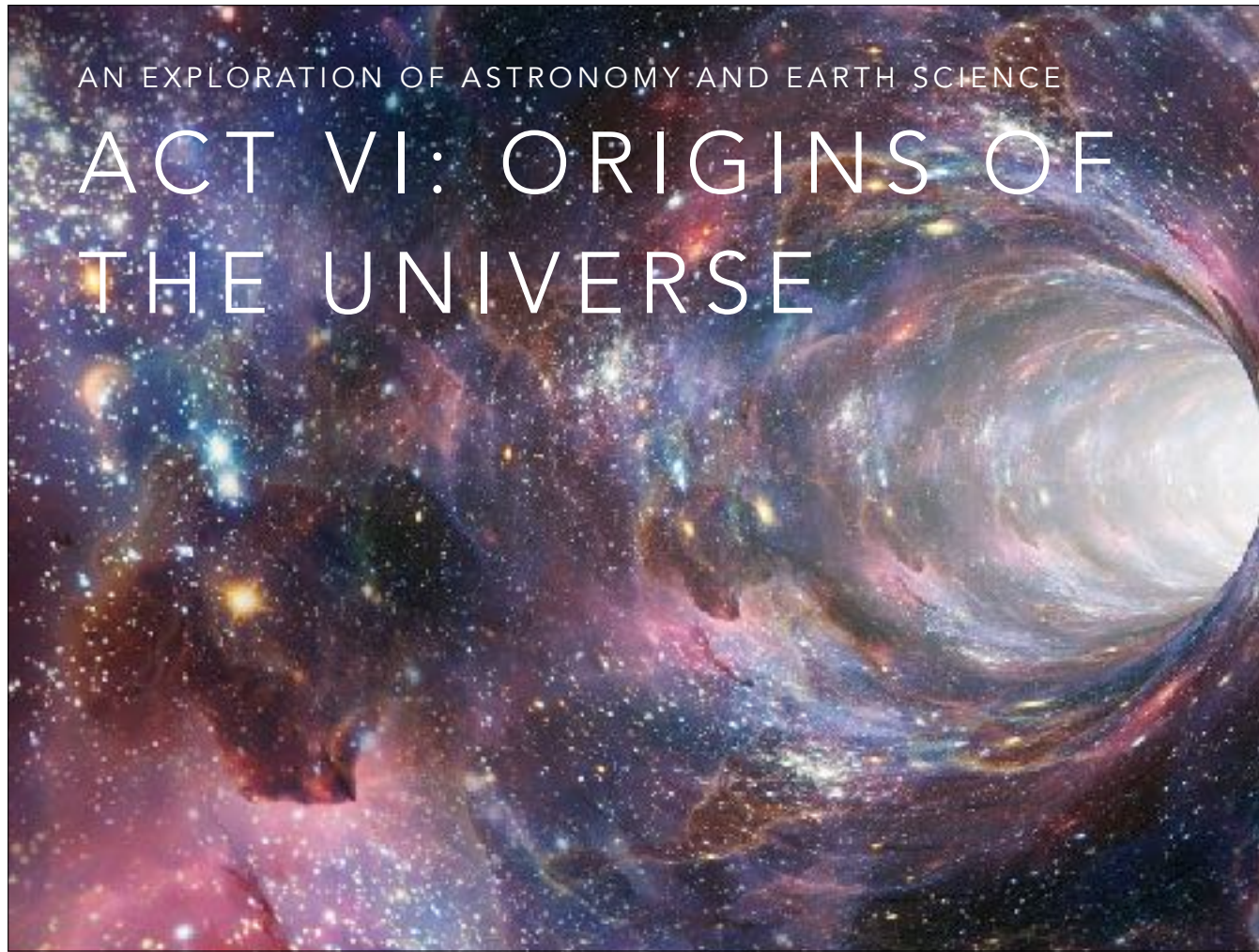



AN EXPLORATION OF ASTRONOMY AND EARTH SCIENCE

ACT VI: ORIGINS OF THE UNIVERSE



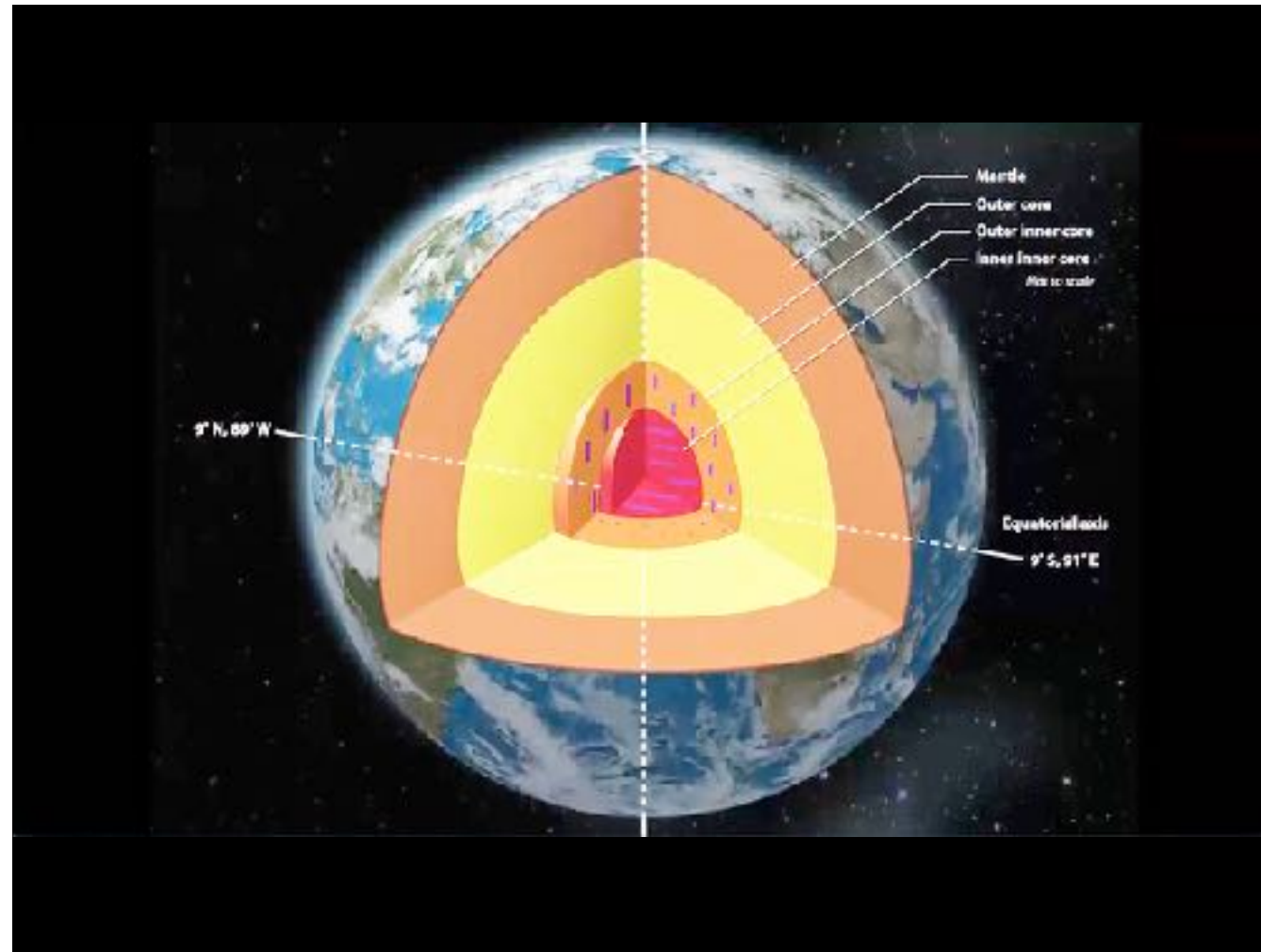


HOW TO OBSERVE A
UNIVERSE

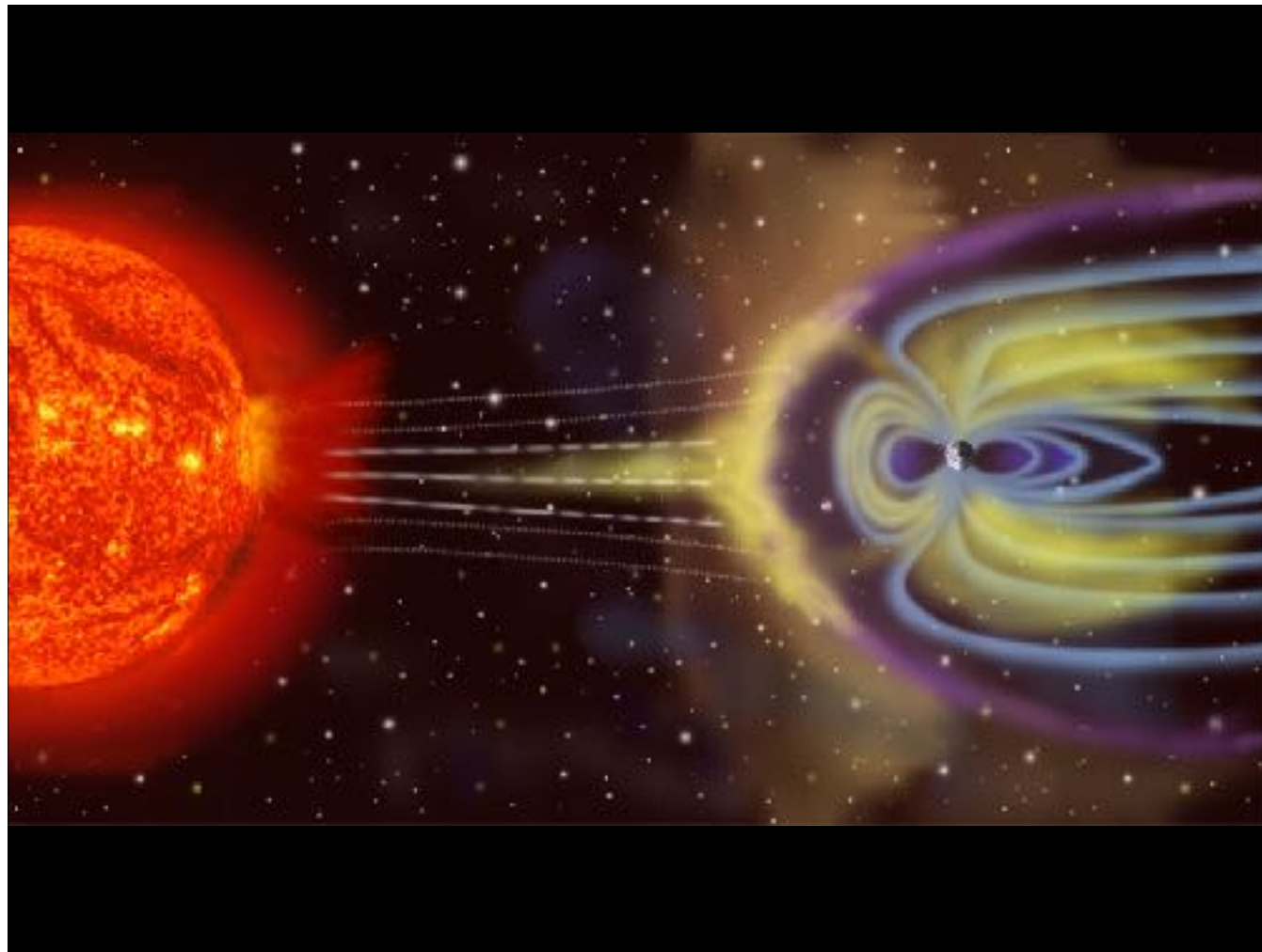
SCENE I:
STARGAZING

WHAT IS ASTRONOMY?

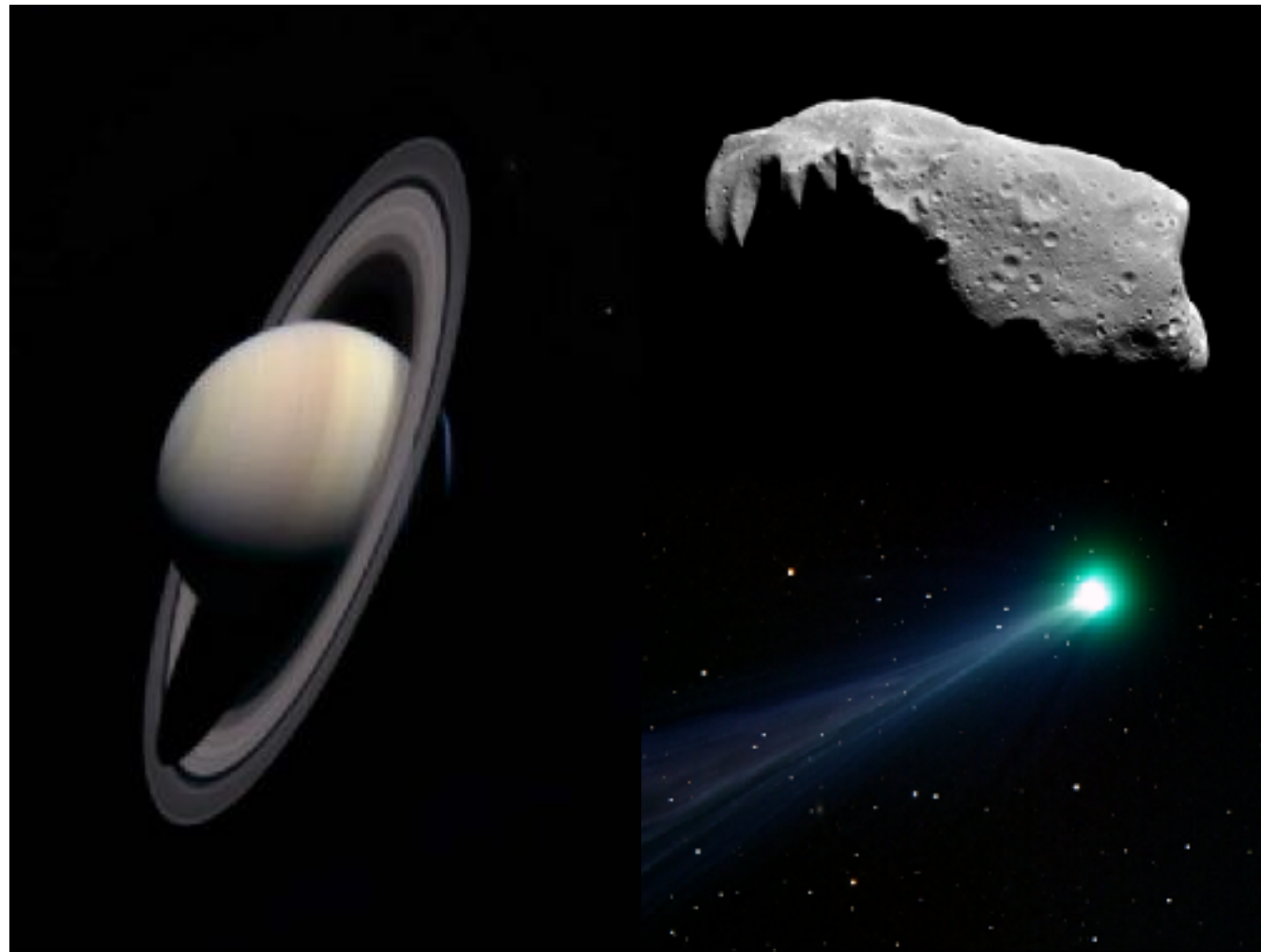
Astronomy puts you in your place. Because of astronomy, we know...



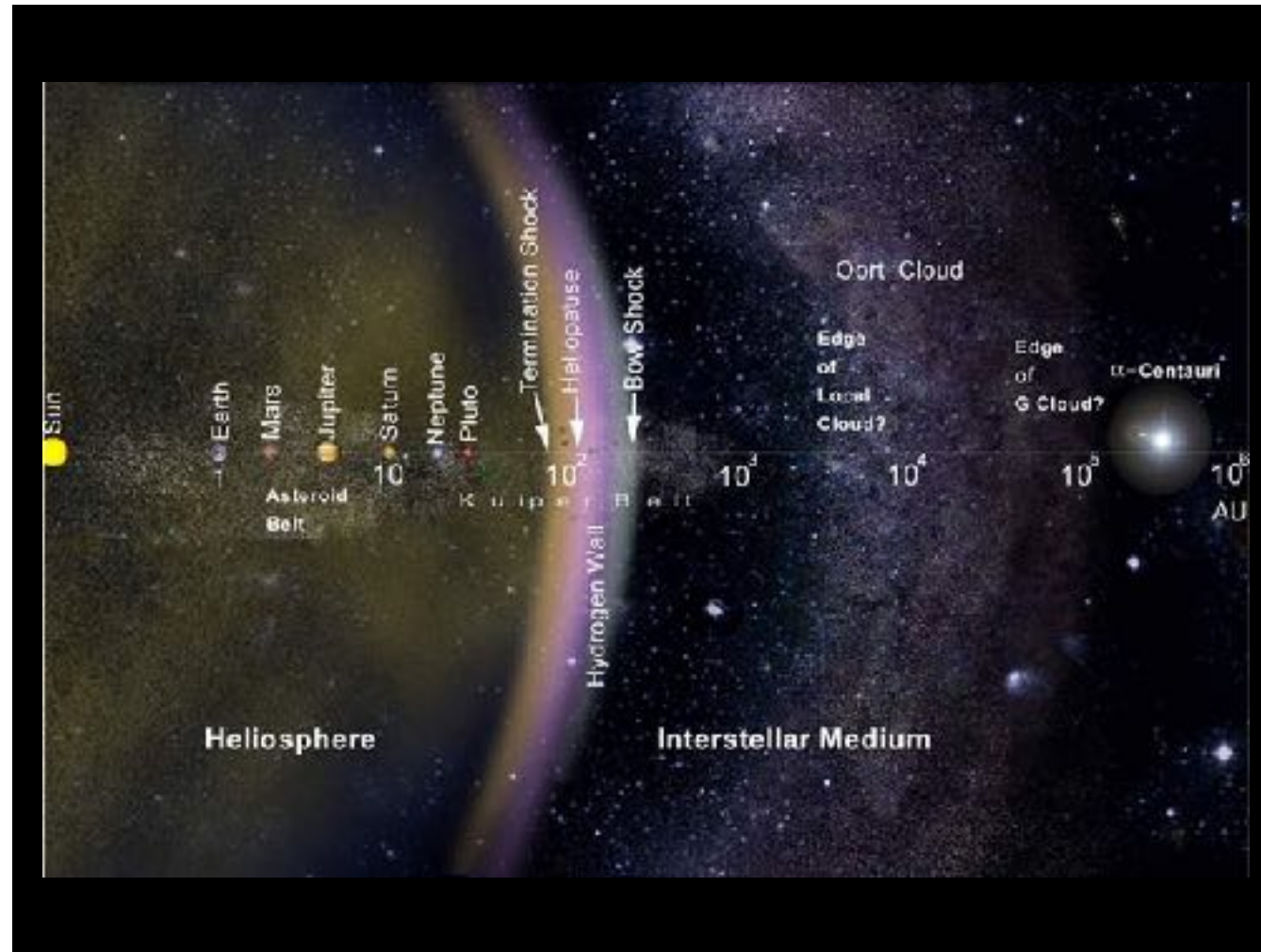
we are on a sphere of mostly molten rock and metal 13,000 km across with a fuzzy atmosphere about 100 km high



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



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

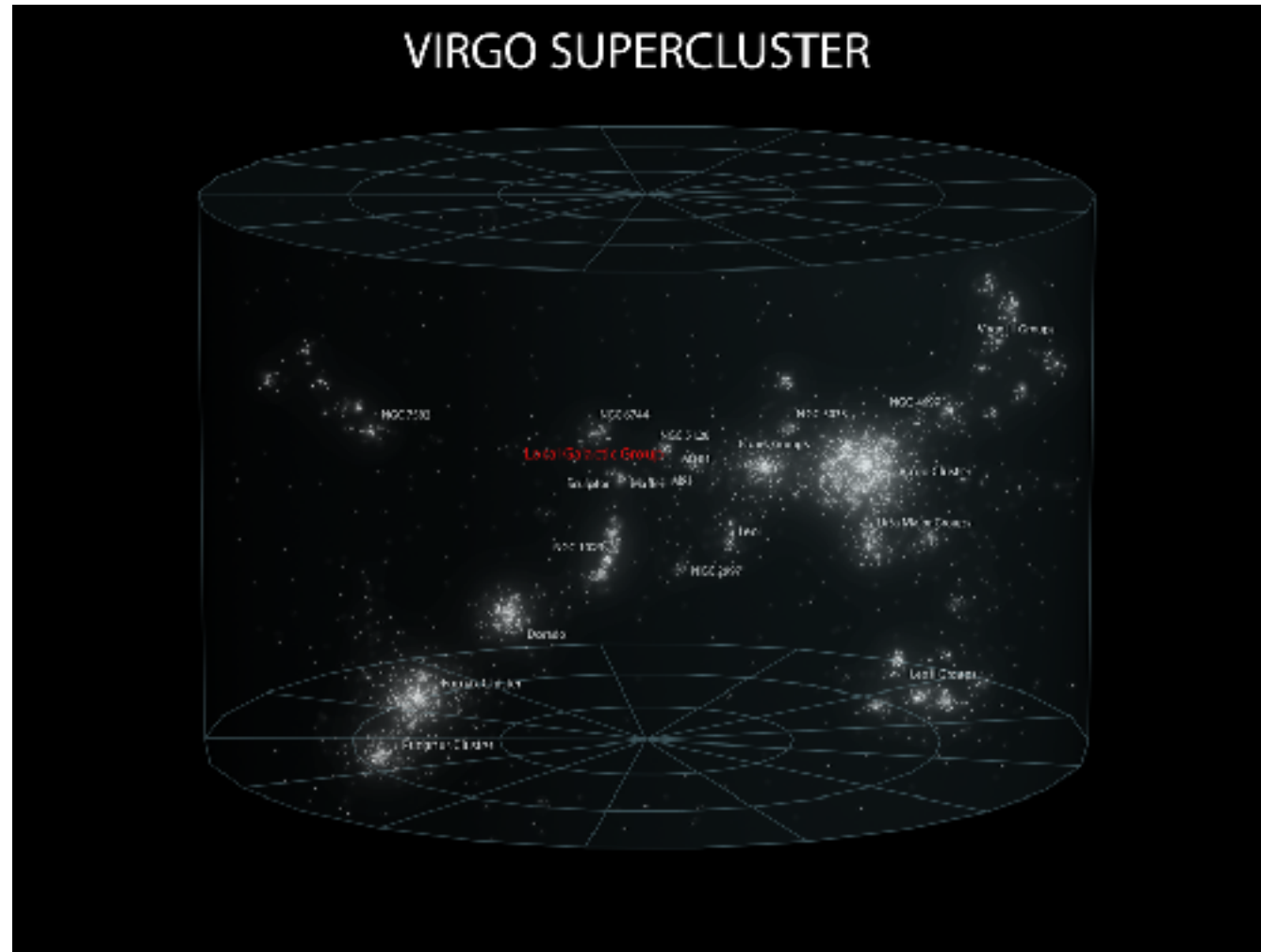


all of which can be seen by other galaxies in our local group, like Andromeda and Triangulum



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

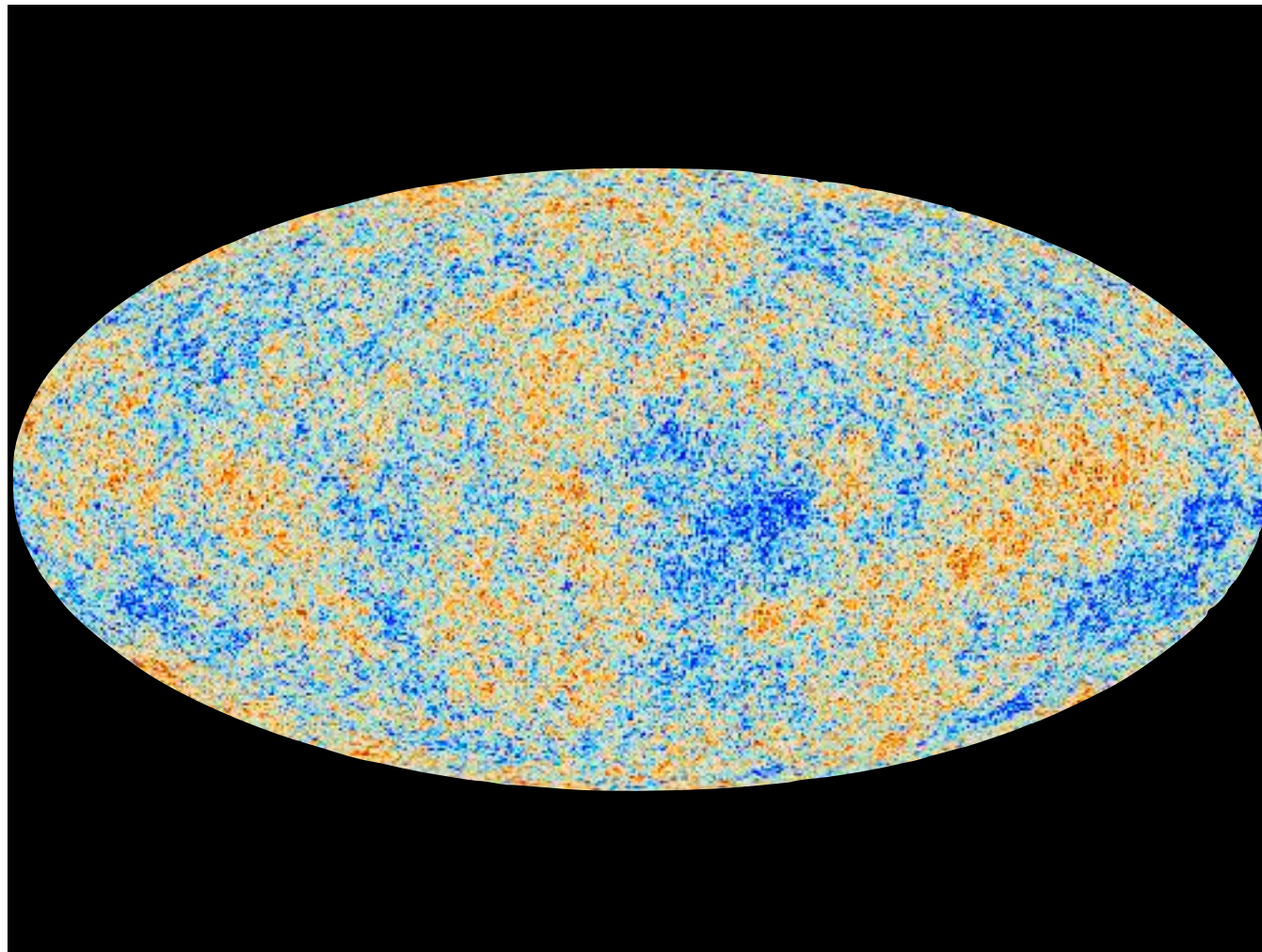
VIRGO SUPERCLUSTER



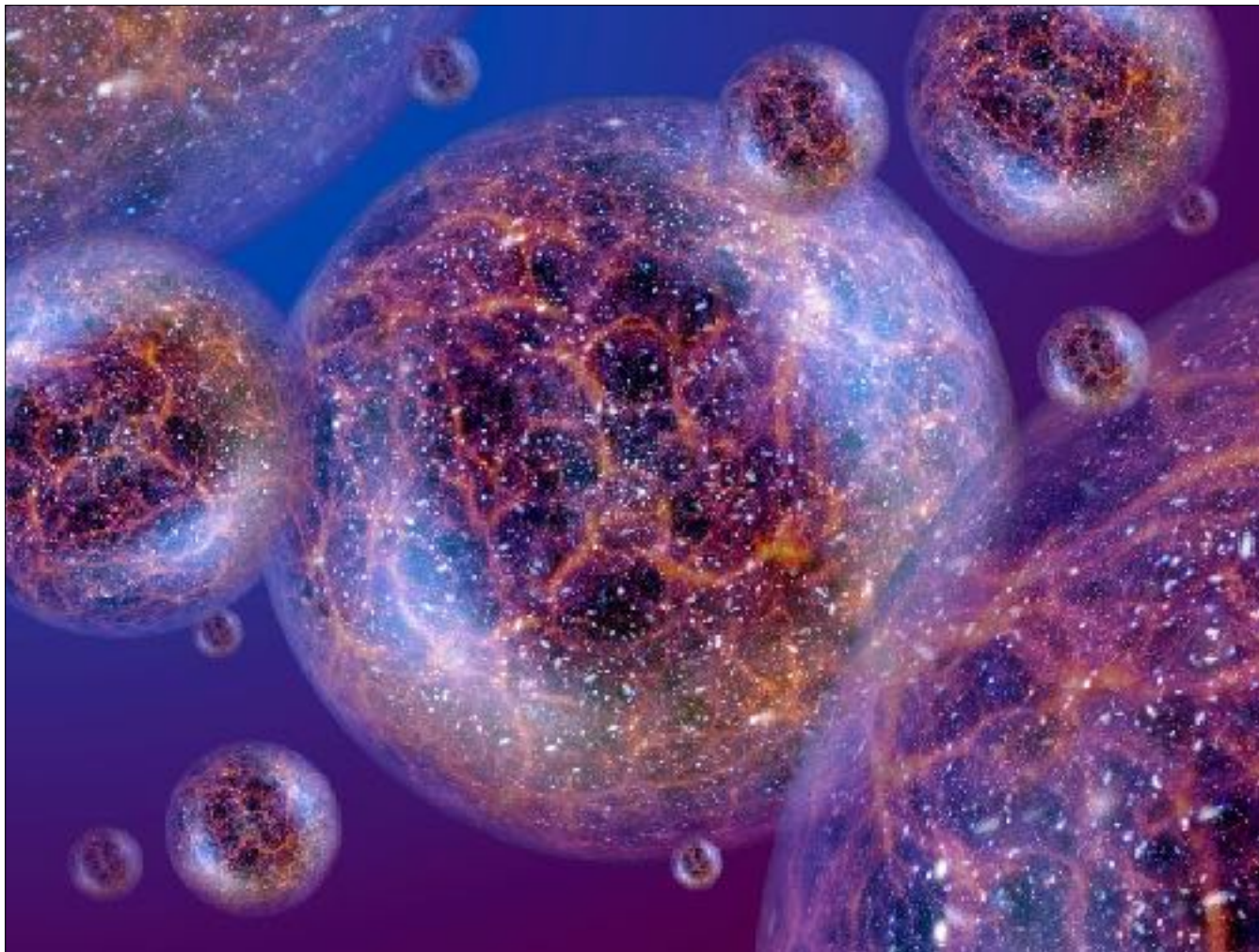
which is part of the Virgo Supercluster



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

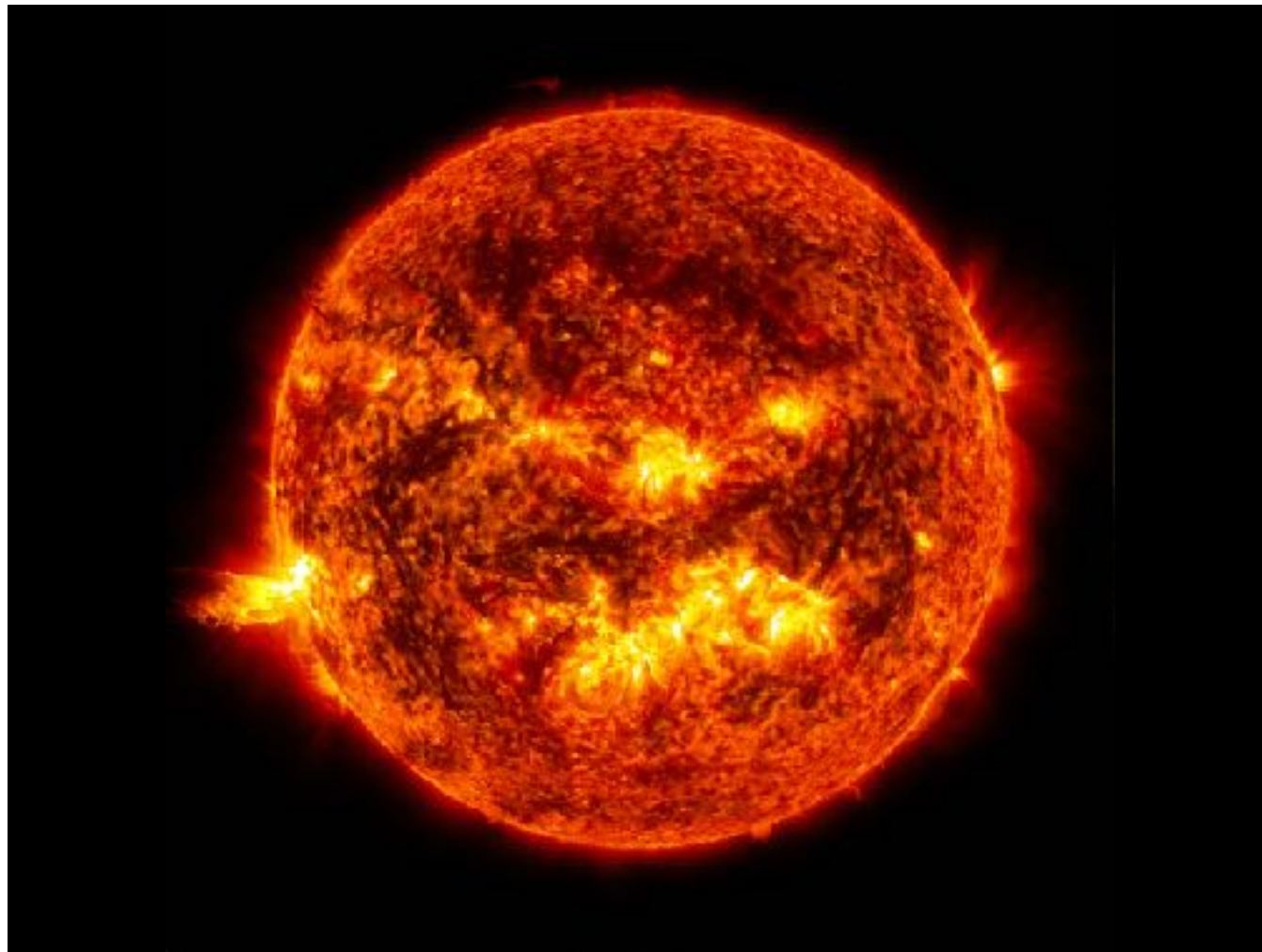


which is 90 billion light years across and expanding everyday, even faster today than yesterday, due to mysterious “dark energy”



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

ASTROLOGY

"STUDY OF THE STARS"

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

Astronomy — SCIENCE

Astrology — NOT SCIENCE

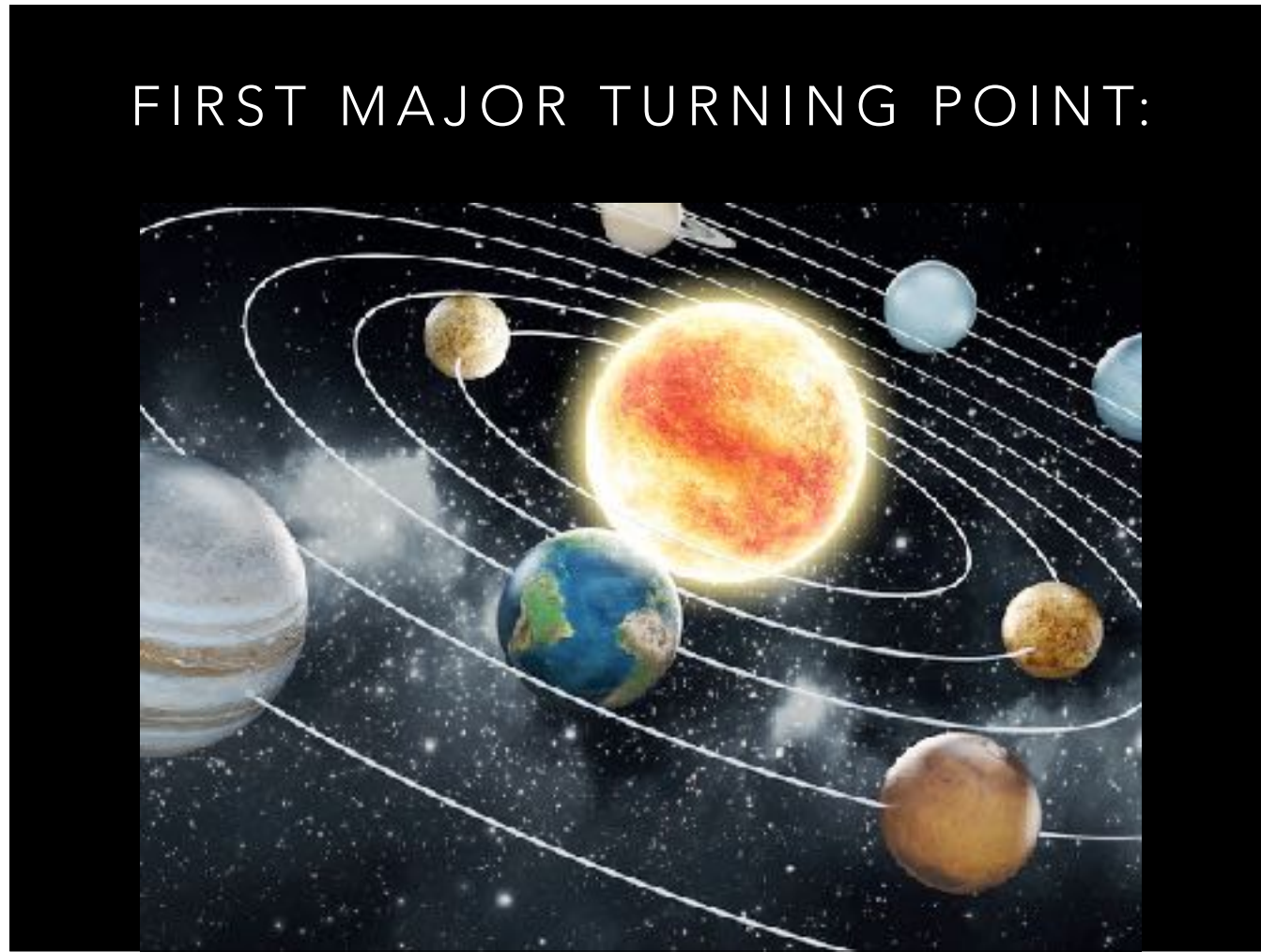
But a millennia ago, astrology was as close to science as you got. It had some of the flavors of science

ASTROLOGERS...

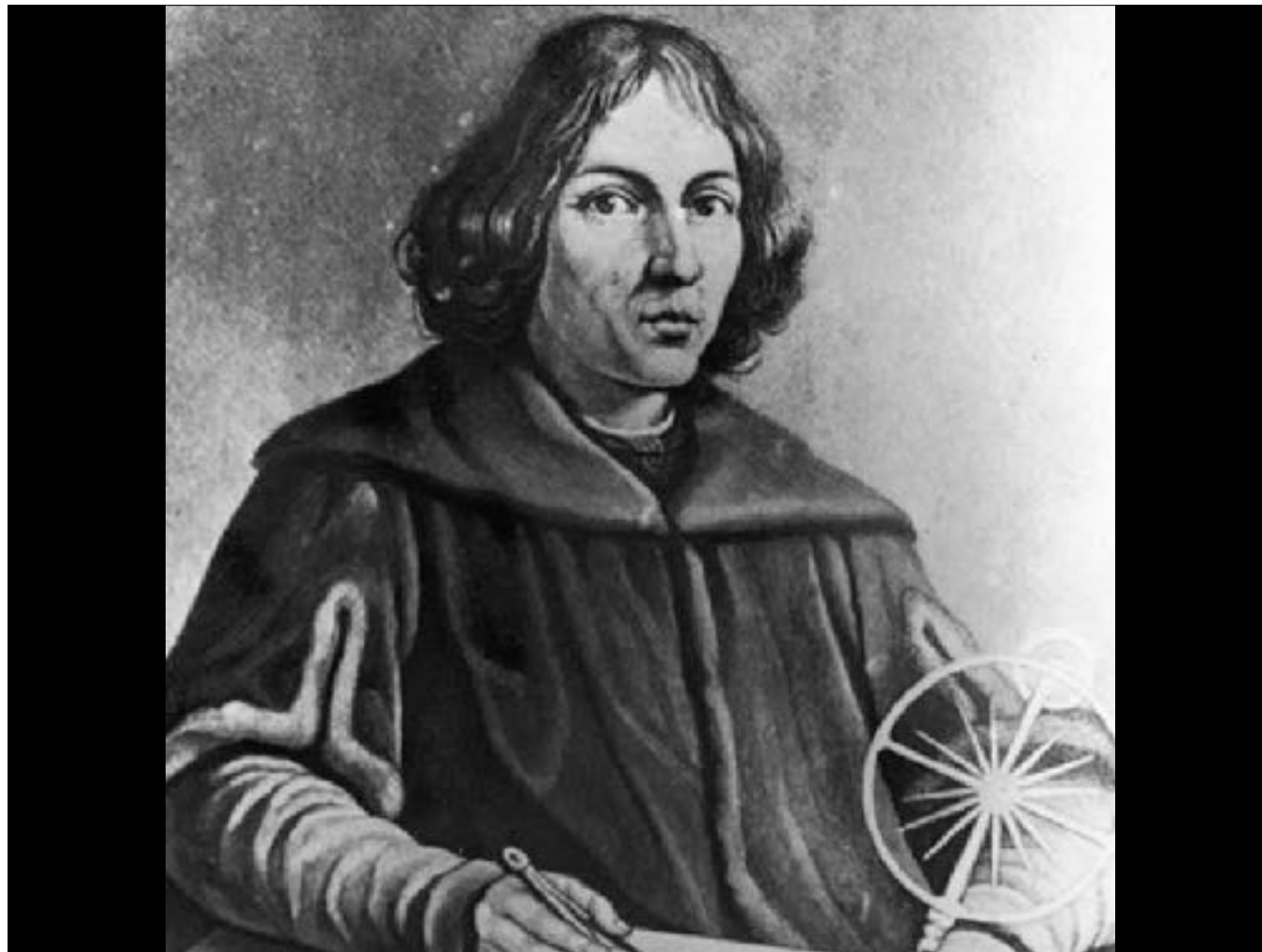
- observed the skies
- and made prediction about how it would effect people
- then those people would provide evidence for it by swearing it worked

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



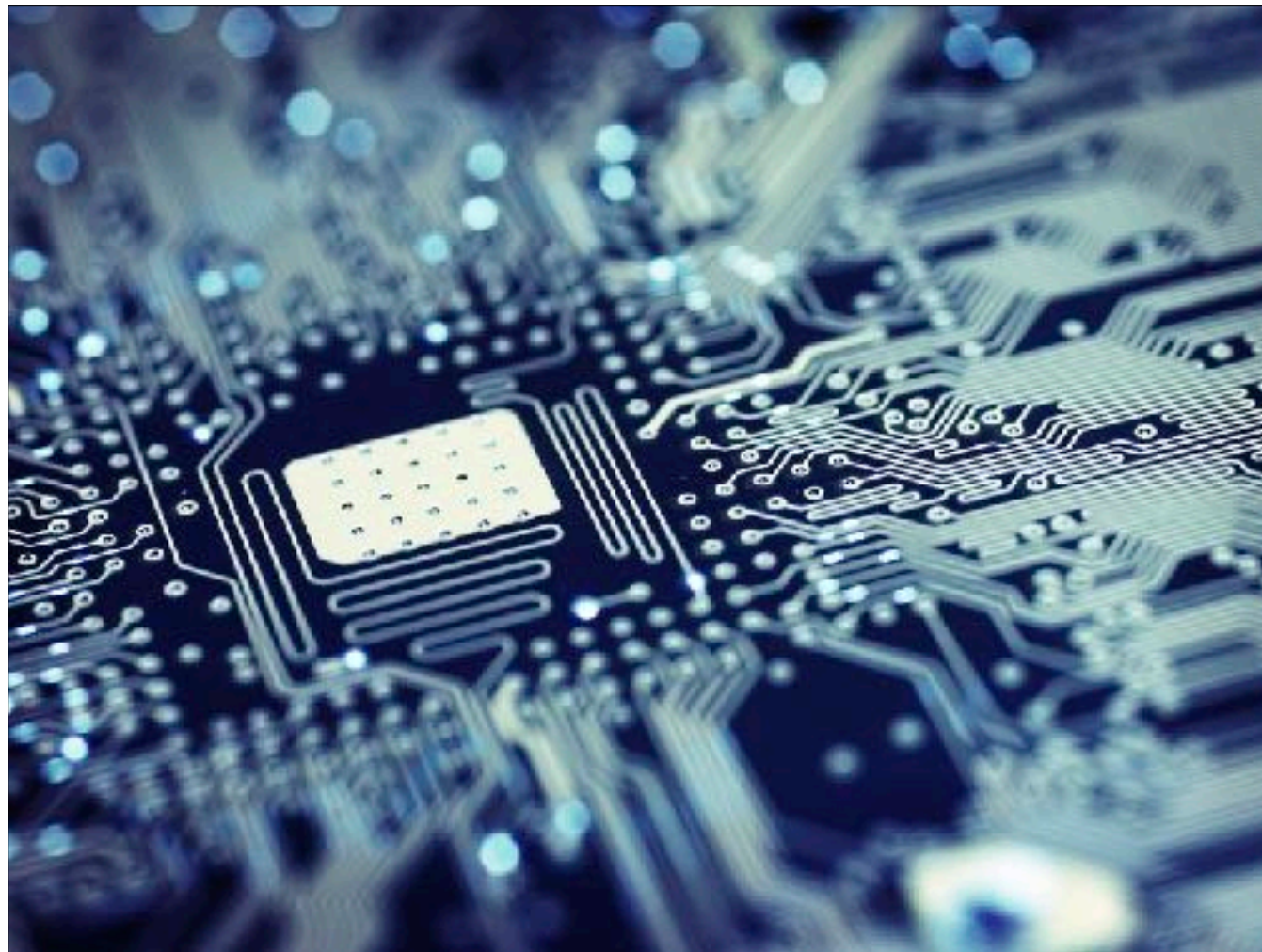
Thanks in large to Isaac Newton, our physics got better, our math got better, and applied mathematics became a revolution in astronomy



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 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



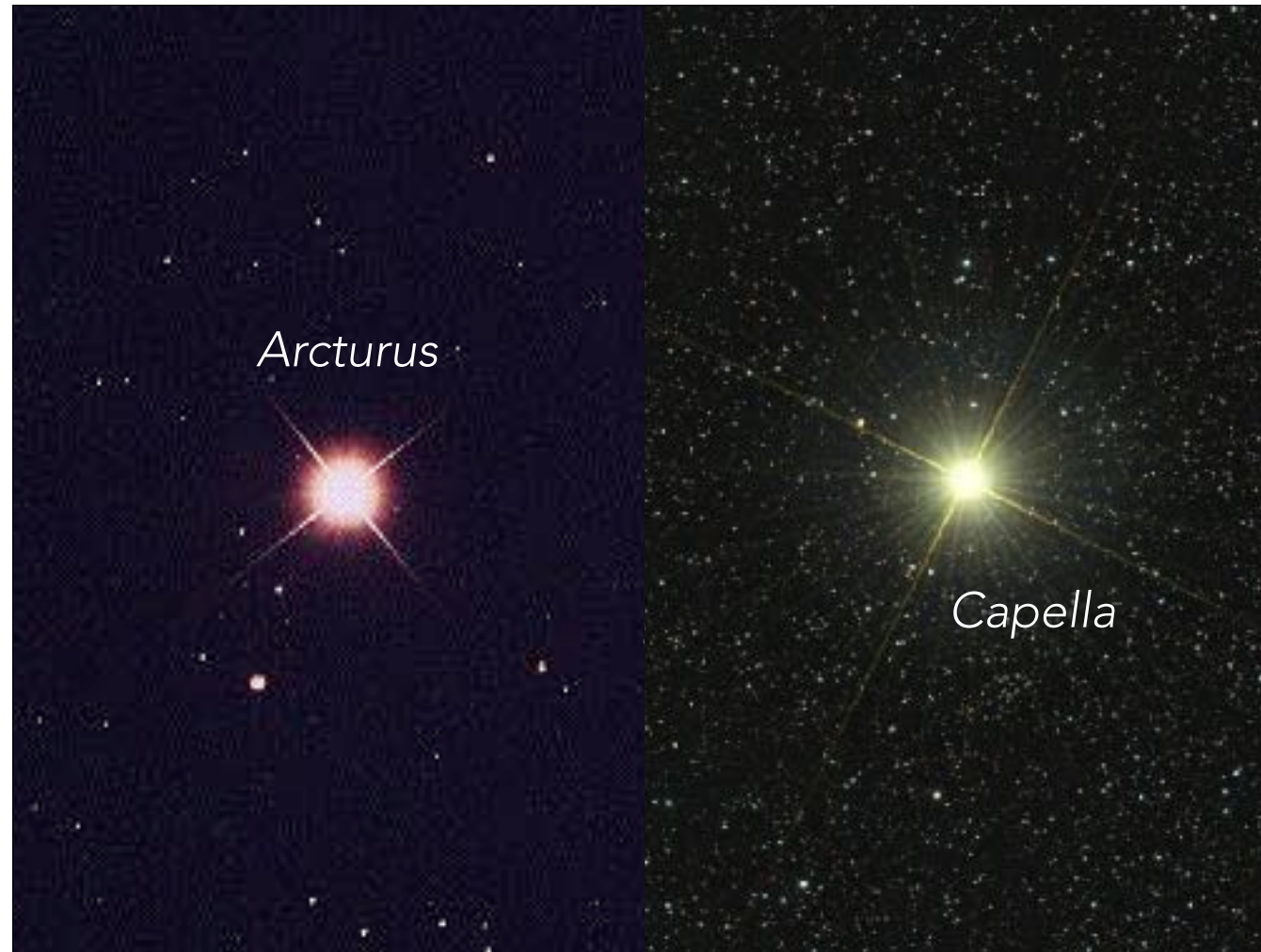
The brightest star in the night sky, Sirius, the Dog Star, is about 1,000 times brighter than the faintest star you can see



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

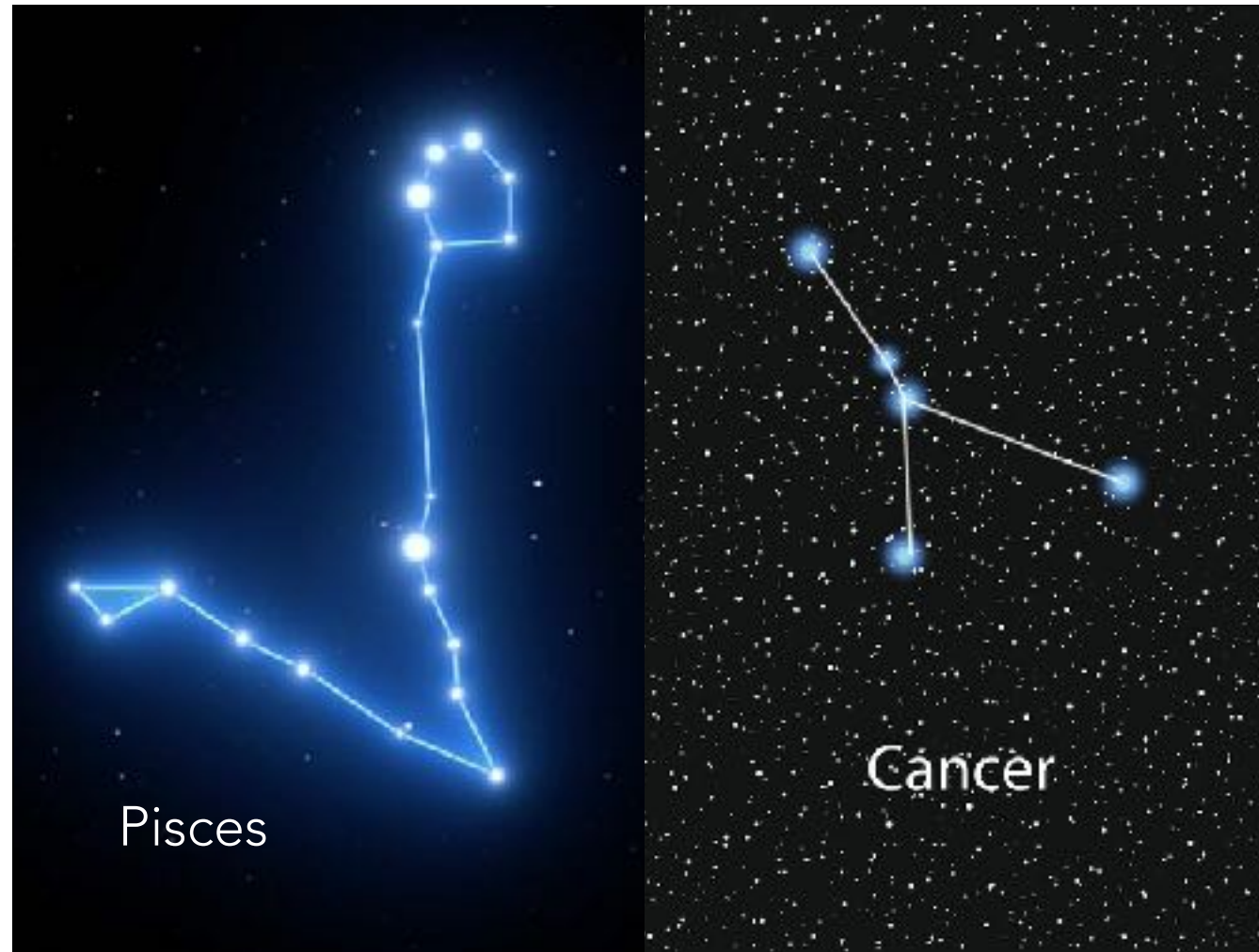
THE HUNTER
ORION



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

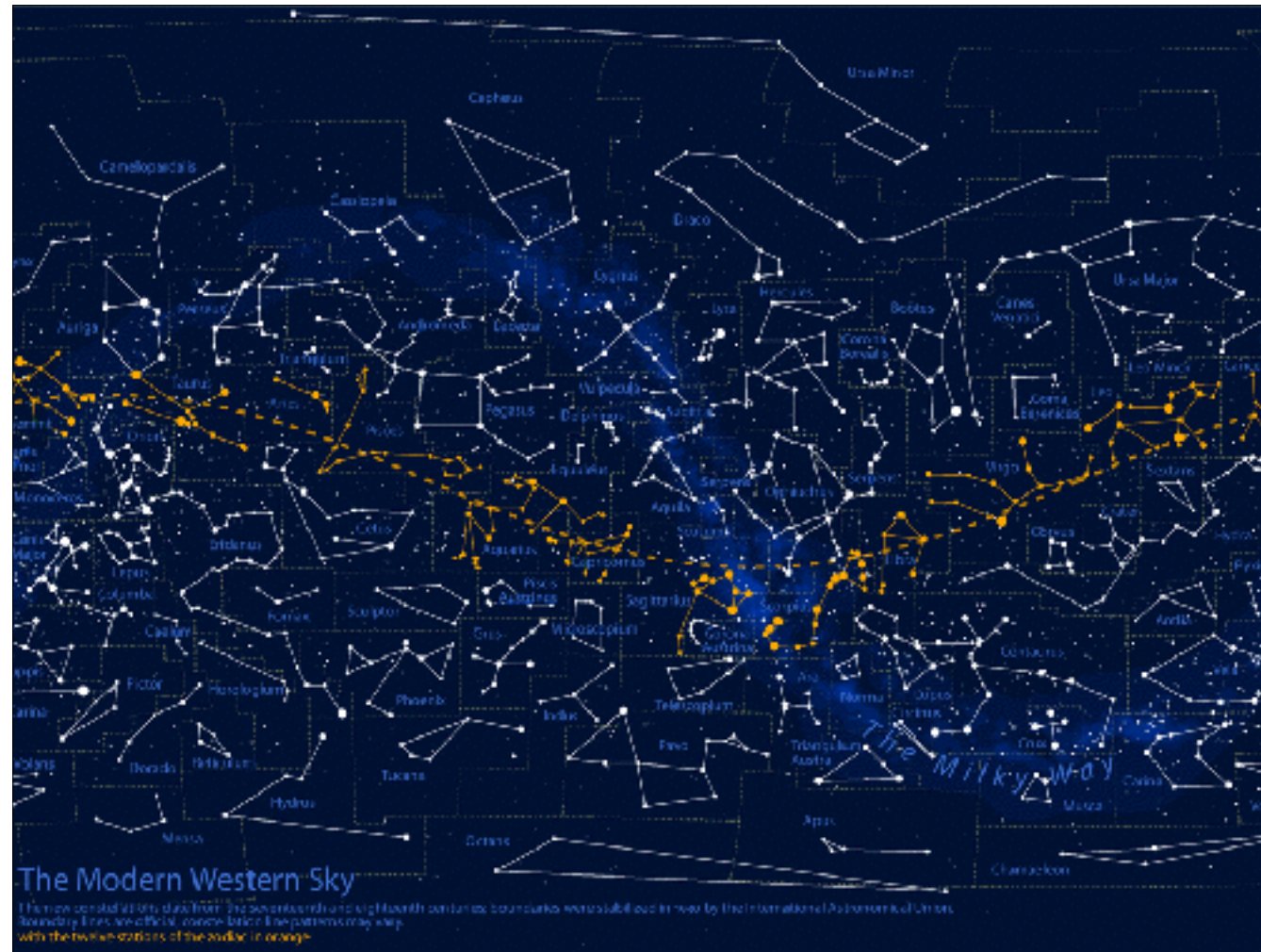


Tiny Delphinus isn't hard to see as a dolphin leaping from the water, and it's not a stretch to see Scorpius as a scorpion



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

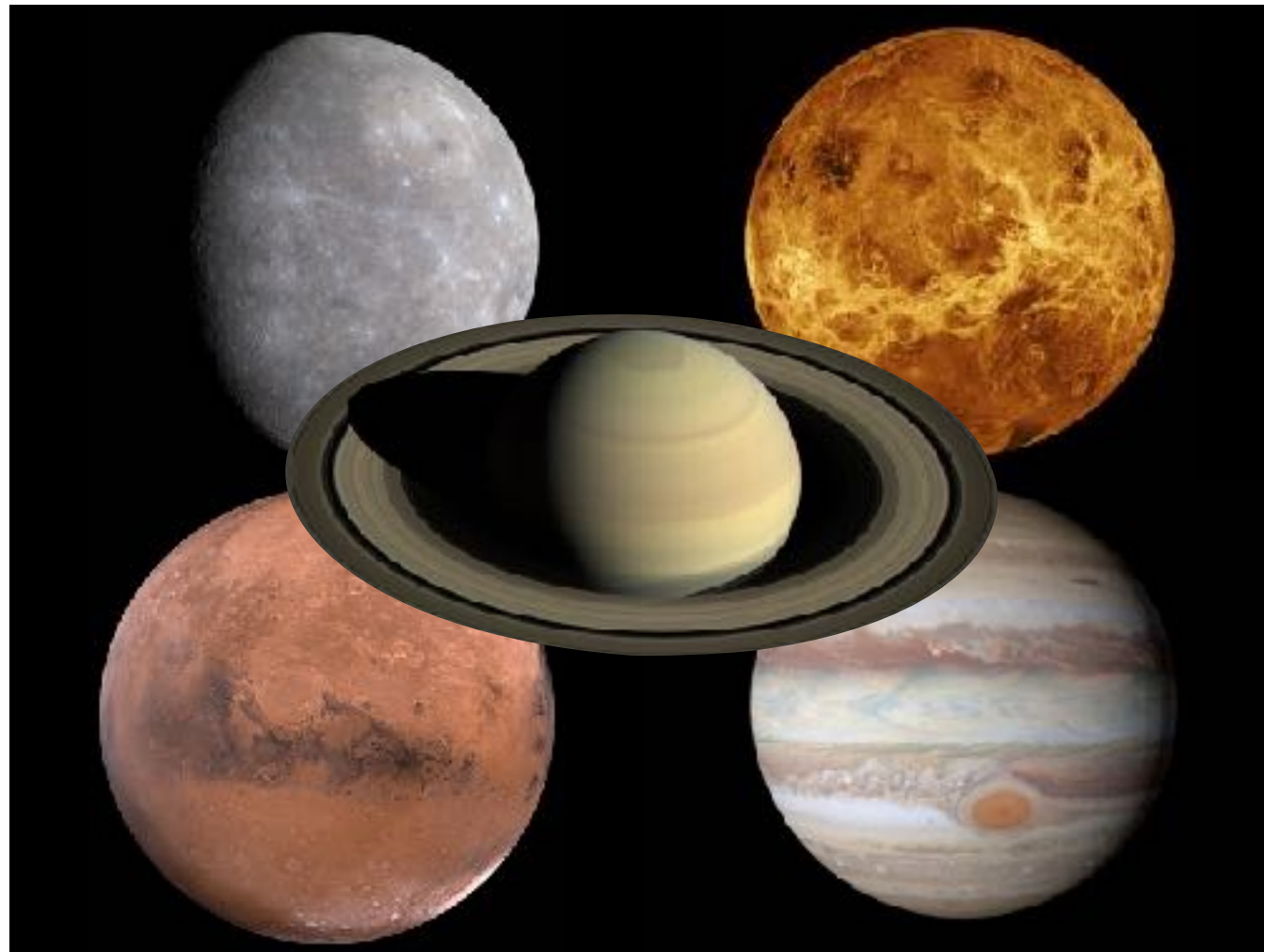
1. There are a *lot* of a stars
2. They're not all the same brightness
3. They're different colors
4. They aren't scattered evenly across the sky
5. Not all "stars" twinkle
- 6.



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
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. 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



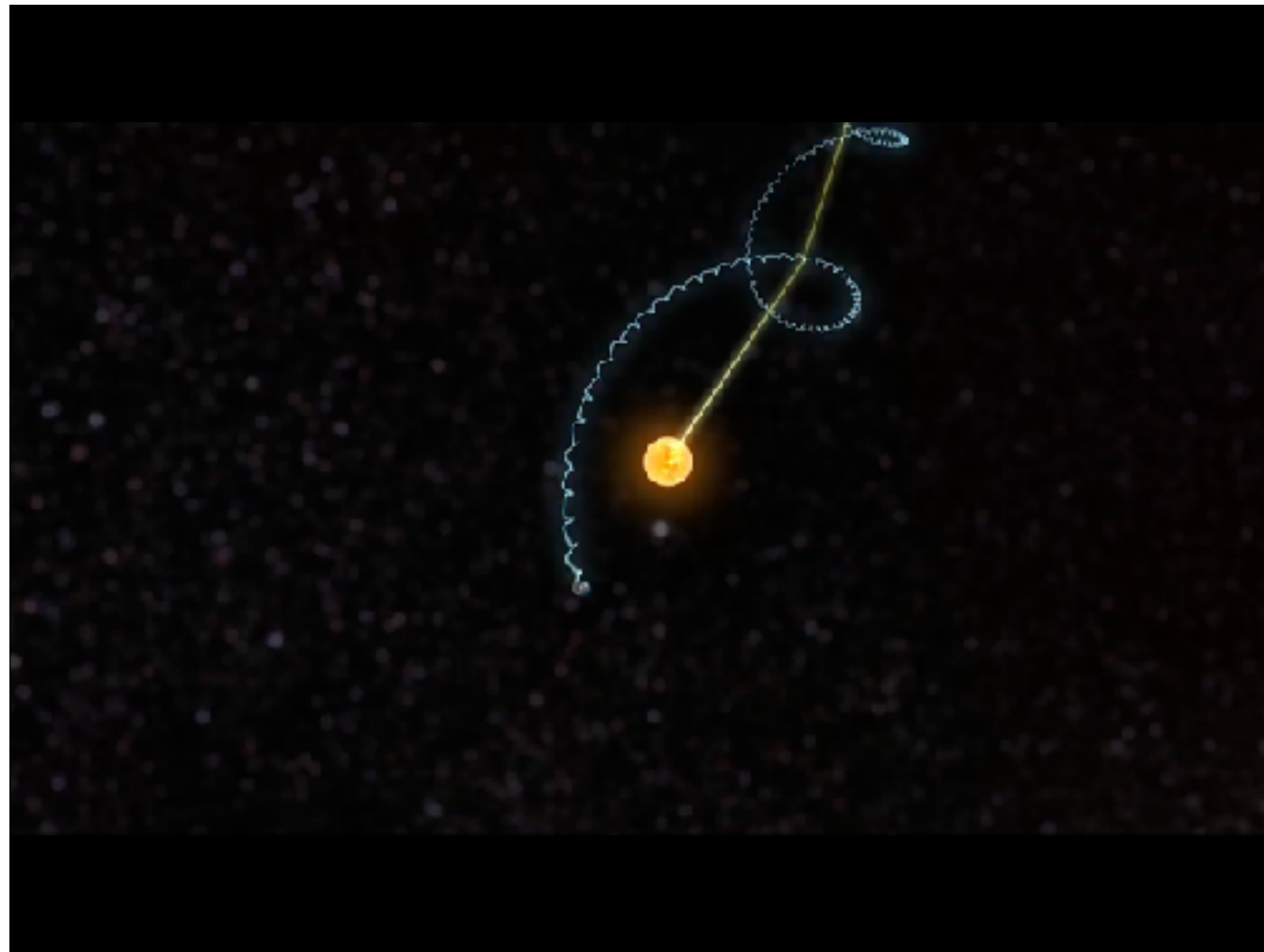
- This apparent movement is really just a reflection of Earth spinning. The Earth rotates once per day, and we're stuck to it, so it looks like the sky is spinning around us in the opposite direction
- Everyday, you make a circle around Earth's axis of rotation. The closer you are to the equator, the 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

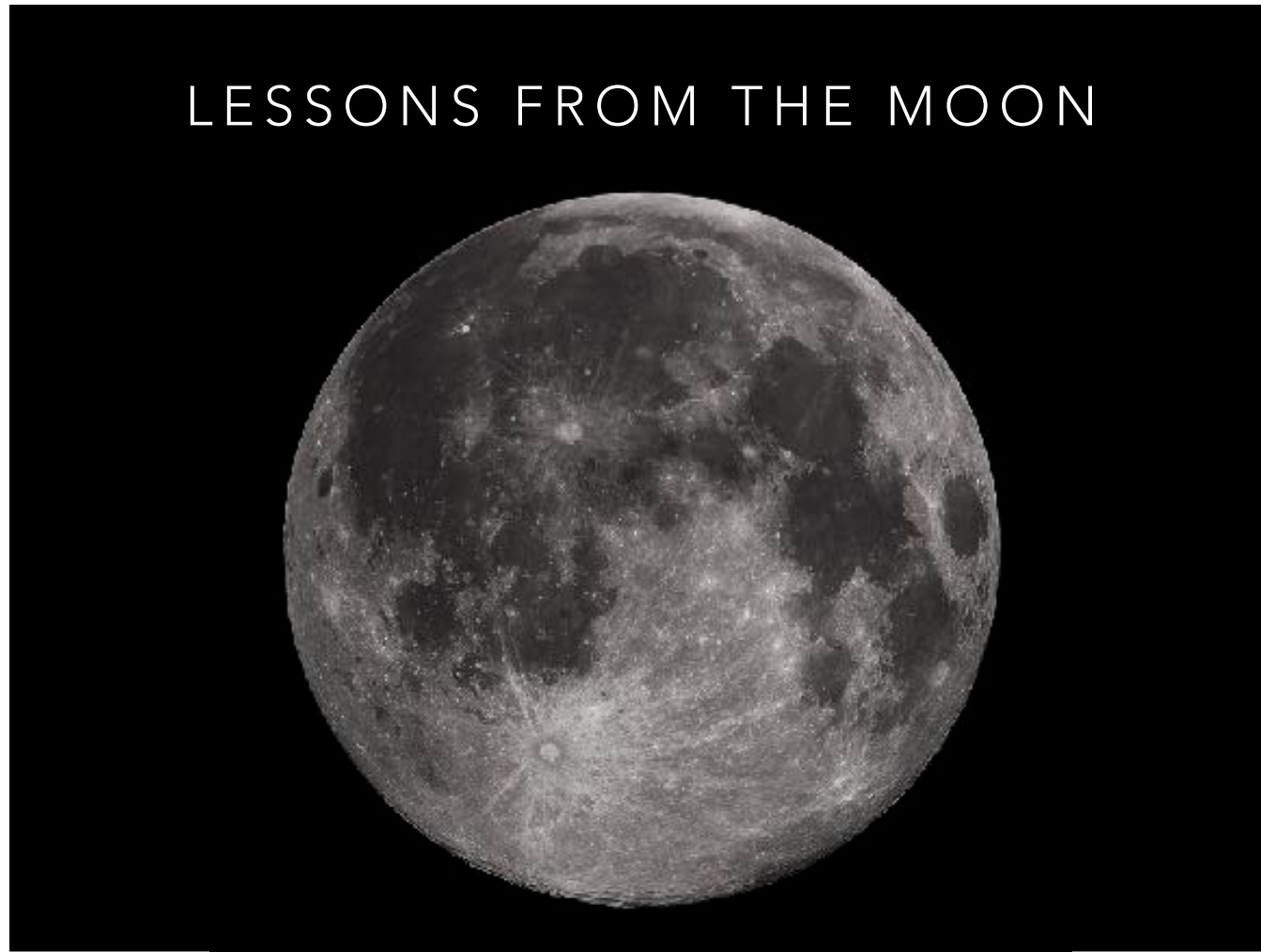
- If you stand on the North Pole, Polaris will directly overhead, and stars on the celestial equator would appear to circle the horizon once per day
- That also means that stars south of the celestial equator can't be seen from Earth's North Pole; they're always below the horizon
 - From Antarctica,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



How Earth Moves (20 min) — VSauce

<https://www.youtube.com/watch?v=IJhgZBn-LHg>

LESSONS FROM THE MOON



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

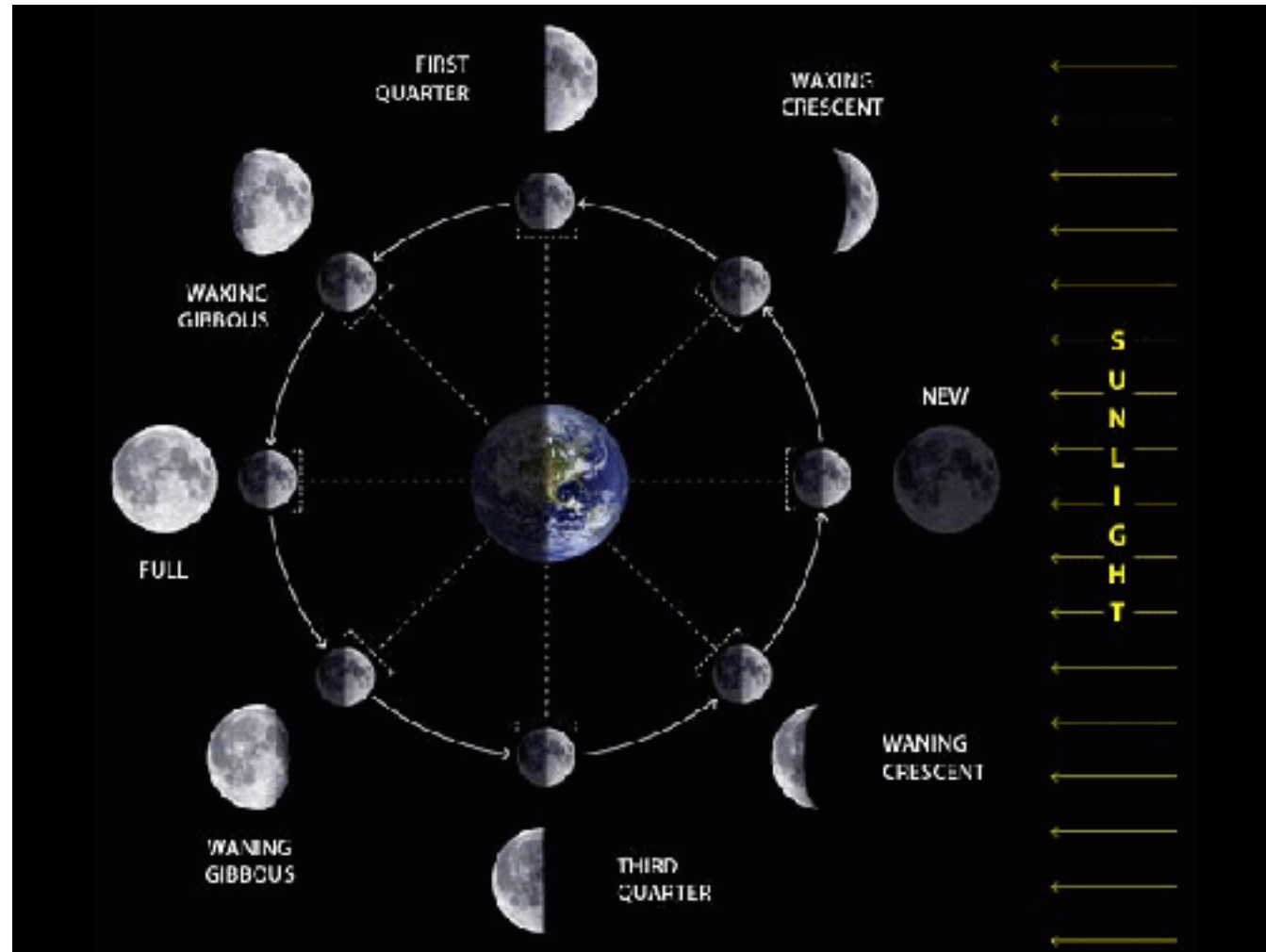


WAXING
CRESCENT
MOON

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 are lit on the left (either way, whichever side points toward the Sun is lit)



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?

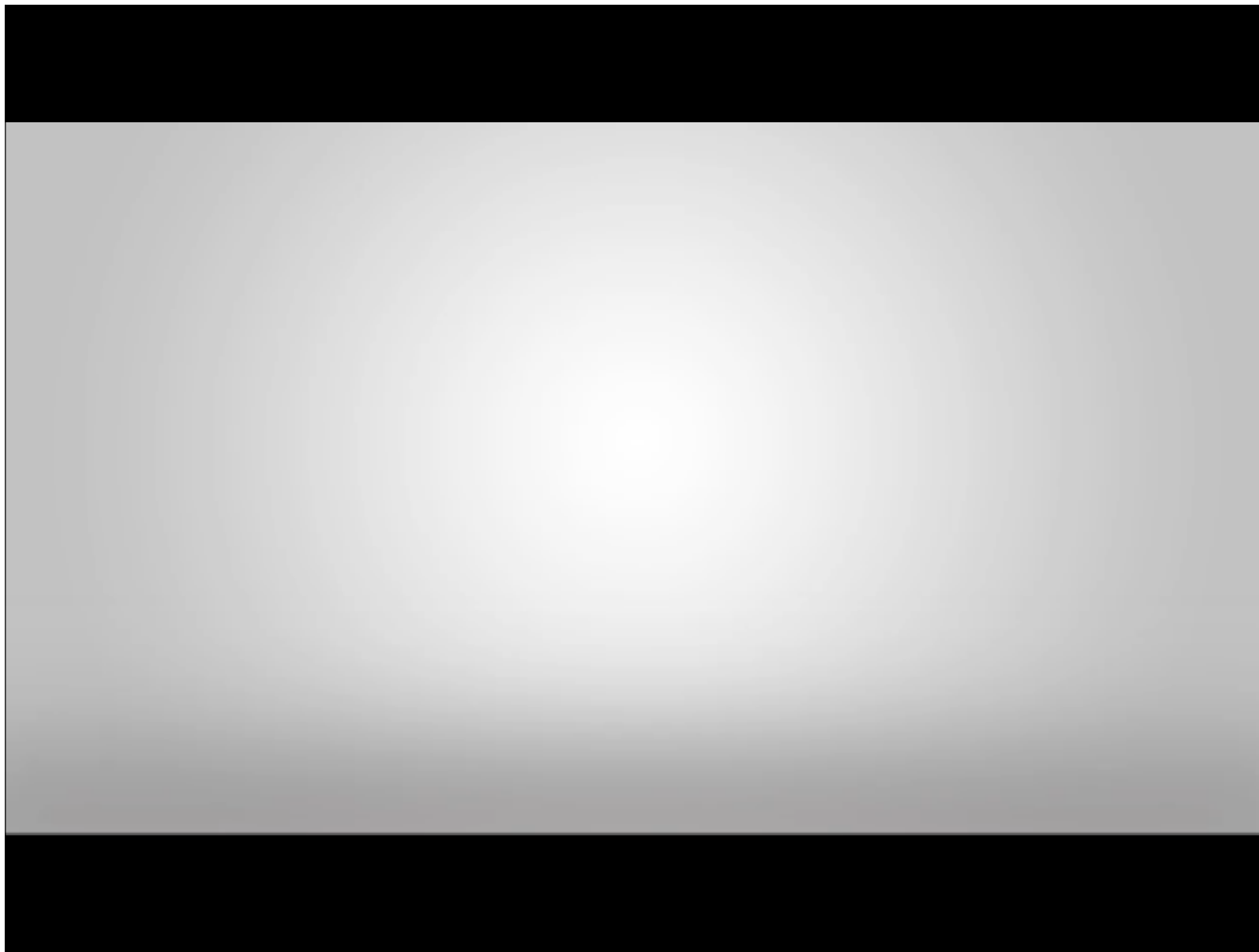
Yes; yes, but upside-down



Northern Hemisphere



Southern Hemisphere



Eclipses: Crash Course Astronomy (10 min)

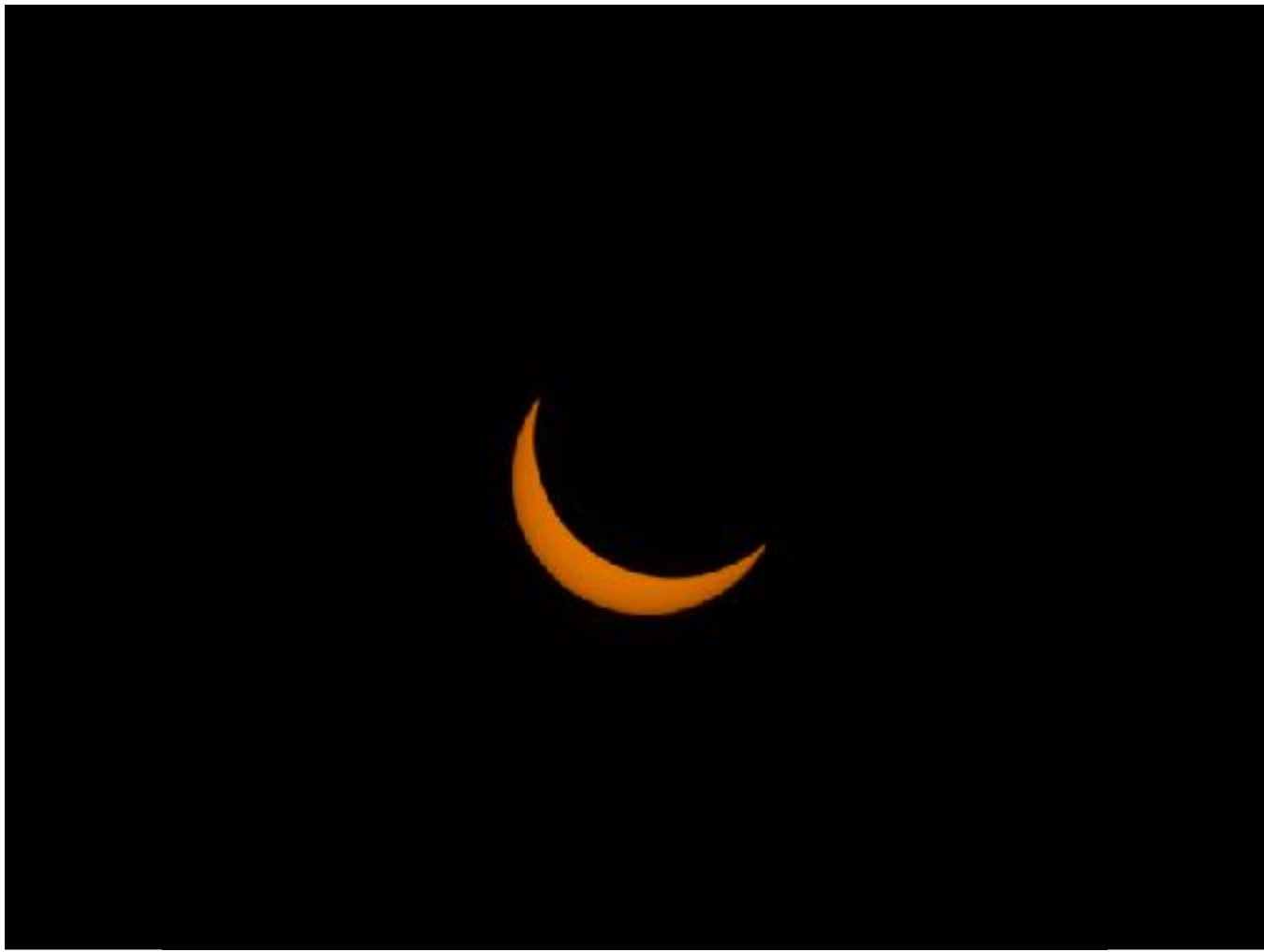
<https://www.youtube.com/watch?v=PRgua7xceDA&t=302s>

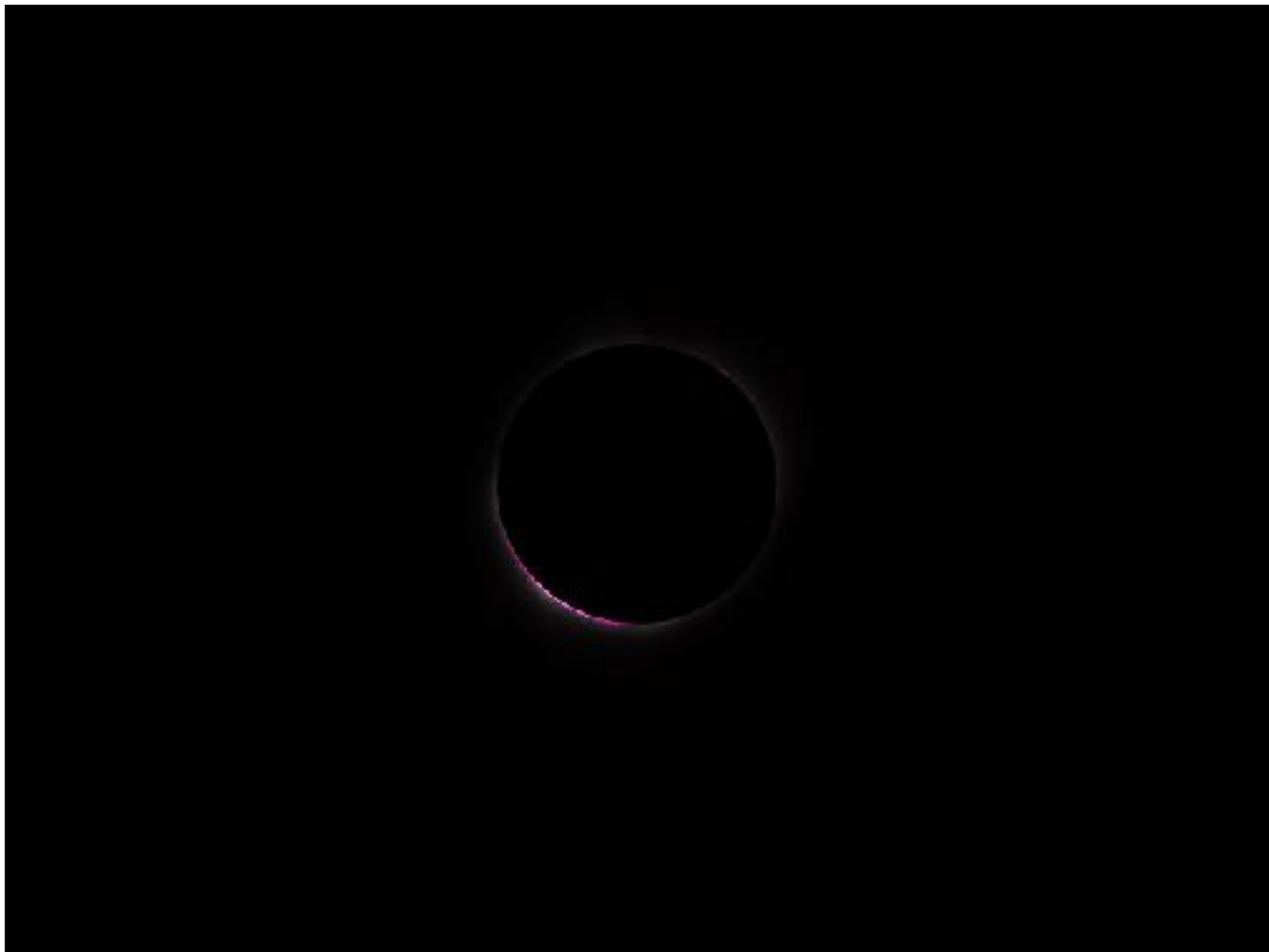
ECLIPSES

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















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



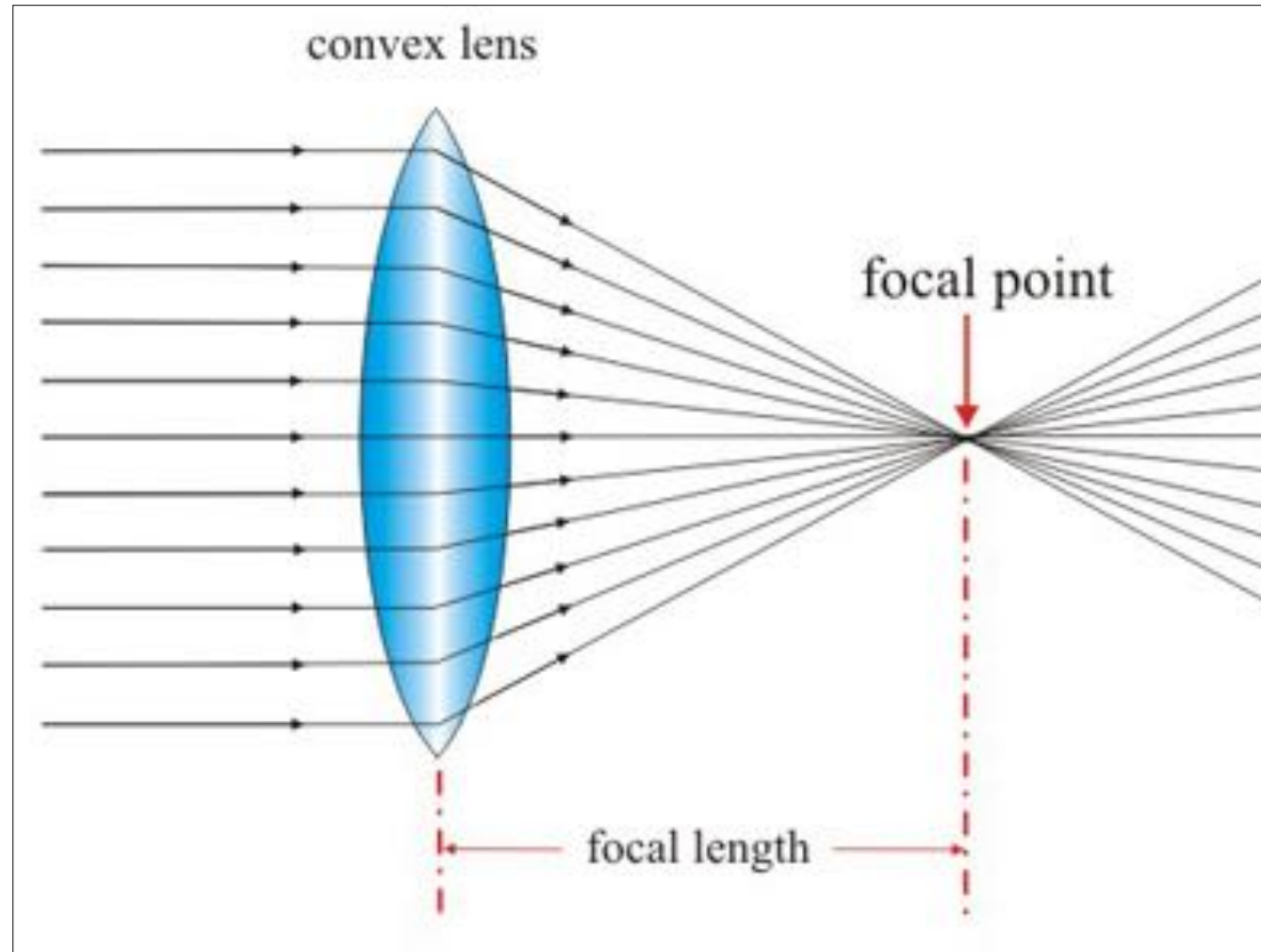
A telescope works by gathering light. Think of it like a bucket in the rain. The bigger the bucket, the more water you collect. Get a big enough bucket, and you'll collect plenty of water even if it's only sprinkling out

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



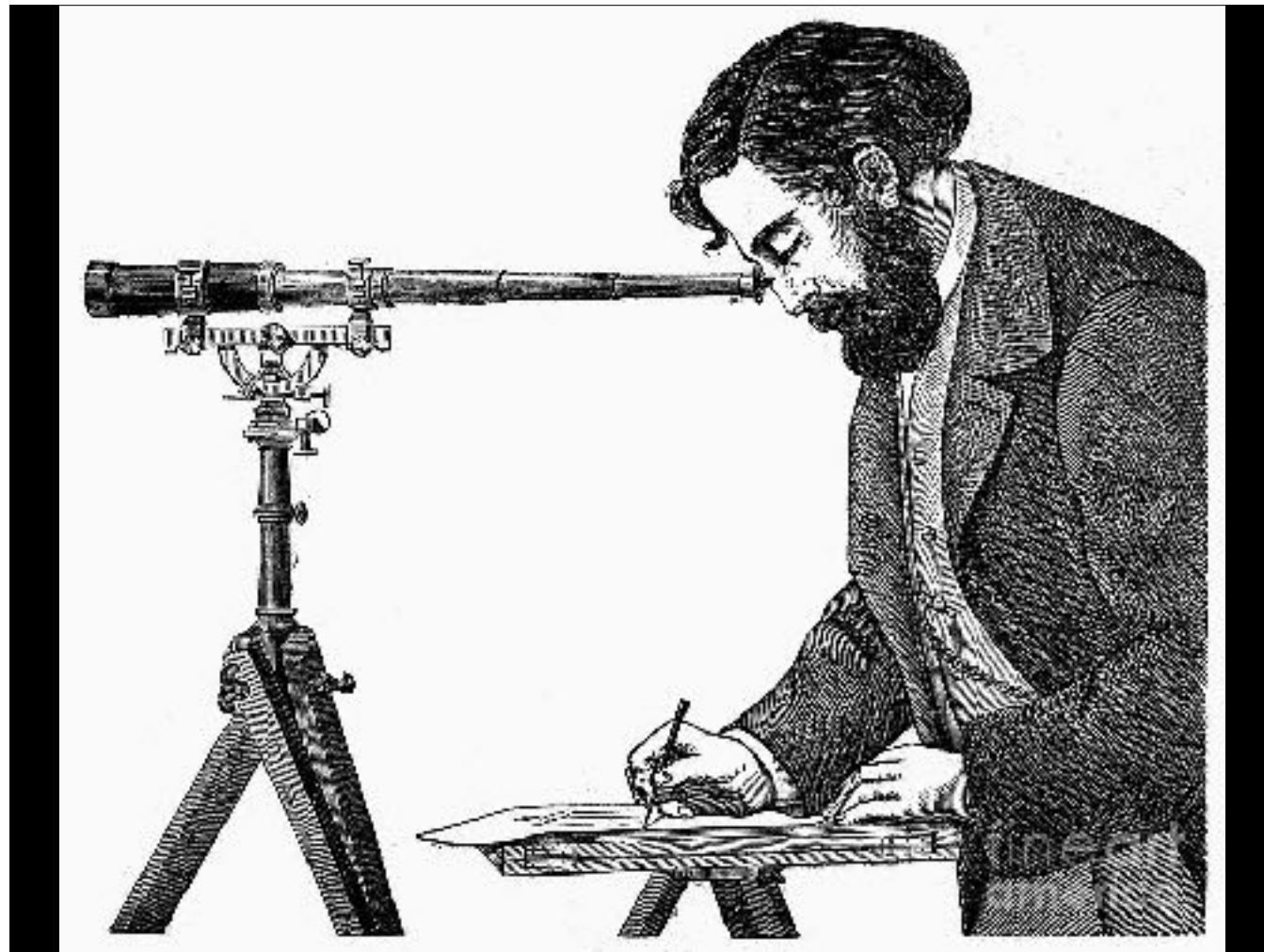
Double the diameter of the collector and you collect 4x as much light. Make it 10x bigger, you collect 100x the light, etc. So a telescope with a lens even just a few centimeters across can easily reveal stars invisible with the naked eye

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 see craters on the Moon, moons around Jupiter, the phases of Venus, the rings of Saturn, and much more

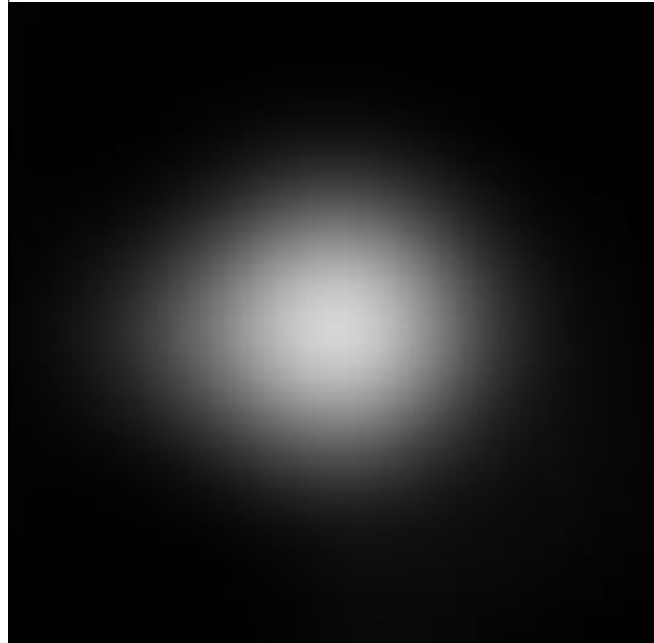
Resolution — the ability to distinguish objects or details that are very close together

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

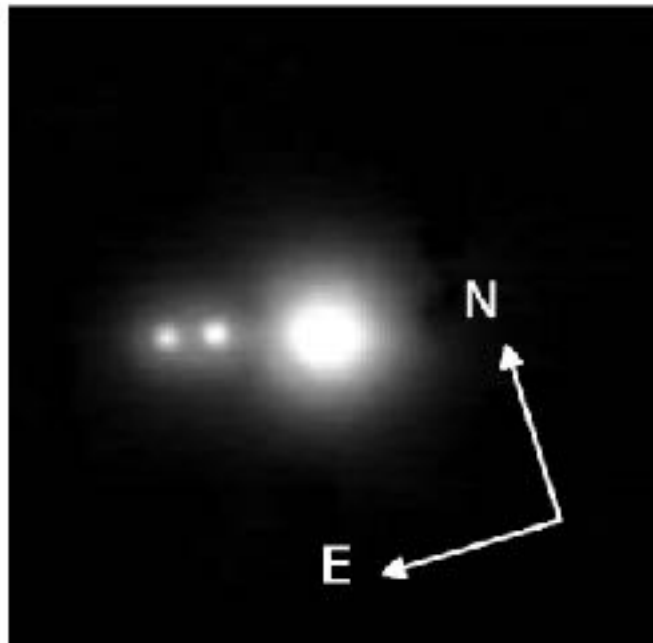


When driving on a road at night, a distant car heading toward you appears as a single light. As it gets closer, the light separates out — *resolves* — into two headlights

Low Resolution



High Resolution



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

RESOLUTION...

- depends on the size of the objective
- is more useful than magnification



- 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

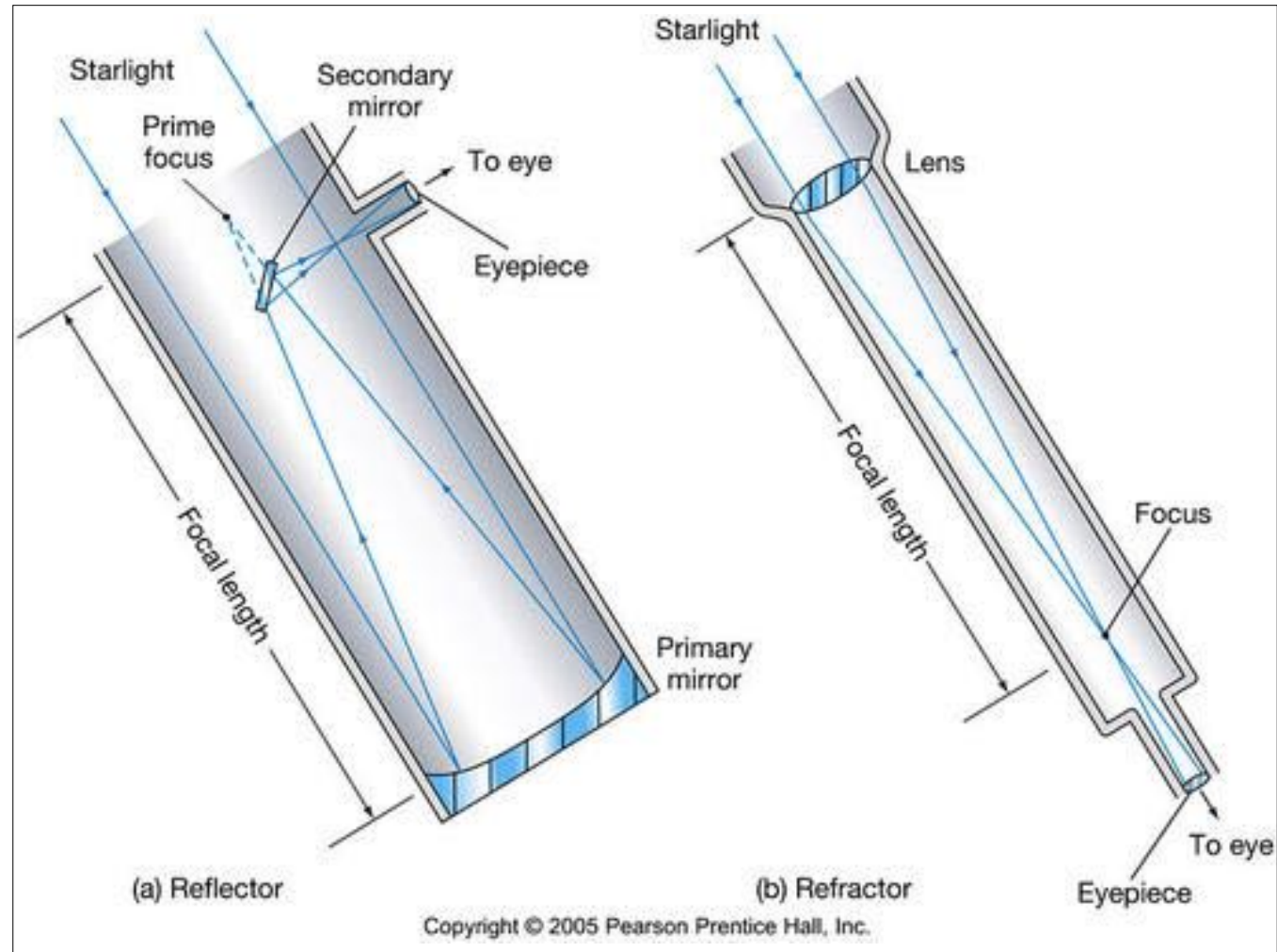
DISADVANTAGES OF REFRACTING TELESCOPES

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



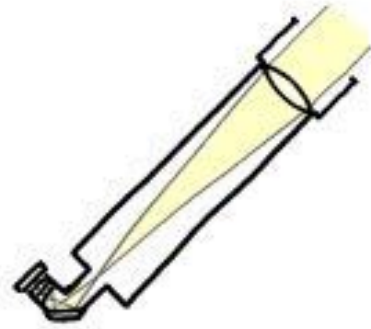
Refracting vs. Reflecting Telescopes

ADVANTAGES OF REFLECTING TELESCOPES

1. You only have to polish one side of a mirror
2. Mirrors can be supported from the back

1. Lenses 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

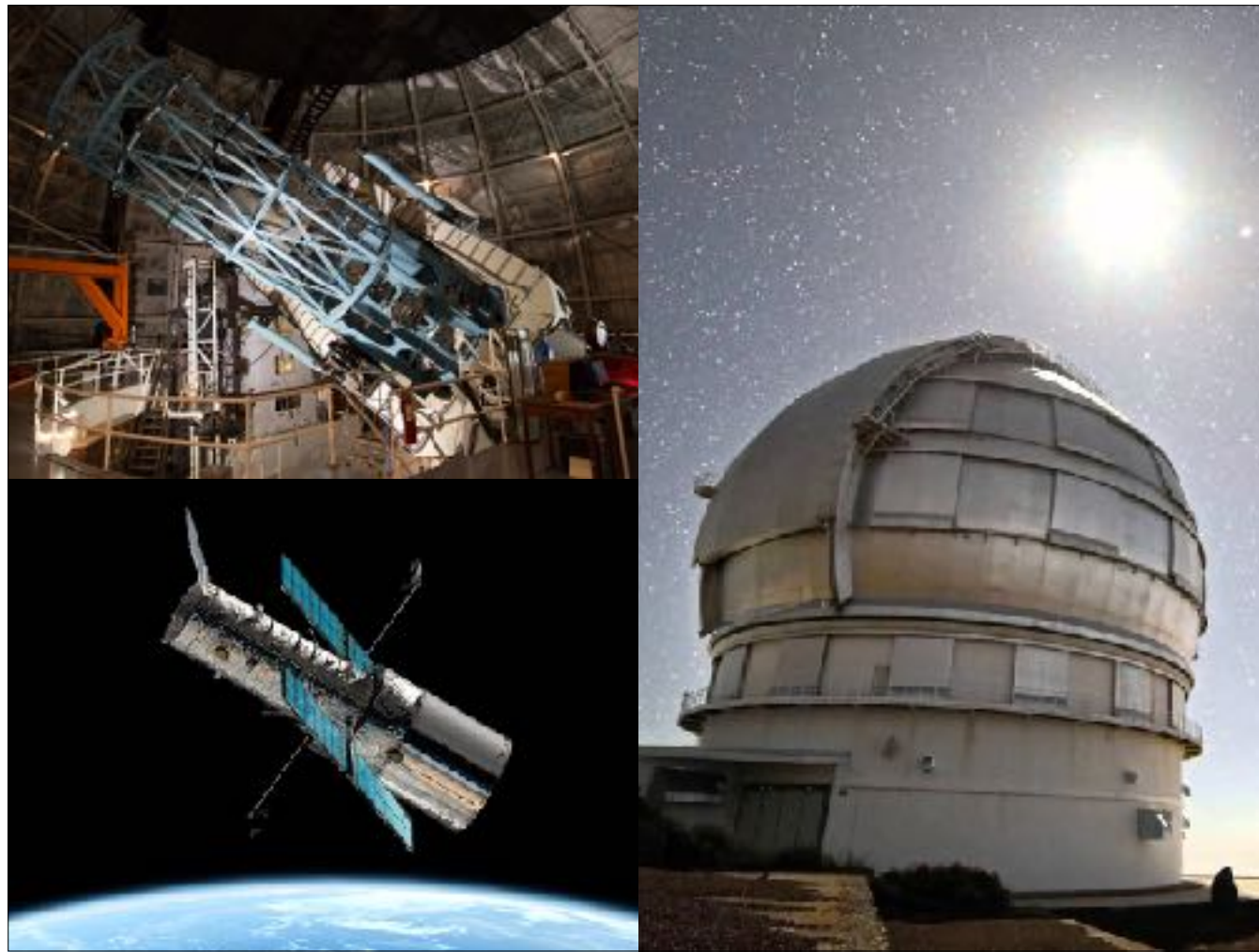


- MORE EXPENSIVE
- LESS COMPACT
- CHROMATIC ABERRATION
- REDUCED LIGHT-GATHERING

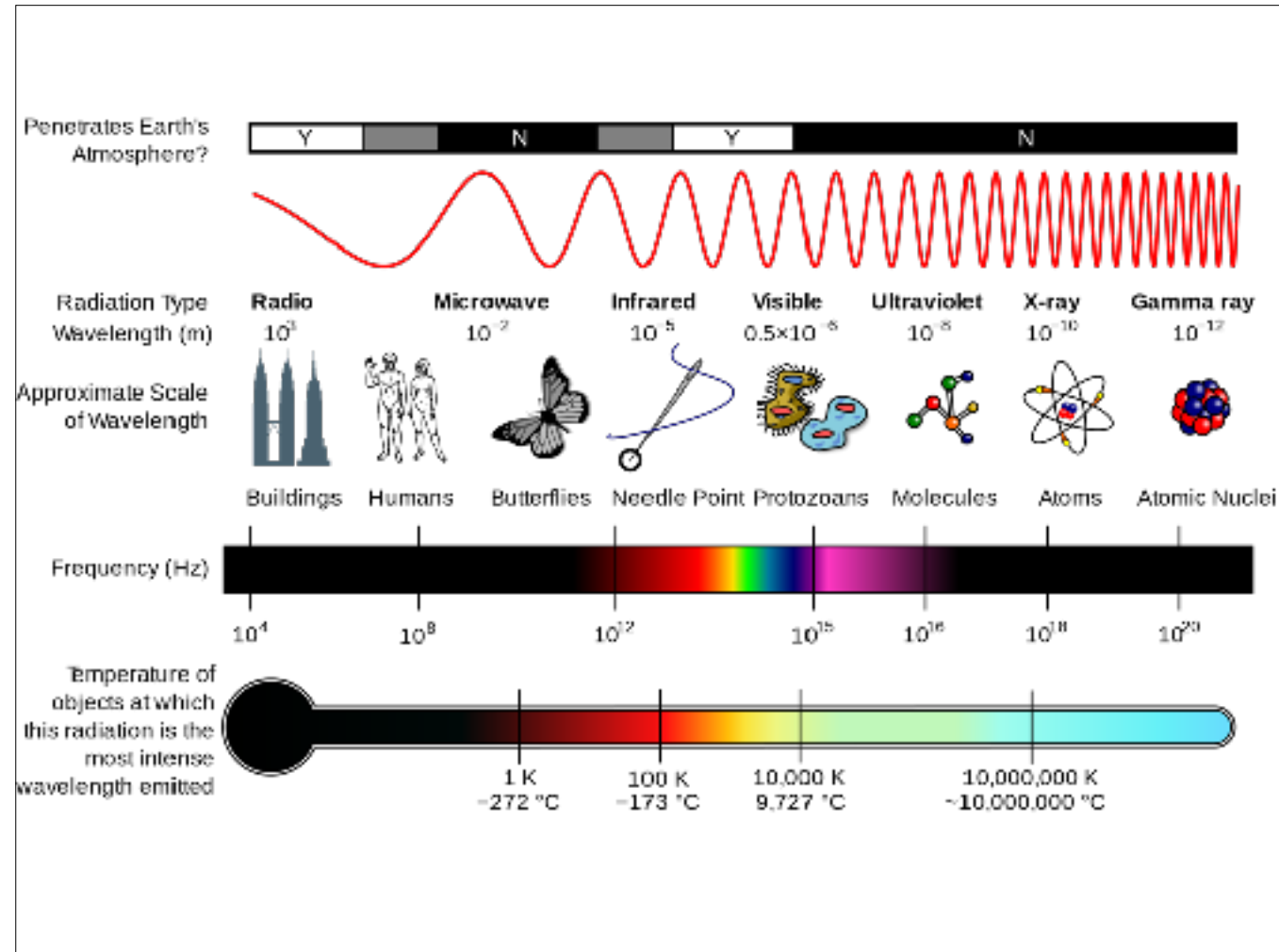
REFLECTOR



- CAN'T SEE SPACE VAMPIRES



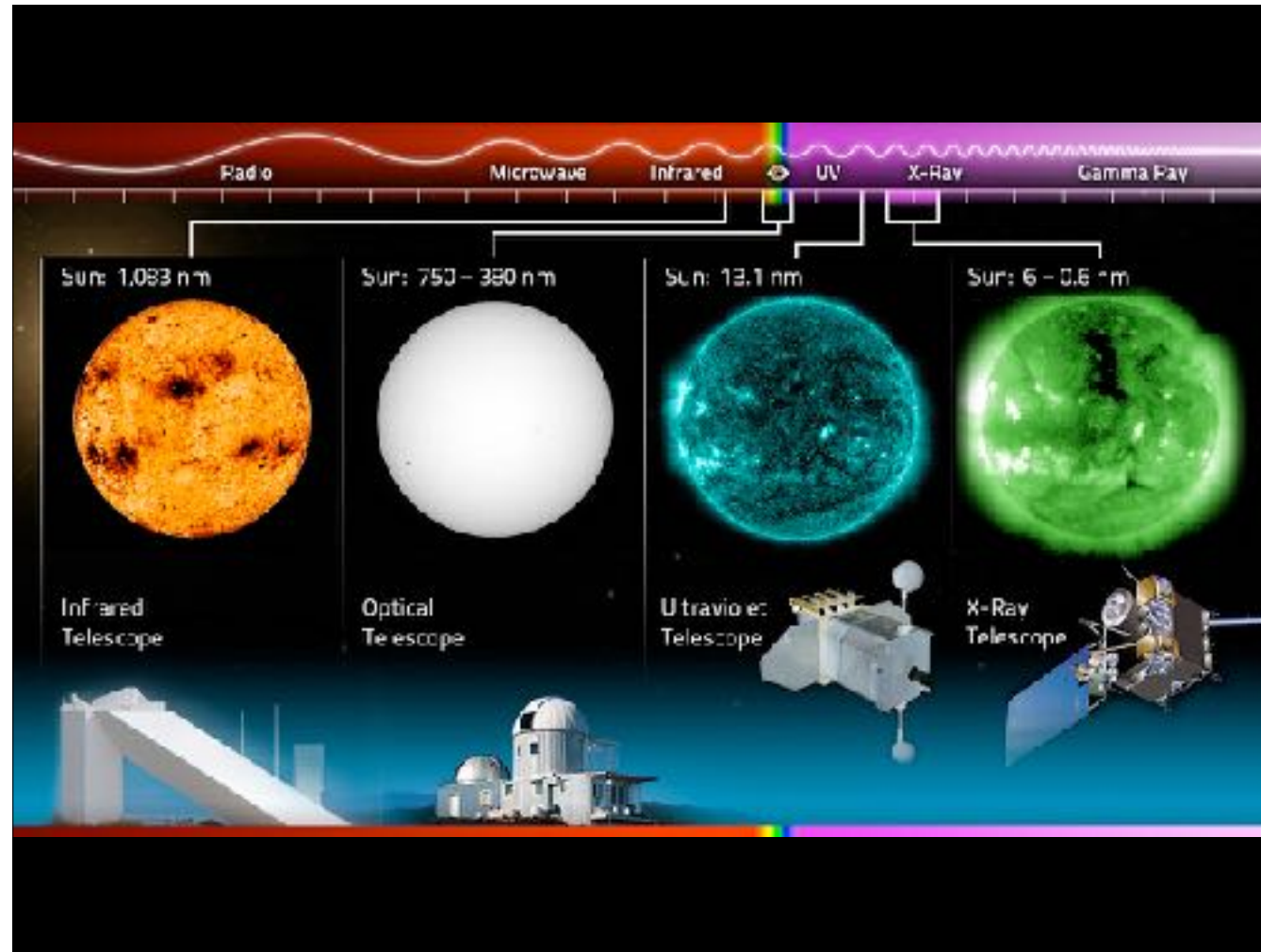
- Mt. Wilson's largest telescope has mirror objective 100 inches across
- The Hubble Space Telescope uses a 2.4 m (~95 in.) objective
- The largest optical reflecting telescope, El Gran Telescopio Canarias in the Canary Islands, Spain, has a 10.4 m (409 in.) objective



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 the 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 more than 19 years. 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.

CHANDRA X-RAY OBSERVATORY

- Year launched:

- 1999

- Types of light

- X-ray

- Primary target:

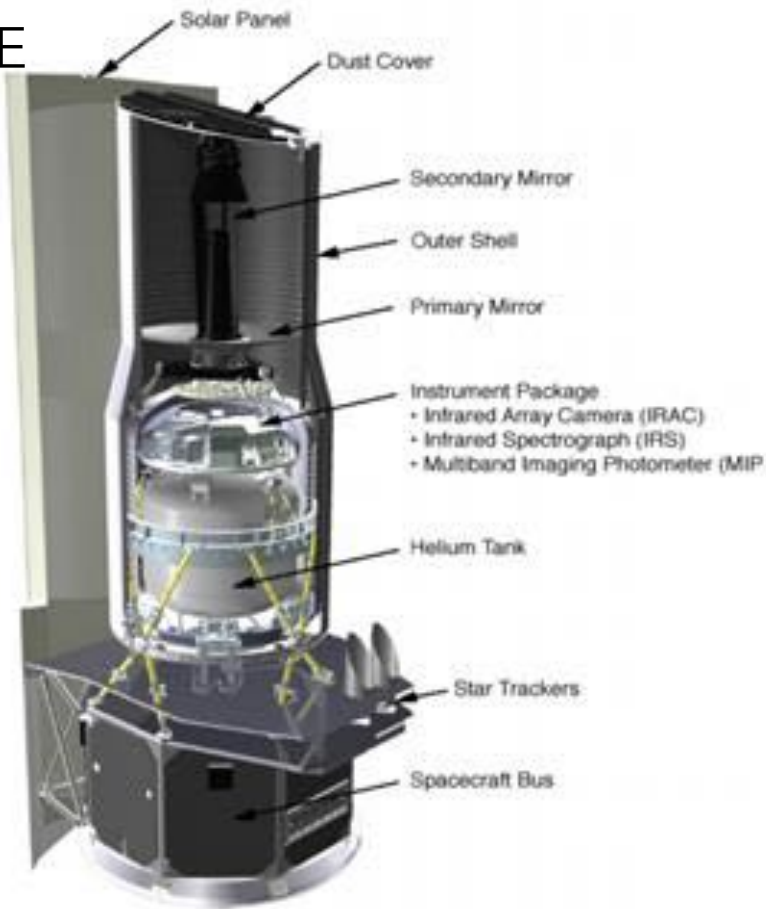
- Various



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

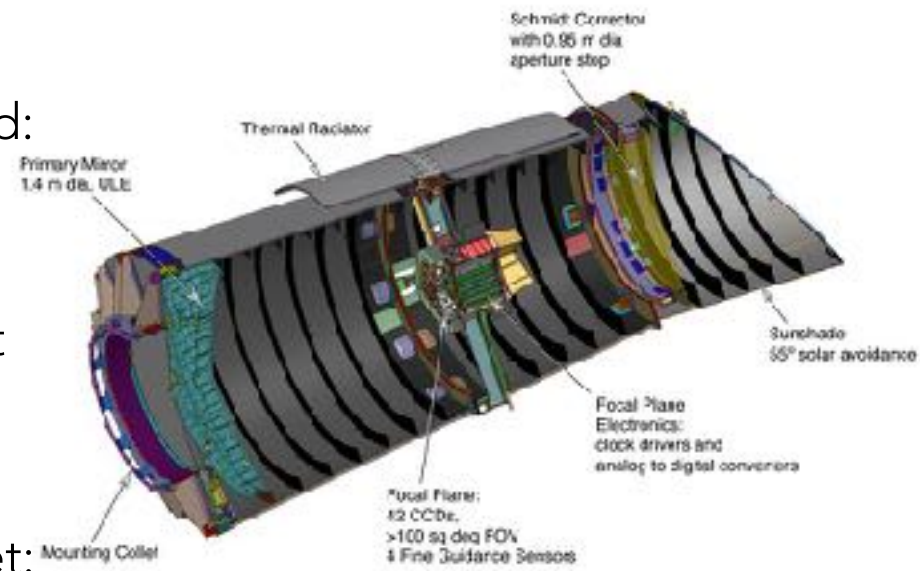
- Year launched:
 - 2003
- Types of light
 - IR
- Primary target:
 - Distant and nearby objects



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 will 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.