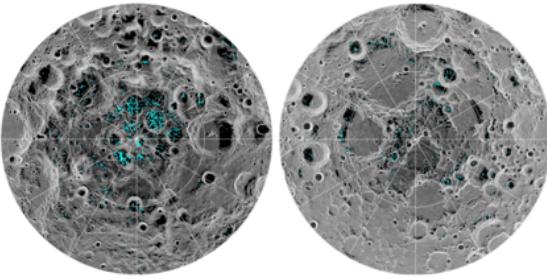


**If your last name is between A-K,  
report directly to the  
planetarium! Petty 310**



## Today in science...



- Water ice found on the moon!
- Located in permanently shadowed craters, -250F!
- Mixed in with lunar soil/rock (called regolith)
- Could be remnant from the Moon's formation
- Reflective like ice
- Distinct infrared spectral signature (tells us it's water and in the ice phase)

<https://www.jpl.nasa.gov/news/news.php?feature=7218>

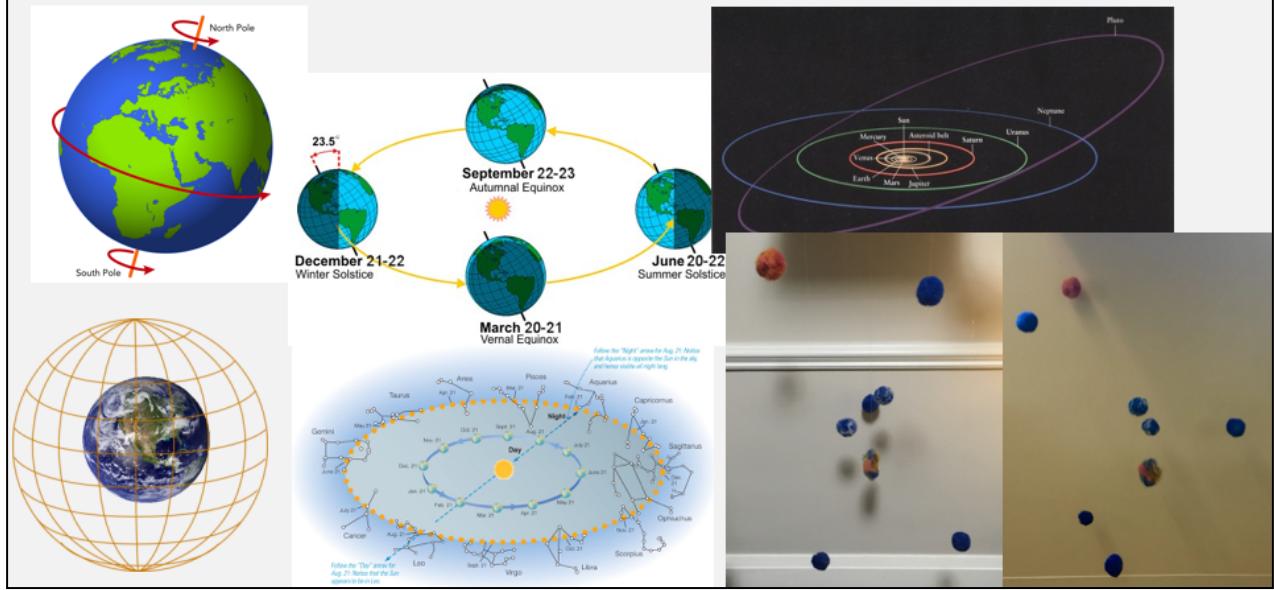
Academic paper: <http://www.pnas.org/content/early/2018/08/14/1802345115>



Photo credit: Dr. Joe Llama, Lowell Observatory

Photo is of star trails over Keck Observatory. Yes, those are laser beams coming out of the telescope dome!

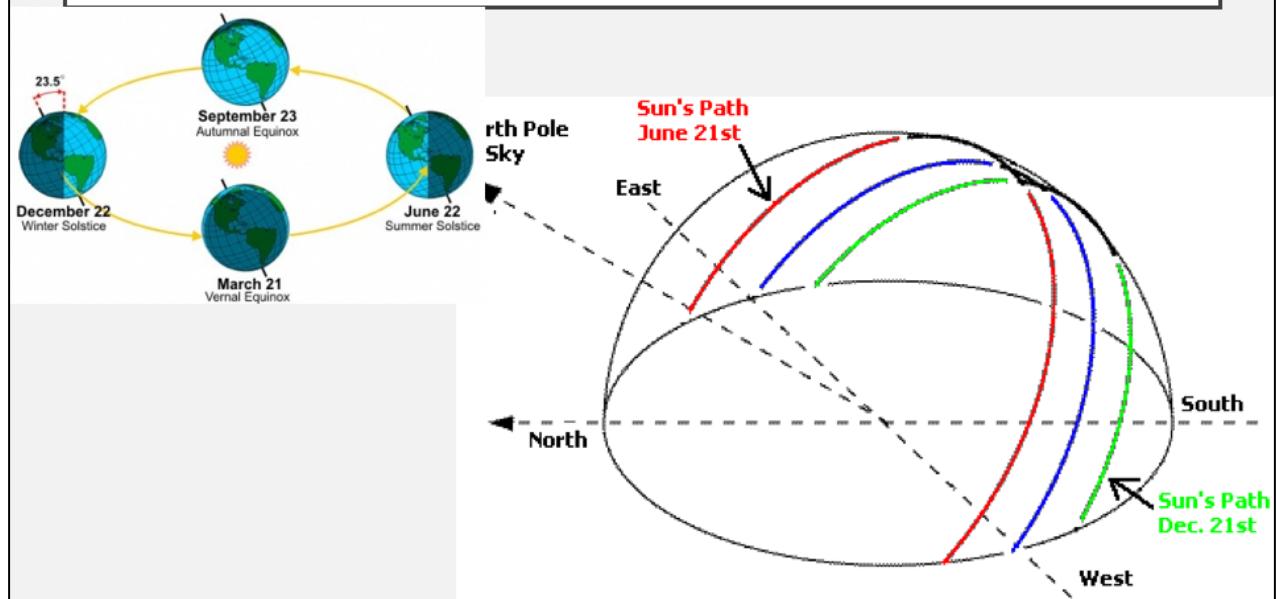
## Recap from last time



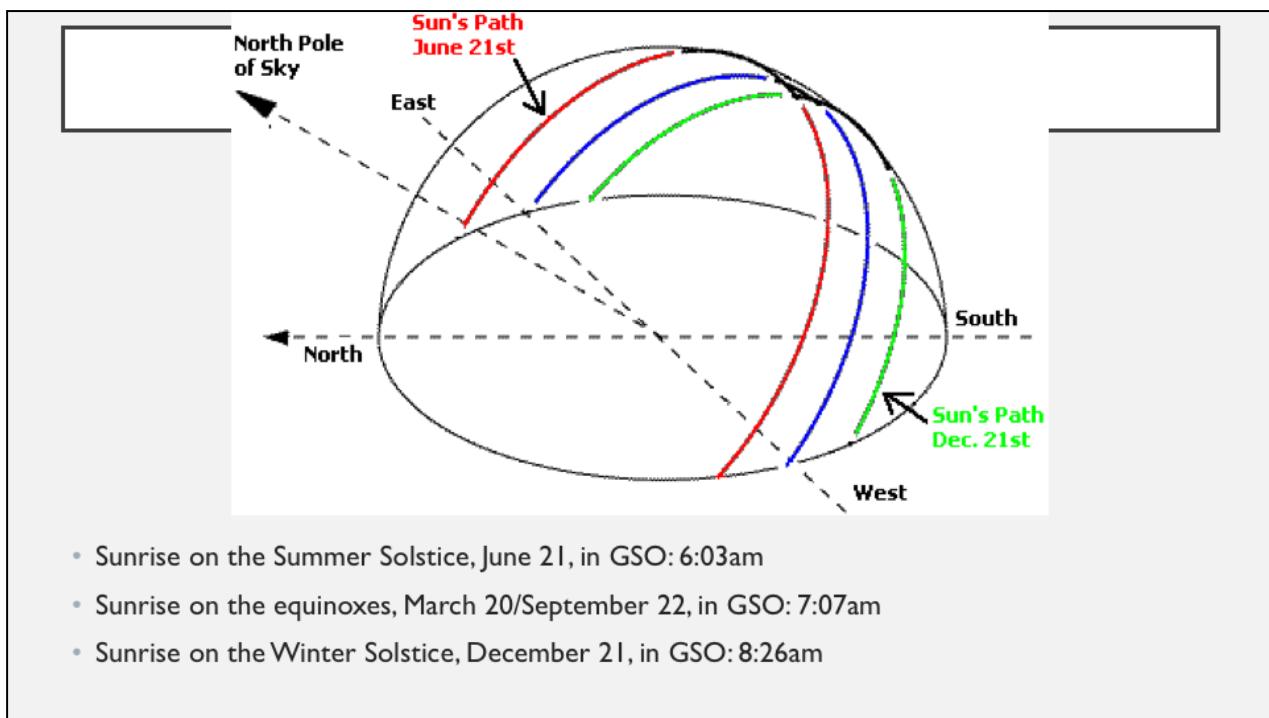
## The Sun's path



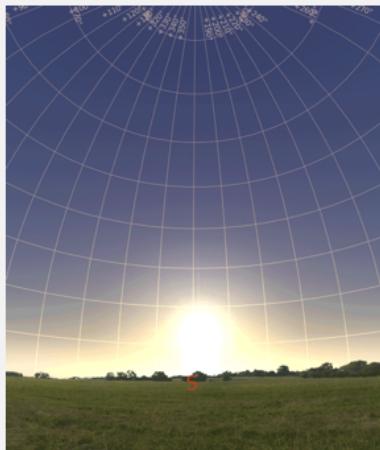
## The Sun's path



This was a bit hurried at the end of last class, let's revisit

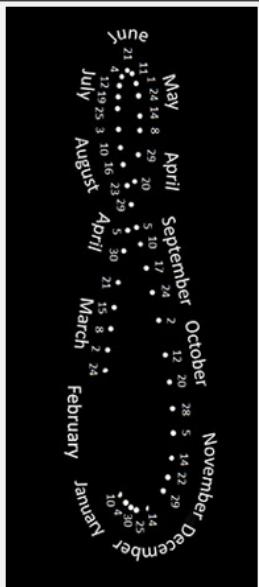


## The analemma



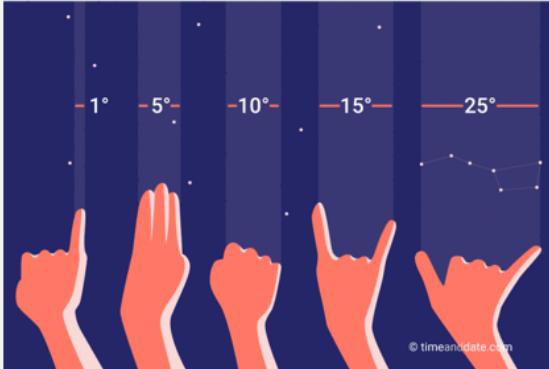
- Measure the altitude of the Sun in the sky at the same time every day for a year. Here's a site in Canada, simulated with Stellarium (!)
- Animation is pointed South because the Sun transits the meridian at local noon
- Notice the figure 8 analemma traced out by the Sun over a year

## The analemma



- Small end is when we're close to the Sun in elliptical orbit and moving faster; wide end is when we're farther away and moving slower
- Top is spring solstice, bottom is winter solstice, equinoxes are in the middle

## Angular size



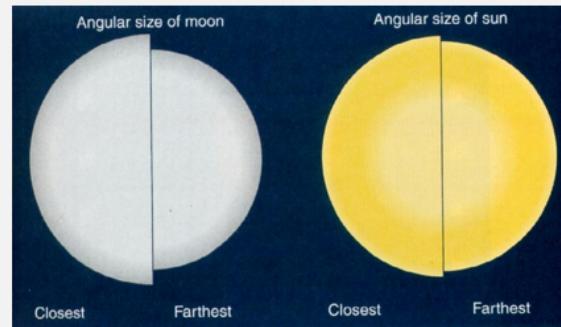
- Angular size is the projected angle subtended by an object on the sky
- Imagine the entire sky around the globe spanning 360 degrees
- Hold your arm out—we're proportionately built so that our own hands and fingers correspond to angles projected on the sky!

Imagine having a protractor projected on the sky. It spans 360 degrees all around you.

<https://www.timeanddate.com/astronomy/measuring-the-sky-by-hand.html>

## Angular size

- The angular size of an object depends on
  - An object's physical size
  - The distance to the object
- Example: both the Sun and the Moon are roughly 0.5 degrees in angular size!
  - The Sun is about 400x bigger than the Moon, but..
  - The Moon is 400x closer to us than the Sun





- Our satellite
  - 1/100 mass of the Earth
  - 384,400 km away (on average)
  - 3476 km in radius

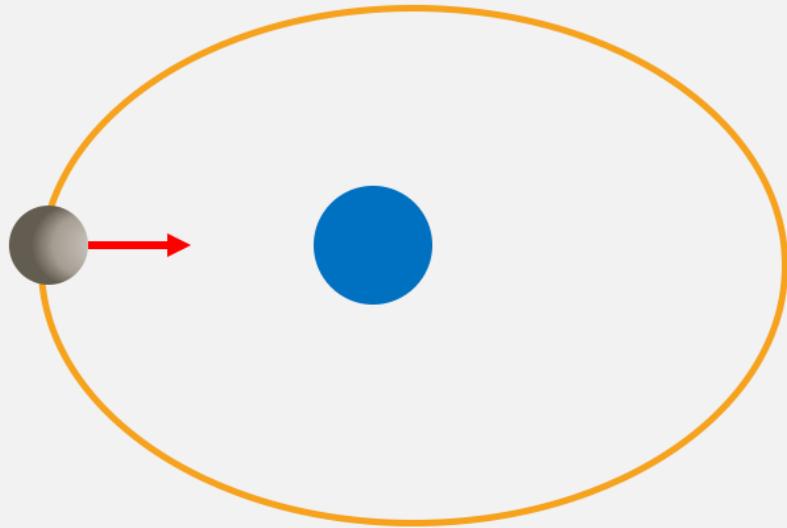


239,000mi away

Radius is 1079mi

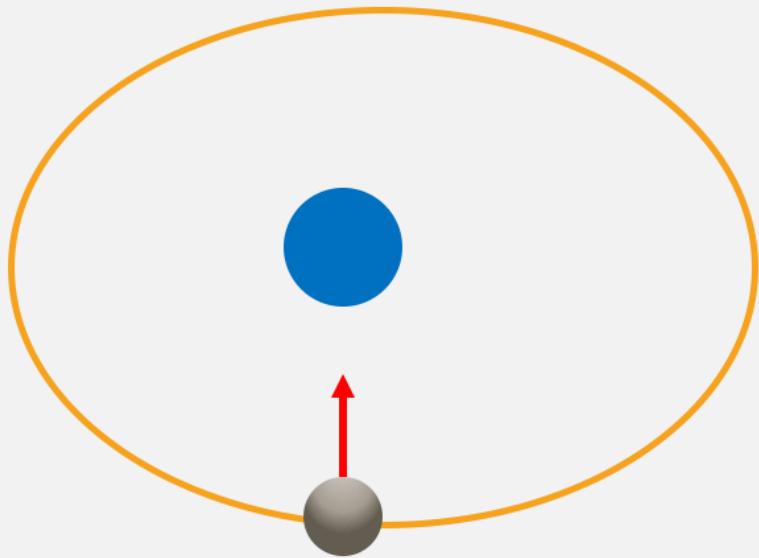
<https://io9.gizmodo.com/5984252/and-now-for-a-sense-of-scale-a-map-of-the-us-overlaid-on-the-moon>

## The Moon's synchronous rotation

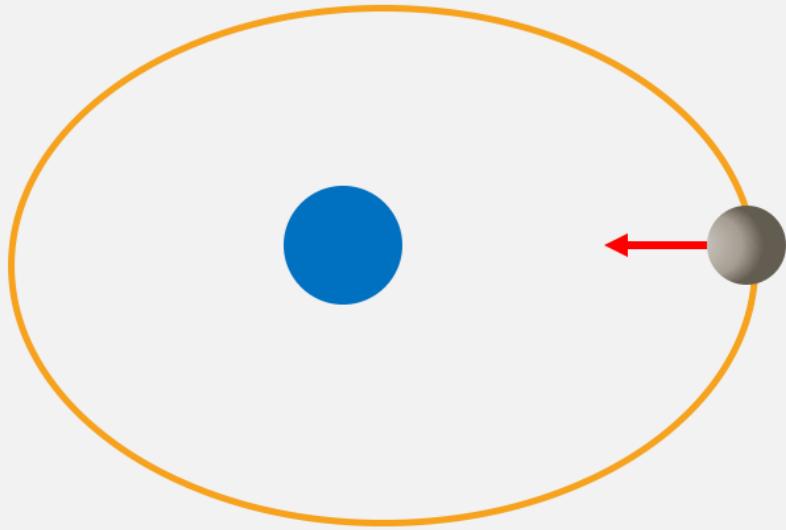


Let's look at one of the Moon's orbital periods.. Take what we know, which is that we always see one part of the moon

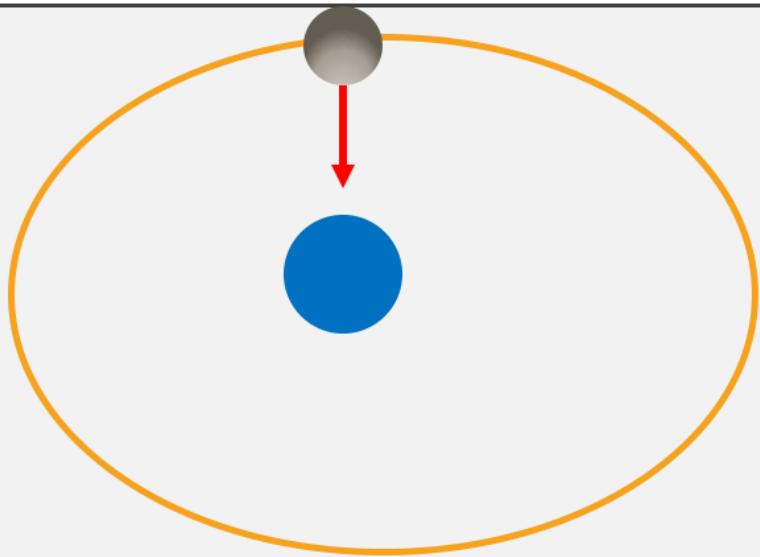
## The Moon's synchronous rotation



## The Moon's synchronous rotation

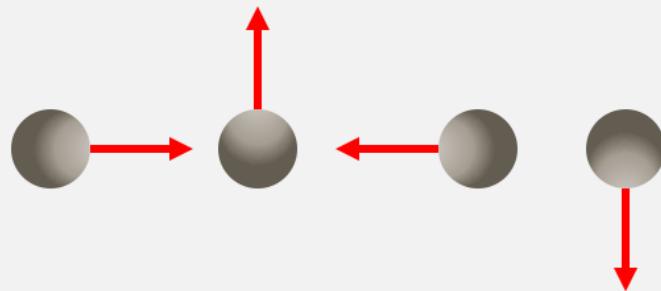


## The Moon's synchronous rotation



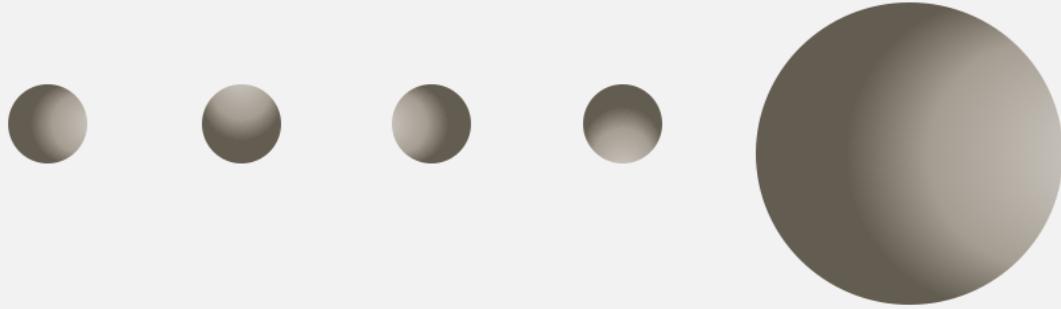
## The Moon's synchronous rotation

- Let's isolate just the Moon, and see what it's doing



## The Moon's synchronous rotation

- Let's isolate just the Moon, and see what it's doing
- Completes one rotation in the time it orbits once!



~29 day rotation period, ~29 day orbital period

Origin of the word 'month' ('mon' instead of 'moon')<sup>th</sup>

## The Moon's orbit

- Tilted 5 degrees with respect to the Earth's orbit around the Sun
- It's not much, but it's why we don't have eclipses all the time!

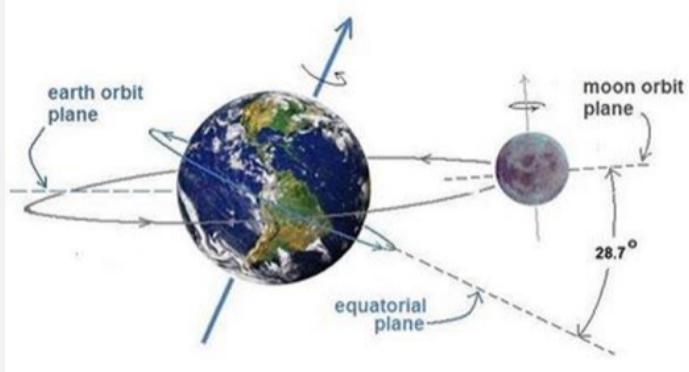
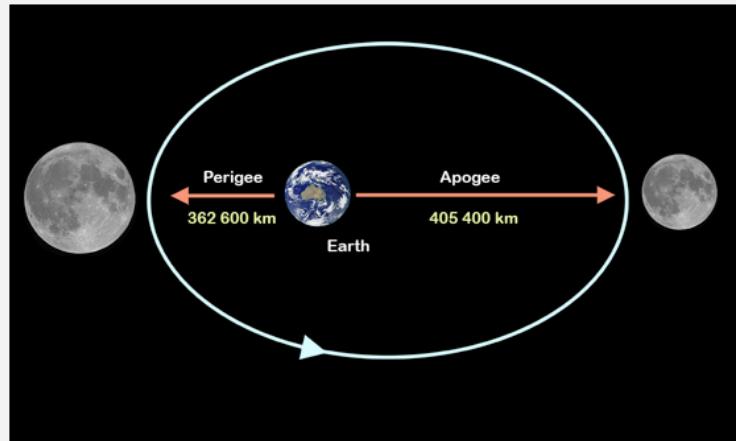


Image source: <https://www.quora.com/Does-the-moon-orbit-the-earth-at-the-equator-Does-the-orbit-vary-much>

Pretty good discussion of earth vs moon's orbital mechanics

## The Moon's orbit



*Credit: Ángel R. López-Sánchez. Moon image: [Paco Bellido](#).*

Remember the first day of class when I talked about prefixes and suffixes and words you'll see in the book- “gee” as a suffix is referring to geo, for Earth

## The Moon's orbit



- What happens when the Moon is both at perigee, and full?
  - A supermoon!!

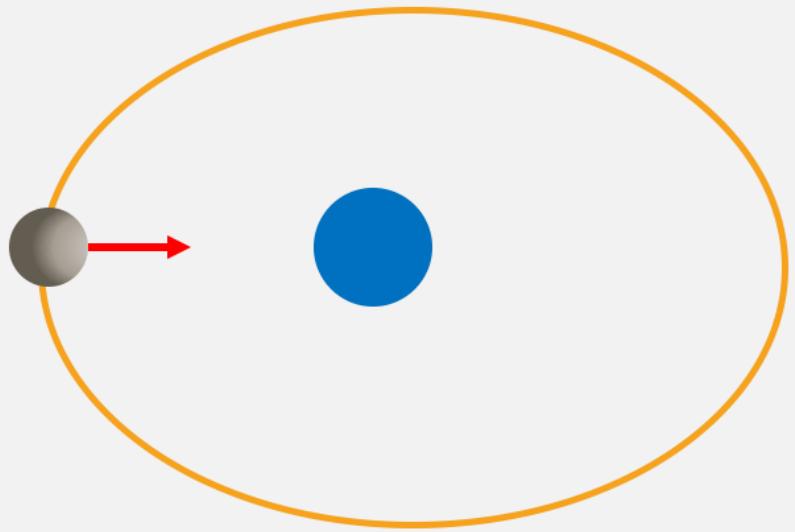
← pictures shown at same scale

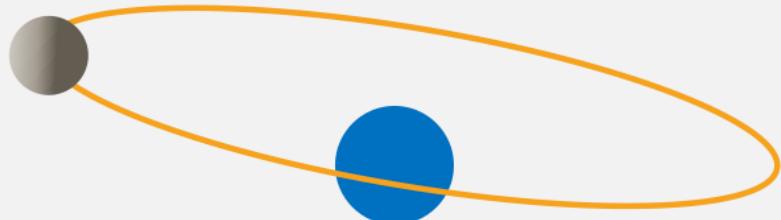
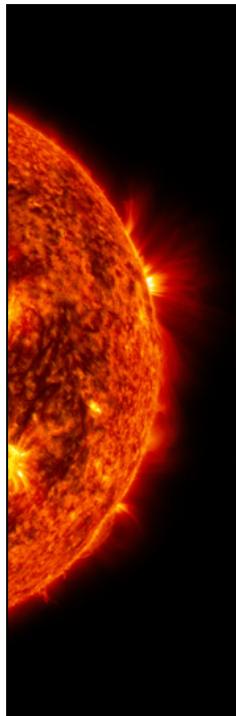
Credit: [Paco Bellido](#).

## **Lunar phases**

- Common misconception: we see phases of the Moon because the Earth is blocking light from getting to the Moon
- Phases are actually due to the relative orientation of the Sun, Earth, and Moon

**My simple picture...**

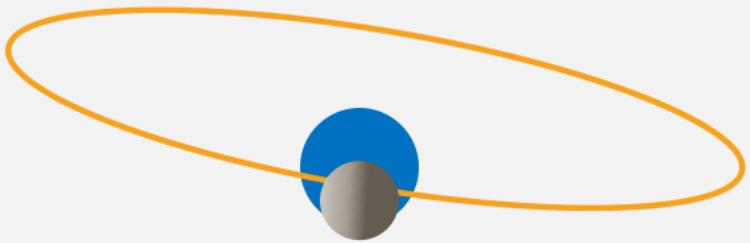
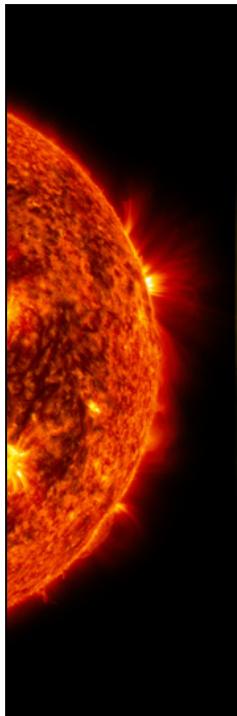




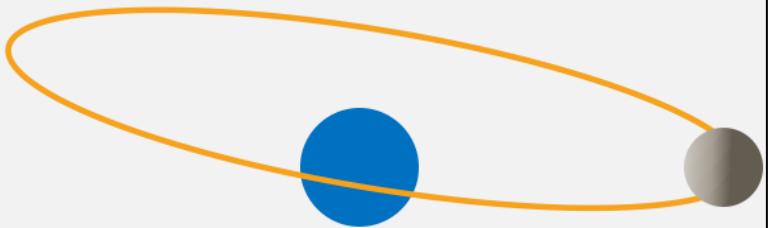
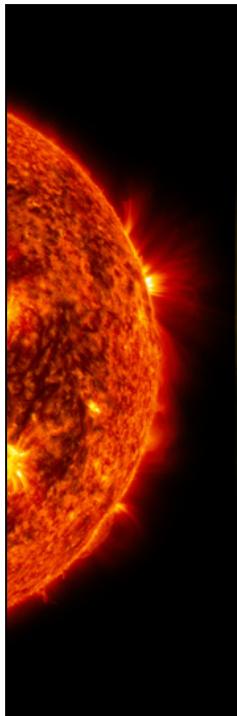
What do we see from Earth?

Let's go back to my simple picture... this time, the light side of the Moon is the side that's facing the Sun.

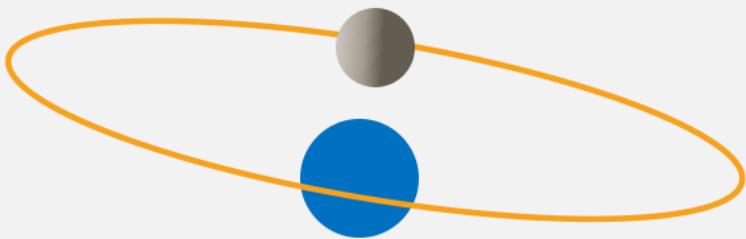
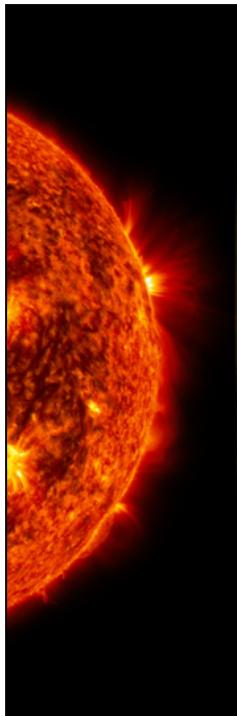
I've exaggerated the Moon's orbit and the Earth's position so you can better see the Moon



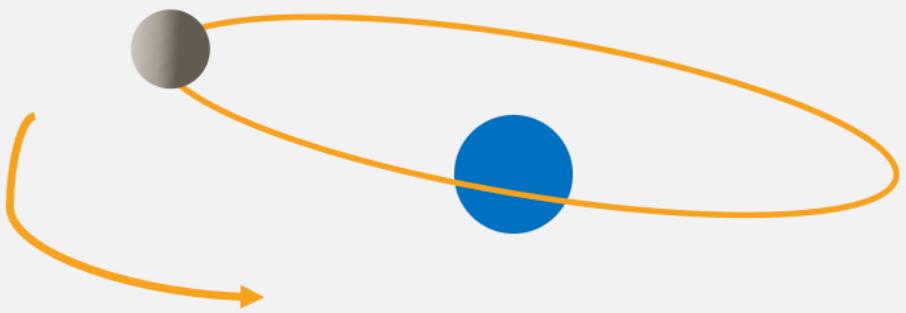
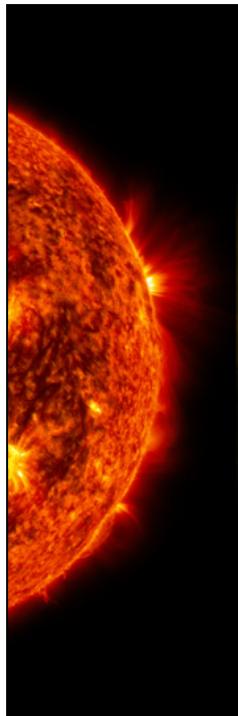
What do we see from Earth?



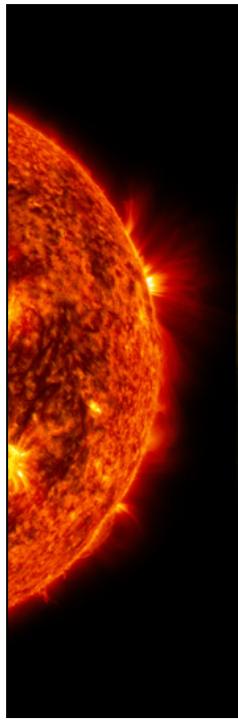
What do we see from Earth?



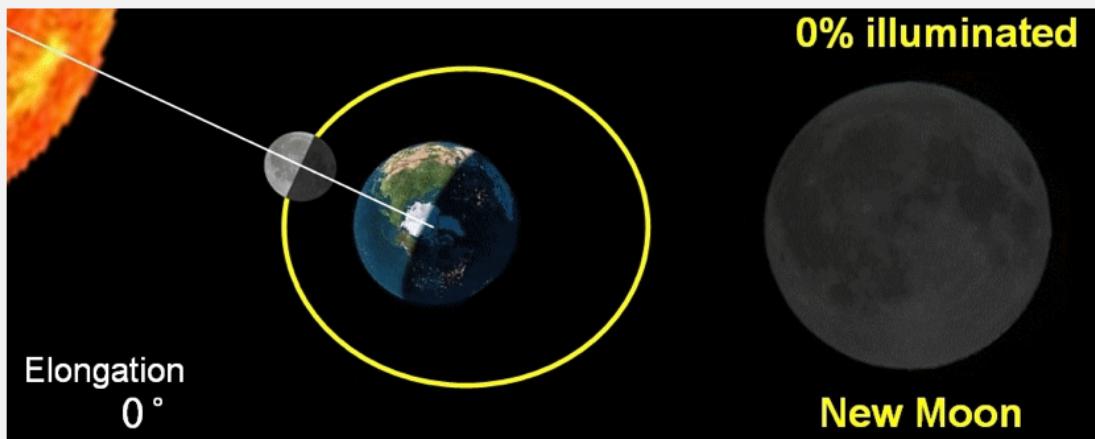
What do we see from Earth?



Waxing



## Lunar phases



<http://moongazer.x10.mx/website/astronomy/moon-phases/>

(don't look at the second gif, it's the view from the South pole so it's a little confusing because the phases are reverse of what we see)



Remember: waxing=getting brighter (New→Full);  
waning=getting darker (Full→New)

**Wax on, brighter (lighter, more wax).. Wax off  
(waning), darker**



In the waxing phase, the right side of the moon is illuminated; in the waning phase, the left side of the moon is illuminated

## Lunar phases



This is a figure showing what we see from Earth depending on where in the lunar cycle we are

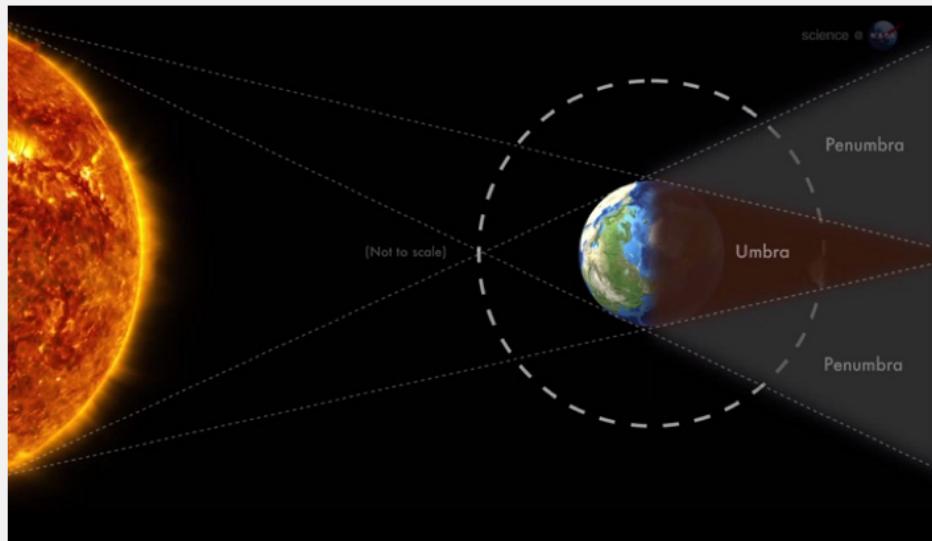
(last night, 8/26, was a full moon!)

## Eclipses

- “an obscuring of the light from one celestial body by the passage of another between it and the observer or between it and its source of illumination.”
- The celestial body being eclipsed is the what the eclipse is named for
  - Lunar eclipse → light aimed for the Moon is being blocked by something (Earth)
  - Solar eclipse → light from the Sun is being blocked by something (Moon)
- Eclipses can be
  - Partial
  - Total
  - Annular (from the word *annulus* meaning *ring*)

This is another way to remember the moon’s phases aren’t caused by Earth obscuring light to it- that would be defined as an eclipse

## Lunar eclipses

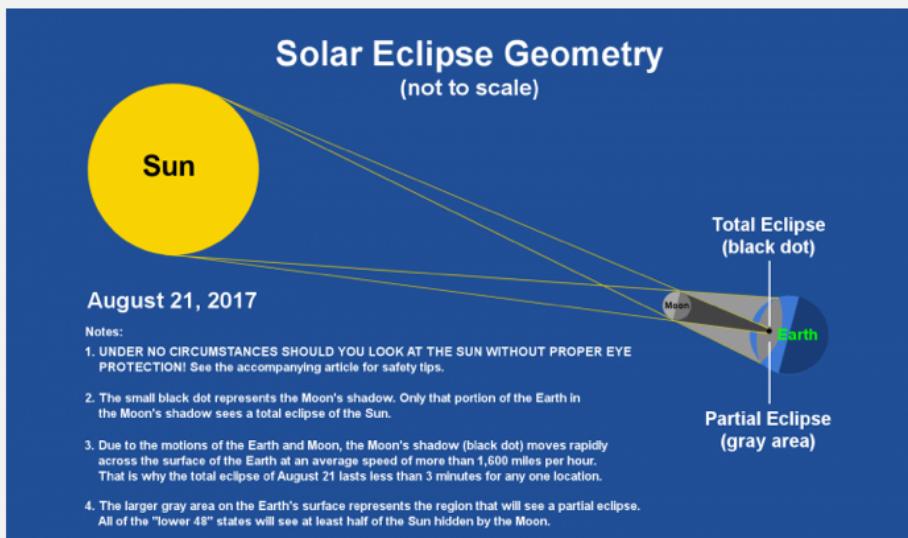


## **Lunar eclipses**



<https://www.naijanews.com/2018/07/23/details-about-the-longest-lunar-eclipse-of-the-century-the-blood-moon/>

## Solar eclipses



<https://www.almanac.com/content/total-solar-eclipse-versus-partial-eclipse-whats-difference>

## Solar eclipse 2017



<https://www.space.com/35080-total-solar-eclipse-2017-path-maps.html>

## **Solar eclipse 2017, from the sky**



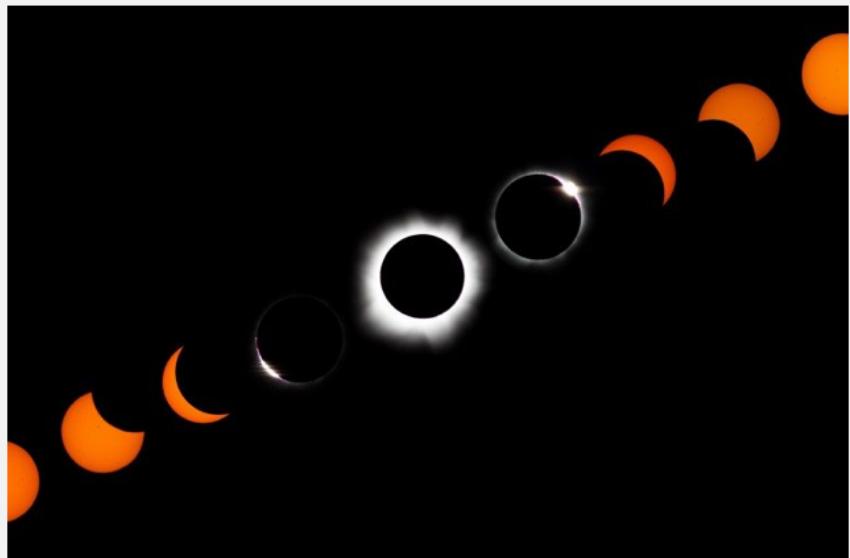
<https://www.tumblr.com/search/north%20america%20solar%20eclipse>

## **Solar eclipse 2017, from the sky**



<https://www.theverge.com/tldr/2017/8/21/16180544/total-solar-eclipse-2017-best-photos-videos-nasa-gifs>

## Solar eclipse 2017



<https://www.milwaukeemag.com/where-can-i-view-solar-eclipse-milwaukee/>

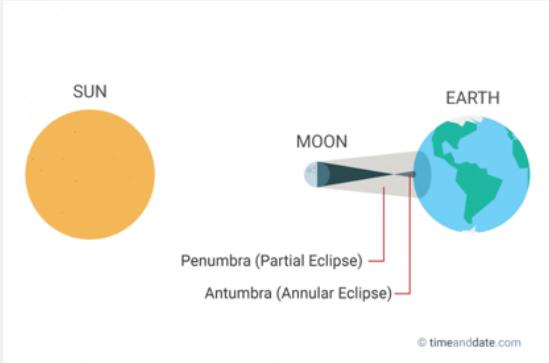
## Partial solar eclipses

- When you're in the penumbra of the eclipse path, or,
- Orientation of Sun, Moon, and Earth doesn't produce an umbra that falls on the Earth



<https://www.timeanddate.com/eclipse/partial-solar-eclipse.html>

## (annular) Solar eclipses



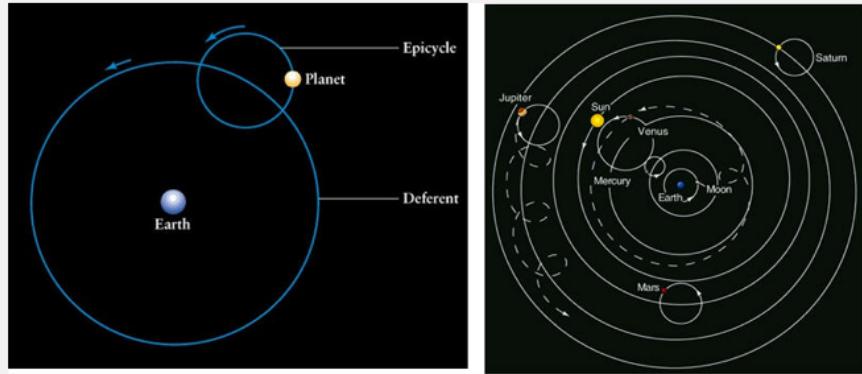
<https://www.timeanddate.com/eclipse/annular-solar-eclipse.html>

## Predicting eclipses

- Surprisingly, not easy to do!
- In ancient times, successful prediction seen as mystical, powerful
- Eclipses themselves invoke strong reactions whether you understand them or not
- Physics making them hard to predict?
  - Precession!
- Today, we're better able to based on knowledge of orbital physics. Many happen over uninhabited areas, so we don't hear about them as often as you might think
- As Earth and Moon's orbits evolve, in a few hundred thousand years, won't be any more full eclipses (angular size of Moon vs Sun changing)

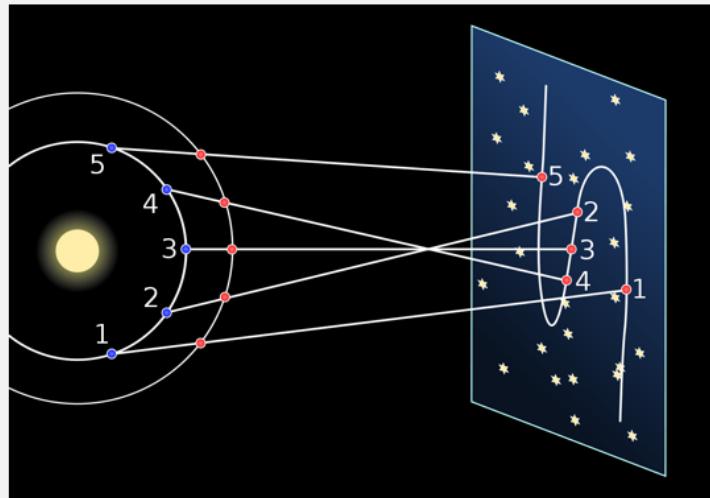
## Planetary motion in the sky

- We easily see 5 planets with the naked eye: Mercury, Venus, Mars, Jupiter, and Saturn
  - When do we see Venus and Mercury?
- Retrograde motion was incredibly difficult to explain in an Earth-centric model



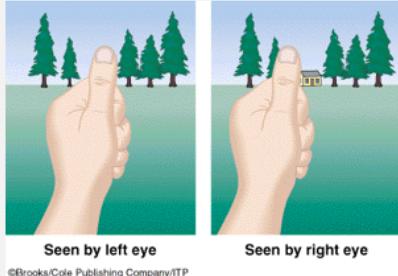
Ended here for group 1

## Retrograde motion

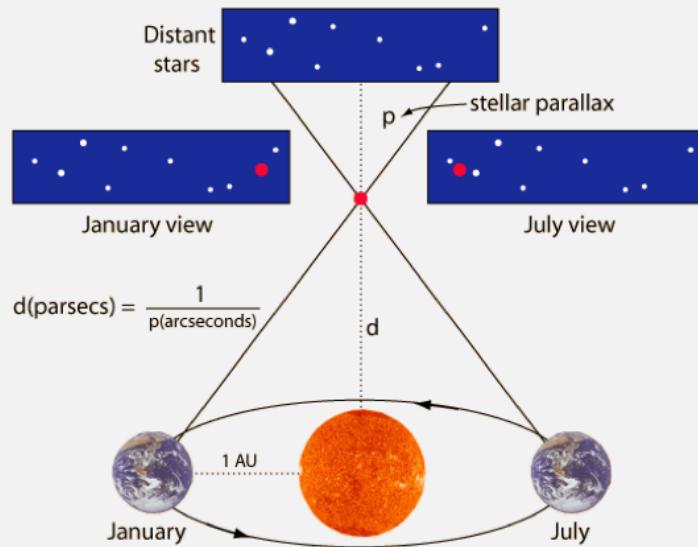


[https://en.wikipedia.org/wiki/Apparent\\_retrograde\\_motion](https://en.wikipedia.org/wiki/Apparent_retrograde_motion)

## Parallax



©Brooks/Cole Publishing Company/ITP



From thumb to stars—parallax is used to determine distances to stars

Fig on right from <http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/para.html>

## Recap

- Today, we talked about...
  - Recap: went over motion of the Sun in the sky, the analemma
  - Angular size of objects in the sky, and how to measure them with our own hands
  - The Moon:
    - Its orbit
    - Phases
  - Eclipses
    - Lunar (when Earth blocks the Sun's light to the Moon)
    - Solar (when the Moon blocks the Sun from Earth's view)
  - The motion of planets in the sky
  - Parallax, a way of measuring distances if you can do it well enough and why the ancient Greeks refused to believe the Earth was not the center of the Universe

## **Logistical notes:**

- Due 11:59pm today–
  - Mastering Astronomy site tutorial
  - Chapter 1 homework
- Next week:
  - Chapter 3 – History of Astronomy, the Scientific Method
  - Starting Chapter 4 – fundamental laws of physics
  - Lab 1 due Thursday, 8/28: based on this week's lectures/planetarium trip
  - Chapter 2 homework due 9/1 → I suggest starting both today, while memory is fresh!