kessel Run




Parallax is great for determining distance but only for stars less then 1000 light-years away. However, once we know those distances, we can use them to determine the distance to even more distant stars. Measure the distance to the nearby star using parallax, and you can determine the distance to the further one by measuring its brightness

Once we know how far away a star is and how bright it appears, we can determine its…

- luminosity
- temperature
- mass
- diameter

This led to other methods for determining distance, like using dying stars, exploding stars, and even pulsating stars that get brighter and dimmer over time

We can see stars in other galaxies, which means we can use them to determine the actual size and scale of the Universe!