The Cosmos

Planets & Life

PHYS 214

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Please start all class related emails with "214:"

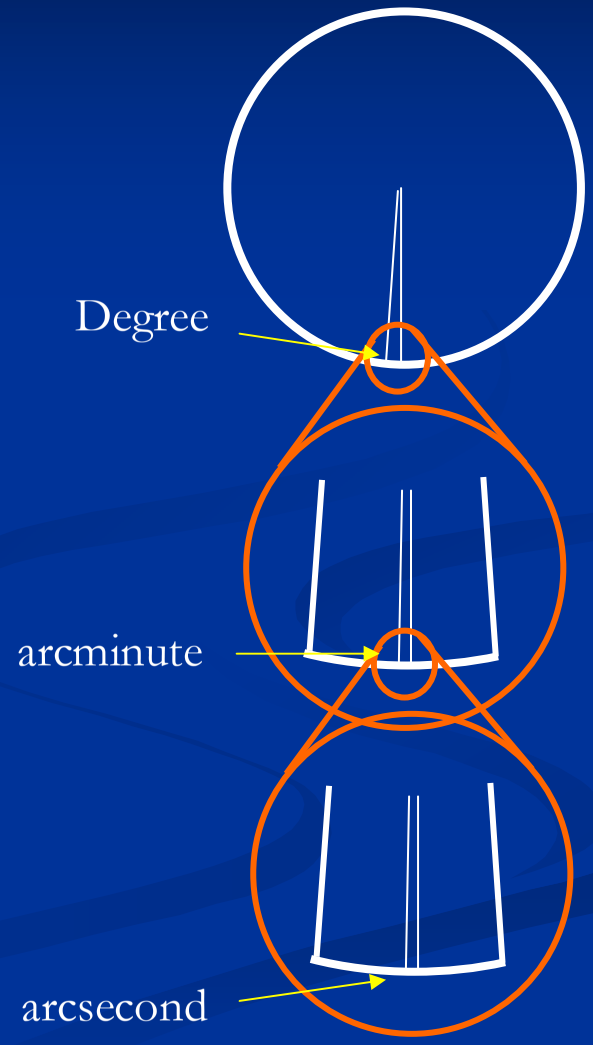
Today's Lecture

- Introduction to fundamental concepts in Astronomy
  - Angular & distance measurements
  - Resolution in telescopes
  - Distance units & relative scale of astronomical systems

1st Pop Quiz on Monday – 10 questions, 10 minutes
Will cover what we have looked at this week

Angular measurements

- 360 degrees in a circle = 360°
- For measurements smaller than a degree we use arcminutes
  - 60 arcmin = 60’ = 1°
- For measurements smaller than an arc minute we use arcseconds
  - 60 arcsec = 60” = 1’
- We may also talk about radians
  - 360°=2π radians



Examples from the sky

- Angular diameter of the Moon is about 30 arcmin~0.5°
  - How many arcseconds would that be?
- Angular diameter of Jupiter is between 32” and 40”
  - Any ideas why it might change?

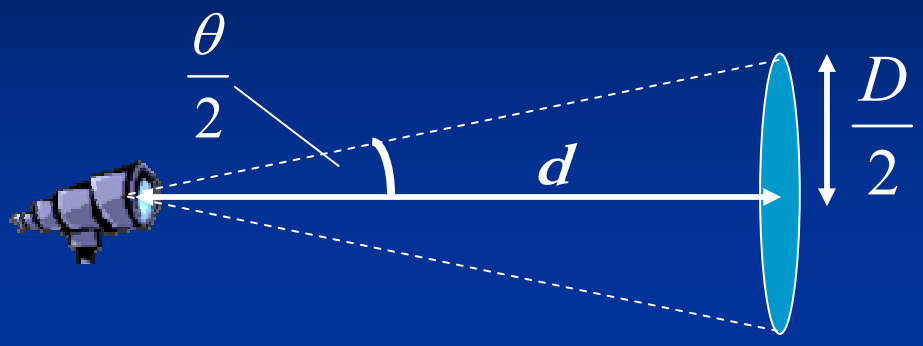
The limit of resolution is set by turbulent motion of air in the atmosphere – about 1”

Angular size & small angle formula

- For an object at distance d, with diameter D

$$2\tan\left(\frac{\theta}{2}\right) = \frac{D}{d}$$

- For astronomical distances the angles are usually very small
  - We can approximate $\tan\theta \approx \theta$ to get



$$\theta = \frac{D}{d}$$

However, θ, must be measured in *radians*.

Relationship when angle is not measured in radians

- In this case we need to include a conversion factor from the angular measure used, to radians
  - For θ in degrees we multiply by $(2\pi/360)$ to get radians
  - Thus the small angle formula for θ in degrees becomes

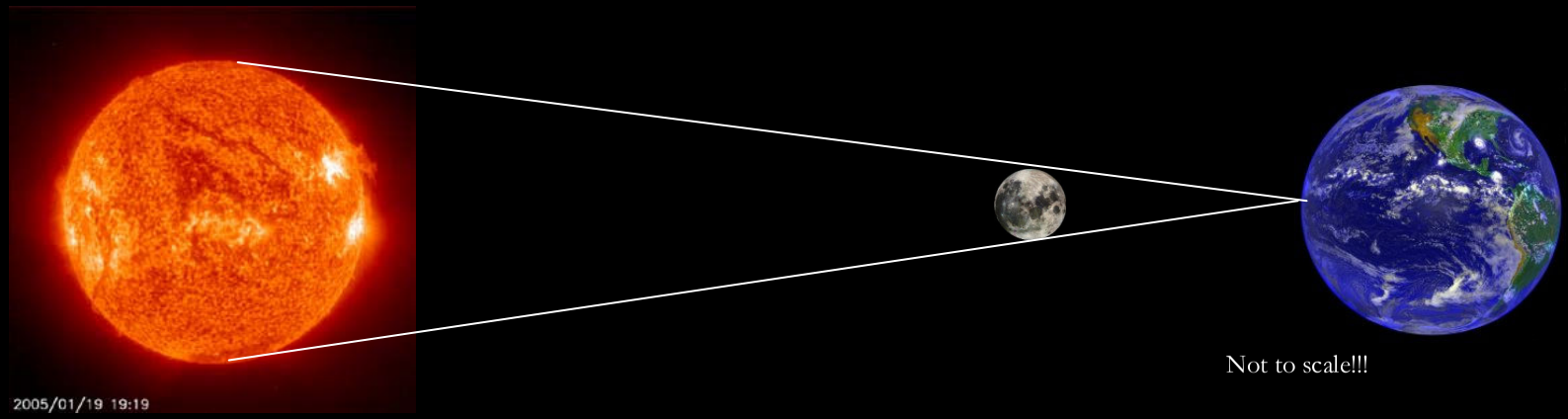
$$\theta = \frac{D}{d}\left(\frac{360}{2\pi}\right) = 57.296\frac{D}{d}$$

  - For θ in arcminutes it becomes

$$\theta = \frac{D}{d}\left(\frac{(60\times 360)}{2\pi}\right) = \frac{D}{d}\left(\frac{21600}{2\pi}\right) = 3437.7\frac{D}{d}$$

Distances to the Sun & Moon

- Total solar eclipses show that the Moon and Sun have almost identical angular sizes, so the $\theta = D/d$ ratios must be the same



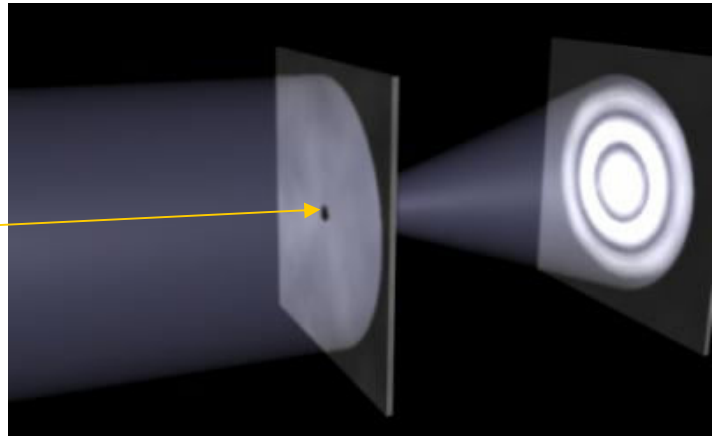
- Thus, if we know the distance to the Moon, and it's size, and we know that the Sun is 400 times more distant, then the Sun must be 400 times larger than the Moon

Sun diameter ~ 1.38 million km, Moon diameter ~ 3476 km

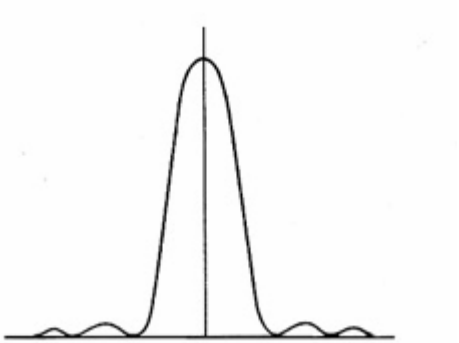
Resolution I – Fundamental optical properties

- A point size of light viewed through an *aperture* leads to *diffraction*

Aperture
(open end of optical system, e.g. telescope)

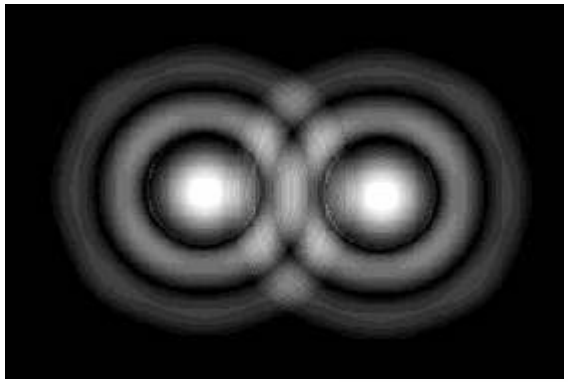


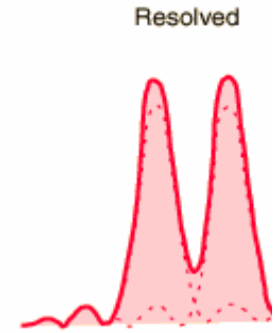
- The resulting intensity of light in the rings is given by the "Airy pattern"



Resolution of two objects

- Suppose we have two objects, the interference of the two diffraction patterns will be progressively more difficult to tell apart





The limiting separation is given by the ***Rayleigh Criterion***

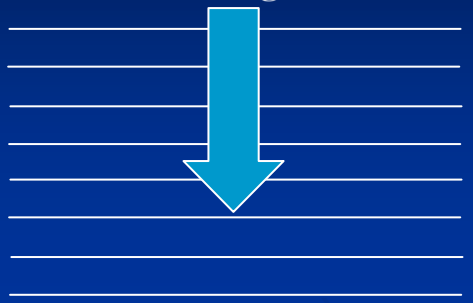
R= 0.25λ/D

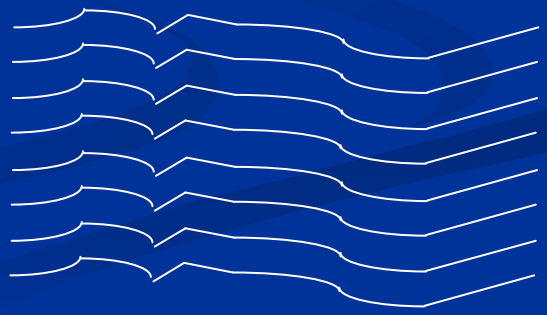
[R in arcsec, D in m, **λ** in μm (10^{-6} m)]

Resolution II – Atmospheric effects

- The light waves from distant stars are initially parallel
- However, the atmosphere is constantly moving causing different densities of air to be intermixed
- Air at different densities refracts (bends) light different amounts
- The path the light takes to you is constantly changing by tiny amounts
  - This is the origin of "twinkling"
- The result is the initially plane waves become bent and distorted

Parallel waves of light from star

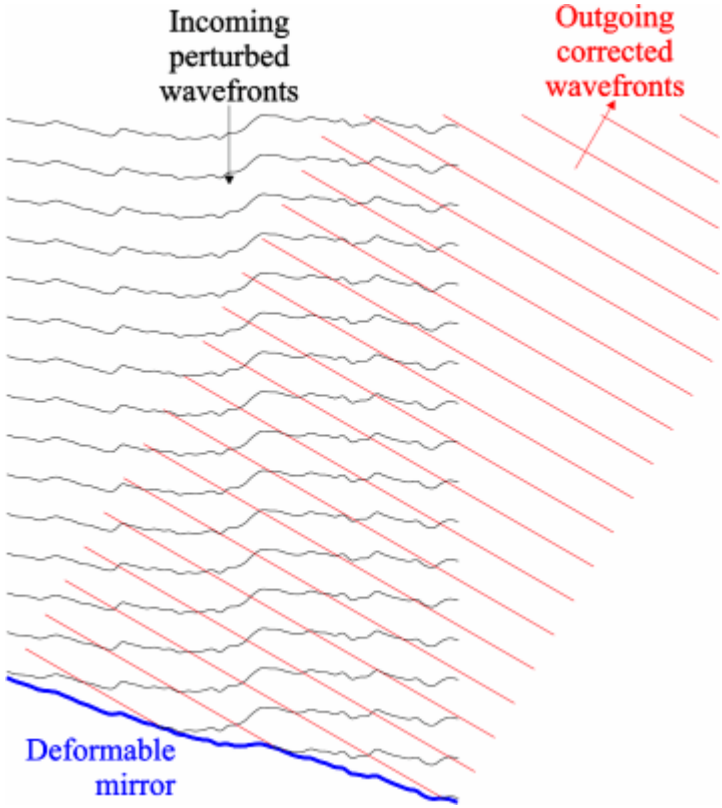




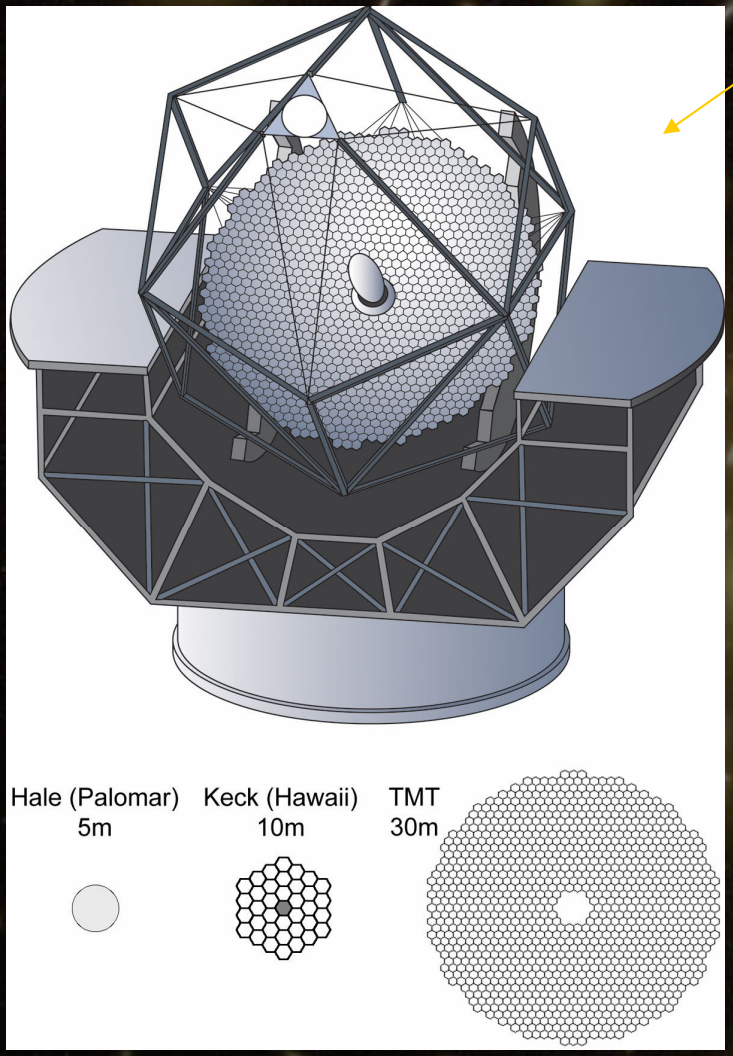
Waves of light refracted by turbulence

Aside – "Adaptive Optics"

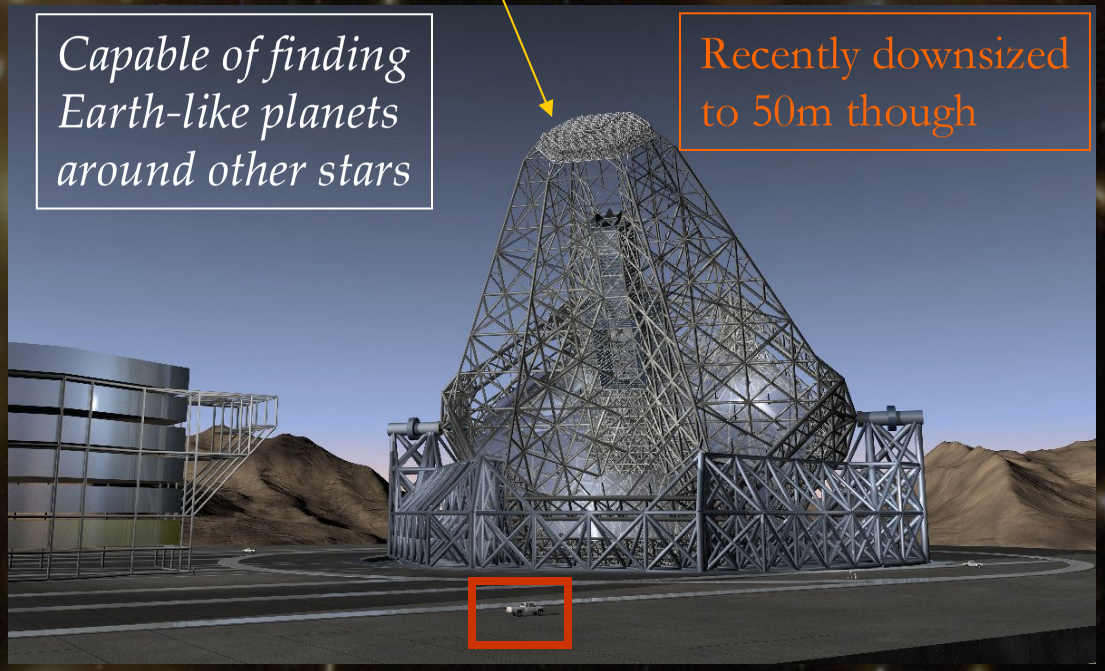
- We can actually correct most of this distortion!
- In the last 30 years, building on earlier research, astronomers have built mirrors that move on very short times scales to correct for the changes in the incoming wavefronts

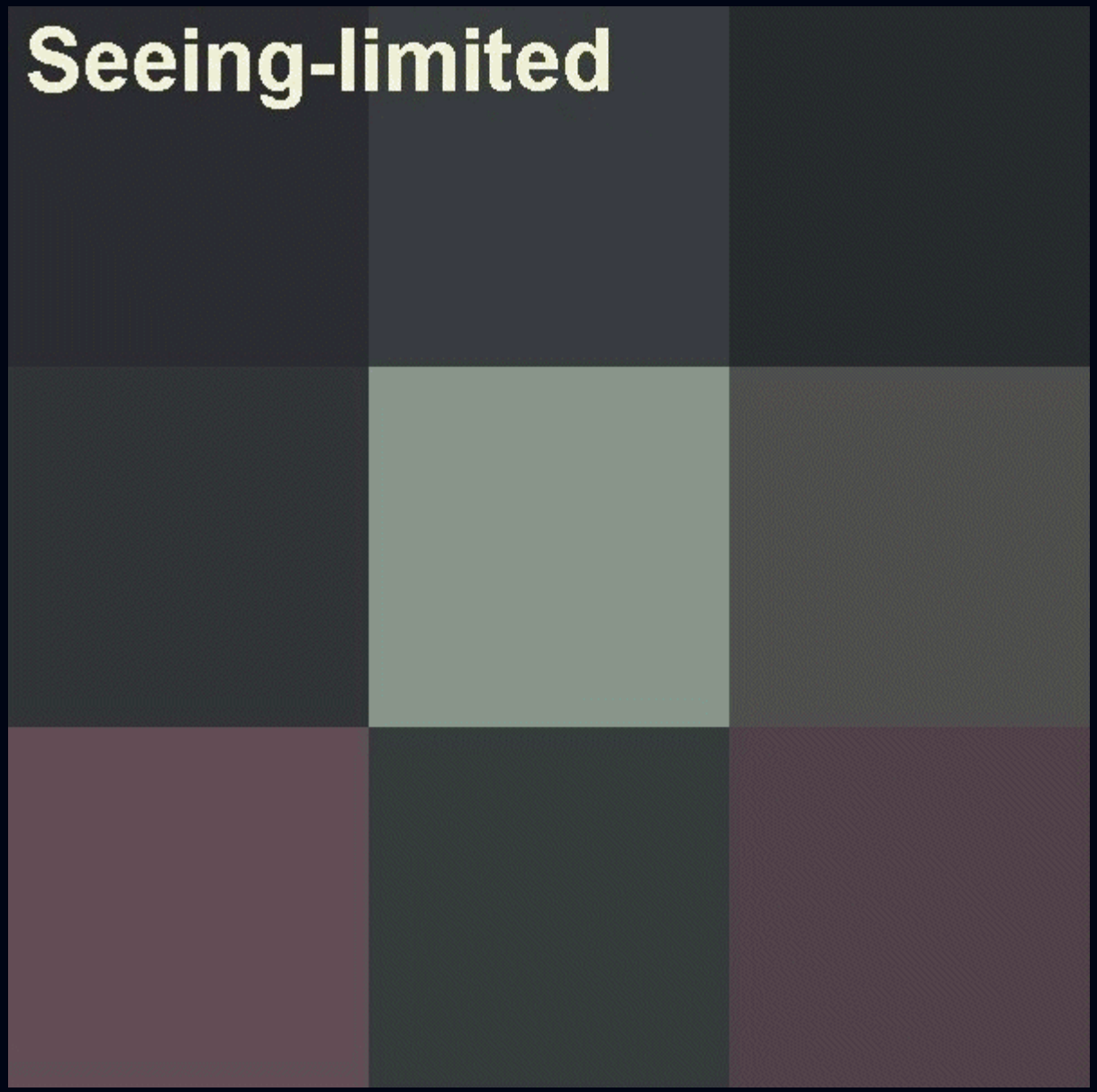


Future telescopes



- "TMT" US-Canada 30m telescope (1 Bn US$)
- European Southern Observatory project: OWL (100m diameter!)
  - *Overwhelmingly large telescope!*
  - Same price!

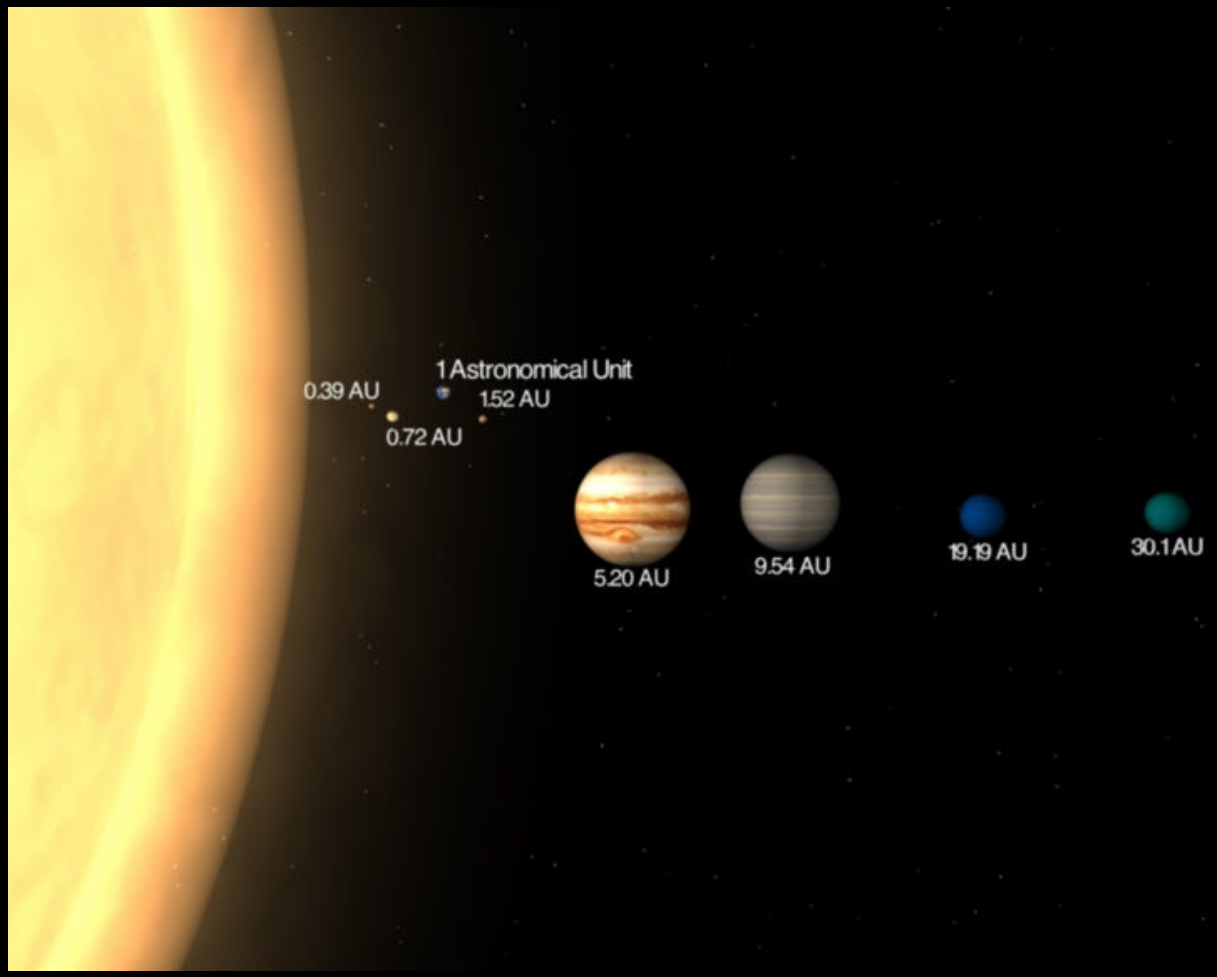




Resolution of a cluster of stars by different telescopes

Distance units used in Astronomy

- 1 Astronomical unit, AU, is the average distance between the Earth and Sun ~150,000,000 km
- It's a useful unit for gauging the relative size of the solar system
- Still a small unit compared to the distance to our stellar neighbours



Humour: "Plutoed"

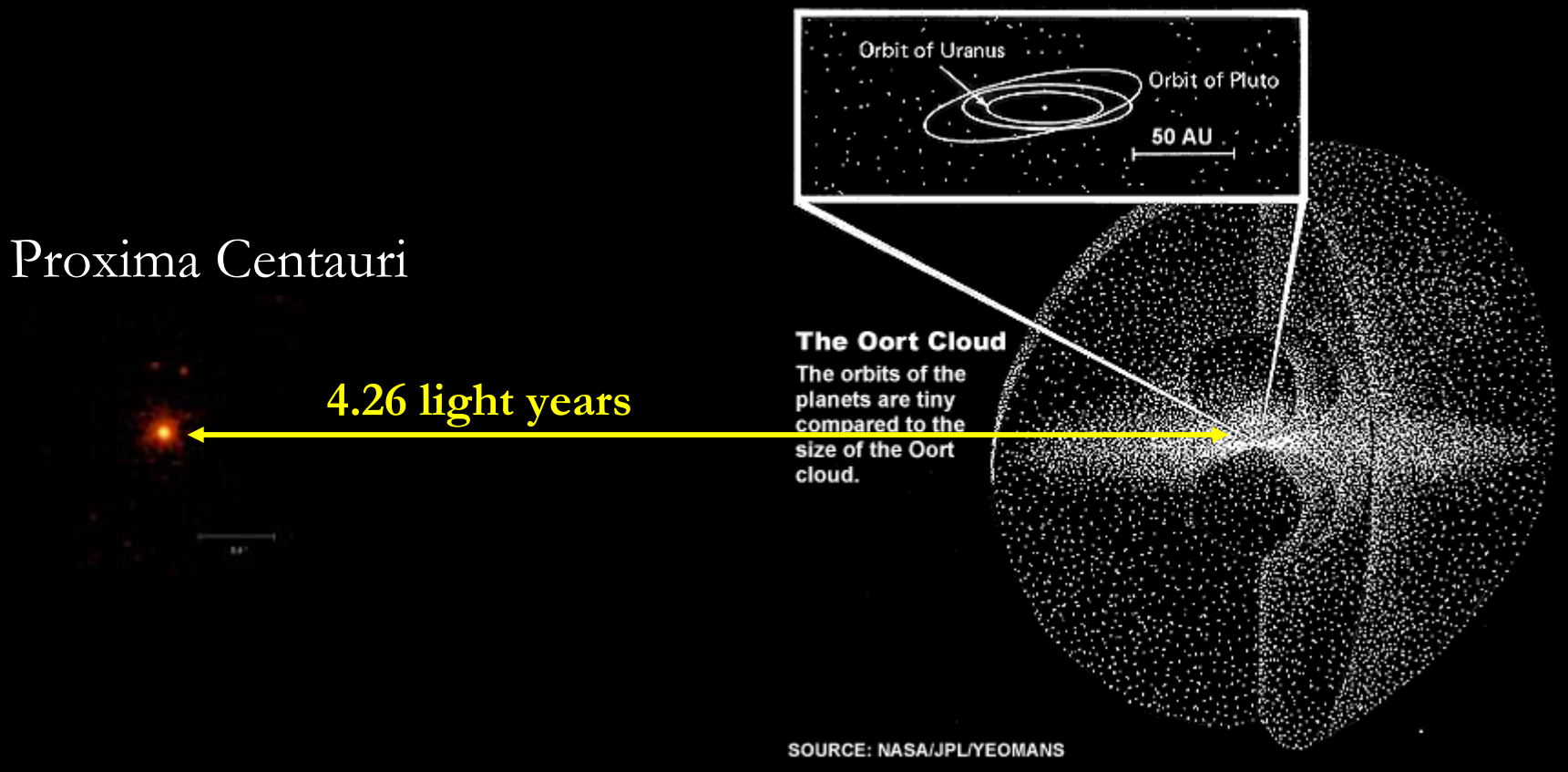
- The International Astronomical Union voted to remove Pluto's planetary status in 2006
- There are now officially 8 planets
- In response to this, the word "Plutoed" has arisen:
  - ***Plutoed*** (verb) meaning: "to demote or devalue someone or something"
- Voted "Word of the Year" for 2006 by the American Dialect Society

Units for measuring larger distances

- Fall into two categories
  - Motivated by distance light travels in a certain time, *e.g.* light year
  - Motivated by small changes in angular positions in the sky as the Earth moves around the sun *e.g.* the parsec
    - We'll look at this next lecture
- outer planets: **light-hours**
- nearest stars: few **light-years**
  - 1 light year = **63,240 AU**
  - 1 parsec = 3.26 light-years
- center of Milky Way: ~ 25,000 light-years
- Andromeda Galaxy (M31): ~ 2 million light-years
- most distant galaxies: 13-14 billion light-years (800,000 years after the Big Bang!)

Distance to the nearest star (Proxima Centauri)

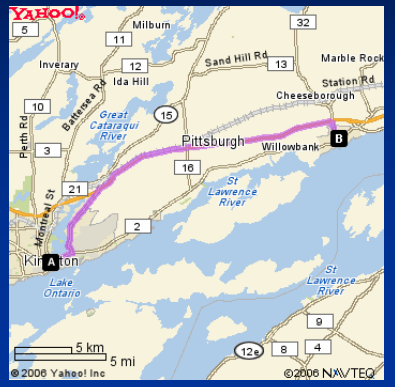
- Edge of the solar system is marked by the Oort Cloud of comets at ~70,000 AU



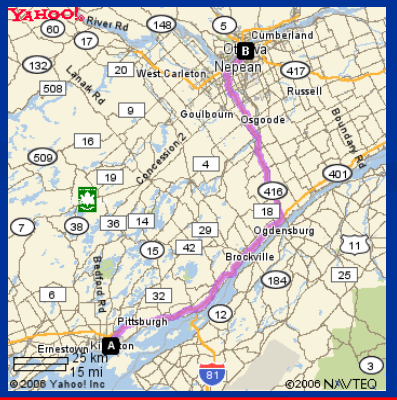
Solar system and stellar scales in comparison

- Let's suppose the orbit of the Earth is represented by 30 ft (= 1 AU)
- How far away is the nearest star in comparison?

Gananoque
~ 20 miles



Ottawa
~ 100 miles

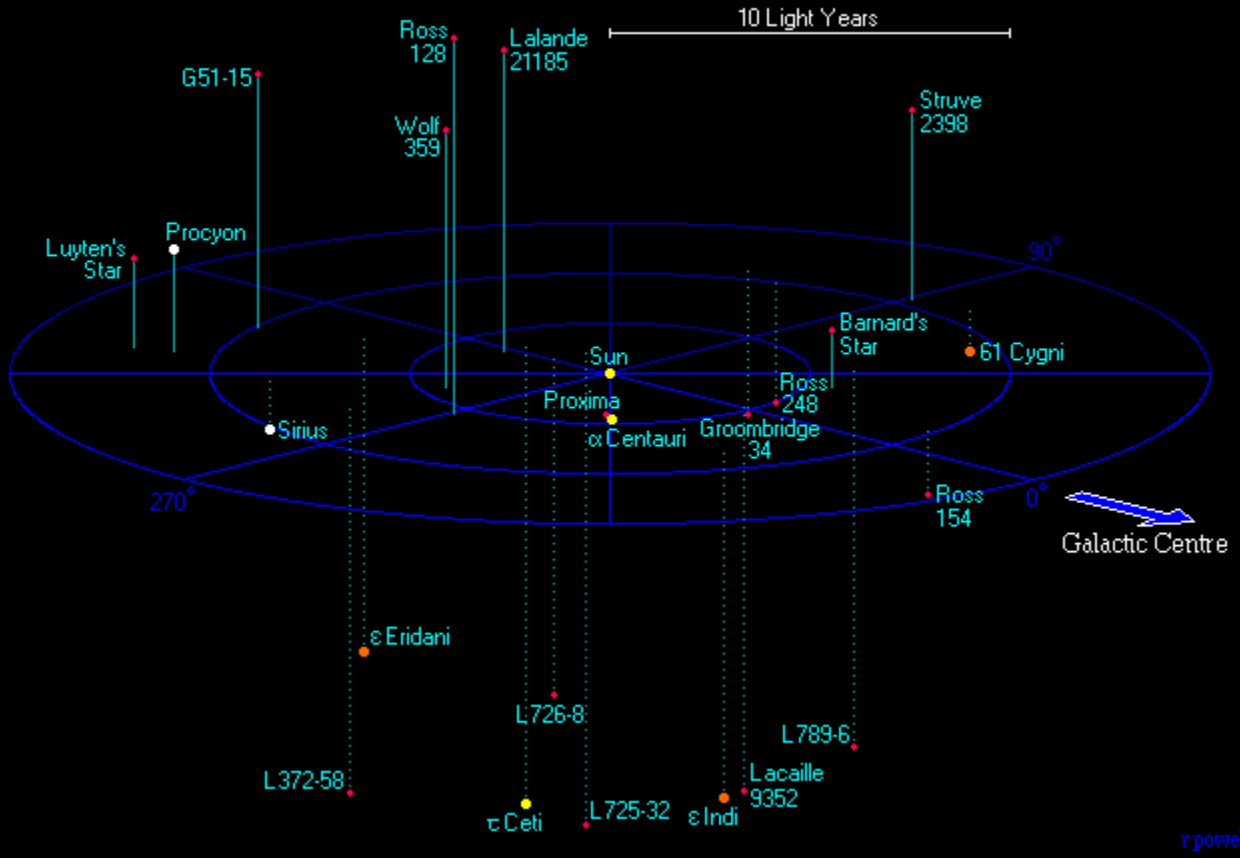


Saskatoon
~ 1500 miles

Hierarchical nature of astronomical structure

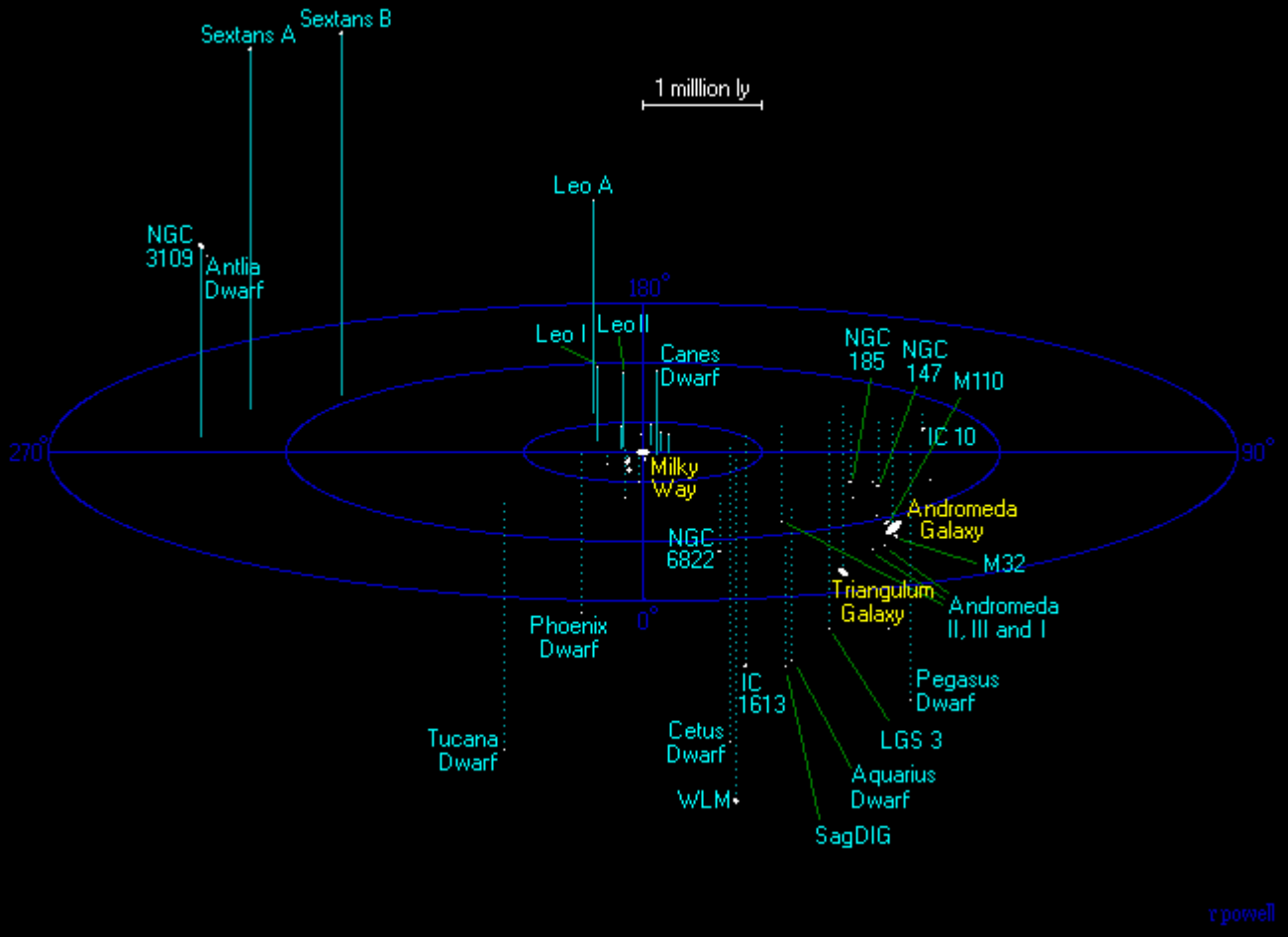
- Planets orbit around stars…
- Stars orbit within the galaxy…
- The galaxy has motions within a local cluster of galaxies…
- The local cluster of galaxies is moving within the influence of the local supercluster…

Local stellar neighbourhood



http://www.atlasoftheuniverse.com

“Local Group” of galaxies



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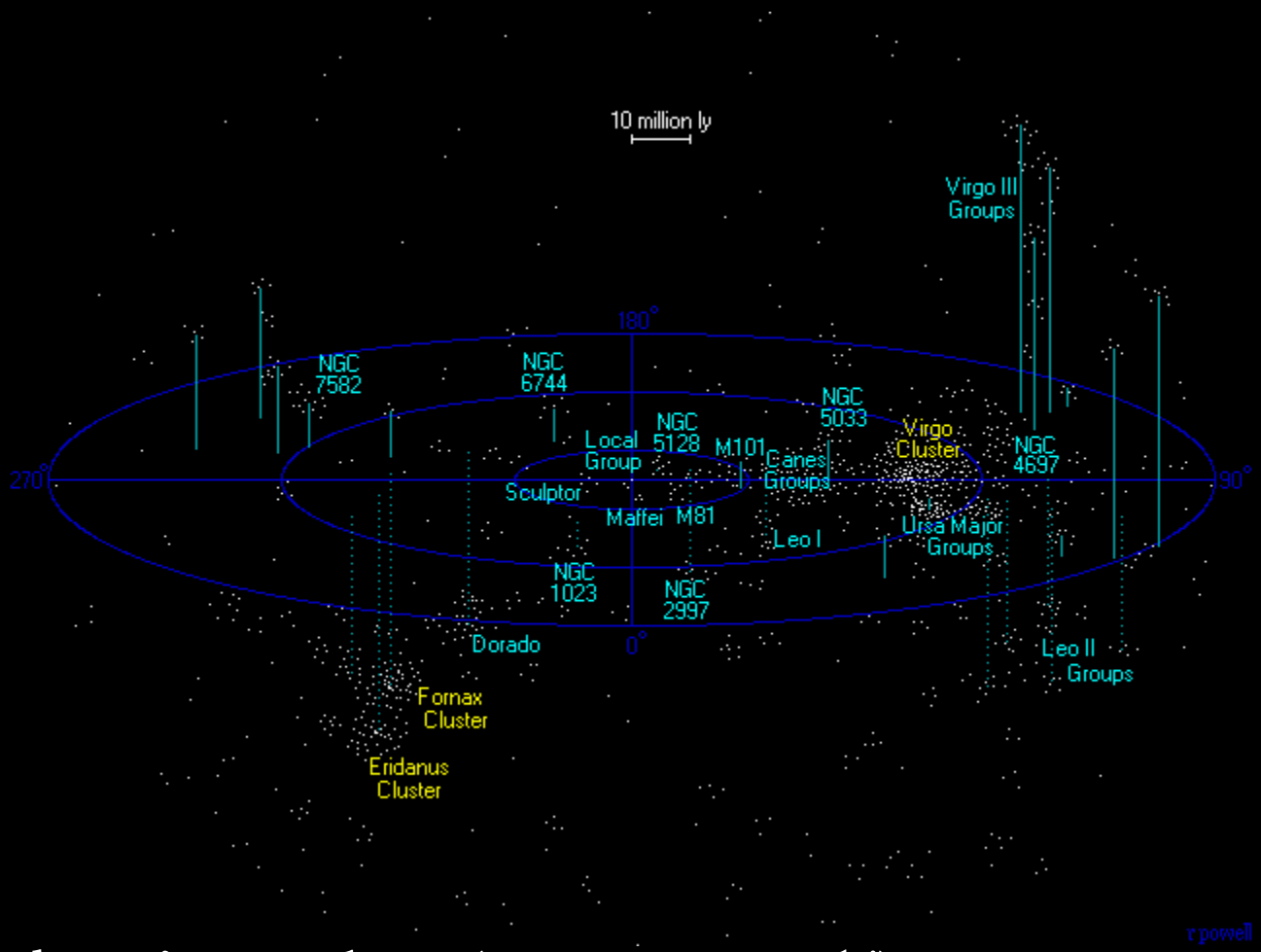
“Virgo Supercluster”



…and it doesn’t stop there (more next week!)

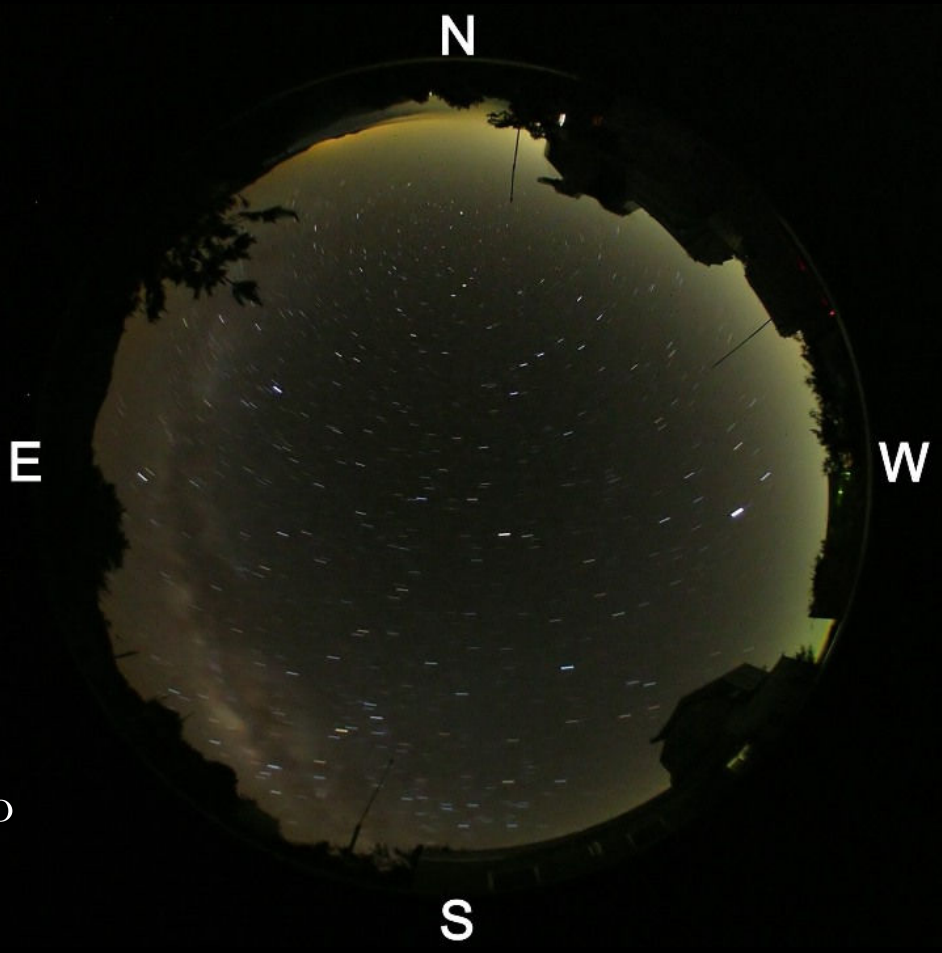
http://www.atlasoftheuniverse.com

The Celestial Sphere

- What do we see when we look up at the sky?

- **Sun**
- **Moon**
- **Planets**
- **Background of stars**
- **Milky Way**: bright band of light across the sky

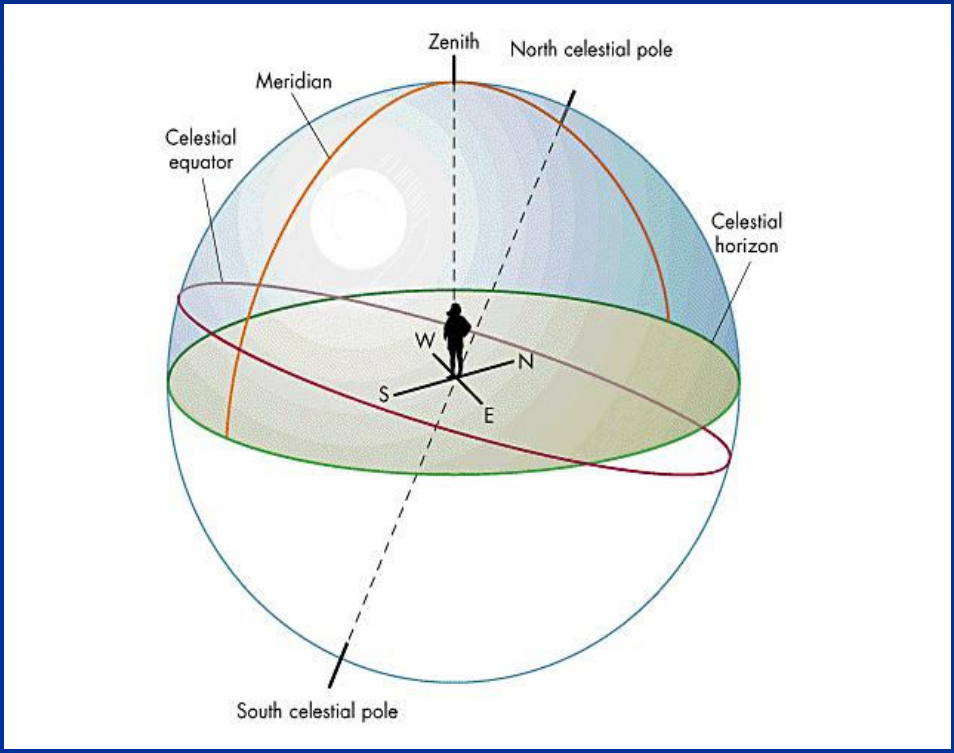
- These objects make up the **Celestial Sphere**, which travels across the sky (rotates) from East to West each day

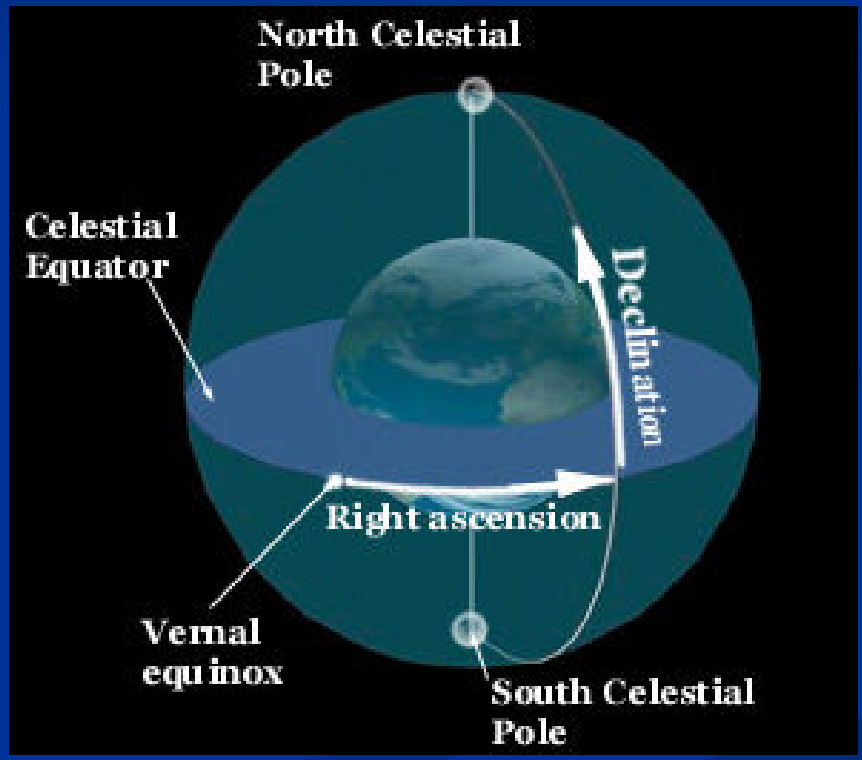


"All sky" photo showing star tracks from the rotation of the celestial sphere

Coordinates & Poles

Zenith = Point that is directly overhead





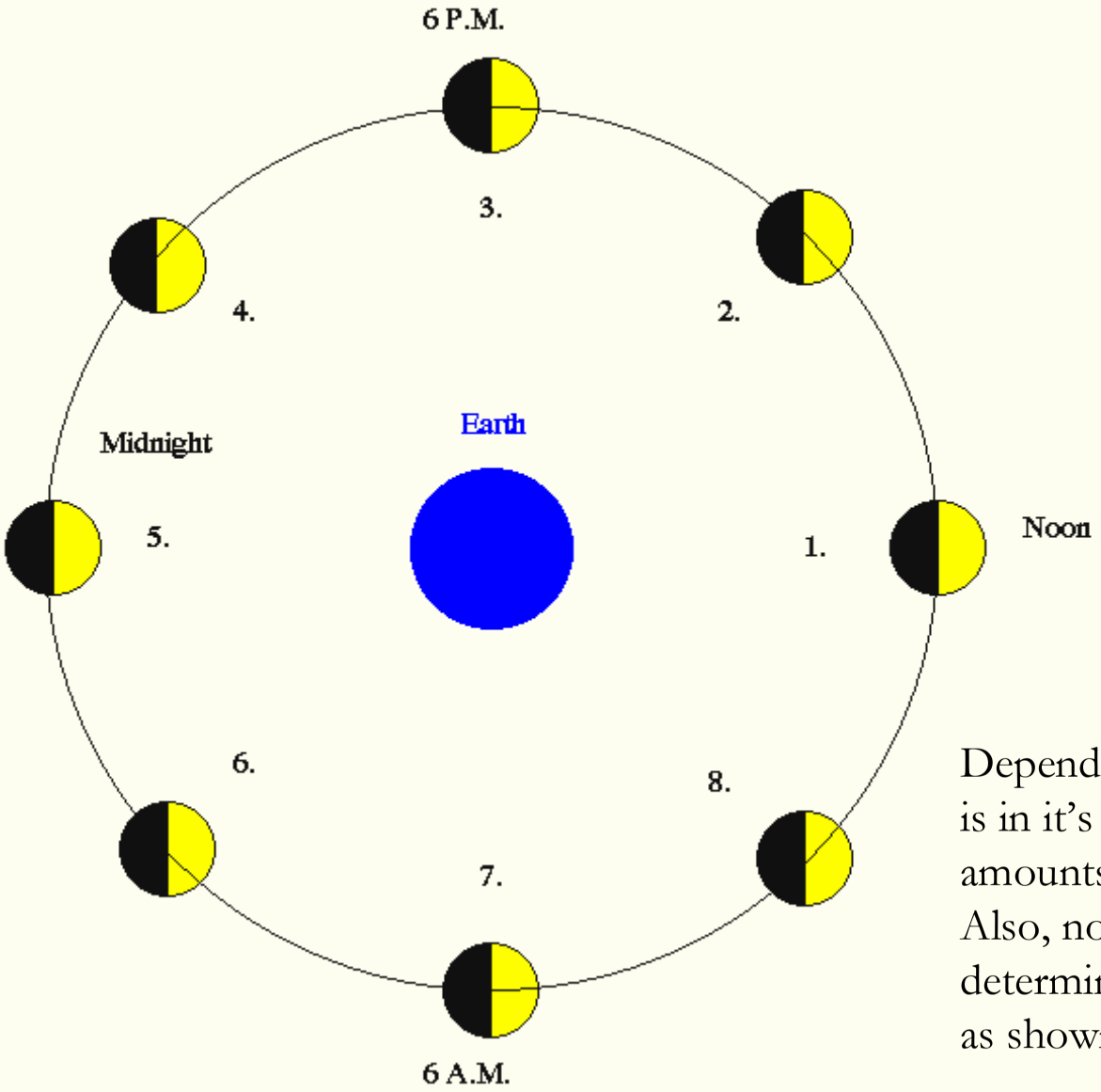
Celestial meridian = line through zenith and Celestial poles

"Celestial Longitude" = Right ascension
"Celestial Lattitude" = Declination

Observed celestial motions

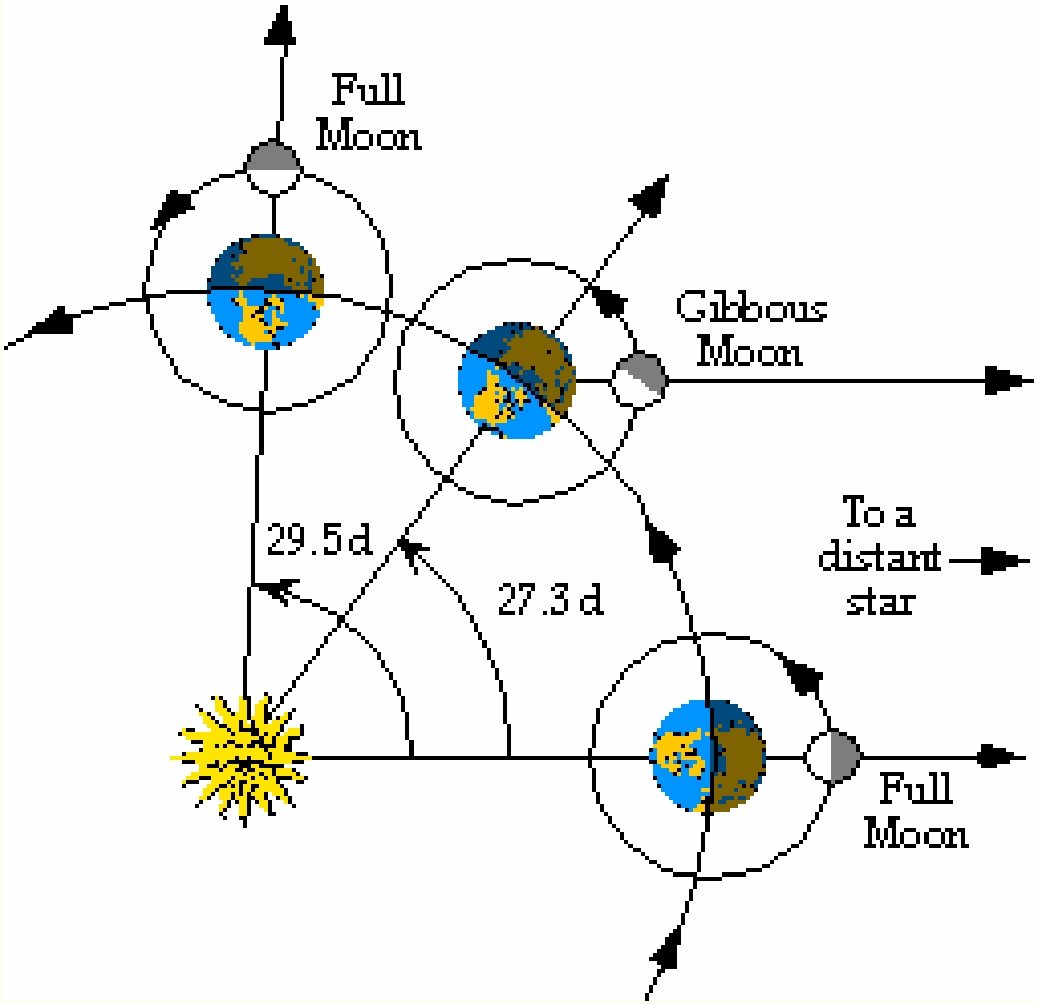
- What motions do we see in the sky?
- Most obvious: traversal of stars, moon, sun, planets from *East to West*, caused by the **rotation of the Earth** from *West to East*
- **Moon:** shows **phases**, which are due to the rotation of the Moon around the Earth

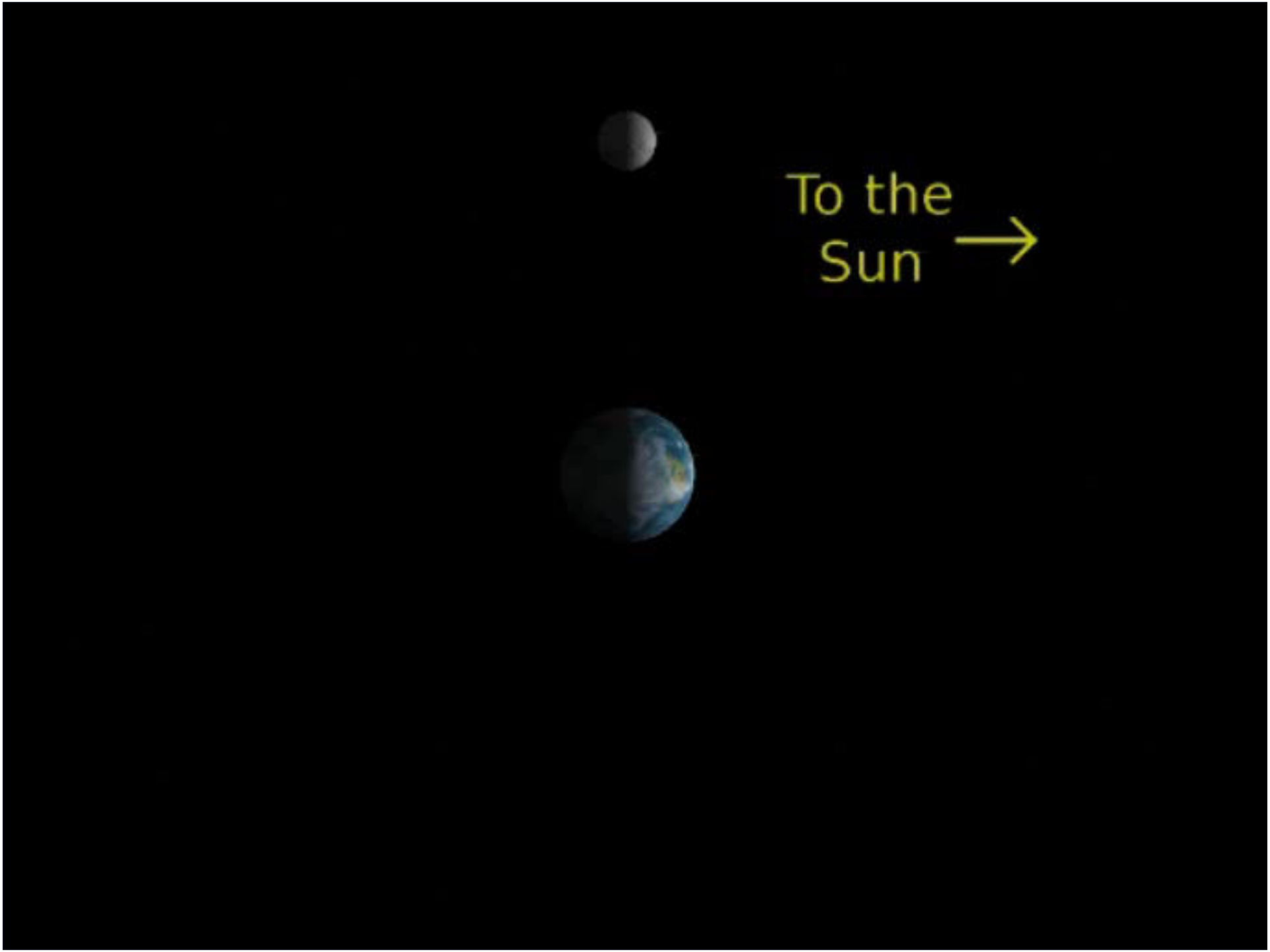
Phases of the Moon



Depending upon where the Moon is in it's orbit we will see different amounts of the surface lit.
Also, note how the incoming sunlight determines the time on the Earth as shown on the diagram.

Moon's Orbit around the Earth

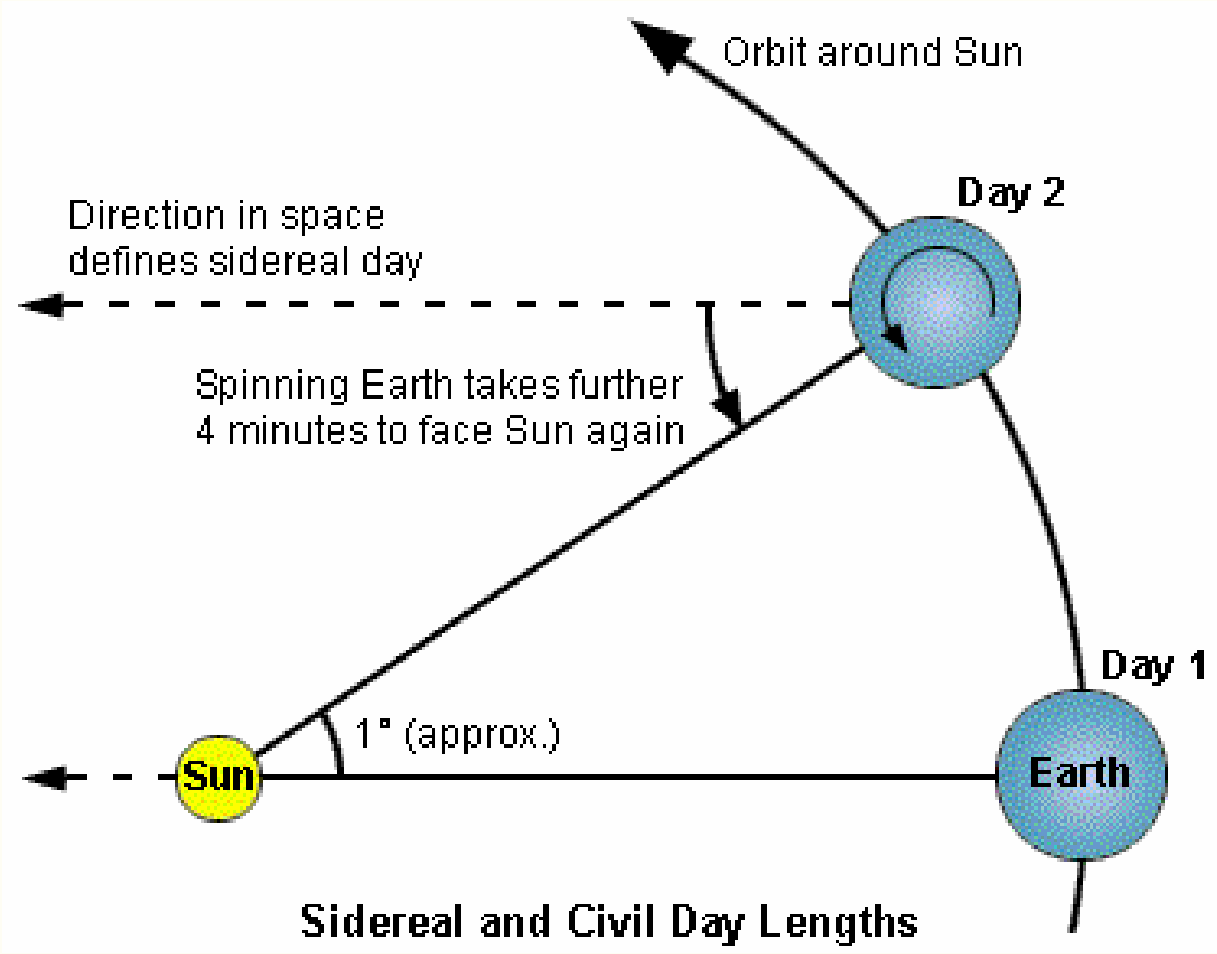



To the
Sun

Motion of the Earth around the Sun: The Ecliptic

- **Solar Day**: the **24 hour period** that it takes the Sun to return to the same position in the sky (e.g. Noon)
- **Sidereal Day:** 23h 56m – the time it takes the stars to return to the same position in the sky
- **Difference** between **Solar/Sidereal Days**: due to the Sun's motion relative to the stars (which is really because of the Earth's orbit around the Sun!)
- **Year:** 365.25 days – the time it takes the Sun to return to the same position **relative to the stars**
  - This is the origin of the *leap year*

Solar & Sidereal Day

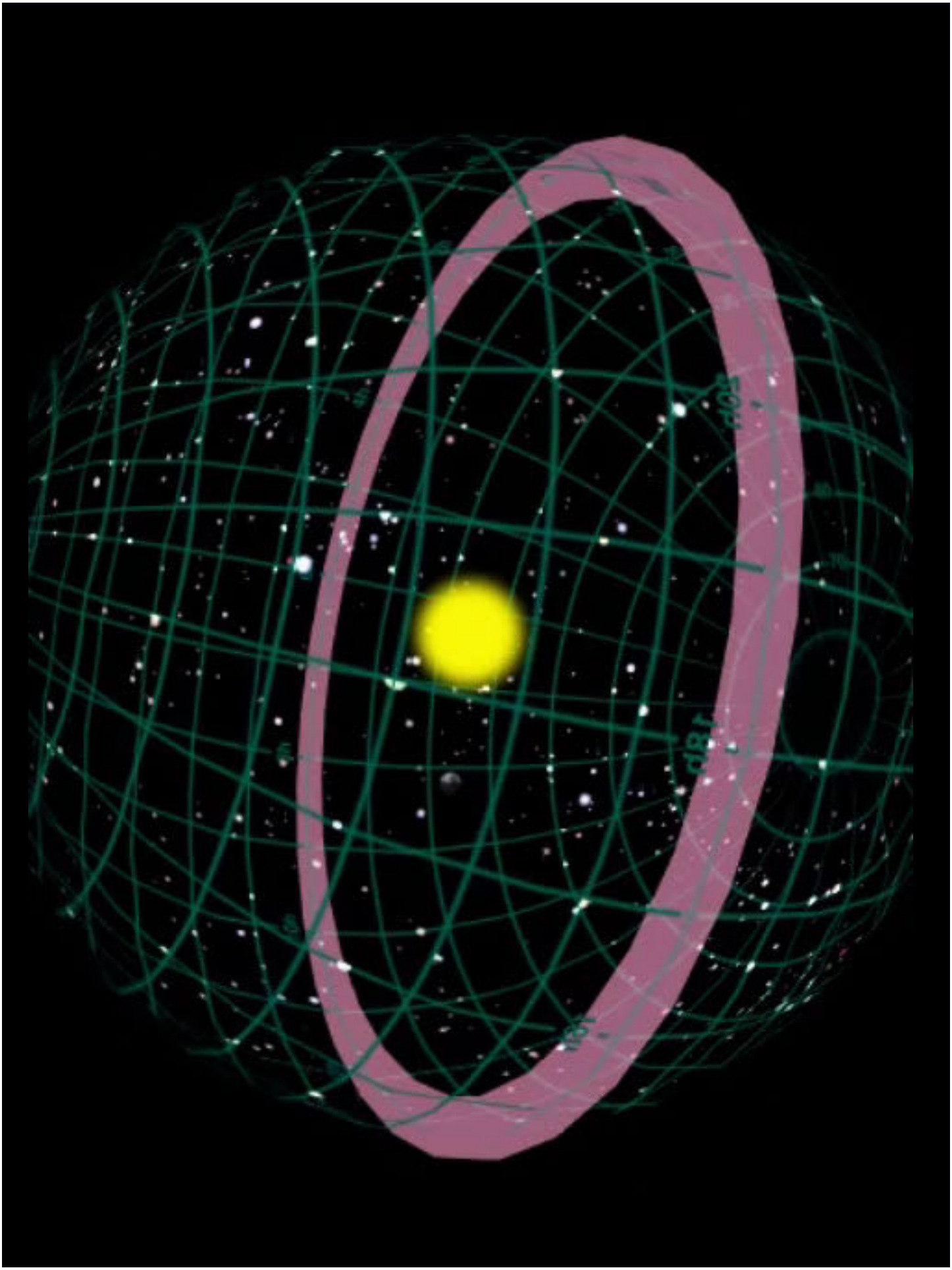


Ecliptic & motion of the Sun on the Celestial Sphere

- **Ecliptic**: the path the Sun takes across the background of stars through the year. It is tilted at an angle of 23.5 degrees to the Celestial Equator, because the Earth's rotation axis is tilted 23.5 deg relative to the plane of its orbit around the Sun

- This apparent motion (Ecliptic) is of course due to Earth's orbit around the Sun

- The following two movies show first the apparent movement of the Sun while the Earth orbits it, then the movement of the Sun around the ecliptic from the Earth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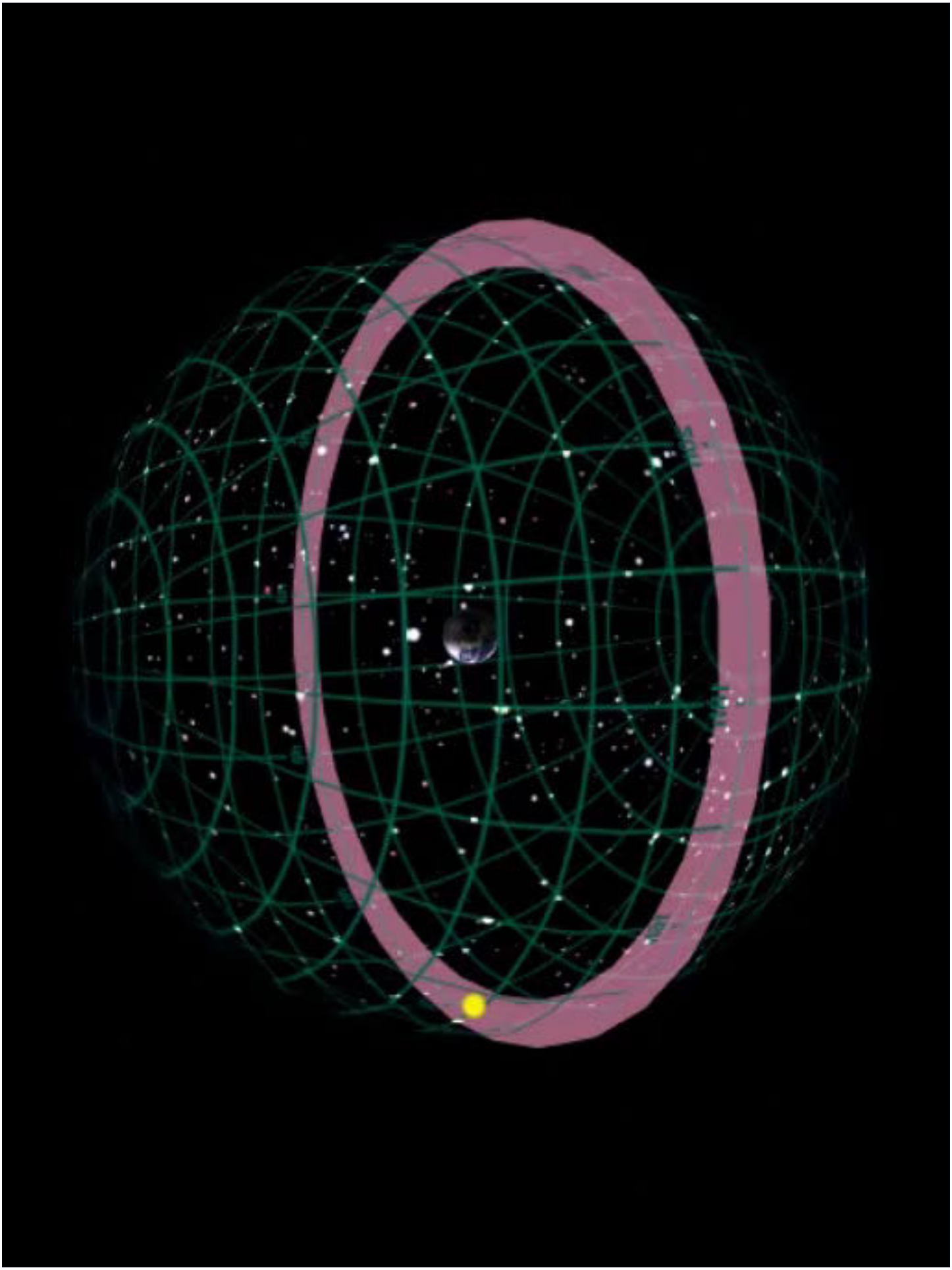
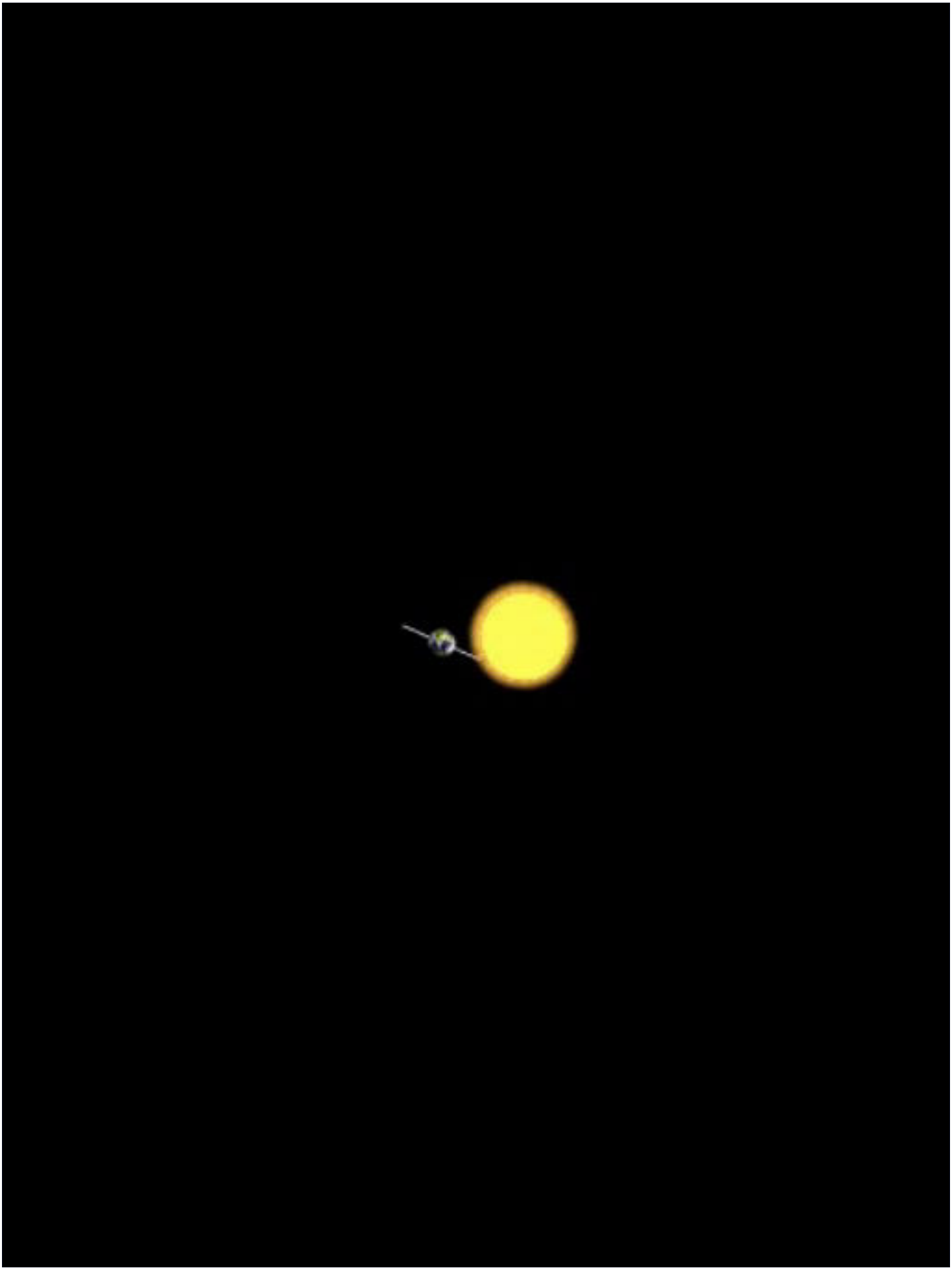
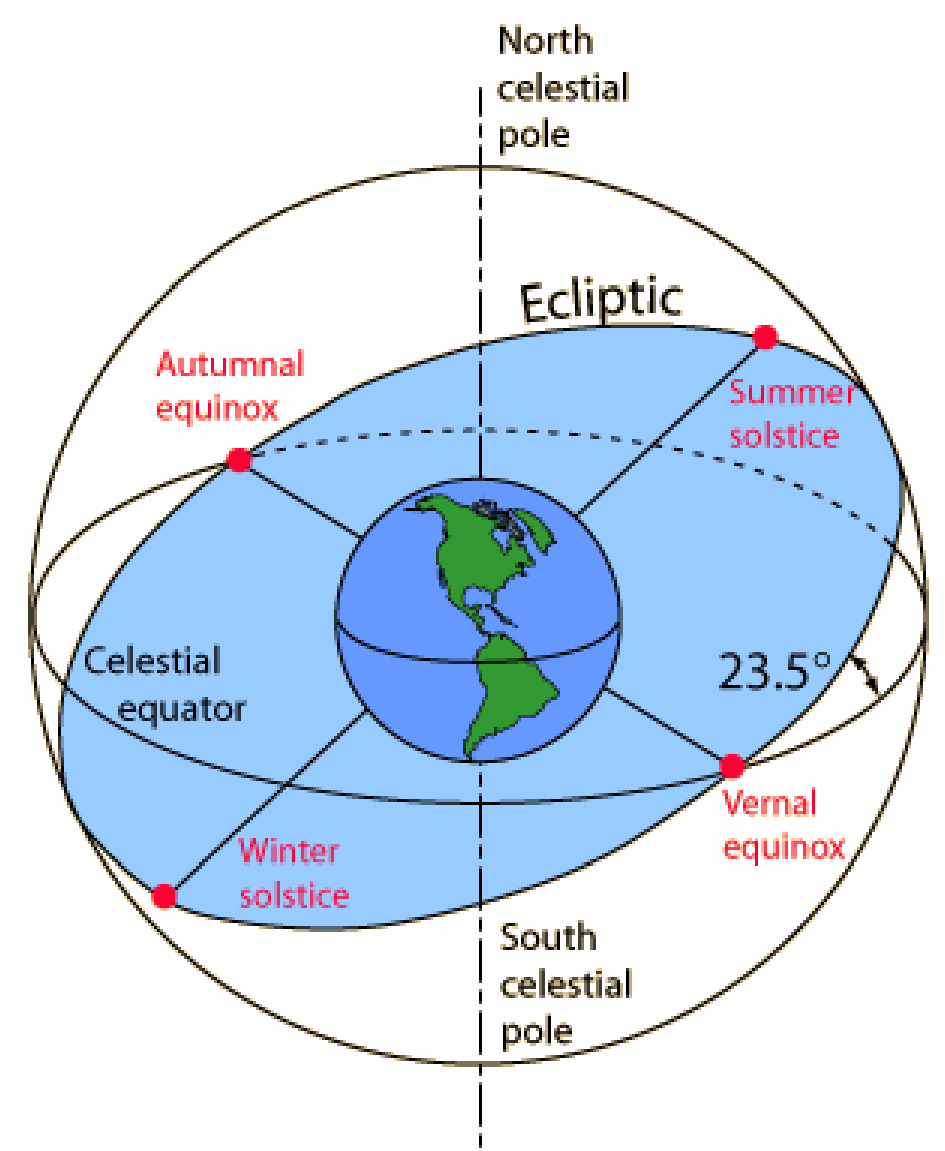


Origin of the Seasons

- As the Earth goes around the Sun, and because of the 23.5 deg tilt, at some times of the year, the Sun will be **below** the Celestial equator, and at other times it will be **above**
- These periods correspond to Winter and Summer in the Northern Hemisphere.
  - *Thus, the tilt of the Earth is is the cause of the* ***Seasons***
- The two points where the Sun crosses the ecliptic are known as *Equinoxes*
  - The zero point of right ascension corresponds to the Vernal (spring) Equinox, the opposite equinox is the Autumnal Equinox
- The highest point above the Celestial Equator is the Summer Solstice, while the lowest point is the Winter Solstice

The following movie shows the effect of the tilt of the Earth by drawing out the Celestial equator as a plane





Solstices & equinoxes

Summary of lecture 2

- To measure scales within the solar system we use Astronomical units
- Beyond the solar system, light years or parsecs are the units of choice
- The Celestial Sphere is a useful artificial construct that allows us to describe the coordinates and motions of astronomical objects relative to the Earth
- The origin of the seasons is due to the Earth's tilt, and not being farther or closer to the Sun

Next lecture

- More astronomical concepts
  - Stellar parallax
  - Luminosity and brightness
  - The magnitude system
  - Electromagnetic spectrum
  - Stellar spectra & atomic absorption/emission