What's out there?

Definitions; Scale

Planet

Dwarf Planet

Moon

Asteroid

Comet

Star

Solar System

Nebula

Galaxy

Universe

Universe $\gg$ Galaxy $\gg$ Star $\gg$ Planet $\gg$ Moons, etc. $\gg$ us.

The universe is incomprehensibly large and perhaps spatially infinite

It is also incredibly ancient, but has a finite age —

if we scale the 14 Billion years of the Universe to a 12-month calendar,

all of human civilization happens in the last minute of the last d

Scientific Method

Hallmarks of Science

#1 : Must explain natural phenomena with only Natural Causes   (NO MAGIC)

#2 : Progress through hypothesis testing

- simplicity preferred : Occam's razor

#3 : Scientific hypotheses must be testable and subject to falsification

Importance of measurement accuracy

A measurement is only as good as its error bar -

A scientific experiment not only measures something, but it also specifies how well that something is measured.

Appearance of the Sky

Local sky specified by 2 angles : Altitude
& Direction (Azimuth)

Horizon : plane tangent to observer

Zenith : point on sky directly above observer ($\perp$ to horizon)

Meridian : N-S line passing through zenith.
   Divides sky into Eastern (AM) and Western (PM) halves.

   Objects rise in East, cross meridian, & set in West.
      ↳ Sun, stars, etc.

Angular measures : $360°$ in circle
   $60'$ in $1°$ 60 arcminutes in 1 degree
   $60''$ in $1'$ 60 arcseconds in 1 arcminute

Rising & Setting motions depend on latitude
   Stars do not rise $\perp$ to horizon except at the equator
   $\angle$ or rising & setting = co latitude
   For a northern hemisphere observer,
      — the North Star remains in a [nearly] fixed position
      — circumpolar stars [far enough north] never set
         e.g. the Big Dipper is always above the horizon in Clevel

Constellations of the Zodiac gradually appear & disappear
   as the Earth orbits the sun.

Latitude & Longitude on Earth project to Declination & Right Ascension on Celestial Sphere
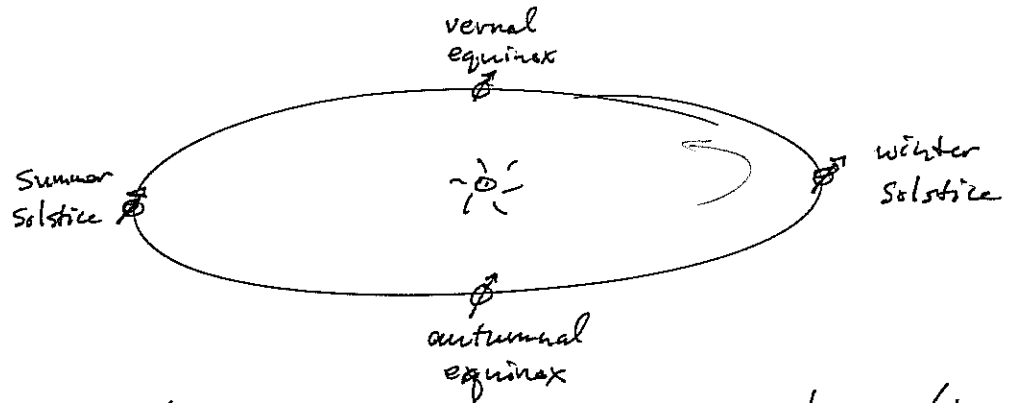
Solar Day = 24^h.   SIDEREAL DAY = $23^h 56^m$
   There would still be one day per year if the Earth stopped spinning

SEASONAL VARIATIONS dominated by AXIAL TILT of Earth NOT DISTAN

Solstices & Equinoxes

vernal
equinox

Summer
Solstice

winter
Solstice

autumnal
equinox

Solstice : maximum north/south position of sun on sky — Longest/short day of year

Equinox : half-way point between solstices.

     — Only day on which northern & southern hemispheres equally illuminated

Ecliptic: — path of sun across sky

Celestial Equator: — extension of Earth's equator onto sky

     These planes tipped wrt each other by axial tilt $(23.5°)$

     The sun's extremal N-S positions vary by 47° from solstice to solstice!

Tropic : latitude where the sun can reach the zenith (± 23.5)

[Ant] Arctic : latitude where the sun never sets on the summer solstice

       $|\ell| > 66.5°$

Precession : wobbling of the Earth's axis

     very slow change of the orientation of the spinning Earth
     with respect to the Celestial Sphere (26,000 yr period

       → Polaris won't be the North Star in a few thousand years

       → Discovered by Hipparchus back in the day (280 B

Lunar Phases

- Phase determined by viewing angle wrt sun
- Consequence of the moon's orbit around the Earth

   Siderial Period : 27.3^d

   Synodic Period : 29.5^d ← what we observe as a consequence of the combined orbit of the moon around Earth and Earth around the sun.

Phases :   New
           crescent (waxing)
           first quarter (half illuminated) ⎫ most prominent in
           gibbous (waxing)   ⎬ early evening
           full   ⎭
           gibbous (waning)
           last quarter   ⎫ most prominent
           crescent (waning) ⎬ before sunrise
           repeat   ⎭

Synchronus rotation : the moon keeps the same face towards us because it is tidally locked into a 1:1 spin-orbit resonance — it turns once on its axis for every one orbit

Eclipses   occur when the shadow of the Earth/Moon is cast on the Moon/Earth

   Lunar Eclipse : the moon passes through Earth's shadow

   Solar Eclipse : the moon's shadow crosses the surface of the Earth

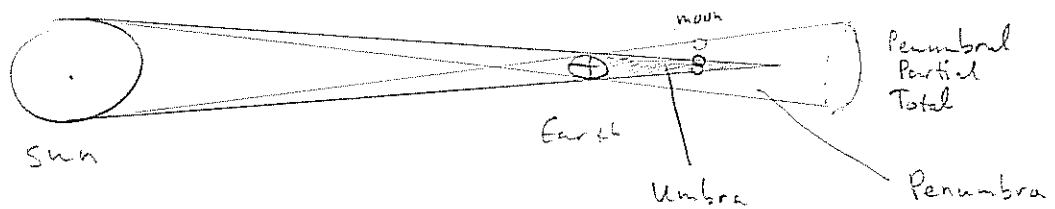Eclipses can only occur when the moon is
   i) either new or full,
AND ii) at a node of its orbit, which is 5° inclined wrt the eclipt
         Gotta line up!

Eclipses (con.)

Lunar eclipses   occur only at full moon

can be   Penumbral   Penumbral passage

Partial   Partial umbral passage

Total   complete umbral coverage

depending on how closely aligned the moon–earth–sun line is

Total Lunar Eclipse coming up Sunday evening 9/27 "Blood moon"
Penumbral eclipse starts shortly after sunset, but not dramatic
Umbral eclipse reaches totality at 10:47 PM (starts ~ 10:11 PM)
Takes several hours

Solar Eclipses   occur only at New moon

Very rare, because the moon is smaller than the Earth.
Its angular size is about the same as the sun's,
so the tip of the umbra just barely reaches the
surface of the Earth. The path of totality is restricted
to a narrow geographical swath, and lasts only a few minutes.
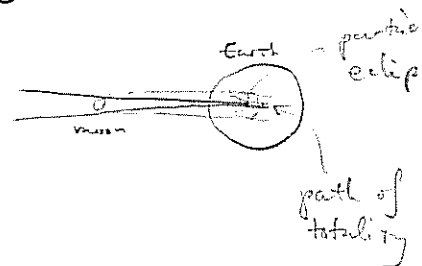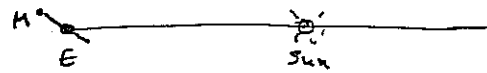
can be   Partial

Total

Annular

depending on where the moon is in its slightly ~~ex~~ eccentric orbit

Eclipses (con.)

Eclipses do not occur every new & full moon because near-perfect alignment is required. The moon's orbit is tipped 5° wrt the plane of the ecliptic, so it must additionally be at the point where these planes intersect (the line of nodes)

This alignment happens twice a year
("eclipse seasons")

Even then, the details depend on exactly when & where
the Earth – Moon – Sun align
as to how much (if any) eclipse occurs.

Ancient Astronomy

Ancient peoples kept a close eye on the sky –
the earliest written records display an advanced knowledge
of astronomical cycles (e.g., the Babylonians knew about
eclipse seasons even if they couldn't predict eclipses).
This implies a long oral tradition before civilization.

All cultures developed calendars; many built elaborate
structures marking celestial events & locations (e.g., Stonehenge)
The Greeks even built an analog computer (the Antikythera device)
Eratosthenes made an accurate estimate of
the circumference of the Earth (c. 240 BC)

Competing Cosmologies

Geocentric	Heliocentric
Ptolemaic	Copernican
Earth at center	Sun at center

The sun is the source of light in both models

Explains — **Explains**

Explains	Explains
• Motion of Sun	• Motion of Sun
• Motion of Moon	• Motion of Moon
• Solar and Lunar Eclipses	• Solar and Lunar Eclipses
• Phases of Moon	• Phases of Moon

Retrograde Motion

Needs epicycles	Consequence of Lapping nicer

Inferiority of Mercury & Venus	
Must tie to sun	Interior to Earth's Orbit nicer

Predicts

- No parallax ✓	- Parallax X
- Venus: crescent phase only X	- Venus: all phases ✓

Galileo's telescopic discoveries

- Stars in the Milky Way

- Mountains on the Moon

- Sun spots (celestial spheres NOT perfect)

- Rings of Saturn (barely resolved)

- Moons of Jupiter ("Medicean stars")

  - Earth NOT center of all revolution

- Phases of Venus

  - Good test of geocentric hypothesis

Galileo also helped overcome common misconceptions
about the nature of motion

- All motion is relative (Galilean relativity)

- Objects fall with the same rate of acceleration
        irrespective of composition   (Equivalence Principle)

  · Horizontal motion is decoupled from verticle acceleration
        - a bullet falls to the ground equally fast
            whether shot or dropped

Tycho Brahe
   - Last great naked eye observer (pre-Galileo)
      · Compiled accurate positions of planets
      · Measured parallax of comet, placing it between planets
      · Could not detect parallax of stars

Kepler's Laws

1. Planetary orbits are ellipses (not just circles) with the sun at one focus (not center)

2. Equal areas are swept out in equal times by a line connecting a planet to the sun (imaginary!)   (Conservation of Angular Momentum)

3. $P^2 = a^3$

   P = Period of orbit in years   (sidereal period)

   a = Semi-major axis of ellipse in AU

Newton's Laws of Motion

1. An object at rest remains at rest and an object in motion maintains a constant velocity unless acted upon by an external force.

2. $\vec{F} = m\vec{a}$ a force F applied to a mass m causes an acceleration $\vec{a}$.

3. For every action there is an equal and opposite reaction.

Tides

Gravity seeks to make isolated masses spherical

Hence stars & planets all round

When masses are not isolated, the effects of other masses distorts the perfect shape from a sphere to an ellipsoid.

e.g., the moon & sun raise tides on the Earth, because the gravitation attraction towards the moon is slightly stronger ~~the~~ on the side of the Earth closest to the moon than on the far side.

Results in 2 high & low tides per day

The strength (amplitude) of tides depends on the alignment of the sun & moon, hence on the phase of the moc

New + Full moon : Spring tides (strong)   E - M - S aligned

First + Last Quarter moon : Neap tides (weak) $\overset{M}{\underset{E}{|}}$ - S $\perp$

Tidal friction is gradually transfering the spin angular momentum of the Earth to the orbital angular momentum of the moon. This gradually lengthens the length of the day and causes the moon to drift outwards (VERY VERY SLOWLY)

Electromagnetic Radiation

Light is just one form

Radio   Microwave   Infrared   Optical   Ultraviolet   X-ray γ-ray

λ Long wavelength

f low frequency

low energy

$$\lambda f = c$$

$$E = hf$$

h = Planck's constant

short wavelength
high frequency
high energy

we see by scattered light

Hot objects emit light (thermal radiation, sometimes called "blackbody" radiation)

e.g., a - hot stove top

- the sun