ASTR 101 Lecture

Exploring the Night Sky (University of Victoria)

Introduction

Monday, May 7, 2018 10:01

Introductio
n

Audio recording
started: 10:36
Friday, May 11,
2018

Introductio
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Audio recording
started: 10:36
Friday, May 11,
2018

Science and Astronomy

Tuesday, May 8, 2018 11:07

Science and Astronomy
Audio recording started: 11:09 Tuesday, May 8, 2018

Introduction

Science and Astronomy

- Lightyear (ly) is a unit of distance
  - Distance light travels in 1 year
- Astronomical unit (AU)
  - Average distance between Earth and Sun
- Scientific notation
  - Size of universe
    - 8.8 x 10626
  - Speed
    - Usually m/s or km/s
  - Using proper unit for measurement
  - 5 362 000 000 = 5.362 x 10^9
- Diameter of Earth = 12742km
- Distance between Earth and Moon = 384 000km
  - 30x the diameter of Earth
- Earth <-> Sun = 150 000 000km = 1 AU
  - Light reaches Earth in 8min
- Diameter of sun = 1 400 000km
- Closest star to Sun
- Size of galaxy = 100 000ly = 6 324 100 000AU
- Local Group size = 10^7ly
- Virgo Supercluster size = 100 000 000ly across
- Brightness Magnitude
  - Magnitude (m), based on human perception of star Vega
    - m = 0.0
  - 10X brighter = -2.5 magnitide
  - 100X brighter = -5 magnitude
  - Human can see ~6.5m
  - Telescopes have m~31

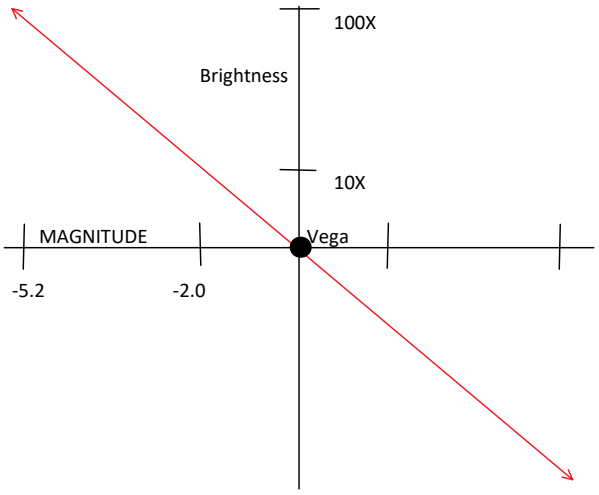
Knowledge

- Inductive reasoning
  - Generalizing based on evidence
  - Throw ball 10 times, hypothesize it will come down
- Deductive reasoning
  - All things have gravity, therefore ball will come down
- Theory
  - Further testing of an idea will create a theory
  - Must be testable
  - Must be falsifiable
  - Must be continually tested
  - Must be simple and elegant
  - Experiments must be repeatable
  - Can be proven wrong, never proven right 100%
- Hypothesis
  - An idea or proposed explanation
- Direct knowledge
- Indirect knowledge
- Scientific method
  - Testing predictions/hypothesis
- Can make observations, predictions, and hypotheses about astronomy
  - It is a science
- timeliness

The Night Sky

Wednesday, May 9, 2018 10:33

The Night Sky
Audio recording started: 10:35 Wednesday, May 9, 2018



- Visible planets
  - Venus is visible
    - Never goes above horizon
  - Mercury is closest to sun
    - Difficult to see
  - Jupiter and Saturn are seen for 3/4 of Earth's orbit
- Stars visible to naked eye
  - Small chunk of MW galaxy is visible at night
  - Red dwarves are nearly invisible
    - Most common star
- Celestial Sphere
  - 2 stars with similar apparent magnitude may have very different true magnitude
  - Betelgeuse is a red giant
  - Orion Nebula (Orion's sword)
- Constellations
  - Mostly cultural
  - Ursa Major used to look like a bear
  - International Astronomical Union standardized the constellations
    - There are 88 constellations
- Stars in constellations
  - Groups of stars that make another constellation within a constellation is called an asterism
    - Big Dipper in Ursa Major
- Zodiac constellations
  - Best known culturally and scientifically
  - Lies on the ecliptic
    - Planets and sun follow these
  - 13, not 12
    - Ophiuchus, between Scorpio and Saggitarius
- Day
  - 24h = 361 degrees
    - The "solar day" or "tropical day"
  - The "Sidereal Day"
    - 23h 56min = 360°
    - Used in observatories
      - Only on the equinoxes are the clocks in observatories correct
- South Celestial Pole
  - Stars appear to rotate 0.25°/min
    - 80°/5.2h
- Motion of sun
  - Due to Earth's axis tilt, the sun does not have a set track
  - In the winter, sun rays are more spread out
    - Less energy per m^2
    - Days are shorter
    - Southern hemisphere is experiencing summer
  - Over at least 10k years, the Earth's tilt is changed
    - Affects climate over time
- Months of the year
  - July = Julius Caesar
  - August = Augustus Caesar
  - September = seven (but it's nine)
- Equinox
  - "equal nights"
  - 12h day and night for both hemispheres
- Earth's orbit is elliptical
  - Closest to the sun in the northern winter
- Earth's changing tilt
  - Pointing at Polaris now
  - 5000 years ago, Thubega was the north star
  - Changes the zodiac
    - I am Cancer, but the sun was in Gemini when I was born
- Measuring angles
  - Approximations with hands
    - Finger is 1°
    - Palm is 10
    - Finger tip is 3°, middle is 4°, and last is 6°
  - Arcminute = 1' = 1/60°
  - Arcsecond = 1" = 1/60' = 1/3600°
- Communicating celestial positions

    - Measure angle relative to north (azimuth)
    - Measure angle above horizon (altitude)
    - Vernal Equinox is (0, 0) point
- Measuring distance using parallax
    - Why humans have stereo/3D depth perception

Celestial Positions

Friday, May 11, 2018 10:35

Measuring Angles

Audio recording started: 10:35 Friday, May 11, 2018

- Communicating celestial positions
  - Ecliptic is 23.5° off the Earth's equator projected on celestial sphere
  - Hour angle goes along celestial equator
  - Declination is measured -90° to 90°
- Parallax
  - Stars appear stationary
    - Move very slowly, arcseconds per year
  - Triangulation is used to measure distance
  - Degree of parallax shift determines the distance of object
- Using Earth's orbit to measure longer distances
  - Take a picture, wait 6 months, take another
    - Parallax of 2AU, diameter of Earth's orbit
  - Angular difference is the parallax
  - Smallest angle 0.001" = 6540ly
- Measuring size of planets
  - Using triagulation
  - Eratosthenes found shadows at the Tropic of Cancer on the summer solstice, and no shadow at the equator on the same day
- If a parallax of a star is 2X as large as another star, it is half the distance away

Sun and Moon

Friday, May 11, 2018 11:07

Sun and Moon
Audio recording started: 11:08 Friday, May 11, 2018

- Moon orbits Earth every 27.3 days
  - Sidereal month
  - Moon is in a tidal lock
  - Waxing is when the moon is becoming more visible
  - Waning is when the moon goes from full to new
  - Ancient calendars were based on lunar cycles
- Lunar eclipse
  - Occurs at full moon
  - Becomes red
    - Depending on position in Earth's shadow
    - Could be rainbow!
    - Dust and water vapor can affect it
  - Occurs when moon is entirely with the Earth's umbra (full shadow)
    - Penumbra is where solar rays are only partially blocked
  - Moon's orbit is off the equator by 5.2°
- Solar eclipse
  - Only occur 2 times a year
    - When Sun, moon, and Earth form a straight line
  - Moon's umbra is so small, and just makes it to the Earth's surface
  - Corona can be seen with special equipment
    - Made up of Sun's atmosphere and magnetic fields

Layout of Solar System

Friday, May 11, 2018 11:36

Layout of Solar Syst...
Audio recording started: 11:36 Friday, May 11, 2018

History of Astronomy

Tuesday, May 15, 2018 10:42

History of Astronomy
Audio recording started: 10:42 Tuesday, May 15, 2018

History of Astronomy
Audio recording started: 10:32 Wednesday, May 16, 2018

History of Astronomy
Audio recording started: 10:35 Friday, May 18, 2018

- Important to explore because it took millenia for humans to understand the stars and planets
- Terminology
  - Retrograde
    - Motion in opposite direction to other object(s)
    - Venus and Uranus rotate in retrograde
  - Prograde
    - Motion in same direction as other object(s)
  - Inferior planets
    - Relative to the Earth, planets closer to the sun
  - Superior planets
    - Further from the sun
  - Planetary alignments
    - Conjunction
      - Inferior
      - Superior
    - Opposition
- Archaeoastronomy
  - The calendar
    - Ancient peoples needed to know when is best to plant crops, or when the cold weather starts
    - How long is a year?
    - Navigation on the ocean (when lost)
    - After awaking on an unknown planet, how would a person figure these out?
  - Predicting weather patterns
    - Ancient Central African peoples used crescent moon's orientation
  - Travelling
    - North star
  - Tools
    - Structures
      - Often marked important celestial alignments such as the solstices
      - Giant calendars, often acted as ritual sites
    - Stonehenge was an ancient calendar
      - Built/modified over 1700 years
      - Summer solstice sunrise aligns with heel stone
  - Babylonian astronomy
    - Had complex math to describe motions of moon and planets
    - Clay tablets
    - Modern astronomy is a direct descendant

- Mayan astronomy
  - Temple at Caracol in Mexico has many windows that aligned with astronomical events
- Ancient Chinese Astronomy
  - Created star charts
  - They saw a star that went supernova, and is now the Crab Nebula
- Arabic Astronomy
  - Terms "zenith" and "azimuth" are Arabic, also many star names
  - Based off of Greek Astronomy
  - Use of astrolabs
- Ancient Greece
  - Distinguished the Sun, Moon, planets and stars as distinct objects
  - Sun and stars move from East to West
  - Planets follow ecliptic, sometimes move in retrograde
  - Plato
    - Perfection of the heavens, perfect spheres and perfect paths of planets
    - Crystalline spheres that carried the planets with Earth as the center
    - Plato's student, Eudoxus, developed system of 27 spheres to describe motion of heavens
  - Aristotle
    - All arguments stem from "first principles"
    - Perfection of heavens was a first principle
    - Could not measure paralax
      - Therefore, Earth was centre
    - Modified Eudoxus model to 55 spheres
  - Aristarchus
    - Proposed idea that Earth rotates around the sun
    - Used triangulation to estimate distance of sun
  - Eratosthenes
    - Calculated radius of Earth
  - Ptolemy
    - Developed mathematical model of geocentric universe
    - All objects had primary path
      - Deferent
    - Planets moved on epicycles to account for retrograde motion
    - Need 80 spheres to describe motion of heavens
    - Alfonsine table in the 13th century tries to explain and refine geocentric model
- Transition to heliocentric model
  - Copernicus
    - Cleric and scientist
    - Rediscovered Aristarchus' writing
    - Developed heliocentric model which was mathematically worse than the geocentric model

        - Because of use of circles
      - Stars are much further away
      - Explained retrograde motion
      - Had to reintroduce epicycles of the planets
    - Galileo Galilei
      - Introduced the scientific method
        - Advocated that this was the way to ask nature its ways
      - Took Leuwenhoek's invention, the telescope, built his own, and observed the sky
        - Observations disagreed with geocentric model
        - Found moon around Jupiter, proving there are bodies orbiting something other than Earth
    - Tycho Brahe
      - Pre-telescope
      - Tried to develop a new geocentric model to replace Ptolemy's
      - Observed a guest star (supernova) that did not show parallax
        - Thus, is part of celestial sphere
        - Thus, celestial sphere was not unchanging, unlike what Aristotle said
      - Built giant observatory with giant sextants
        - Recorded date-time-positions of planets, stars, comets, and supernovae, accurate to 1'
        - Johannes Kepler joined him in the observatory
    - Kepler's Laws
      - 1st - Orbits are elliptical
      - 2nd - Orbits sweep equal areas in equals amount of time
        - Conservation laws
        - Conservation of angular motion
          - L=r(mv) or v=L/rm
        - Objects speed up as distance decreases
      - 3rd - turns out to be incorrect
        - Center of mass is the focus of the ellipse
          - Affected by other planets
          - Centre of mass of the sun changes
- Ellipses
  - Perihelion
    - Closest point to sun
  - Aphelion
    - Furthest point from the sun
  - Perigee
    - Moon's closest point to Earth
  - Apogee
    - Furthest point from Earth
- Newton's Laws
  - Sir Isaac Newton
  - 1st law - Inertia

    - 2nd law - F = ma
    - 3rd law - for every action, there is an equal and opposite reaction
    - Gravitation as being connected to mass
        - Any object with mass exerts gravitational force on any other object with mass
        - Gravitational force is the only force that is always positive
        - $F = (Gm_1m_2)/r^2$
- Lagrange Points
    - L1 - object feels equal pull from Sun and Earth
    - Spacecraft are often put in L1 and L2
- Albert Einstein
    - Frames of reference
    - Speed of light in a vacuum is the same in all frames of reference
        - Maximum possible speed in the universe
        - Special theory of relativity
    - General theory of relativity
        - Gravity does not produce a force, but instead it curves/warps space-time, resulting an acceleration toward the centre of gravity
        - Light is affected by gravity
    - Gravitational lensing
    - Waves transmitting energy without transporting material

Light

Tuesday, May 22, 2018 10:30

Light

Audio recording started: 10:32 Tuesday, May 22, 2018

- Light strikes material and does one of 4 things;
  - Reflection
  - Transmission
    - Atmosphere scatters more blue light than red light
    - Atmosphere is mostly opaque to other lengths of light
  - Absorption
  - Scattering
- Long wavelengths can pass through small material
- Very short wavelengths can disrupt atomic nucleus
- Sources of light
  - Excited particles emit light
  - Slow particles absorb light
  - Changes in state cause emission/absorption
  - Changes in state are cause by collisions or excitations
- 0° Kelvin = absolute 0
  - 273° Kelvin = 0°C
- Thermal light
  - Lower frequency than visible light
  - If a hot thing emits light, it is very freaken hot
    - Infrared is relatively cold
  - Blackbody radiation
    - Object is emitting thermal energy over a wide frequency of light that is not visible
    - The peak frequency corresponds directly to the temperature
    - Used to determine the temperature of distant object (eg stars)
      - Colour of stars indicate the temperature (eg blue are very hot), blackbody can determine colours of comets, planets, etc.
- Our Sun
  - Atoms in Earth's atmosphere absorb certain frequencies
    - Sun's atmosphere absorbs certain frequencies, too
      - Disrupts its own blackbody radiation

Atomic Light

Tuesday, May 22, 2018 10:56

Atomic Light

Audio recording started: 10:56 Tuesday, May 22, 2018

- Photoelectric effect
  - Can only be understood if light is behaves as particles
  - Photons proposed by Einstein
  - When light shines on metal, electrons are emitted from metal
    - Frequency must be higher than a minimum
- Particle-wave duality
  - Think of photon as "wave packet"
    - "discreet"
- Bohr model
  - Not correct
  - Correct in explaining periodic table
- Isotopes
  - Different numbers of neutrons in nucleus
- Electron orbits
  - More energetic electrons go to higher shells
  - A photon is emitted as an electron goes down 1 or more levels
  - Photon is absorbed when an electron goes 1 or more levels
  - Cold atoms have their electrons at the ground state
- Particles move as waves
  - Paul de Broglie
  - Waves in an atom depend on the momentum (p)
    - p = mv
  - Wavelength = size of orbit around atom
- Atomic spectra
  - Each atom emits its own distinctive spectra
    - Even molecules!
- 3 types of spectra
  - Blackbody spectrum is continuous
  - Going through a cloud of gas
    - Absorption line spectrum
    - Emission line spectrum
      - Inverse of absorption line
  - Known as Kirchhoff's laws
    - Hot solid, liquid, or gas gives off continuous spectrum
- Atmospheres of planets
  - Can be determined using emission spectra

Doppler Effect

Tuesday, May 22, 2018 11:39

Doppler Effect

Audio recording started: 11:39 Tuesday, May 22, 2018

- Moving wave sources can affect the wavelength
  - Common example is a car or train moving toward and away from an observer as it honks
- Spectra lines are shifted if an object is moving toward or away from Earth

Telescopes

Wednesday, May 23, 2018 10:31

Telescopes

Audio recording started: 10:31 Wednesday, May 23, 2018

Telescopes

Audio recording started: 10:32 Friday, May 25, 2018

- Use lenses and mirrors
  - Purposed with focusing light
- Refraction
  - Light passes through a material and slows down and bends
  - Huygen's Principle
  - Common wavefront is at a different angles after the interference
  - Particles, too, will bend toward the normal if speed in increased
- Lenses
  - Thickness/fatness of convex lens determines how close the focal point is
    - Length of focal length
  - Concentrates light
  - The larger the prism, the larger the refraction angle
- Refracting telescope
  - Eyepiece is a concave lens to convert rays back to parallel rays
  - Make things appear closer and brighter
    - Not bigger, that's a microscope
- Chromatic aberration
  - Different colours bend by different amounts
    - Red will have a longer focal length than blue
  - Thicker the lens/prism, the bigger the problem
  - Fixed by achromatic lenses
    - Resolves for 2 colours, any pair, but not 3
    - Helps, but don't entirely resolve problem
- Reflecting telescopes
  - Goes around chromatic aberration
    - Reflect all colours equally
    - Light will reflect off any smooth surface
  - Curved mirrors
- Comparison: Mirrors Vs Lenses
  - Mirror telescopes are superior in telescope industry
- Yerkes Observatory
  - 1890
  - 102cm diameter lens
  - Largest refracting telescope in the world
- Keck telescopes in Hawaii
  - 10m diameter optical telecopes
  - Use of hexagonal-segmented mirrors controlled by actuators
    - Changes shape of mirror to accommodate for atmospheric fluctuations
- Newtonian Telescopes
  - Newton made a leap in telescope tech
  - Reflecting telescope

- Cassegrain telescope
  - Reflecting telescope
    - Uses one concave primary mirror, one convex secondary mirror, and lens eyepiece
  - Secondary mirror sends light through the middle of primary
- Nasmyth telescope
  - Reflecting telescope
  - Advanced, for professionals
  - 3 mirrors
- Recording light
  - First done by using photographic plates
    - Large, high quality material that reacted to light
    - One-use-only
    - Pixels were massive
  - CCD cameras
    - Charge-coupled device
    - Take images in 1 colour
      - Multiple lenses to correct colour
  - Spectroscopy
    - Tells elemental composition of gases in space
    - Use of prisms/diffraction gratings and filters
    - Spectral lines
      - Tell composition and motion of object
  - Photometry
    - Precisely measuring intensity of light
    - Light intensity decreases with inverse square law
    - Knowing distance, can calculate a normalized intensity magnitude
- Challenges
  - Light decreases $1/\text{distance}^2$
  - Need large reflecting area
  - Long exposure time
    - Exposure time x radius^2
    - Motor systems track motion of Earth to focus on stars without creating blur lines
    - Long exposures limit the amount of time that can be used to study other regions of space
    - Wiggling
    - Solution: take many short exposures and stack on top of each other
  - Resolving power
    - Finest camera resolution needed
  - Diffraction limit
    - Larger the lens needed to reduce diffraction
    - Effects
      - Waves will diffract and spread out through an apperature
  - Bigger telescopes
    - Collect more light
    - Achieve better resolution

- Segmented telescope
  - Mirrors are different hexagonal pieces
  - Useful to apply correctors
  - Easy to fix
  - Easy and cheaper to manufacture
- Atmospheric dispersion
  - Why sky appears blue
  - Telescopes try to get above the atmosphere
  - Take images in different filters, reconstruct images
  - Stars 'twinkle' due to atmospheric blurring
  - Fixed in telescopes with active optics or adaptive optics
    - Adaptive is faster
- Adaptive optics
  - Use a laser to excite sodium atoms in the atmosphere to create an artificial guide star
  - Only light permitted through the guide is a specific wavelength that the laser is
  - Distorted light is corrected by a distorted mirror
  - Multiple guide stars used for large areas of sky

Radio Astronomy & Other Waves

Friday, May 25, 2018 11:22

Radio Astronomy
Audio recording started: 11:22 Friday, May 25, 2018

- Uses very long wavelengths
  - Telescopes are very large in order to catch the long wavelengths
  - Reflecting surface must be perfect to a nm of a wavelength
  - Diffraction limit is really bad
- Can be radio transmitters
- Interferometry
  - Using multiple radio telescopes as one big telescope
    - Same angular resolution, just faint
- Arrays
  - ALMA in Chile
  - Very large array in New Mexico
- Piercing the cloud
- Observing planet formation

Art of Astronomy

Friday, May 25, 2018 11:41

Art of Astronomy
Audio recording started: 11:41 Friday, May 25, 2018

- Images are reconstructed from multiple filters
- Photoshop could be used
- Stars are best seen in infrared

Sun

Tuesday, May 29, 2018 10:32

- From Earth
  - Average distance = 1AU
  - Angular diameter = 0.533°
  - Apparent magnitude = -26.74
- The Sun is an average star, there is nothing really special about it compared to other stars
  - Medium-low mass star
- Observable properties
  - Radius 696 000km
  - Mass 10^{30}kg
  - Density 1.41g/cm^3
  - Escape velocity 618km/s
  - Surface temperature 5500°C
- Observed from ground-based observatories, but some satellites are in space for studying the Sun
  - Solar and Heliospheric Observatory (SOHO) launched into L1 point in space, about 1.5M km from Earth
  - Solar Dynamics Observatory (SDO) is in geosynchronous position
- Atoms in the Sun are completely ionized
  - Result in plasma
- Composition of the Sun
  - 91% hydrogen
  - 8.4% helium
  - Oxygen, carbon neon, nitrogen, magnesium, iron, silicon
- Sun is in hydrostatic equalibrium
  - Outward forces of heat and pressure
  - Inward force of gravity
- Energy is measured in Joules (J)
  - 4.2J of energy to heat 1mL of water by 1°C
  - Watts (W) is J/sec
- Solar radiation
  - Solar constant
    - Intensity, power per m^2 as measured from Earth's orbit
    - Roughly 1370W/m^2
  - Power density
    - 4e26W works out to onlu 0.0002W for the sun
      - More energy is expelled when burning wood
- Standard Solar Model
  - Mathematical model to help understand the Sun
- Surface of the sun
  - Photosphere is 5500°C
  - Estimated 700 000km from the center of the Sun, and about 500km thick
  - Thinner than Earth's atmosphere
  - Granulation
    - Tiny spots on surface
    - Tops of giant convection cells
  - Sunspots
    - Regions of cooler temperature

        - Cooler than surrounding surface (about 4000K)
        - Always come in pairs
            - North and South pairs
        - Center region is called umbra, surrounding is penumbra
            - Like a shadow
    - Super-granules
        - Contain about 300 granules
        - Reveal much about the inner workings of the Sun
- The core is much hotter than the surface
    - Darkening toward the surface is called limb darkening
- Rotation
    - Equator rotates in about 25 days
    - Poles rotate in 35 days
- Solar atmosphere
    - Difficult to observe
        - In the past, was only observable during solar eclipses
    - Chromosphere is upper part of solar atmosphere
        - Has an emission spectrum
    - Spicules are flame-like bursts/jets of gas that spew upward
        - Cooler gas that gets pushes upward
- Corona is upper atmosphere that extends for multiple solar radii
    - 1M°C!
        - Mystery as to why it is so hot
    - Temperature is determined from spectra
        - Iron spectral lines are produced form iron raised to very high temperatures
- Sun has 'magnetic carpet' that cause solar wind
    - Magnetic loops can extend and become unstable
        - If two loops cross each other, the result is an explosion that is solar wind
    - Carries 2B kg of material away from the Sun
    - Winds are essentially the Sun evaporating
        - Black holes are also evaporating
- Magnetic field is created by the Dynamo Effect
    - Electric charges moving in circular patterns produce magnetic fields
        - How electric motors work
    - Sun is giant rotating sphere of plasma, which is our best explanation for the origin of the magnetic field
        - How it works is not completely understood
    - MF plays a crucial role in Sun's behaviour
        - Responsible for sunspots, and aurora on Earth
        - Responsible for solar eruptions and wind, coronal mass ejections, and prominences
    - Solar flares/coronal mass ejections can release 10^{25}J of energy
        - Equivalent to 10 000 y of human power
        - Can knock out sections of electric power on Earth
    - Sun's magnetic field superheats gases/plasma within the elements and cause them to arc through space
- Sunspots
    - Localized cooling of the surface
    - Solar cycle
        - Over hundreds of years, the number of sunspots cycle between a minimum and a maximum
        - Every 11 years
        - Explanation is tied to magnetic field

        - Poles flip completely, and in between there is a chaotic amount of sunspots
        - Differential rotation on the magnetic field
        - Earth's climate may be correlated to the amount of sunspots
- Inside the Sun
    - Helioseismology studies what is inside the Sun
        - Uses absorption lines and emission lines and Doppler shift info
        - Listens to the Sun, there is very long sound waves coming from it
    - Core
        - Hydrogen and atomic fusion
        - Thought to be as hot as 10M°C
        - Ongoing hydrogen bombs
    - Radiative zone
        - Very very hot
        - Material is completely ionized
        - Heat must escape, but Sun is opaque to light
        - Photon will take millions of years to escape this zone
    - Convective zone
        - Very top is seen in photosphere
        - Density and temperature are lower nearer the surface
- Standard Solar Model
    - Sun is understood to be hot enough to cause nuclear reactions
    - 4 Hydrogens to make helium
- Habitable Zone
    - Where liquid water can exist on a planet
    - Mars is in the habitable zone
    - Venus is on the edge
- Solar Evolution and Death

Earth & Moon

Friday, June 1, 2018 10:32

Earth

- Seismology
  - Seismometers detect pressure (P)-waves and shear (S)-waves
    - P-waves are longitudinal compression waves
      - Get refracted in the magma
      - Can be detected on the other side of the planet
      - Tells us about the internal structure of Earth
    - S-waves are perpendicular to wave path
      - Do not travel through the liquid magma
      - Can travel through gas either, but there is no gas in the Earth
- Layers
  - Solid inner core
  - Liquid outer core
  - Asphalt-like, 'plastic' mantle
  - Solid crust
  - When Earth was molten, heavy metals and elements sunk to the core, while light material went to the surface
    - Differentiation
    - Seen in other inter-solar bodies
- Surface is comprised of the crust and the hydrosphere
  - Only planet with liquid water on the surface
  - Known as an 'active planet'
    - Surface is constantly changing
- Volcanism
  - Volcanoes bring material from just beneath the crust to the surface
  - CO_2 and other gases are brought to the surface
    - Carbon dioxide is important for Earth warmth
    - Humans produce too much
- Water
  - Constantly erodes the shores, riverbanks
  - Changes the surface of the Earth over long periods of time
- Atmosphere
  - We live in troposphere
    - Where most weather occurs
  - Stratosphere has higher temp due to UV absorption
  - Flow is influenced from Earth rotation, solar radiation
  - Polar cells and Hadley cells (near equator) influence Ferrel cells
    - Hurricanes form in Hadley cells
  - Jet streams are ideal for planes to fly in
    - Shortens travel time
  - Polar vortex
    - Net circular flow
    - Often sweeps across
  - Made up of nitrogen (78%), oxygen (21%) and argon (0.9%)
    - Carbon dioxide is low, but has huge impact
    - Oxygen is highly reactive, does not occur in large quantities
  - O_3 is poisonous to humans
    - Comprises ozone layer, which is effective at blocking ultraviolet radiation
    - Ozone hole over Antarctica
      - Resulted from CloroFluoroCarbons in aerosols and refrigerators
  - Earth has a blackbody spectrum at 300K
  - 59% of heat is radiated back into space
    - 41% works to keep Earth warm
    - Keeps us from freezing at night
  - Greenhouse effect
  - Climate change
    - Naturally, climate change happens as Earth changes
    - Earth should be cooling, but greenhouse effect is warming it up
    - Oceans will expand by 0.5m for every degree risen
- Planetary evolution
  - Differentiation suggests Earth was molten at one point
  - Constant bombardment of other objects caused a lot of energy
    - No solid surface to record the impacts
    - The Nastapoka arc in the Canadian Shield may be a crater
      - Canadian Shield is among the oldest crust on Earth
  - Early atmosphere probably contained methane, ammonia, and water vapour
  - UV impacted the ozone development
    - Around the same time life was forming in the liquid oceans
    - When ozone was thick enough, life moved onto land
  - Fossil records tell of 5 mass extinctions
    - 5th global extinction is cause by humans
      - 80% of Asia's mammals have gone extinct
- Magnetic field
  - More uniform than the sun's
  - Does go through magnetic reversals, but last one was 780 000 years ago
  - Not stable, always shifting
  - Magnetosphere

Moon

- Distance is accurate as astronauts left mirrors on surface for lasers to be shot at and measured
- Tidally locked with Earth
  - One side faces Earth
  - Tidal bulge is very large
- Spends 2 weeks in solar day, 2 weeks at night
  - Temp range -170°C to 130°C
- Apollo 11 mission was political
  - Space Race
- 2 distinct terrain
  - Mare
    - Dark regions
    - Thought to be seas
    - Rock
      - is essentially lava
      - Called Basalt
      - Formed 3.2-3.9B years ago
    - Caused by heavy bombardment
  - Terrae
    - Older crust
    - Highland
    - Lighter regions
    - Rock
      - Lunar anorthosite
      - 4.4B years old
- Composition
  - Surface is comprised of ejecta from collisions
  - Regolith
    - Dust created by impacts
    - Very sharp, can wreak havoc on space suits and equipment
    - Solar wind electrically charges dust and causes it to stick to space equipment
    - Dangerous if breathed in, like asbestos
  - Elemental composition is similar to Earth's surface, but different from Earth's core
  - May have a partially molten core
- Formation of Moon
  - Leading theory is Giant Impact Hypothesis
    - Something the size of Mars, called Theia, smashed into Earth
    - A piece of Theia and debris from Earth formed Moon
    - Also caused the Earth's rotational axis to tilt
    - Could have formed the continents
      - Theian impact could have caused a sea of magma, magma cooled, any convection areas became plates and continents

        - Dynamo theory
            - Electromagnetism as the origin of the field
        - Convective motion of core results in field
    - Magnetic pole has shifted higher in latitude by 1102km
    - Field provides protection from atoms, ions, and solar radiation from solar wind
        - Outer van Allen belt collects electrons
        - Inner van Allen belt collects heavier protons
        - Charged particles are dumped at the magnetic poles, excite atoms in atmosphere, cause emission radiation
            - Aurora borealis and australis
    - Where solar wind and magnetosphere meet is the Bow Shock
        - 1856, it was so large it swept away the field
- Tides
    - Occur approx every 12 hours
    - Moon produces largest tidal effect
        - Sun produces some effect
        - When Moon and Sun are alligned, spring tide
        - When moon is perpendicular to Sun, tides are out of phase, neap tide
            - Like lining up sine waves
    - Friction of the tides against the land slows the Earth's rotation
        - In long term, 10B years, Earth will be tidally locked to Moon
        - Not gonna happen before Sun balloons and destroys Earth

Terrestrial Planets

Wednesday, June 6, 2018 10:25

- All have rocky surfaces
- Vary in atmospheres
- Space exploration
  - USSR and USA Cold War
    - Fight for political superiority
  - Now purely scientific
  - More missions to Moon

Mercury

- Almost same size as Moon
  - Slightly bigger
- Tidally locked to Sun
  - Solar day is 2 Mercurian years
- Most elliptical orbit of any planet
- 3:2 orbital resonance
  - 3 sidereal rotations = 2 solar days
  - To compare, Moon has 1:1
- MESSENGER mission needs a heat shield
  - There to discover chemical composition, geography, history
- Fewer craters than the Moon
  - Smaller ejecta due to higher gravity
- Caloris impact basin
  - Impact was so strong, caused a shockwave through the planet, created 'weird' terrain on the opposite side
- Core takes up a higher fraction of the planet
- Magnetic field
  - Relatively larger for a slow-rotating planet
  - May have a molten core from the Sun's warmth
    - Cooled slower
    - Cooling caused a contraction of the planet, causing cliff-like wrinkling

Venus

- 'Earth's twin'
  - Not really
  - Similar chemical composition, size, and density as Earth
- >96% carbon dioxide in the atmosphere
  - Has sulpheric acid clouds/rain
  - Very very thick
- Slowest rotating object in solar system
  - -243 days = sidereal day
    - Sun rises in west
  - Slowing down rapidly
  - Longer to rotate on axis than to orbit Sun
- Very strong winds
- Rotation may have been influenced by a massive object collision
- Atmosphere
  - 90X the mass of Earth's
  - 96% CO_2, 3.5% N and sulfur compounds
    - Amount of carbon in atmosphere = amount of carbon in Earth's crust
  - May have had water
    - Water destroyed by UV radiation
  - Circulation causes night side to be as hot as day side
    - Poles are slightly colder
    - Atmosphere rotates every 4 days
- Crust has volcanic rock
  - Craft that has landed on surface had been destroyed, melted and crushed
- Some 'continents' have been detected by radar
  - May have plate tectonics
    - Has volcanoes
    - No motion, however
- Volcanism
  - Has mostly shield volcanoes

Mars

- Schiaparelli noted 'canali' on the surface
  - English media mistranslated as 'canals'
    - Lead to the belief of life on mars/Martians
  - Life on Mars was believed until 1960s, when images found craters and no life
- Mars 3 (USSR) landed first, but failed
  - Vikings 1 & 2 successfully landed and gave close up of surface and seasons
- Sojourner (1998)
  - Roamer with wheels
- Spirit and Opportunity (2004)
  - Rovers
  - Opportunity is still roaming
    - Solar powered
- Curiosity (2012)
  - Biggest yet
- Interior
  - Differentiated
    - Nickel core
      - Solid?
    - 'plastic' mantle
    - Crust, mostly iron
  - Volume to surface area ratio is smaller
    - Cooling quicker
  - Used to have a magnetic field
    - Remnant frozen into the rock
    - No magnetic field = atmospheric distruction
- Northern hemisphere is newer than southern
  - A quarter of the planet's age
  - May be a giant impact basin that filled with new lava
    - Caused by planetesimals
    - Utopia Planetia is confirmed impact
    - Borealis Basin is suspected impact
  - Northern hemisphere was covered in ocean
    - 3-4B years ago
    - Evidence of water ice in the basins
- Cratering
  - Few small craters
  - Atmosphere burns up small meteors
  - Wind erosion
- Volcanism
  - Largest volcano in the solar system, Olympus Mons
  - No plate motion, so volcanoes just get bigger rather than creating chains of volcanoes
  - Tharsis Bulge
  - Valles Marineris, rift valley that could be evidence of plate tectonics
    - Larger than the Grand Canyon
  - All volcanoes are shield volcanoes
- Atmosphere & Climate
  - 95% carbon dioxide, 3% Nitrogen, some methane
  - 1/150th the atmospheric pressure of Earth's
  - Water-ice clouds
  - 30°C during the day midsummer, but mostly subzero
  - 4 extreme seasons
    - 24.6° axial tilt
    - Winter in northern hemisphere, Mars is at perihelion
  - Ice caps
    - 1m thick frozen carbon dioxide
    - Can store 30% of entire atmosphere
    - Below surface is solid water
- Moons
  - Look like asteroids
  - Phoboes and Deimos

Water on Terrestrial Planets

- Moons of Jovians, Europa and Titan, have water
  - Water is rock on Titan
    - Seas are made up of liquid methane
- Kuiper belt objects are made up in a large part of water
- Earth's Moon has had its water (if ever existed) baked off the surface
  - Craters on north and south poles could have been made by comets
    - Could contain water-ice
  - LCROSS found water-ice
- Water on Venus
  - Evidence did have water
    - Evidence of deuterium in the atmosphere
  - Used to have as much water as Earth
  - Solar wind and radiation destroyed all the water
- Water on Mars
  - Was too small, lost its heat and magnetic field
  - Flash flood would occur after meteor strikes

Greenhouse Effect & Climate Evolution

- Venus
  - Very thick CO2 atmosphere
- Mars
  - Was warm enough to sustain water

Jovian Planets

Tuesday, June 12, 2018 11:05

Jupiter
- Atmosphere
  - Visible bands of ammonia clouds
  - Great red spot
  - Eddie currents
  - Zones are warm material rising
  - Belts are cooler sinking material
  - 86% H, 13.8% He, 0.2% methane, ammonia and water
    - Methane and ammonia can form ice near the upper atmosphere
- Would be a star if it had fusion at its core
- spins faster at the equator than at the pole
  - Differential rotation
- Core
  - Liquid metalic hydrogen
  - Cause convection of the weather
  - For all Jovians, the heat source is the core
- Storms last hundreds of years as they are not interrupted by land

Uranus
- 97° rotational axis
- ~ and Neptune experience diamond rain
  - Source of heat

Inside Jovians
- Magnetosphere
  - Very strong aurora
  - Jupiter's magnetic field tail extends beyond Saturn's orbit
- High pressured atmospheres destroyed a couple space crafts
- Hight speed rotations flatten the planets
- Interior

Moons & Rings
- Observations of the moons ended the geocentric theory
- Big Jovian Moons
  - Titan is the 2nd largest moon after Ganymede
  - Callisto is the furthest from Jupiter, then Ganymede, Europa, then Io
    - Io is volcanically active
  - Ganymede has nearly 40X the water as Earth has
  - Jupiter has 69+ known moons
    - Captured objects
    - Io, Europa, and Ganymede have orbital resonance
      - 4:2:1 orbits respectively
    - Callisto is not fully differenciated
      - Io, Ganymede, and Europa have an iron core
    - Europa and Ganymede have oceans
    - Io is completely molten due to gravitational flexing
    - Callisto has evidence of 'dirty' water
      - Impacts cause waves and ripples
    - Ganymede
      - Largest moon in Solar System
      - Very geologically active
      - May have multiple layers of salt water oceans and ice
        - More saline as going deeper
    - Europa
      - Surface of predominantly water-ice
      - Orange stuff flowing out of cracks in the ice could be organic material
      - Evidence of a salt water ocean with thermal activity occurring on the ocean floor
    - Io
      - Devoid of impact craters
      - Completely volcanic, have been so for millions of years
      - Sulfur within the lava is in solution in the rock
        - Near the surface of volcano, sulfur vaporizes and explodes the lava
        - Same thing happens with water in lava on Earth
      - No water
      - Io gets deformed by about 100km by the other moons and Jupiter
  - Saturn has 62 known moons
    - Titan
      - Prime candidate for alien life
      - Atmosphere is 98% nitrogen, and 2% methane
      - Has a global ocean
      - Methane is like water on Earth
        - There are rivers and lakes and rain and seas of methane
      - Sand dunes cover equator of moon
      - UV light reacting with methane and other hydrocarbons, creating organic material
    - Enceladus
      - 99% reflective
      - Covered in water-ice
      - Tidally heated
      - Ice and water escapes through cracks and geysers
        - Cassini found complex organic molecules in the vapor
  - Uranus has 27 known moons
    - Moons have water-ice surfaces
    - UV light could be changing water-ice into complex molecules
  - Neptune has 14 known moons
    - Triton is Pluto-like
      - Could be a Kuiper Belt object
      - 7th largest moon in solar system
      - Lacking craters, been completely resurfaced
      - Has nitrogen ice geysers
      - Somewhat differentiated crust
        - Rock, water-ice, and nitrogen
  - Pluto
    - Is geologically active
      - Has a heat source heating the nitrogen on the surface
    - Smaller than 7 of the other moons in the solar system
    - Has an orbital resonance with Neptune
      - 1 orbit of Pluto for every 3 orbits of Neptune
    - Largest of the Plutinos
    - 'Heart-shaped' area is called Sputnik Planitia

Rings
- Saturnz Barz
  - Can be as bright as 0.43 or as dim as 1.45
  - Moons orbit further than the rings
  - Large objects that get too close to Saturn get distorted and ripped apart, creating rings
    - Caused by the Roche Limit
      - On Saturn, the limit is 144 000km from planet
    - That's the F rings
  - E rings seem to be water vapor and fed by geysers on Enceladus
  - Rings are made up of particles and objects >10m
  - There are tiny moons in the gaps of the rings
    - Strong enough to overcome the Roche limit
  - Huygen gap is thought to be caused by a 2:1 resonance with Mimos
  - Daphnis causes a gap by spreading the material apart
- Jupiter
  - Has faint rings
- Uranus
  - More pronounced rings
- Neptune
  - Has faint rings

- Covered in churning cells of nitrogen ice
- Core is very similar to Tritons
  - Possible for an ocean to exist between the rock and water ice
- Has 5 known moons
  - Pluto is a double planet with Charon
    - Tidally locked with one another

Comets, Asteroids & Dwarf Planets

Friday, June 15, 2018 11:29

Asteroids

- Ceres was discovered in 1881
  - Is the biggest asteroid, but is known also as a dwarf planet
- Half a billion asteroids in the Asteroid belts
- 3 classes
  - C-type
    - Carbonaceous
    - Low reflectivity (high albedo)
    - More common further from the Sun
  - S-type
    - Silicate/stony
    - High reflectivity (low albedo)
  - M-type
    - Metallic
    - High amounts of iron and nickel
    - Could be from the core of a protoplanet
- Belts created by protoplanets crashing into each other
  - Were not able to become planets because of Jupiter
- Trojan, Apollo, Amor
- Main belt asteroids have orbital resonances with Jupiter
- Ceres is a protoplanet/dwarf planet
  - biggest
  - Is a spherical asteroid
  - Has some differentiation and some water
  - Is geologically cold
  - About as wide as Ontario

Meteoroids/Meteors/Meteorites

- Usually less than 1m
  - Usually burns up in the atmosphere
  - Asteroids are greater than 1m
- Called 'meteorite' when found on the planet
  - Otherwise, 'meteoroid' when in space
  - 'meteor' when it's in the atmosphere
- When burning in the atmosphere, different burning material cause different colours
- Meteor showers are the result of comets
  - Debris is left behind in a comet's orbit
  - Earth passes through the debris field, meteors look like they're emanating from one place in the sky
- Many meteorites are found in Antarctica
- Hazardous meteors are >150m in diameter and within 0.05AU of Earth

Comets

- Helped Tycho Brahe contradict the geocentric theory
  - Comets (new stars) are further from Earth than the moon
- Have tails of dust, vaporized water and ammonia ices, gaseous ions
  - Both are produced from the radiation pressure and solar wind from the Sun
  - Dust tail is curved because of the movement of the comet
  - Ion tail is tied with the solar wind
- Most comets are from the Kuiper belt or Oort Cloud, way beyond Neptune
  - Gravity assist from planets or passing stars can push asteroids out of the Kuiper belt or Oort Cloud
    - Those that fall inward are comets
- Halley's Comet is unusual for comets

Dwarf Planets

- Classification criteria
  - Mass and gravity is sufficient to shape it into a sphere/spheroid
  - Have not been able to dominate their region of space
    - Pluto's area is dominated by Neptune
  - Orbits the Sun
    - Not a moon
  - Has not cleared its path of debris

Origin of the Solar System

Wednesday, June 20, 2018 10:32

Theories

- Estimated age of universe = 14 billion years
- Estimated age of the Solar System = 4-5 billion years
  - Nothing on Earth is never older than 4.6B years
- Accepted theory
  - Sun formed from nebula
  - Material disk tumbled into planets
    - Reason all planets orbit in a prograde around the Sun
    - Sun and planters rotate in the same direction
      - Venus and Uranus are exceptions
- Evolutionary Theories
  - Everything happens gradually
- Catastrophic Theories
  - One-off events
  - Explain an unusual properties that can't be considered evolutionarily
- Collisions
  - Evolutionary and catastrophic

Terrestrial Planets Origins

- The Sun is large enough to produce carbon
  - Larger stars can form iron, but no further
    - When this star explodes, the material get spread out quickly
      - Shockwave -> nebular collapse
  - Supernovae and cosmic rays produce elements heavier than iron
- Differentiation
  - While planet is molten, the heavy elements sink to the core
    - Radioactive elements such as uranium and iron
    - Radioactive elements may be a heat source along with the residual heat from formation
  - Moons of Jovians are completely cool, however show signs of differentiation
  - High concentration of uranium in found in Africa
    - A 2 billion y/o nuclear reactor

Explaining the Solar System

- When creating an origin theory, we need to explain and explore the origin and nature of:
  - Sun
  - Planets
  - Asteroids
  - Kuiper Belt
  - Oort Cloud
- Densities of object as we move outward the Solar System decrease steadily
- Distinct differences of Jovian planets and Terrestrial planets
- All orbits lie on or close to the ecliptic
- Solar System is gravitationally enclosed
- Looking at star-forming regions, we can estimate the origin of the Sun

Origin of the Sun/Stars

- Nebular Contraction Theory
  - Evidence is the Oort Cloud
    - Stuff that got left behind/ejected
  - Pierre-Simon de Laplace
  - Material falls in, particles collide and create thermal energy from kenetic, form the Sun
    - Conservation of angular momentum
  - Molecular cloud was cold enough to condense and collapse
    - Any motion it had was sped up, creating a flat disk
  - More evidence
    - Radio and infrared show extrasolar protoplanetary disks
  - Large nebulas have been observed to be the birthplaces of many stars
  - Supernovae can send a shockwave through the molecular medium, triggering star formations
  - Galactic collisions can trigger star formation as intergalactic nebula collide with each other
- Early Formation Theories
  - Rene Descartes (1644)
    - Invisible aether formed a collapsing vortex within a nebula
    - No gravity explanations
  - Georges-Louis Leclerc
    - Comets with high gravity pulled material from the Sun and became the planets
    - Later astronomers modified the theory, asserting that a passing star pulled the material

Exoplanets & Exobiology

Friday, June 22, 2018 11:00

- Protoplanetary disks have been observed to form around new stars
- 55% of nearby 'stars' are in binary, trinary, or greater combinations
  - Large Jovian planets can ignite and become stars
- Exo-terrestrials
- Searching
  - First exoplanets was found around a pulsar in 1994 using optical spectrum telescope
  - 44 exoplanets have been discovered using imaging
    - Not easy
  - Large planets can wobble their stars, making the system detectable
    - Can be found through spectroscopy
- When a planet is aligned within 2 degrees of the sun, we can measure the size of the planet
- Super earths have been found

Habitably

- Habitable zone of a solar system is where water can exist as a liquid
  - Too close to the Sun, water vaporizes
  - Too far, water freezes
- Size of planet matters as well
  - Mars could have had liquid water, however was too small to contain it
    - Lost its magnetic field
- Kepler 22b is orbiting within the habitable zone, but is much too large for humans
  - Considered a small Neptune
- The bigger the star, the sooner it dies
  - Larger stars have larger habitable zones, but do not live long enough for biological evolution to take place
- The galactic habitable zone
  - Radiation from the black hole in the center of the galaxy could possibly kill life
- Other habitable zones
  - Some zones could be created by tidal heating
  - Natural solvents other than water
    - i.e. ammonia, which can exist as a liquid at -30°