**Astronomy 1F03 | September 6, 2016 | Lecture Notes**

Introduction

* iClickers will be used
  + Marks are participation only
* Assessments are broken down as:
  + 25% labs (in class ≈ 6); Homework problems (≈4)
  + 15% participation: observing, planetarium, iClickers
    - More info. provided by TAs
  + 20% midterm
    - Thursday, October 20th, 7-9 PM
  + 40% final exam
* Textbook
  + Astronomy: A beginner’s guide to the universe
    - 8th edition provides access to online resources
    - All other editions will suffice

Chapter 0 – Charting The Heavens

* Preliminaries
  + Why does the week have seven days?
    - Objects in heavens divided into fixed stars and the seven wandering stars known in antiquity
      * Wandering stars: moon, mars, mercury, Jupiter, Venus, Saturn, sun
  + What is the milky way?
    - It’s our galaxy
      * Contains our solar system
* Astronomy in human culture
  + Astronomical influences
    - Time
      * Year, month, week, day
    - Constellations (star groupings)
      * Myths
      * Astrology
        + Even if it is bullshit
    - Eclipses
      * When sun gets in the way of the moon, and vice versa
* Syllabus of the course
  + The scale of the universe
  + Earth’s orbital motion
  + Motion of the moon
  + Measurement of distance
  + Science and the scientific method
* Scales
  + Earth is average – we don’t occupy any special place in the universe
  + Universe: Totality of space, time, matter, and energy
  + Astronomy: Study of the universe
  + Scales are very large; Measured in light-years,
    - The distance light travels in a year is 1013 Km
      * YouTube: Powers of Ten By Charles & Ray Eames
* Naïve view of the universe
  + Stars that appear close in the sky may not actually be close in space. Objects are so distant it is hard to perceive depth
    - Some stars are closer than others. They may appear to be very far, but might actually be nearby, and vice versa
      * Stars can be as far as 1000 light-years, and greater
* The celestial sphere
  + Stars seem to be on the inner surface of a sphere surrounding the Earth
    - They aren’t, but we can use two-dimensional spherical coordinates (similar to latitude and longitude) to locate sky objects
* Angles in astronomy
  + Full circle contains 360o (degrees)
  + Each degree contains 60’ (arc-minutes)
  + Each arc-minute contains 60’’ (arc-seconds)
  + Angular size of an objects depends on actual size and distance away
    - A finger held at arm’s length subtends ≈ 1o; The moon subtends ≈ 30’
* Angular coordinates on the celestial sphere
  + Declination: Degrees north or south of celestial equator
  + Right ascension: Measured in hours, minutes, and seconds eastward from the vernal equinox
    - Vernal equinox: When the sun is on the equator
* Earth’s orbital motion
  + Daily cycle, noon to noon, is diurnal motion – solar day
  + Stars aren’t in quite the same place 24 hours later, though, due to earth’s orbit around the sun; when they were in the same place again, one sidereal day had passed
  + Earth rotates 1o in ≈ 60x24/360 = 4 mins
    - Solar day is ≈ 4 minutes longer than sidereal day
  + Solar Day: Defined as the time it takes to get from one noon to the next
  + Sidereal Day: Time it takes for one star to cross the meridian
* iClicker Question
  + Suppose that the Earth orbits the sun as now but that it rotates on its axis in the opposite sense (at the same rate). Which of the following is true of the lengths of the sidereal & solar days?
    - A) They both remain the same as now
    - **B) The sidereal day remains the same**
    - C) The solar day is longer
    - D) The sidereal day is shorter
    - E) Both get longer
      * Reason: The solar day gets shorter but the sidereal day remains the same because only the direction has changed, not speed. Hence solar day is affected and not sidereal because sidereal is based off distance stars and a tiny movement is basically negligible.
* Earth’s Orbital Motion
  + The 12 constellations the Sun moves through during the year are called the Zodiac; path is ecliptic
* iClicker Question
  + What causes Earth’s seasons?
    - A) Wobble of Earth’s rotation axis
    - B) The Greenhouse Effect
    - **C) The 23.5 degrees tilt of Earth’s rotational axis**
    - D) The movement of Earth’s path around the sun
    - E) Climate Change/Global Warming
      * Explanation: Our planet’s tilt, and not its changing distance from the sun, creates seasons. The tilt causes the same amount of sunlight to be spread over a larger distance
* Earth’s orbital motion
  + Ecliptic is plane of Earth’s path around the sun; at 23.5o to celestial equator
  + Northernmost point (above celestial equator) is summer solstice
    - Southernmost is winter solstice
      * Points where path crosses celestial equator are vernal and autumnal equinox
  + Combination of day length and sunlight angle gives seasons
    - Time from one vernal equinox to next is tropical year
  + Precession: Rotation of Earth’s axis itself; makes one complete circle in about 26,00 years (due to tidal effect of Moon & Sun on Earth’s rotational bulge).
  + Sidereal Year: Time for earth to orbit once around the sun, relative to fixed stars
    - Tropical year follows seasons; sidereal year follows constellations – in 13,000 years July and August will still be summer, but Orion will be a summer constellation
* The Motion of the Moon
  + The moon takes about 29.5 days to go through whole cycle of phases – synodic month
  + Phases are due to different amounts of sunlit portion being visible from Earth
    - Phases of the moon include waxing crescent, waning crescent, etc.
  + Time to make full 360 degrees around Earth, sidereal month, is about 2 days shorter than synodic month
* iClicker Question
  + Considering the Moon’s phases, everyone on Earth sees
    - **A) The same phase in 24 hours**
    - B) Different phases in 24 hours
    - C) A lunar eclipse once a month
    - D) Different sides of the moon
      * Explanation: No matter where you are, you see the same phase because sunlight doesn’t change. The moon goes through its cycle of phases in about 30 days; the Earth rotates once in only 24 hours. Hence, everyone has a chance to see the same phase.
* The Motion of the Moon
  + Lunar eclipse:
    - Earth is between the moon and the sun
    - Partial lunar eclipse: Occurs only when part of the moon is in shadow
      * Total lunar eclipse: Occurs when all of the moon is in shadow
  + Solar eclipse
    - The moon is between the earth and the sun
      * The sun and the moon have the same apparent size
        + Meaning, the moon can just cover the sun, when viewed on planet earth
      * Partial eclipse: The moon covers a partial part of the sun
      * Total eclipse: The moon covers the entire sun
      * Annular eclipse: The moon does not cover the outer rim of the sun. This occurs when the moon is too far from earth for a total eclipse to occur
    - Eclipses don’t occur every month because earth’s and moon’s orbits are not in the same plane (~5-degree tilt)
      * Conditions are favourable for an eclipse, about every 6 months
        + April 8th, 2024 is a forecasted solar eclipse for Americans
* Measuring Distances
  + Triangulation: Measure baseline and angles, and you can calculate distance
  + Parallax: Similar to triangulation, but looking at apparent motion of object against distance background from two vantage points
    - Only works for nearby stars because as the star gets farther and farther away, the parallax angle gets smaller and smaller
      * 1 pc ~ 3.26 lyr ~ 206,000 AU
* Scientific Method
  + Scientific theories:
    - Must be testable
    - Must be continually tested
    - Should be simple (Occam’s razor)
      * Makes the fewest assumptions – keep it simple
    - Should be elegant
  + Scientific theories can be proven wrong, but they can never be proven right with 100% certainty
  + Observations leads to theory explaining it
  + Theory leads to predictions consistent with previous observations
  + Predictions of new phenomena are observed.
    - If the observations agree with the prediction, more predictions can be made.
      * If not, a new theory must be made
* Astronomy & Astrophysics
  + Astronomy is observation, measurement, what’s out there? Telescopes, data analysis, software tools
  + Astrophysics is a physical understanding; what’s going on inside? Computer modelling, simulation, interpretation
  + Both cannot perform experiments in the normal way (distance and timescales are too large)
    - Often must look at populations to understand evolution etc. – frequently cannot see evolution in individual objects
    - Basic assumption of unity of structure and behaviour throughout the universe – supported by observation
* iClicker Question
  + Constellations appear to move across the sky at night because
    - A) The earth orbits the sun
    - B) The moon orbits the earth
    - C) Starts are in constant motion
    - D) The sun orbits the earth
    - **E) The earth spins on its axis** 
      * Explanation: The sun, moon, stars, and planets all rise and set because our planet rotates once each day
  + What is the path that the sun, moon, and planets follow through the constellations?
    - A) The celestial equator
    - B) The north celestial pole
    - C) The milky way
    - D) The Zodiac
    - **E) The ecliptic**
      * Explanation: The ecliptic also marks the plane of Earth’s orbit around the sun
  + How long does it take the sun to complete one circuit of the ecliptic?
    - A) One hour
    - B) One day
    - C) One month
    - **D) One year**
    - E) One decade
      * Explanation: The sun moves around the ecliptic once as the Earth orbits in one year
  + How long does it take the moon to go around the ecliptic?
    - A) One day
    - B) One hour
    - C) One week
    - **D) One month**
    - E) One year
      * Explanation: The moon orbits Earth in a month, and passes in front of the constellations of the zodiac, which are arranged around the ecliptic
  + Stars in a constellation are:
    - A) Physically close to each other
    - B) Usually equal in brightness
    - C) About the same age
    - D) About the same distance away
    - **E) In the same part of the sky**
      * Explanation: Stars within a constellation might be very different distances, ages, types, and brightness, but all appear to be emerging from the same part of the sky
  + A total lunar eclipse occurs:
    - A) During the new moon phase
    - B) When the sun blocks the moon
    - **C) During the full moon phase**
    - D) Always around the summer solstice
      * Explanation: During a full moon, light from the sun passes through earth’s atmosphere and is reflected onto the moon, causing a lunar eclipse
  + The vernal equinox marks the beginning of
    - A) Summer
    - B) Fall
    - C) Winter
    - **D) Spring**
      * Explanation: The vernal equinox occurs around March 21 – 22
  + Conditions are favorable for a solar eclipse
    - A) Every month at new moon
    - B) Every week at the quarter phases
    - C) Every month at full moon
    - **D) About every six months at new moon**
    - E) Every year at new moon
      * Explanation: Solar eclipses occur about every six months due to the moon, earth and sun not being on the same plane
  + The angle of parallax increases as:
    - A) Distance to stars increase
    - **B) The baseline gets larger**
    - C) The baseline gets smaller
    - D) The earth moves faster in its orbit
      * Explanation: The greater the distance between two observation points (the baseline), the larger the angle of parallax
  + Precession is caused by:
    - A) The rotation of Earth’s molten core
    - B) The slow movement of the continents (plate tectonics)
    - **C) The gravitational pull of the sun & moon**
    - D) The weight of the ice at the poles
    - E) Gravitational attractions from comets
      * Explanation: The moon’s tug creates a slow “wobble” that takes 26,000 years for one rotation

Chapter 1: The Copernican Revolution

* Overview
  + The motions of the planets
  + The birth of modern astronomy
  + The laws of planetary motion
  + Newton’s laws
* The motion of the planets
  + The sun, moon, and stars all have simple movements in the sky, consistent with an earth-centered system, but…
    - Planets:
      * Move with respect to fixed stars
      * Change in brightness
      * Change speed
        + Due to elliptical orbit. As planets get closer to sun, so does the gravitational pull, hence affecting speed

i.e. Halley’s comet

* + - * Have retrograde motion
      * Are difficult to describe in earth-centered system
  + A basic geocentric model, showing an epicycle (use to explain planetary motions)
    - Lots of epicycles were needed to accurately track planetary motions, especially retrograde. This is Ptolemy’s model.
  + A heliocentric (sun-centered) model of the solar system easily describes the observed motions of the planets, without recourse to complications such as epicycles
* Birth of modern astronomy: Copernicus to Kepler
  + Nicholas Copernicus [1473 – 1543]
    - Heliocentric model
  + Galileo Galilei [1564 – 1642]
    - Many key, telescopic, astronomical observations
      * Observations of Galileo:
        + The moon has mountains, valleys, and craters
        + The sun has imperfections, and it rotates
        + Jupiter has moons
        + Venus has phases
      * All of these were in contradiction to the general belief that the heavens were constant and immutable
        + Jupiter has moons, which proves that the earth is not the center. Venus has phases which begs the question: how?

The phases of Venus are impossible to explain in the earth-centered model of the system

* + Tycho Brahe [1546 – 1601]
    - Meticulous observations of planetary motion
  + Johannes Kepler [1571 – 1630]
    - “Discovered”/developed the laws of planetary motion
    - Kepler’s laws of planetary motion:
      * 1. Planetary orbits are ellipses, sun at one of ellipse’s foci
        + Aphelion: Greatest distance from the focus (sun)

Planet moves slowest here

* + - * + Perihelion: Closest approach to focus (sun)

Planet moves fastest here

* + - * 2. An imaginary line connecting the sun and any planet sweeps out equal areas in equal times. Imagine fictitious triangles that connect the earth and the sun. The area of this triangle is the same when measured, for any distance travelled or time taken
        + Proves that the planet moves faster when closer to the sun, and slower when further away because the base of the triangle is greater when closer and smaller when far
      * 3. Square of period of planet’s orbital motion is proportional to cube of semi-major axis
        + P2 (Years) = a3 (AU)
        + As orbital semi-major axis increases, so does orbital period. AKA as the path increases, so does the time it takes to orbit the sun

Note: All calculations use earth as a reference point

* + - * + This law is applicable for Jupiter and Saturn’s moons, but a constant must be applied

i.e. P2 (Years) = C **.** a3 (AU)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Planet | Orbital Semi- major Axis, ‘a’ (AU) | Orbital Period, ‘P’ (Earth Years) | Orbital Eccentricity, ‘e’ | P2 (Years) ÷  A3 (AU) |
| Mercury | 0.387 | 0.241 | 0.206 | 1.002 |
| Venus | 0.723 | 0.615 | 0.007 | 1.001 |
| Earth | 1.000 | 1.000 | 0.017 | 1.000 |
| Mars | 1.524 | 1.881 | 0.093 | 1.000 |
| Jupiter | 5.203 | 11.86 | 0.048 | 0.999 |

* The laws of planetary motion
  + The dimensions of the solar system:
    - The distance from the earth to the sun is called an AU. Its length may be measured by bouncing radar signals to Venus and measuring the transit time
      * We use AU to define measurements within our solar system
        + 1 AU ≈ 1.5x108 Km

More precisely it is: 149,598,000

Newton’s [1643 – 1727] Laws

* + Newton’s laws of motion explain how objects interact with the world and with each other
    - First Law: An object at rest will remain at rest until acted on by an external force. And an object moving in a straight line at a constant speed will not change its motion, unless an external force acts on it
    - Second Law: When a force is exerted on an object, its acceleration is inversely proportional to its mass: a = F / m
    - Third Law: When object A exerts a force on object B, object B exerts the same force on object A.
      * Every action has an opposite and equal reaction. Same magnitude but different direction
  + On earth’s surface, the acceleration due to gravity is approximately constant, and directed toward the center of Earth
  + For two massive objects, the gravitational force is proportional to the product of their masses divided by the square of the distance between them
    - A graph of the famous inverse square law describes gravity’s influence on objects. Increase the distance by 10, and gravity is affected by 100
      * F = (GM1M2) / r2
  + The gravitational pull of the sun is what keeps the planets moving in their orbits.
    - Explains why celestial bodies are able to orbit larger celestial bodies, without going off course
      * i.e. Halley’s comet and the sun, moon and the earth, etc.
    - Kepler’s (empirical) laws are a consequence of Newton’s (predictive) laws
  + Massive objects actually orbit around their common center of mass; if one object is much more massive than the other, the center of mass is not far from the center of the more massive object. For objects more equal in mass, the center of mass is between the two
    - i.e. Between a large planet and a small planet – the large planet will orbit slower than the small planet
    - A large celestial body (i.e. our sun) is responsible for earth’s elliptical orbit
      * Common method of detecting stars (look for elliptical orbits)
* For a Comet with:
  + Perihelion: 1 AU
  + Aphelion: 161 AU
* Calculate ‘a’, ‘e’, & ‘P’
  + “a” = Semi-major axis
    - 2a = 1 + 161AU = 162 AU
    - a = 81 AU
  + “e” = Eccentricity
    - 1 AU = a(1 – e)

= 1 – 1/81

= 80/81

* + “P” = Period
    - P2 (years) = a3 (AU)

P = a3/2 = (81)3/2 = (92)3/2 = 93 = 729 years

* iClicker Questions
  + Mars, Jupiter, and Saturn show retrograde motion because:
    - A) Planets move on epicycles
    - B) Planets orbit the Sun in the same direction
    - **C) Earth moves faster in its orbit**
    - D) They are closer than Uranus
    - E) They rotate quickly on their axes
      * Explanation: As earth overtakes and passes the outer planets, they seem to slow down and then reverse direction
  + How did the geocentric model account for day and night on Earth?
    - A) The earth rotated
    - B) The sun rotated
    - C) The geocentric model couldn’t account for day and night
    - D) The earth revolved around the sun
    - **E) The sun orbited earth**
      * Explanation: The geocentric model held that the earth was motionless in the center of the universe
  + Epicycles were used in Ptolemy’s model to explain
    - A) Why planets moved in the sky
    - B) Why earth was at the center
    - **C) Why retrograde motion occurred**
    - D) Why earth wobbled on its axis
    - E) Earth’s orbit
      * Explanation: Planets were assumed to move uniformly on an epicycle, as it moved uniformly around earth
  + The geocentric model was supported by Aristotle because
    - A) Stars don’t seem to show any parallax
    - B) We don’t feel as though the earth moves
    - C) Objects fall toward Earth, not the Sun
    - D) We don’t see an enormous wind
    - **E) All are valid reasons**
      * Explanation: Aristotle thought that if the earth rotated and orbited, we would feel its motion. In Aristotle’s time, the size of the solar system and distances to stars were assumed to be much smaller. Parallax was expected to be seen.
  + The heliocentric model assumes:
    - A) Planets move on epicycles
    - B) Earth is the center of the solar system
    - C) The stars move on the celestial sphere
    - **D) The sun is the center of the solar system**
    - E) Earth’s axis wobbles over 26,000 years
      * Explanation: Heliocentric models proposed by Aristarchus and others were considered wrong by Aristotle and his followers
  + Copernicus’ important contribution to astronomy was
    - A) Proving planets move around the sun in elliptical orbits
    - B) The theory of gravity
    - **C) Proposing a model that easily explained the retrograde motions of the planets**
    - D) Discovering the sun was not at the center of the milky way
    - E) Discovering the four moons Jupiter
      * Explanation: His heliocentric model easily explained retrograde motion because planets orbited the sun at different speeds
  + Copernicus’ heliocentric model was flawed because
    - A) He assumed planets moved in ellipses
    - B) He didn’t know about Uranus & Neptune
    - C) He couldn’t account for gravity
    - D) He couldn’t explain retrograde motion
    - **E) He did not assume planets moved in ellipses**
      * Explanation: Copernicus’ model still needed small epicycles to account for observed changes in planetary speeds
  + Who published the first telescope observations?
    - A) Hipparchus
    - **B) Galileo**
    - C) Tycho
    - D) Copernicus
    - E) Kepler
      * Explanation: Galileo published the “Starry Messenger” in 1610, detailing his observations of the Moon, Jupiter’s moons, stars, and nebulae
  + Which of Galileo’s initial observations was most challenging to established geocentric beliefs?
    - A) Craters on the moon
    - B) Sunspots
    - C) Lunar Maria
    - **D) Satellites of Jupiter**
    - E) Stars of the milky way
      * Explanation: Seeing four moons clearly move around Jupiter disproved that everything orbited Earth and showed Earth could orbit the sun and not lose its moon, too
  + Which hero of the Renaissance postulated three “laws” of planetary motion?
    - **A) Kepler**
    - B) Newton
    - C) Galileo
    - D) Tycho Brahe
    - E) Copernicus
      * Explanation: Note that Isaac Newton is also well known for three general laws of motion. But Kepler’s laws are objects in orbits, like planets orbiting a star
  + Kepler’s 1st law of planetary orbits states that:
    - A) Planets orbit the sun
    - B) Orbits are noncircular
    - C) Orbits are elliptical in shape
    - **D) All of the above are stated**
      * Explanation: Kepler’s laws apply to all orbiting objects. The moon orbits Earth in an ellipse, and the Space shuttle orbits earth in an ellipse, too
  + Earth is closer to the sun in January. From this fact, Kepler’s 2nd law tells us:
    - A) Earth orbits slower in January
    - **B) Earth orbits faster in January**
    - C) Earth’s orbital speed does not change
      * Explanation: Kepler’s 2nd law means that a planet moves faster when closer to its star
  + Kepler’s 3rd law relates a planet’s distance from the sun and its orbital
    - A) Speed
    - **B) Period**
    - C) Shape
    - D) Velocity
      * Explanation: Kepler’s 3rd law is P2 = a3, which means that distant planets orbit more slowly
        + i.e. Mercury’s period = 88 days
        + i.e. Earth’s period days = 365 days
  + Newton’s law of gravity states that the force between two objects:
    - A) Increases with distance
    - B) Depends on the state of matter (solid, liquid, or gas)
    - C) Can be attractive or repulsive
    - **D) Increases with mass**
      * Explanation: The attractive force of gravity INCREASES with greater mass, and DECREASES QUICKLY with greater distance. The force doesn’t depend on the kind of matter

Chapter 2: Light & Matter

* Overview:
  + Information from the skies
  + Waves in what?
  + The electromagnetic spectrum
  + Thermal radiation
  + Spectroscopy
  + The formation of spectral lines
  + The Doppler effect
* Information from the skies
  + Electromagnetic radiation: Transmission of energy in a vacuum via varying electric and magnetic fields
    - i.e. Visible light
  + Most of the data we receive from the universe is in electromagnetic radiation
* Waves
  + Wave motion: Transmission of energy without the physical transport of material
    - i.e. Sound waves
    - i.e. Water waves
      * Water just moves up and down, but it can transmit energy
        + i.e. Hydroelectric dams
* iClicker Question
  + The distance between success wave crests defines the \_\_\_\_\_\_\_ of a wave
    - **A) Wavelength**
    - B) Frequency
    - C) Period
    - D) Amplitude
    - E) Energy
      * Explanation: Light can range from short-wavelength gamma rays to long-wavelength radio waves
* Waves
  + Frequency: Number of wave crests that pass a given point per sound (v)
  + Period: Time between passage of successive crests
    - Period = 1 / Frequency (P = 1/v)
  + Wavelength: Distance between successive crests (λ)
  + Velocity: Speed at which wave travels
    - V = Wavelength / Period

= Wavelength x Frequency

* Diffraction and interference
  + Diffraction: The bending of a wave around an obstacle
    - i.e. Breakwater or just about anything sturdy and rigid
* Interference: The sum of two waves; may be larger or smaller than the original waves
  + Constructive interference: Two waves combine to produce a wave equal to the sum of the two
  + Destructive interference: Waves combine and produce a smaller wave
* Types of wave
  + Water waves, sound, etc. travel in a medium (i.e. Water, air, etc.)
  + Electromagnetic waves need no medium
    - Created by accelerated charged particles
    - Oscillating electric and magnetic fields: changing electric field creates magnetic field, and vice versa
      * Waves are perpendicular to one another
* The electromagnetic spectrum
  + Different colors of light are distinguished by their frequency and wavelength
    - Red is the longest (≈700nm), violet is the shortest (≈400nm)
  + The visible spectrum is only a small part of the full electromagnetic spectrum
    - 6 distinct aspects of the electromagnetic spectrum
      * i.e. Radio, Infrared, Visible, Ultraviolet, X-ray, Gamma ray
        + In order from weakest to strongest
  + Different parts of the full electromagnetic spectrum have different names, but there is no limit on possible wavelengths
    - Atmosphere transparent only to certain wavelengths
* iClicker
  + Which of these is not a form of electromagnetic radiation?
    - A) Gamma Rays
    - B) Infrared
    - **C) Sound**
    - D) Visible Light
    - E) Radio
      * Explanation: Sound comes from pressure waves; all other are EM radiation
* Thermal radiation
  + Blackbody spectrum: Radiation emitted by an object depending only on its temperature – has a characteristic spectral shape
    - Wien’s law states that the black body radiation curve for different temperatures peaks at a wavelength inversely proportional to the temperature.
  + Radiation laws:
    - 1. Peak frequency is proportional to temperature
      * VPeak ∝ T
    - 2. Total energy emitted per unit area is proportional to fourth power of temperature
      * F = σ T4
* Spectroscopy
  + Spectroscope: Splits light into component colors
    - Pass a continuous source of light through a prism to produce a spectrum of all the colors, from red to blue, and everything in between
      * Prisms can also be supplemented with diffraction gradients
  + Emission lines: Single frequencies emitted by particular atoms
    - Emission spectrum can be used to identify elements, because all elements have their own unique spectra/signatures
      * Analogous to barcode on items in stores that help scanners identify the product name and price
        + i.e. Sodium emits two distinct yellow emission lines. This explains why sodium street lamps shine a yellow color
  + Absorption spectrum: If a continuous spectrum passes through a cool gas, atoms of the gas will absorb the same frequencies they emit
    - Most stars require the use of absorption spectrum
      * i.e. Our sun
  + Kirchhoff’s laws
    - 1. Luminous solid, liquid, or dense gas produces continuous spectrum
    - 2. Low – density hot gas produces emission spectrum
    - 3. Continuous spectrum incident on cool dilute gas produces absorption spectrum
* The formation of spectral lines
  + Existence of spectral lines required new model of atom, so that only certain amounts – quanta – of energy could be emitted or absorbed
  + Bohr model had certain allowed orbits for electron
  + Emission energies correspond to energy differences between allowed levels
  + Related to electrons and electron states/orbitals (ground vs excited)
    - Electrons can be excited when electricity is passed through them.
      * When electricity is passed through them, the electrons gain energy and get excited, jumping to a higher state
      * And when the current is stopped, they jump back down, releasing that energy in the form of visible light
  + Atomic excitation leads to emission
    - A) Direct decay
    - B) Cascade
      * When atoms de-excite the photons are emitted in a random direction (cf lasers)
  + Multielectron atoms: Much more complicated spectra, many more possible states
    - Molecular spectra are much more complex spectra, even for hydrogen
      * i.e.
        + A) Molecular Hydrogen H2 (complicated)
        + B) Atomic hydrogen (simple)
* The Doppler effect
  + Depends on the relative motion of source and observer
    - If one is moving toward a source of radiation, the wavelengths are shorter, if moving away, they are longer
      * Analogy: Police use handheld radar guns – and the Doppler effect – to catch speeders
    - The Doppler effect shifts an object’s entire spectrum either toward the red or toward the blue. Use the effect to measure radial velocities
      * Red shift: All spectral lines shift toward red end
        + Redshift: Objects are moving further away
      * Blue shift: All spectral lines shift toward blue/violet end
        + Blueshift: Objects are moving closer
* iClicker
  + Rigel appears as a bright bluish star, where as Betelgeuse appears as a bright reddish star. Fill in the following: Rigel is \_\_\_\_\_\_ Betelgeuse
    - A) Cooler than
    - B) Same temperature as
    - C) Older than
    - **D) Hotter than**
    - E) More massive than
      * Explanation: Hotter stars look bluer in color; cooler stars look redder
  + Analyzing a star’s spectral lines can tell us about all of these EXCEPT:
    - A) Its composition
    - B) Its surface temperature
    - **C) It’s transverse (side-side) motion**
    - D) Its rotation
    - E) Its density
      * Explanation: Only motion toward or away from us influences a star’s spectral lines. Spectra can also tell us about a star’s magnetic field
  + The frequency at which a star’s intensity is greatest depends on directly its:
    - A) Radius
    - B) Mass
    - C) Magnetic field
    - **D) Temperature**
    - E) Direction of motion
      * Explanation: Wien’s law means that hotter stars produce much more high-frequency light
  + If a light source is approaching you, you will observe:
    - A) Its spectral lines are red-shifted
    - B) The light is much brighter
    - **C) Its spectral lines are shorter in wavelength**
    - D) The amplitude of its waves has increased
    - E) Its photons have increased in speed
      * Explanation: The Doppler Shift explains that wavelengths from sources approaching us are blueshifted. The spectral lines are shorter in wavelength because red wavelength ≈ 700nm while blue is about ≈ 400nm. And since a light source is approaching you/coming closer, it is blueshifted; blue = shorter wavelength
  + The wavelengths of emission lines produced by an element
    - A) Depend on its temperature
    - **B) Are identical to its absorption lines**
    - C) Depend on its density
    - D) Are different than its absorption lines
    - E) Depend on its intensity
      * Explanation: Elements absorb or emit the same wavelengths of light based on their electron energy levels
  + What types of electro-magnetic radiation from space reach the surface of Earth?
    - A) Radio & Microwaves
    - B) X-rays & Ultraviolet light
    - C) Infrared & Gamma rays
    - **D) Visible light & Radio waves**
    - E) Visible & Ultraviolet light
      * Explanation: Earth’s atmosphere allows radio waves and visible light to reach the ground

Chapter 3: Telescopes

* Overview
  + Optical telescopes
  + Telescope properties
  + High-resolution astronomy
  + Radio astronomy
  + Observing at other wavelengths
* Optical telescopes
  + Images can be formed through reflection or refraction
    - Reflecting mirror
      * All rays pass through the focus
      * Curved form
    - Refraction lens
  + The larger the diameter of the mirror or lens, the more photons are collected and the brighter the image
    - Analogy: Telescopes are like light buckets that collect photons, just as buckets collect raindrops falling into them
      * The bigger the bucket, the more water it accumulates
  + Modern telescopes are all reflectors:
    - Light traveling through lens is refracted differently depending on wavelength – “chromatic aberration”
    - Some light traveling through lens is absorbed
    - Large lens can be very heavy, and can only be supported at the edges
    - Lens needs two optically acceptable surfaces, mirror only needs one
* Types of reflecting telescopes
  + 1. Prime focus
  + 2. Newtonian focus
    - Big – measured in meters
  + 3. Cassegrain focus
    - Divert light right back to the lens using a small hole in the lens
      * The small hole doesn’t affect performance
  + 4. Nasmyth/coudé focus
* Telescope mounts
  + Must allow for rotation of the earth
  + Equatorial mount
    - Simple motions
    - Massive engineering for large apertures
  + All large, modern telescopes are Altitude – Azimuth (Alt-Az) mounted
    - Easier engineering
    - Requires simultaneous rotation about 3 axes; computer controlled
  + i.e. Keck telescopes
    - Mauna Kea, Hawaii
      * Produce very high resolution images
* Detectors
  + Image Acquisition: Charge-coupled devices (CCDs) are sensitive electronic devices, and can be quickly read out and reset.
    - Output directly readable by computer
      * Similar to camera technology, but way way bigger
* Telescope size
  + Light-gathering power:
    - Improves ability to detect faint objects
    - Brightness proportional to square of radius of mirror
    - The figure, part (b) was taken with a telescope twice the size of (a)
      * Mauna Kea
        + Many many large telescopes in Hawaii
      * VLT = Very Large Telescope
        + Atacama, Chile

Atmosphere is thin and easy to penetrate

* Telescope resolution – diffraction
  + Resolving power: When better, can distinguish objects that are closer together
    - Resolution (“) = 0.25(λ/d)
      * λ = μm
      * d = m
    - Blue light (400nm) in a 1m telescope 🡪 0.1” resolution
    - The lower the arc seconds, the better the resolution
      * i.e. 1” > 5” > 10’ > 15’
        + Bad 🡪 Amazing graphics
* High resolution astronomy
  + Atmospheric blurring due to air movements
    - Variations in the air can lead to small refractions
      * Light coming in a straight line becomes skewed, producing an inaccurate and low resolution image
        + Due to air molecules and other tiny inconsistencies in the atmosphere
        + Rays deflect slightly while passing through Earth’s turbulent atmosphere
    - Solutions:
      * Put telescopes on mountaintops, especially in deserts
      * Put telescopes in space
      * Active optics
        + They control primary mirror segments based on temperature and orientation
      * Adaptive optics
        + Compensate for “seeing” using laser guide star

Study, in real time, how a distorted star looks like by replicating the problem, and fixing it

* The Hubble space telescope
  + Consists of several instruments: optical, UV, IR, spectrograph
    - Only 2.4m mirror but produces high resolution pictures by being above the earth’s atmosphere
* iClicker
  + Modern telescopes use mirrors rather than lenses for all of these reasons EXCEPT…
    - A) Light passing through lenses can be absorbed or scattered
    - B) Large lenses can be very heavy
    - C) Large lenses are more difficult to make
    - D) Mirrors can be computer controlled to improve resolution
    - **E) Reflecting telescopes aren’t affected by the atmosphere as much**
      * Explanation: Atmospheric effects are independent of type of telescope
  + Resolution is improved by using
    - A) Larger telescopes and longer wavelengths
    - B) Infrared light
    - **C) Larger telescopes and shorter wavelengths**
    - D) Lower frequency light
    - E) Visible light
      * Explanation: Diffraction limits resolution; larger telescopes and shorter-wave light produces sharper images
* Radio Astronomy
  + Radio telescopes
    - Similar to optical reflecting telescopes
      * Prime focus
    - Less sensitive to imperfections (due to longer wavelength); can be made very large
      * Largest radio telescope: 300m dish at Arecibo
    - Longer wavelength means poorer angular resolution
  + Advantages of radio astronomy
    - Can observe 24 hours a day
    - Clouds, rain and snow don’t interfere
    - Observations at an entirely different frequency – get totally different information
* Radio astronomy – Interferometry
  + Combines information from several widely spread radio telescopes as if it came from a single dish
    - Resolution will be that of a dish whose diameter = largest separation between dishes
  + Interferometry requires reserving relationship between waves over the distance between individual telescopes
    - Requires a lot of computing power
      * Waves that arrive out of step = Destructive interference
      * Waves that arrive in step = Constructive interference
  + Can get radio images whose resolution is close to optical
  + Also at optical wavelengths – i.e. Keck telescopes – but difficult due to short wavelengths
    - You can use optical wavelength and radio astronomy telescopes together, and achieve a high resolution picture
* iClicker
  + Diffraction is the tendency of light to
    - **A) Bend around corners and edges**
    - B) Separate into its component colors
    - C) Bend through a lens
    - D) Disperse within a prism
    - E) Reflect off a mirror
      * Explanation: Diffraction affects all telescopes and limits the sharpness of all images
  + Radio dishes are large in order to
    - **A) Improve angular resolution**
    - B) Give greater magnification
    - C) Increase the range of waves they can collect
    - D) Detect shorter waves than optical telescopes for superior resolution
      * Explanation: Resolution is worse with long-wave light, so radio telescopes must be large to compensate. They are often several meters in diameter
* Other wavelengths: IR
  + Infrared radiation can image where visible radiation is blocked; generally, can use optical telescope mirrors and lenses
    - Gas blocks and scatters light
      * IR radiation goes straight through gas clouds and provides a much better picture
  + Infrared telescopes can also be in space or flown on balloons
    - Get it very very high, above the earth’s atmosphere
  + Water in earth’s atmosphere interferes with IR telescopes
* Other wavelengths: X-ray
  + X-ray and gamma rays will not reflect off mirrors as other wavelengths do; need new techniques
  + X-rays will reflect at a very shallow angle, and therefore can be used with special mirrors
    - Gas at very high temperatures emit X-rays
      * i.e. Supernova [when a star explodes]
        + Gas is very hot [10 million degrees and counting]
* Other wavelengths: gamma rays
  + Gamma rays cannot be focused at all; images are therefore somewhat coarser
  + Simply count photons coming from a given direction
    - Resolution ≈ 1o
* Multi-wavelength studies
  + Series of picture taken with all telescopes, from IR to X-ray, etc.
    - Produces different images from different angles
  + Much can be learned from observing the same astronomical object at many wavelengths
    - i.e. Mapping out the Milky Way
      * i.e. Mapping out other galaxies
* iClicker
  + Seeing in astronomy is a measurement of
    - A) The quality of the telescope’s optics
    - B) The transparency of a telescope’s lens
    - C) The sharpness of vision of your eyes
    - **D) The image quality due to air stability**
    - E) The sky’s clarity & absence of clouds
      * Explanation: “Good Seeing” occurs when the atmosphere is clear and the air is still. Turbulent air results in “poor seeing”, and fuzzier images
  + An advantage of CCDs over photographic film is:
    - A) They don’t require chemical development
    - B) Digital data is easily stored and transmitted
    - C) CCDs are more light sensitive than film
    - D) CCD images can be developed faster
    - **E) All of the above are true**
  + Adaptive optics refers to:
    - A) Making telescopes larger or smaller
    - **B) Reducing atmospheric blurring using computer control**
    - C) Collecting different kinds of light with one type of telescope
    - D) Using multiple linked telescopes
      * Explanation: Shaping a mirror in “real time” can dramatically improve resolution
  + Radio telescopes are useful because
    - A) Observations can be made day & night
    - B) We can see objects that don’t emit visible light
    - C) Radio waves are not blocked by interstellar dust
    - D) They can be linked to from interferometers
    - **E) All of the above are true**
      * Explanation: The Very Large Array links separate radio telescopes to create much better resolution images
  + Infrared telescopes are very useful for observing
    - A) Pulsars & black holes
    - B) From locations on the ground
    - C) Hot stars & intergalactic gas
    - D) Neutron stars
    - **E) Cool stars & star-forming regions**
      * Explanation: Infrared images of star-forming “nurseries” can reveal objects still shrouded in cocoons of gas and dust
  + The Hubble Space Telescope (HST) offers sharper images than ground telescopes primarily because
    - A) HST is closer to planets & stars
    - B) HST uses a larger primary mirror
    - C) It gathers X-ray light
    - **D) HST orbits above the atmosphere**
    - E) It stays on the nighttime side of Earth
      * Explanation: HST orbits less than 400 miles above Earth – not much closer to stars & planets. But it can gather UV, visible, and IR light, unaffected by Earth’s atmosphere

Chapter 4: The Solar System

* + Overview
    - An inventory of the solar system
    - Interplanetary matter
    - The formation of the solar system
    - Planets beyond the solar system
* Inventory of the solar system
  + Early astronomers knew moon, Mercury, Venus, Mars, Jupiter, Saturn, comets, meteors, and stars
    - Now known: Solar system has one star, 169 moons orbiting 8 planets (plus Uranus and Neptune), asteroids, comets, meteoroids, dwarf planets, Kuiper Belt objects and Oort cloud
  + All orbits but Mercury’s are close to the same plane
* Measuring properties of the solar system
  + Orbital period can be observed
  + Kepler’s laws 🡪 Distance from the sun
  + Angular size 🡪 Radius
  + Newton’s laws 🡪 Mass
    - Observe the effect one celestial body has on another body
  + Observe rotation periods
  + Mass and radius 🡪 Density
    - Earth’s density ~ 4500kg/m3 uncompressed
      * Water’s density = 1000kg/m3
* iClicker
  + Pluto seems to be similar to
    - A) The terrestrial planets
    - B) The jovian planets
    - C) Asteroids
    - **D) The moons of jovian planets**
    - E) The moons of terrestrial planets
      * Explanation: Pluto is perhaps best categorized as a Kuiper belt object rather than a planet
* Relative scales in the solar system
  + Suppose that the sun was a (1m diameter ≈ 1:109) beach ball
    - Earth would be a marble (1cm diameter) in MUSC (150m away)
      * Moon would be a pinhead (≈ 2mm diameter) about a foot away from Earth
        + Radius of the moon’s orbit is about 60x earth’s
    - Jupiter would be a grapefruit (≈ 10cm) in Westdale (750m away)
    - Pluto would be a sesame seed (1.5mm diameter) at Main & Wentworth (6km away)
    - Next nearest star would be twice the flying distance to Australia (Proxima Centauri; size of a watermelon)
      * YouTube: Solar System Nevada Desert
* Terrestrial VS Jovian planets
  + Terrestrial: Mercury, Venus, Earth, Mars
  + Jovian: Jupiter, Saturn, Uranus, Neptune
    - Refer to chart below

|  |  |
| --- | --- |
| Terrestrial | Jovian |
| Close to the sun | Far from the sun |
| Closely spaced orbits | Widely spaced orbits |
| Small masses | Large masses |
| Small radii | Large radii |
| Predominantly rocky | Predominantly gaseous |
| Solid surface | No solid surface |
| High density | Low density |
| Slower rotation | Faster rotation |
| Weak magnetic fields | Strong magnetic fields |
| No rings | Many rings |
| Few moons | Many moons |
| Warmer | Colder |

* Differences among terrestrials
  + Atmospheres and surface conditions are very dissimilar
  + Only earth has oxygen in atmosphere and liquid water on surface
  + Earth and mars rotate about the same rate
    - Venus and Mercury are much slower
      * Venus rotates in the opposite direction
  + Earth and Mars have moons
    - Mercury and Venus do not
  + Earth and Mercury have magnetic fields
    - Venus and Mars do not
* iClicker
  + The major difference(s) between the terrestrial and jovian planets involve(s)
    - A) Mass
    - B) Density
    - C) Surface gravity
    - D) Density and surface gravity
    - **E) Mass and density**
      * Explanation: Jovian planets are more massive, but less dense, than terrestrial planets. This is due to the composition of the planets. Jovian are gaseous and terrestrial are rocky
* Interplanetary matter
  + The inner solar system, showing the asteroid belt, Earth-crossing asteroids, and Trojan asteroids
    - Most of the solar system is empty space
      * Chance of being hit by an asteroid is relatively small
  + The path of Icarus, an earth crossing asteroid
  + Asteroids and meteoroids have rocky composition; asteroids are bigger
    - Range in size from a few kilometers to a couple thousand
      * i.e. Asteroid Gaspra [10km]
      * i.e. Asteroid Mathilde [30km]
    - To small to be spherical
      * Small mass
  + Asteroid Eros
    - Can only resolve with spacecraft – NEAR – Shoemaker
      * Mass: 7x1015
      * Density: 2400kg/m3
      * Loose rock plies
      * Total mass in asteroids < 1/10 of Earth’s moon
* iClicker
  + Most asteroids are found
    - A) Beyond the orbit of Neptune
    - B) Between Earth and the Sun
    - **C) Between Mars and Jupiter**
    - D) In the orbit of Jupiter but 60 degrees ahead of behind it
    - E) Orbiting the Jovian planets in captured retrograde orbits
      * Explanation: The asteroid belt is located between 2.1 and 3.3 AU from the sun
* Interplanetary matter: Comets
  + Comets are icy, with some rocky parts
  + The basic components of a comet
    - Tail, coma, nucleus
      * Dust tail, ion tail
* Comet orbits and tails
  + The solar wind means the ion tail always points away from the sun
  + The dust tail also tends to point away from the sun, but the dust particles are more massive and lag somewhat, forming a curved tail (angular momentum)
  + If the comet gets to close to the sun, it can be eradicated
* Comet Halley
  + The internal structure of the cometary nucleus
    - Fragmented material, intact interior, surface layers, etc.
* Cometary orbits
  + The size, shape, and (random) orientation of cometary orbits depend on their location. Oort cloud comets rarely enter the inner solar system
    - Comets are highly elliptical [most of them]
    - They orbit the sun in all directions
* Comets and meteor showers
  + Meteor showers are associated with comets – they are the debris left over when a comet breaks up
    - After a comet breaks, big pieces of the comet continue to orbit the sun. Sometimes, if the orbit of the asteroid/comet intercepts with earth’s orbit, a meteor shower will be observed
      * Earth passes through broken up comet debris
    - Every 33 years, as Earth passes through the densest region of this meteoroid swarm, we see intense showers, reaching 1000 meteors per minute for brief periods of time
* Earth impacts
  + The large impacts of a large meteor can create a significant crater
    - i.e. The Barringer meteor crater in Arizona
      * 50 to 100m in diameter of crater
        + Over 1km wide
  + Sometimes an asteroid/comet is large enough to burn straight through Earth’s atmosphere and continue until impact
  + The Manicouagan reservoir in Quebec
    - Over 30km in diameter
* Earth impacts: What killed the dinosaurs?
  + The dinosaurs may have been killed by the impact of a large meteor or small asteroid
    - The larger an impact is, the less often we expect it to occur, but the more damaging it is
      * We frequently get small asteroid collisions [yearly]
        + Very rarely get large asteroid collisions [millions of years]
* Formation of the solar system
  + Nebular contraction
    - Cloud of gas and dust contracts due to gravity; conservation due to gravity; conservation of angular momentum means it spins faster and faster as it contracts
      * Collapse accelerates when density increases, causing gravity to go up very quickly
      * As the cloud contracts, it spins and forms a disk
  + Conservation of angular momentum
    - The product of radius and rotation rate must be constant
      * Large radius = slow rotation
      * Small radius = rapid rotation
        + An ice skater can pull his arms in to spin faster
      * Therefore, as a dust cloud collapses, its rate of rotation will increase. It will get to a point where rotation is sufficiently fast that it can collapse no further towards the rotation axis leading to a rapidly spinning disc
  + Condensation theory:
    - Interstellar dust grains help cool the cloud, and act as condensation nuclei
      * After several million years, after the gas cloud cools, a solar system starts to form
  + The star Beta Pictoris is surrounded by a disk of warm matter, which may indicate planetary formation
    - Temperature in cloud determines where various materials condense out; this determines where rocky planets and gas giants form
    - As you go further out from the sun, the temperature decreases, which alters the materials that can be cooled
      * In the hot central regions, only metals form
        + i.e. Mercury
      * In the cool regions, you get silicates, and rocky materials
      * Further out from the sun, you get icy planets like Pluto
* Planets beyond the solar system
  + Many planets have been discovered in other solar systems
    - Neptune has several planets that are just like it
      * i.e. GJ 1214b & CoRoT 7b
    - More jovial planets are discovered than terrestrial because it is harder to detect terrestrial planets
      * Most newly discovered planets have masses closer to that of Jupiter’s than Earth’s
        + Develop an intrinsic bias – people believe that there are more jovial planets than terrestrial planets
  + Some planets are discovered through the “wobble” they create in their parent star’s orbit
  + Other planets are discovered through the periodic dimming of the parent star’s luminosity (needs good alignment)
    - Detect slight decrease in brightness when the planet intersects the star
    - You can work out the radius and diameter of the planet
    - Using Kepler’s laws, you can determine the orbit
* “Earth-like” planet around Proxima Centauri
  + 11.2 day orbit
  + 1.3x the mass of the earth
  + 1/20 AU orbit
  + Cooler star than sun, planet lies in habitable zone
    - Habitable zone = Liquid zone; possibility of life
      * To close = Water boils away
      * To far = Water freezes
    - Proxima Centauri is very active and has a lot of flares that knock out tech equipment, and is harmful to life
* iClicker
  + Which of the following are terrestrial planets?
    - A) Only Earth
    - B) Earth, Moon, and Venus
    - **C) Mercury, Venus, Earth, and Mars**
    - D) Mercury, Venus, Earth, Moon, Mars, and Pluto
    - E) Mercury, Venus, Earth, Moon, Mars, and Ceres
      * Explanation: Terrestrial planets are “earth-like”. This means that they are rocky, small, dense, close to the sun, warm, have a smaller orbital period, and quicker rotation than Jovian planets
  + The angular diameter of an object
    - A) Increases if the object is farther away
    - **B) Decreases if the object is farther away**
    - C) Is measured in light-years
    - D) Determines its parallax
    - E) Depends on its location in the sky
      * Explanation: Angular diameter depends directly on size and inversely on distance
  + Compared with terrestrial planets, jovian planets share all of the following characteristics EXCEPT
    - A) Low density
    - B) Large size
    - C) Many moons
    - D) Ring systems
    - **E) Slower rotation**
      * Explanation: Jovian planets rotate quicker on its axis, and terrestrial planets rotate slower on their axis. Refer to chart for more information.
  + The asteroid belt is evidence of
    - A) A planet that once orbited the sun but later was destroyed
    - **B) Ancient material from the formation of the solar system**
    - C) A collision between Jupiter and one of its larger moons
    - D) Comets that were trapped by Jupiter’s gravitational field
      * Explanation: Asteroids, meteoroids, and comets may have not changed at all since the solar system formed
  + Compared to asteroids, comets show all of these properties except
    - **A) Their densities are higher**
    - B) Their orbits tend to be less circular
    - C) They tend to be made of ice
    - D) They can look fuzzy, whereas asteroids appear as moving points of light
    - E) Their average distances from the sun are far greater
      * Explanation: Comets have densities much lower than asteroids or planets. This is because comets are composed of ice, while asteroids are rocky. Rock is denser than ice, hence comets are less dense than asteroids.
  + What causes a meteor shower?
    - A) A comet and an asteroid collide
    - B) Earth runs into a stray swarm of asteroids
    - **C) Earth runs into the debris of an old comet littering its orbit**
    - D) Meteorites are ejected from the moon
    - E) Debris from a supernova enters Earth’s atmosphere
      * Explanation: Meteor showers can generate a few shooting stars to hundreds of thousands, seen an hour
  + Any theory of the origin of the solar system must explain all of these EXCEPT
    - A) The orbits of the planets are nearly circular, and in the same plane
    - **B) The direction that planets orbit the sun is opposite to the Sun’s spin**
    - C) The terrestrial planets have higher density and lower mass
    - D) Comets do not necessarily orbit in the plane of the solar system
      * Explanation: The planets DO orbit in the same direction that the Sun spins. Most also spin in that direction, and most also have large moons that orbit in that direction. The only planets that do not spin in the same direction as the Sun are Venus and Neptune
  + The condensation sequence theory explains why:
    - A) Our planet Earth has water and rain
    - B) Stars are more likely to form large planets orbiting very near
    - **C) Terrestrial planets are different from Jovian planets**
    - D) The moon formed near to Earth
    - E) Pluto has such a circular orbit
      * Explanation: The condensation sequence theory explains how the temperature of the early solar nebula controls which materials are solid, and which are gaseous
  + Astronomers have detected most extrasolar planets by observing
    - **A) The “wobble” of their parent stars using spectroscopy**
    - B) Starlight reflected by their surfaces
    - C) Eclipses when the planets block the light of their parent stars
    - D) The planets’ changing phases as they orbit their stars
      * Explanation: Measurements of the periodic Doppler shift in the spectra of the star 51 Pegasi indicate it has a planetary companion
  + Extrasolar planets the size of Earth have NOT been seen yet with current techniques because
    - A) Small planets probably don’t exist
    - B) The large planets nearby have swept them up
    - C) Earth-like planets take time to form
    - **D) Large planets orbiting near to their stars are more easily detected**
    - E) Small planets can only be seen if they cross in front of their star
      * Explanation: Looking for detectable “wobbles” in the spectra of stars finds massive planets with small orbits. Other techniques may be needed to see less massive Earth-like planets
  + Which of the following defines density?
    - A) Mass times surface gravity
    - **B) Mass divided by volume**
    - C) Size divided by weight
    - D) Mass times surface area
    - E) Mass times surface area
      * Explanation: Density can be thought of as (Matter/Space). Lots of matter in a small space = high density. A small amount of matter in a large space = low density. Similar to objects in a room.

Chapter 5 – Earth & Its Moon

* Overview
  + Earth and the Moon in bulk
  + The tides
  + Atmospheres
  + Interiors
  + Surface activity on Earth
  + The surface of the Moon
  + History of the Earth – Moon system
  + Magnetosphere
* Earth and the Moon in bulk
  + The moon weighs less, smaller diameter, lower density, and lower gravity
    - The moon’s mantle is made of mainly basalt
* Tides
  + Tides are due to differential gravitational forces on Earth from Moon: force on near side of Earth is greater than force on far side. Water can flow freely in response
    - During a full moon/new moon, the force is greater at the equator and tropic lines, and weaker at the poles
      * During a quarter, the force is greater at the poles, and weaker at the tropics and equator
  + The sun has less effect (more massive but much more distant), but it does modify the lunar tides
  + Tides tend to exert a “drag” force on Earth, slowing its rotation
    - This will continue until Earth rotates synchronously with the moon, so that the same side of earth always points towards the moon. Also causes recession of the moon ≈ 4cm/year
      * The moon is very slowly moving away from the earth
        + Soon, it’ll have no effect on earth and its tides
  + This has already happened with the moon; whose near side is always toward Earth – it is tidally locked to Earth
    - Called tidal lockage
      * i.e. Pluto and its moon
* iClicker
  + At what lunar phase would the variation between high and low tides be the greatest?
    - A) New moon
    - B) Waxing crescent moon
    - C) Full moon
    - D) Third quarter moon
    - **E) Both new and full moon**
      * Explanation: At new and full moon phases, the Sun and Moon combine to stretch the Earth and its oceans even more. We see higher high tides and lower low tides
  + What force caused the Moon’s near side to constantly face Earth?
    - A) The sun’s gravity
    - B) Earth’s magnetic field
    - **C) Earth’s tidal force**
    - D) The solar wind
    - E) The moon’s magnetic field
      * Explanation: Just as the Moon creates tides on Earth with its gravitational force, the Earth affects the Moon, too. Tidal locking is a minimum energy state
* Planetary Atmospheres
  + Gravity and temperature determine which gases a planet can retain
    - Determines whether the planet will be Jovian or Terrestrial
      * Vav = (3kT/m)0.5
      * Vesc = (2GM/R)0.5
        + Retains molecule if

6Vav = Vesc

* + Jovian planets have high escape velocities and are much cooler
  + Terrestrial planets have moderate escape velocities and have high temperatures
* Atmosphere
  + The blue curve shows the temperature at each altitude
    - Refer to graph on PPT
  + Troposphere is where convection takes place – responsible for weather
    - Troposphere 🡪 Stratosphere 🡪 Mesosphere 🡪 Ionosphere
  + Ozone layer is in stratosphere; just above the clouds
    - Absorbs ultraviolet radiation
  + Density of atmosphere decreases as you go up
  + Convection: Depends on the warming of the ground by the sun
  + Ionosphere is ionized by solar radiation, and is good conductor
    - Reflects radio waves in the AM range, but transparent to FM and TV
  + The ozone hole
    - Chlorofluorocarbons [CFCs] have been damaging the ozone layer, resulting in the “ozone hole”
    - 1980s: Production and use curtailed but may take decades to recover
  + Greenhouse effect
    - Sunlight (mainly visible, UV) that is not reflected is absorbed by Earth’s surface, warming it
    - Surface re-radiates as infrared thermal radiation
    - Atmosphere (H20, CO2, CH4, etc.) absorbs some infrared causing further heating
      * Earth needs to absorb the same amount of radiation it releases
  + Global warming
    - There is extremely strong evidence that Earth is getting warmer. The cause of this warming is debated by some; almost all scientists believe it is related to the corresponding increase in carbon dioxide gas
* iClicker
  + A planetary atmosphere with ozone could protect surface dwellers from
    - **A) Ultraviolet radiation**
    - B) Charged particles in the solar wind
    - C) Meteor impacts
    - D) Optical radiation
    - E) Radar waves
      * Explanation: Ozone in the stratosphere absorbs UV light, and heats the upper atmosphere
  + The principal greenhouse gases in our present atmosphere are
    - A) Hydrogen and helium
    - B) Oxygen and nitrogen
    - **C) Water vapor and carbon dioxide**
    - D) Methane and ammonia
    - E) Sulfuric acid vapor and CO2
      * Explanation: These two are the dominant gases in earth’s atmosphere
  + Without the greenhouse effect in our atmosphere
    - A) We would not have to worry about ecological problems
    - **B) The earth’s oceans would be frozen**
    - C) The amount of nitrogen & oxygen would be much less
    - D) Icecaps would have melted
    - E) Global warming would still occur
      * Explanation: Earth’s greenhouse effect makes the planet about 40o C hotter than it would otherwise be. This raises the average surface temperature above the freezing point of water
* Interior Structure
  + Seismic waves:
    - Earth (moon) quakes produce both pressure and shear waves
    - Pressure waves travel through both liquids and solids
      * Shear waves will not travel through liquids, as liquids do not resist shear forces
    - Wave speed depends on density of material
  + The pressure wave is a longitudinal wave, whereas the shear wave is a transverse wave. A shear wave cannot propagate within a liquid
* Seismology
  + Can use pattern of ‘P’ & ‘S’ wave’s propagation during earthquakes to deduce interior structure of Earth
    - S- waves cannot penetrate the outer core because it is liquid lava
* Interior structure of earth
  + Mantle is much less dense than core
  + Mantle is rocky; core is metallic, consisting of iron and nickel
  + Outer core is liquids; inner core is solid, due to pressure
  + Volcanic lava comes from mantle, allows analysis of composition
* Plate tectonics
  + Continental drift: Earth’s entire surface is covered with crustal plates, which can move independently. At plate boundaries, earthquakes, and volcanoes can occur
    - Plate moving away from each other create rifts
* Tectonic movement over geological periods
  + If we follow continental drift backward, the continents merge into one, called Pangaea, 200 million years ago
* The surface of the moon
  + Does not show any tectonic movement
    - Large dark flat areas, due to lava flow, called Maria
      * The far side of the moon shows little evidence of lava flow; heavily cratered
  + Crater formation
    - Meteoroids striking the moon have tremendous energy
      * A 25kg object at 20km/s ≈ 1 tonne TNT
    - Very large and small lunar craters
  + Surface
    - Regolith: Thick layer of dust left by meteorite impacts
    - The moon is still being bombarded, especially by very micro-meteoroids – very small soft rocks
    - Craters are typically about 10 times as wide as the meteoroid creating them, and twice as deep
      * Rock is pulverized to a much greater depth
    - Most lunar craters date to at least 3.9 billion years ago
      * Much less bombardment since then
    - Maria are due to few large late impacts on near side, cracked surface and allowed lava to flow; 4.1 – 3.9 Gyr ago
  + Formation of the moon
    - Current theory of the moon’s origin glancing impact of mars-sized body on the still-liquid earth caused enough material, mostly from the mantle, to be ejected to form the moon
* Magnetospheres
  + Region around earth where charged particles from the solar wind are trapped by earth’s magnetic field
    - Creates a barrier around the earth
  + These charged particles are trapped in areas called the Van Allen belts, where they spiral around the magnetic…
* iClicker
  + Lunar maria are found
    - A) Uniformly all over the moon
    - **B) Mostly on the side facing earth**
    - C) Mostly on the far side of the moon
    - D) Only in the dark areas, out of sunlight
    - E) In the highlands, among mountains
  + The region around Earth where the magnetic field traps charged particles is the
    - A) Ozone layer
    - B) Exosphere
    - **C) Van Allen radiation belts**
    - D) Corona
    - E) Aurora borealis and australis
  + Which of these is NOT a result of the Earth’s magnetic field?
    - A) A compass pointing north
    - B) Aurorae
    - C) The Van Allen radiation belts
    - **D) Volcanic eruptions**
    - E) The comet-like tail of charged particles that extends past our moon

Chapter 6 – Terrestrial Planets

* Overview
  + Orbital and physical properties
  + Rotation rates
  + Atmospheres
  + The surface of Mercury
  + The surface of Venus
  + The surface of Mars
  + Internal structure and geological history
  + Atmospheric evolution on Earth, Venus, and Mars
* iClicker
  + Mercury is very hard to observe from Earth because
    - A) It appears only half lit
    - **B) It is never more than 28o from the sun**
    - C) Its elliptical orbit causes it to change speed unpredictably
    - D) Its surface reflects too little sunlight
    - E) Its surface does not allow radar to bounce back to Earth
      * Explanation: Mercury’s inner orbit keeps it close to the sun, visible only for an hour or two before sunrise or after sunset
        + Applies to Venus as well

THIS IS AN EXAM QUESTION!!!

* Orbital and physical properties
  + Because the orbits of Venus and Mercury are interior to the Earth’s orbit, these planets never appear far from the Sun; Mars can appear anywhere on the ecliptic
  + The terrestrial planets have similar densities and roughly similar sizes, but their rotation periods, surface temperatures, and atmospheric pressures vary widely
    - Earth and mars have a similar rotation period
    - Venus has a retrograde motion
      * Rotates counter clockwise
    - Mercury has the fastest revolution of 88 days
* Rotation rates
  + Mercury is difficult to image from earth
    - Rotation rates can be measured by radar
  + All planets rotate in a prograde direction
    - Except Venus, which is retrograde
* Mercury’s rotation
  + Mercury was long thought to be (simply) tidally locked to the sun; measurements in 1965 showed this to be false
    - Rather, Mercury’s day and year are in a 3:2 resonance:
      * Mercury rotates 3 times while going around the sun twice
        + This is a stable configuration for a significantly elliptical orbit (e=0.2)
* iClicker
  + Which statement about the rotations of Mercury & the Moon is false?
    - A) Our moons keeps the same side toward us
    - B) The rotation period of Mercury is 59 Earth days
    - **C) Like our Moon, Mercury does not rotate at all, keeping the same side facing the Sun**
    - D) On Mercury, three “days” equal two “years”
    - E) On the Moon, each “day” lasts about 15 earth days of constant sunlight
* Atmospheres
  + Mercury has no detectable atmosphere, it is too hot, too small, and too close to the sun
  + Venus has an extremely dense atmosphere. The outer clouds are similar in temperature to Earth, and it was once thought that Venus was a “jungle” planet
    - We now know that its surface is hotter than Mercury’s
      * Hot enough to melt lead
  + The atmosphere of Mars is similar to Earth’s composition, but very thin
* The surface of Mercury
  + Mercury cannot be imaged well from Earth
    - Pictures are from the “Messenger”
  + Cratering on Mercury is similar to that on the Moon
  + Some distinctive features: Scarps (cliffs), several hundred kilometres long and up to 3 km high, thought to be formed as the planet cooled and shrank – wrinkles
  + Caloris Basin, very large impact feature; ringed by concentric mountain ranges
* iClicker
  + Mercury has extreme high and low temperatures between night and day because:
    - A) It is close to the sun
    - B) Its surface rocks don’t retain heat
    - C) It spins too fast to cool down
    - D) Mercury’s axis has no tilt; its equator receives direct sunlight
    - **E) It has no atmosphere to moderate temperatures over the globe**
      * Explanation: Mercury’s very high sunlit surface temperature of 700K, and low mass, explains why it has no atmosphere
* The surface of Venus
  + Venus is so hot that it’s surface melts within a couple of hours
    - Unable to obtain data to the extent we can for Mars
  + Lots of volcanic activity in the past
  + Venus corona, with lava domes
  + Coronae: Lava upwelling(s) which never quite developed into convection
  + Surface is relatively young
    - Because of volcanic activity and lava flowing across the surface
* The surface of Mars
  + Most visited and studied
  + Major features:
    - Tharsis bulge, size of North America and 10km above surrounding
      * Huge canyon system
  + Mars’ radius is about half of earth’s
  + North hemisphere is rolling volcanic terrain
  + Southern hemisphere is heavily cratered highlands; average altitude 5km above northern
  + Assumption is that northern surface is younger than southern
  + Means that northern hemisphere must have been lowered in elevation and then flooded with lava
  + No evidence for plate tectonics
  + Mars has the largest volcano in our solar system
    - Olympus Mons
      * 700km diameter at base
      * 25km high (low g)
        + You can build really high on mars [compared to earth]
    - Caldera
      * 80km in diameter
    - Three other volcanoes are only slightly smaller
  + Impact craters less than 5km across have mostly been eroded away
  + Analysis of craters allows estimation of age of surface
  + Crater in image was made when surface was liquid
  + Water on mars?
    - Runoff channels resemble those on Earth
    - Much of northern hemisphere may have been ocean
      * Ancient river delta?
    - Lots of evidence for flash flooding
  + Water on mars confirmed by NASA in 2015; active “briny” water
  + Martian polar caps
    - Known to contain carbon dioxide ice
      * May also be vast reservoirs of water ice
* iClicker
  + Which of the following inner solar system bodies has the largest volcanoes?
    - A) Mercury
    - B) Venus
    - C) Earth
    - **D) Mars**
    - E) Moon
      * Explanation: Mars’ largest volcano, Olympus Mons, rises more than 25km above the surrounding plains
  + How do the atmospheres of the Moon and Mercury compare?
    - A) Mercury’s is denser, with carbon dioxide
    - B) They are similar, only 1% as dense as ours
    - C) The cooler Moon retains a thicker nitrogen atmosphere
    - D) As no spacecraft has yet landed there, no information exists about Mercury’s
    - **E) Neither body has a permanent atmosphere**
* Internal structure and geological history
  + Internal structure of mercury, mars, and the moon, compared to earth
    - All celestial bodies consist of a mantle and a core
      * Venus; little known but believed to be similar to Earth
* iClicker
  + The weakness of the magnetic field of Mars is because:
    - A) It spins much slower than Earth does
    - B) Its core may no longer be molten
    - C) Its core contains less iron than our Earth
    - **D) Both B and C are probable**
    - E) All of the above
      * Explanation: Mars is smaller and would have cooled more quickly
* Atmospheric evolution on Earth, Venus, and Mars
  + At formation, planets had primary atmosphere – hydrogen, helium, methane, ammonia, water vapor – which was quickly lost
  + Secondary atmosphere – water vapour, carbon dioxide, sulfur dioxide, nitrogen – comes from volcanic activity
    - These gases come from within the planet
  + Earth now has a tertiary atmosphere, 20 percent oxygen due to the presence of life
  + Earth has a small greenhouse effect; it is in equilibrium with a comfortable surface temperature (for us, humans)
  + Venus’ atmosphere is much denser and thicker; a runaway greenhouse effect has resulted in its present surface temperature of 730K
  + Any water would have been due to a high “water tap” (irreversible)
  + Earth occupies “sweet spot” in carbon cycle
    - Not too close to the sun to lead to runaway greenhouse
    - Enough volcanic activity to keep some CO2 in atmosphere
* iClicker
  + Mercury’s surface most resembles which of these?
    - **A) The moon’s far side**
    - B) Venus’ polar regions
    - C) Earth’s deserts
    - D) The moon’s near side
    - E) Mars’ deserts
      * Explanation: Both Mercury and the Moon’s far side are heavily cratered
  + What effect does the greenhouse effect have on the surface environment of Venus?
    - A) Little or no effect
    - B) About the same as on Earth
    - C) To reduce the surface temperature by about 30o Celsius
    - **D) To raise the surface temperature by hundreds of degrees Celsius**
    - E) To cause the surface temperature of Venus to become hotter than the Sun

Midterm Details & FAQ

* Thursday, October 20th, 2016
  + 7:00 – 8:30PM
* Eclipses, Moon Phases
* Seasons
* Kepler’s Laws
* Newton’s Laws
* Tides
* Planetary Atmosphere / Greenhouse Effect & Jean’s Theory
* Wien’s Law
* Spectra / Kirchhoff’s Law
* Observations / Limitations of Observations / Atmosphere / Wavelength
* Exoplanets

Chapter 7: Jovian Planets

* Overview
  + Observations of Jupiter and Saturn
  + The discoveries of Uranus and Neptune
  + Bulk properties of the Jovian Planets
  + Jupiter’s atmosphere
  + The atmospheres of the outer Jovian worlds
  + Jovian interiors
* Earth-Based Observation of Jupiter
  + Jupiter can be imaged well from Earth, even with a small telescope
    - Jupiter with its Galilean moons
      * Discovered by Galileo
* Exploring the outer solar system
  + Energy budget to climb out of the “gravitational well” of the sun is significant – harness energy of planets: “gravitational slingshot”
    - Use gravity of other planets to slingshot into a different angle with a higher velocity
* Discovery of Uranus and Neptune
  + Jupiter and Saturn known in antiquity
  + Uranus discovered serendipitously by William Herschel in 1781; quickly realised that it was solar system’s 7th planet
  + By 1840s a discrepancy of 1’ (1-minute arc) in orbit was noted; could be resolved by gravitational influence of an as yet unknown planet
    - Urbain Leverrier & John Adams separately predicted position of planet
  + “Neptune” observed by Johann Galle in 1846 within 1o of predicted position
  + Triumph of determinism, Newtonian mechanics and predictive science
* Bulk properties of the Jovian planets
  + The Jovian planets are large and much less dense than the terrestrial planets; fast rotators, strong magnetic fields
    - More massive, less dense, due to gaseous composition
* iClicker
  + Jupiter and the other Jovian planets are noticeably oblate because they have
    - A) Very strong magnetic fields
    - B) Powerful gravity pulling on the poles
    - **C) Rapid rotation and a fluid interior**
    - D) Many moons that tidally distort their shapes
    - E) All of the above
      * Explanation: All of the Jovian planets are larger than Earth, all spin faster, all have lower density, and all show a flattened, “oblate” shape
* Peculiar seasons on Uranus
  + Axis of rotation lies almost in the plane of its orbit
    - Seasonal variations are extreme
      * Seasons last a long long time (couple of years)
        + Uranus’ equatorial regions have two summers at the two equinoxes – 42 years apart, and two winters at the solstices, with its poles plunged into darkness, also for 42 years at at time
* Jupiter’s Atmosphere
  + Atmosphere has bright zones and dark belts
  + Zones are cooler, and are higher than belts
  + Stable flow underlies zones and bands, called zonal flow
  + No solid surface; take top of troposphere to be 0 km
    - Mixture of gases ranging from water vapour to…
  + Lowest cloud layer cannot be seen by optical telescopes
  + Measurements by Galileo probe show high wind speeds even at great depth
    - Probably due to heating from planet, not from the Sun
  + Major features:
    - Bands of clouds; spots; Great Red Spot – long lived storm
      * The Great Red Spot has been around for several hundred years
* Saturn’s Atmosphere
  + Similar to Jupiter’s, except colder and pressure is lower
  + Cloud layers are thicker than Jupiter’s
    - You can only see the top layer
  + Layers consist of:
    - Water ice, ammonium hydrosulfide ice, ammonia ice, etc.
* Atmosphere of the outer Jovians
  + Uranus and Neptune
    - Appear blueish because of methane in upper layers
    - Rotation or Uranus can be measured by watching storms
  + Neptune has storm systems similar to those on Jupiter, but fewer
    - The large storm system at top has disappeared in recent years
* iClicker
  + Which of these is TRUE about the seasons on Uranus?
    - **A) Its strange tilt produces extreme seasonal variations**
    - B) With its tilt of 29o, Uranus has four seasons similar to those on Earth
    - C) It never shows any weather in its bland clouds
    - D) It spins so fast all seasons are the same
  + The outer Jovian planets appear bluish in color because
    - A) Gaseous ammonia in their atmosphere absorbs blue light
    - **B) Methane absorbs red light**
    - C) Cold hydrogen reflects blue light
    - D) Dust in their atmosphere scatters blue light, similar to Earth
* Jupiter’s interior
  + No direct information is available about Jupiter’s interior, but its main components, hydrogen and helium, are quite well understood
    - Use knowledge of density, gravity, magnetic fields etc. and properties of matter to infer interior state. The central portion is thought to be a rocky core
      * Icy, rocky core 🡪 Metallic hydrogen 🡪Molecular hydrogen
* Jovian interior
  + Emit more energy than they absorb from Sun: left over heat (Jupiter); gravitational differentiation of H, He (Saturn)
    - Rocky core, metallic hydrogen, molecular hydrogen
      * Interior of Jupiter and Saturn
  + Interior structure of Uranus and Neptune is comprised of:
    - Rocky core, surrounded by “slush”, then by molecular hydrogen
* Jupiter’s magnetosphere
  + Intrinsic field strength is 20,000 times that of Earth
  + Magnetosphere can extend beyond the orbit of Saturn
    - Long, long tail
      * Detected by the Pioneer 10
  + Polar aurorae seen
* Jovian magnetic fields
  + Uranus and Neptune both have substantial magnetic fields, but a large angle to their rotation axis
  + The rectangle within each planet shows a bar magnet that would produce a similar field. Note that both Uranus’ and Neptune’s are significantly off center
    - Uranus and Neptune have large rocky cores, the magnetic field isn’t in the rocky core, it’s from an offset location
      * Not the case of Jupiter
* iClicker
  + Both Jupiter and Saturn
    - A) Have liquid metallic hydrogen in their interiors
    - B) Have rings
    - C) Emit more energy than they absorb from the Sun
    - D) Rotate very rapidly
    - **E) All of the above**
  + Jovian planets share all of the following traits EXCEPT
    - **A) A low-density gaseous core**
    - B) Large magnetic fields
    - C) Lots of hydrogen & helium gas
    - D) Many moons
    - E) Differential rotation
      * Explanation: All of the Jovian planets have dense, compact cores more massive than Earth, surrounded by liquid gaseous layers
  + What is the probable source of the variations in Jupiter’s belt and zones?
    - A) Convection of ammonia ice upward
    - **B) Differential rotation and underlying zonal flow**
    - C) Oblateness due to low density
    - D) Thermonuclear fusion
    - E) Jupiter’s huge magnetosphere
  + What is the source of Jupiter’s large magnetic field?
    - A) Charged particles moving in the atmosphere
    - B) Thermonuclear fusion in Jupiter’s core
    - C) The gravitational attraction of Jupiter’s many large moons
    - D) The Great Red Spot
    - **E) Metallic hydrogen swirling in its interior**
  + Saturn radiates even more excess energy than Jupiter because
    - A) Saturn is still radiating heat left over from its formation
    - B) Saturn’s thick cloud layer contributes to a larger greenhouse effect
    - **C) Helium rain gives off heat as it falls toward Saturn’s center**
    - D) Saturn’s atmosphere contains methane
    - E) Saturn can fuse hydrogen into helium in its core, like the Sun
  + The magnetic fields of which two planets are most unusual?
    - A) Jupiter and Neptune
    - B) Jupiter and Saturn
    - C) Jupiter and Earth
    - D) Saturn and Earth
    - **E) Uranus and Neptune**
      * Explanation: Both Uranus and Neptune have fields that are off-centre, and inclined to their rotation axes

Chapter 8: The Moon

* Overview
  + The Galilean moons of Jupiter
  + The large moons of Saturn and Neptune
  + The medium-sized Jovian moons
  + Planetary Rings
  + Pluto
  + Plutoids and the Kuiper belt
* Large moons in the solar system
  + All four Jovian planets have extensive moon systems, and more are continually being discovered
  + The Galilean moons of Jupiter are those observed by Galileo, Europa, Ganymede, and Callisto
  + As you go outward in the solar system, the density of moons starts to decrease due to the formation of the moons and the nebular theory
* The Galilean moons of Jupiter
  + Moons are quite close to Jupiter
    - i.e. IO in particular
  + As you go further from Jupiter, the moons get more icy
  + IO
    - Densest of Jupiter’s moons, and the most geologically active object in the solar system
      * Many active volcanoes, some quite large
      * Can change surface features in a few weeks
      * No impact craters; they full in too fast – IO has the youngest surface of any…
    - Volcanism on IO
      * IO is very close to Jupiter in a not quite tidally-locked, slightly elliptical orbit (due to gravitational influence of Europa). The tidal forces are huge, and provide the energy for the volcanoes
        + Europa stops IO from getting into a circular orbit
  + Europa
    - No craters; surface is water ice, possibly with liquid water below
    - Tidal forces stress and crack ice; water flows, keeping surface relatively flat
    - Not as close to Jupiter as IO is but still subject to tidal forces
  + Ganymede
    - Largest moon in the solar system – large than Pluto and Mercury
    - Parallels with Earth’s Moon, but with water ice instead of lunar rock
    - Old and young surface distinguished by cratering
  + Callisto
    - Similar to Ganymede; no evidence of tectonic activity; heavily cratered.
    - Many detailed oddities
      * i.e. Ganymede has a magnetic field, Callisto does not
* The moons of Saturn: Titan
  + Thick atmosphere makes surface impossible to see
    - Icy volcano? Few craters; active surfaces
      * Very hard to map out surface due to atmosphere
  + Titan’s atmosphere
    - Thick atmosphere primarily Nitrogen & Argon
    - Trace chemicals in Titan’s atmosphere makes it chemically complex
    - Photochemical “smog”
* Neptune’s Moon: Triton
  + Is in retrograde orbit; its surface has few craters, indicating an active surface
    - Is spiralling in towards Neptune
    - Probably captured from Kuiper belt
  + Nitrogen geysers have been observed on Triton, likely contributing to the thin atmosphere
  + Believed that Triton formed after the other Galilean moons due to its retrograde motion
* Medium sized Jovian moons
  + Have similar surface imperfections
    - i.e. Craters
* iClicker
  + As the…
  + What is thought to cause IO’s volcanism?
* Planetary rings
  + The ring system of Saturn is large and complex, and easily seen from Earth
  + The other Jovian planets have ring systems as well
  + The rings are not solid, they are composed of small rocky and icy particles
    - The bright rings are thought to be water-ized
* The Roche Limit
  + Where the tidal forces of the planet are too strong for a moon to survive; this is where rings are formed
    - Moons near the Roche limit can get seriously distorted by tidal action and those inside the limit can be completely destroyed
  + All observed ring systems for the Jovian planets are within the Roche limit
    - Roche limit is affected by density, composition, etc.
* Planetary Rings
  + Voyager proves showed Saturn’s rings to be much more complex than originally thought
  + Gravitational interactions with small moons important: resonances; shepherding
* Pluto
  + Pluto was discovered in 1930
    - Discovery was pure luck
  + Thought to be needed to explain irregularities in the orbits of Uranus and Neptune, but it turned out that there were no such irregularities and its gravity was far too small
    - Surprisingly dynamic surface – atmosphere interaction
  + Pluto’s moon: Charon
    - Discovered in 1978
    - It is about 1/8 mass of Pluto
    - Pluto and Charon are tidally locked to each other
  + Pluto has two smaller moons: Nix and Hydra
    - Discovered in 2005
* Plutoids and the Kuiper Belt
  + The first Kuiper belt objects were observed in the 1990s, and more than 1200 are now known. Some of them are comparable in size to Pluto
  + About 25% of Kuiper Belt objects, like Pluto, have orbital periods exactly 1.5 times that of Neptune
* iClicker
  + .
  + Why are the rings of Saturn so bright?
  + .
  + Which moon…

Chapter 9: The Sun

* Overview
  + The Sun in bulk
  + Interior
  + .
  + .
  + .
* The Sun in bulk
  + Some solar properties
    - Radius
      * Average sized star
    - Mass
    - Average density
      * Sun is made up gas, not rocks
    - Rotation period
    - Surface temperature
    - Luminosity
* Sun’s luminosity
  + Luminosity: Total energy radiation by the sun can be calculated from the fraction of that energy that reaches the earth
    - Total luminosity: 4 x 1026 W
      * ≈ 10 billion 1-megaton nuclear bombs per second
* The solar interior
  + Mathematical models, consistent with observation and known physics, provide information about the Sun’s interior
    - In hydrostatic equilibrium, inward gravitational force is balanced by outward pressure
* Helioseismology
  + Doppler shifts of solar spectral lines indicate a complex pattern of vibrations, allow us to determine interior structure
* The solar interior
  + Solar density and temperature, according to the standard solar model
  + Nuclear fusion in core
  + Outer layers
    - Core 🡪 Radiation zone 🡪 Convection zone 🡪 Photosphere 🡪 Chromosphere 🡪 Transition zone
* Energy transport
  + The radiation zone is relatively transparent; the cooler convection zone is opaque
  + The visible top layer of the convection zone is granulated,
* iClicker
  + The Sun is stable as a star because
    - A) Gravity balances forces from pressure
    - B) The rate of fusion equals the rate of fission
    - C) Radiation and convection balance
    - D) Mass is converted into energy
    - E) Fusion doesn’t depend on temperature
      * Explanation: The principle of hydrostatic equilibrium explains how stars maintain their stability
  + .
  + .
  + .
* The solar atmosphere
  + Spectral analysis can tell us what elements are present in the chromosphere and photosphere, their state of excitation and the temperature
    - Also indicates the density, pressure, etc.
      * Doesn’t tell you anything directly about the interior of the sun
  + The cooler chromosphere is above the photosphere
  + Difficult to see directly, as photosphere is too bright unless Moon covers photosphere and not chromosphere during eclipse
  + Small solar storms in chromosphere emit spicules of gas at ≈ 100km/s
* Solar corona & Solar wind
  + Solar corona can be seen during eclipse if both photosphere and chromosphere are blocked
  + Emission spectrum of highly ionized elements
  + Very hot and low density; drives solar wind at ≈ 500km/s
  + Carries off ≈ 109 kg/s
* The solar atmosphere
  + Corona is much hotter than layers below it
    - Must have a heat source, probably electromagnetic interactions
  + Temperature of the sun increases as the distance from photosphere increases
* Historical variations in sunspot…
  + Maunder minimum: Few, if any sunspots. Very cold winters rec…
* Solar magnetism
  + Sunspots dynamic: come and go, typically in a few days
  + Sunspots are linked by magnetic field lines
  + The rotation of the sun drags magnetic field lines around with it, causing kinks
* The active sun
  + Areas around sunspots are active; larger eruptions – prominences – may occur in photosphere
    - Last days or weeks
  + Interfere with electrical communications and disrupt technology
  + Solar flare is a large…
* Coronal mass ejection
  + Large ejection of magnetically – threaded charged particles. Can reconnect with Earth’s magnetic field and affect communications and power systems
    - Knocked out the hydro infrastructure for a couple of days
      * Important to monitor the activity of the sun
* Nuclear fusion
  + Nuclear fusion requires that like-charged nuclei get close enough to each other to fuse
  + This can happen only if the temperature is extremely high – over 10 million K
  + In the center of the sun, the energy comes from the fusion of protons
    - Fusion of hydrogen into Helium
  + The process that powers most stars is a three-step process
    - Protons form Deuterons
      * And positron
  + Mass of protons: 6.6943 x 10-27
  + Mass of 4He nucleus: 6.6466 x 10-27
    - Mass deficit (binding energy) is about 0.7%, and is released as E=mc2
* Neutrinos
  + Emitted directly from the core of the sun. Takes a million years to escape
    - Need a massive detector on earth that is deep within to observe these Neutrinos
  + Have to have mass
* iClicker
  + .
  + .
  + .
  + .
  + .

Chapter 10: Measuring The Stars

* Overview
  + The solar neighbourhood
  + Luminosity and apparent brightness
  + Stellar temperatures
  + Stellar sizes
  + The Hertzsprung-Russell Diagram
  + Extending the cosmic distance scale
  + Stellar masses
* Measuring the solar neighbourhood
  + Find the distance to nearby stars using parallax
  + Distance (in parsecs) = 1/parallax (arc seconds)
    - 1pc ≈ 3.26 lyr
  + Proxima centauri has a parallax angle of just less than an arc second
  + Nearest star to the sun: Proxima Centauri, 1.3pc, which is a member of a 3 – star system: Alpha Centauri complex
    - If:
      * Sun were a marble
      * Proxima Centauri would be another (smaller) marble 270 km away
      * Solar system (out to Pluto) would extend about 50m from the Sun; rest of the distance to nearest star is basically empty
* Stellar motion
  + Doppler effect can measure radial motion
* Luminosity and Apparent Brightness
  + Luminosity, or absolute brightness, is a measure of the total power radiated by a star
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  + Two stars that appear equally bright might actually be a closer, dimmer star and a farther, brighter one
    - Knowing the distance to a star allows us to determine the true (absolute) luminosity
* Absolute and Apparent Magnitude
  + Greeks denoted brightest stars as being of 1st magnitude; faintest naked-eye star of 6th magnitude (about a factor of 100 in brightness)
  + Define the absolute magnitude, M, to be the brightness this star would have this scale if viewed from a distance of 10pc
  + Apparent magnitude, m, is then related to distance, d, by:
    - m – M = 5log10 = (d/10pc)
      * Called distance Modulus
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* Stellar temperatures
  + The radiation from stars close to blackbody; observations at two wavelengths are enough to define an approximate temperature
  + Spectra are much more informative than blackbody curves
  + There are seven general categories of stellar spectra, corresponding to different temperatures
  + From highest to lowest, the categories are:
    - O B A F G K M
      * 10 subdivisions; 0 (hottest) to 9 (coolest)
* Stellar sizes
  + A few very large, very close stars can be imaged directly
    - i.e. Betelgeuse
  + For the vast majority, size must be calculated knowing the luminosity and temperature using Stefan’s law
    - L = 4(pi)R2(sigma)T4
  + Dwarfs:
  + Giants:
  + Supergiants:
* The Hertzsprung-Russell Diagram
  + The H – R diagram plots stellar luminosity against surface temperature
    - High temperatures on the left and low on the right
      * Backwards
    - Luminosity is relative to our sun
  + Plotting many stars forms a pattern
    - i.e. 80 closest stars to us (to earth)
      * A dark curve is formed called the main sequence
        + This is where majority of the stars lie
      * Also indicated is the dwarf region
  + About 90% of stars lie on the main sequence; 9 percent are red giants, and 1% are white dwarfs
* Luminosity classes
  + Not all stars of a given spectral type are on the main sequence. Can use the width of spectral lines to define luminosity
* Spectroscopic Parallax
  + Has NOTHING to do with parallax
    - Uses spectroscopy to find the distance to a star
      * Can be used at much greater distance than parallax
        + 10,000 pc while parallax struggles with 200 pc
    - 1. Measure the Star’s apparent magnitude and spectral & luminosity class
    - 2. Use spectral & luminosity classes to estimate luminosity
    - 3. Apply inverse-square law (distance modulus) to find distance
* Stellar masses
  + Many stars are in binary systems; measurement of their orbital motion allows determination of the masses of the stars
    - Visual binaries
    - Spectroscopic binaries
    - Eclipsing binaries
  + Kepler III 🡪 M1 = M2
  + Relative size of orbits 🡪 M1 / M2
* Stellar mass and the HR diagram
  + Find that mass is the main determinant of a star’s place on the main sequence
    - Luminosity is…
* Stellar mass – Luminosity relation
  + L inversely proportional to M4
    - Lifetime
  + The life time of the sun is 10 billion years; the lifetime of a 10 solar mass, O-type star will be about 10 million years. Thus any O-type stars we see will be young
* Stellar mass distribution
  + < 0.25 solar masses

Chapter 11:

* Overview
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* Interstellar matter
  + The interstellar medium consists of gas and dust
  + Gas is atoms and small molecules, mostly hydrogen and helium
  + Dust is more like soot or smoke; larger clumps of particles.
  + Dust absorbs light, and reddens light that gets through
* Reddening
  + Dust clouds absorb/scatter blue light preferentially; spectral lines do not shift
* Star-forming region
  + Section of the milky way galaxy towards the centre (Sagittarius), showing several nebulae, areas of star formation
  + These nebulae are very large and have very low density; their size means that their masses are large despite the low density
  + Nebula is a term used for fuzzy objects in the sky
  + Dark nebula: Dust cloud
  + Emission nebula: Glow, due to hot stars; generally, glow red – this is the Halpa line
  + The dust lanes visible in the image are part of the nebular, and are not due to intervening clouds
* Why nebulae look as they do?
  + Visible starlight going through a dusty cloud becomes un-scattered red light, and scattered blue light
* Star-forming regions
  + There is a strong interaction between the nebula and its stars; the fuzzy areas near the pillars are due to photo-evaporation
    - Symbiotic relationship between star forming regions and the gas clouds
      * Once a star is formed it blows the gas away
  + Emission nebulae are made of hot, thin gas, which exhibit distinct emission lines
* Dark dust cloud
  + Average temperature of dark dust clouds is a few tens of Kelvin
  + These clods absorb visible light (left; obscure background stars), and emit radio wavelengths (middle)
  + Atomic hydrogen has a 21cm radio emission
    - Its radio waves pass unaffected through clouds of interstellar dust
  + Horsehead nebula is a particularly distinctive dark dust cloud
* Molecular gas
  + Cold, dense, 10 – 20K, 1012 particles/m3, molecular clouds. Only radio wavelengths can escape
  + Composed primarily of H2 – but does not emit in radio
  + Observe other molecules including CO, H2CO, HCN, NH2, and H2O
* Formation of stars – Jeans’ instability
  + Clouds are generally believed to be balanced against their self gravity by interval pressure forces (gas, pressure, turbulence, magnetic fields)
  + Gravity is very weak but if a large enough region is compressed – perhaps by a pressure wave or shock from a nearby star – the self gravity will rise faster than the opposing forces even as the compression heats the interior
  + Cloud becomes unstable, collapses and fragments until, eventually, thermonuclear reactions tart in dense protostellar cores which provide pressure to restore a new equilibrium
  + Stable, main sequence, stars are formed
* The formation of stars like the sun
  + CHART
    - Stage 1: Interstellar cloud starts to contract, probably triggered by shock or pressure wave from nearby star. As it contracts…
    - Stage 2: Individual cloud fragments begin to collapse. Once the density is high enough, there is no further fragmentation
    - Stage 3: The interior of the fragment has begun heating and is about 10,000K (becomes opaque to its own radiation)
      * The Orion nebula…
    - Stage 4: The core of the cloud is now a protostar and makes it first appearance on the HR diagram
  + Collapse leads to a rapidly spinning protostar and disc. Planetary formation has begun. Protostar is still not in equilibrium – all heating comes from the gravitational compression/collapse
  + Stage 5: The last stages can be followed on the HR diagram. The protostar’s luminosity decreases even as its temperature rises because it is becoming more compact
  + Stage 6: The core reaches 10 million K, and nuclear fusion begins. The protostar has become a star
  + Stage 7: The star continues to contract and increase in temperature, until it is in equilibrium. The star has reached…
  + Young stars when newly formed, have a jet around them in the polar direction. This is due to young stars having a strong magnetic field. These jets are being emitted as material…
* Stars of other masses
  + This HR diagram shows the evolution of stars somewhat more and somewhat less massive than the Sun. The shape of the paths is similar, but they wind up in different places on the main sequence
  + If the mass of the original nebular fragment is too small (<0.08 solar masses), nuclear fusion will never begin. These failed stars are called brown dwarfs
* Star clusters
  + Because a single interstellar cloud can produce many stars of the same age and composition, star clusters are an excellent way to study the effect of mass on stellar evolution
  + Stars formed at the same time have similar ages
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Chapter 12: Stellar Evolution

* Overview
  + Leaving the main sequence
  + Evolution of a sun-like star
  + The endpoint of a low mass star
  + Evolution of stars more massive than the sun
  + Supernova explosions
  + Observing stellar evolutions in star clusters
  + The cycle of stellar evolution
* Leaving the main sequence
  + On the main sequence stars are in hydrostatic equilibrium
  + Eventually, as hydrogen in the core is consumed, the star begins to leave the main sequence
  + Its evolution from then on depends critically on the mass of the star
  + Various different equilibria are reached
  + Stars typically have their inward gravity and outward pressure balanced
* Evolution of a sun-like star
  + Even while on the main sequence, the composition of a star’s core is changing
  + Star is mostly hydrogen, and then helium
    - Core fuses hydrogen into helium
      * Process continues until no more hydrogen is available
  + As the fuel in the core is consumed, the core contracts; when it is used up the core begins to collapse
    - Hydrogen beings to fuse outside the core
* Stages 8 & 9 subgiant, redgiant
  + As thee core continues to shrink, H shell burning intensifies, the outer layer of the star expands and cool.
  + It is now a red giant extending out as far as the orbit of mercury
  + Despite its cooler temperature, its luminosity increases enormously due to its large size
    - Luminosity is dependant on radius and temperature
* Stage 10: Helium fusion
  + Once the core temperature has risen to 100 million Kelvin, the helium in the core starts to fuse
  + In a star like the sun, this happens very quickly
    - This is referred to as the helium flash
      * Helium begins to fuse extremely rapidly; within hours the enormous energy output is over, and the star once again reaches equilibrium
* Stage 11: Back to the giant branch
  + As the helium in the core fuses to carbon and oxygen, the core becomes hotter and hotter, and the helium burns faster and faster
  + Similar to the condition just as the star left the main sequence, except now there are two shells
* Stage 12: Planetary nebula
  + There is no more outward fusion pressure from the C core which continues to contract
    - H, He, shell burning continue causing outer layers of star to drift away. Results in a very hot and dense carbon core surrounded by a “planetary nebula” (can be 1pc across)
* Degenerate matter
  + In a low mass star, the core never gets hot enough to fuse C
  + Instead of thermal pressure balancing gravity, balance is provided by a quantum mechanical effect – electron degeneracy pressure
  + Arises when electrons become very closely packed (Heisenberg uncertainty principle)
  + Very “stiff” state of matter
  + Core temp. stabilizes at about 300 million Kelvin; density ≈ 109 kg/m3; ½ solar masses (dwarf about the size of earth)
* Stage 13 & 14: White & black dwarf
  + Once the nebula has gone, the remaining core is extremely dense and extremely hot, but quite small
  + It is luminous only due to its high temperature
  + Slowly cools at constant size
* White dwarfs
  + The small star Sirius B is a white dwarf, companion of the much larger Sirius A
  + The Hubble…
* Novae
  + A nova is a star that flares up very suddenly and then returns slowly to its former luminosity
    - Can happen repeatedly
  + A white dwarf that is a part of a close binary system can undergo repeated novae as it captures material from a companion that overflows its Roche lobe
* Stars more massive than the sun
  + Stars more massive than the sun follow very different paths when leaving the main sequence
* Evolution of stars more massive than the sun
  + All stars, leave the main sequence when there is no more hydrogen fuel in their cores. The first few events are similar to those in lower-mass stars – first a hydrogen shell, then a core burning helium to carbon, surrounded by helium – and hydrogen burning shells
* Formation of the elements
  + Before nuclear fusion in stars, the universe contained only H, He and small amounts of Li (& Be)
  + Elements up to Iron (Fe) are synthesized in the cores of massive stars
  + Heavier elements are made primarily by neutron capture in supernovae
    - Supernovas create new elements by bombarding Fe with neutrons
* Supernova explosions
  + A supernova is incredibly luminous – more than a million times as bright as a nova. Can outshine host galaxy for a period of a couple days
    - Type I: White dwarf accumulates mass – more mass than it can sustain
      * Highest mass = 1.4 million solar masses
        + Chandrasekhar limit
    - Type II: Death of a high-mass star
      * i.e. Core-collapse supernova
* Supernova remnants
  + Supernova leave remnants – the expanding clouds of materials from the explosion
    - The crab nebula is a remnant from a supernova explosion that occurred in the year 1054 (visible during the day for nearly a month)
* Observing stellar evolution in star clusters
  + The HR diagram shows how stars of the same age, but different masses, appear as the cluster as a whole ages
  + After 10 million years, the most
  + High mass stars evolve quicker than low mass stars
  + This globular cluster, M80, is about 10 – 12 billion years old, much older than the previous examples
* The cycle of stellar evolution
  + Star formation is cyclical: stars form, evolve, and die
  + In dying, they send heavy elements into the interstellar medium
  + These elements then become parts of new stars (planets, us…)
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Chapter 13: Neutron Stars & Black Holes

* Overview
  + Neutron stars
  + Pulsars
  + Neutron star binaries
  + Gamma-ray bursts
  + Observational evidence for black holes
  + Einstein’s theory of relativity
  + Space travel near black holes
* Neutron stars
  + At the end of its life, a massive star, > 10 solar masses, explodes as a supernova leaving a neutron degenerate core
    - 1 – 3 solar masses
    - 10 km diameter
    - Rapid rotator P<1s
    - Strong magnetic field
* Pulsar
  + The first pulsar was discovered in 1967. It emitted extraordinarily regular radio pulses; nothing like it had ever been seen before
* Black holes
  + Schwarzschild radius
    - 2GM/c2
      * ≈ 1cm for an Earth mass
      * 3km for a solar mass
* Observational evidence for black holes
  + Cygnus X-1 is a very strong black hole candidate
  + Its visible partner is about 25 solar masses
  + The system’s total mass is about 35 solar masses, so the X-ray source must be 10 solar masses > NS limit
  + Hot gas spears to be flowing from the visible star in an unseen companion
  + Short-time scale variations indicate that the source must be very small
  + There are several other black hole candidates in binary systems with characteristics similar to Cygnus X-1
  + The centers of many galaxies are believed to contain supermassive black holes – 1 million to 1 billion solar masses. Inferred from stars and gas orbiting a compact but massive, unseen object
  + Recently, evidence for intermediate-mass black holes have been found; these are about 100 to 1000 solar masses. Their origin is not well understood
* Special Relativity
  + Einstein’s response to the – failed – Michelson-Morley experiment which tried to detect the ether
    - 1. The speed of light is the maximum possible speed, and it is always measured to have the same value by all observers
    - 2. Principle of Relativity: There is no absolute frame of reference, and no absolute state of rest
      * (Space and time are not independent, but are unified as space-time)
      * There is no object in the universe that is at rest
    - Concluded that the ether does not exist because light does not need a medium to transport it
  + No absolute space. Observers in relative motion observe space and time differently
    - i.e. Idea of simultaneity no longer holds
* Time Dilation
  + One tick of the clock according to A is a photon travelling vertically from floor to ceiling in time, t
  + According to B, this takes time t’ and photon travels at an angle due to train speed, v
* General Relativity
  + Special relativity (1905) rewrote mechanics but could not incorporate gravity. This was rectified in 1915 by Einstein’s theory of general relativity
  + Principle of Equivalence
    - It is impossible to tell, from within a closed system, the difference between inertial and gravitational forces
    - Force from a massive object = acceleration
    - Weightlessness in deep space = free fall under gravity
  + Matter warps space-time, and in doing so redefines straight lines (the path a light beam would take)
  + Energy also contributes to gravity
  + Speed of light is constant and finite
* Tests of General Relativity
  + 1. Bending of starlight
  + 2. Advance of the perihelion of Mercury
  + 3. Gravitational redshift
  + 4. Gravitational wave
* Falling into a black hole
  + The gravitational effects of a black hole are unnoticeable beyond a few Schwarzschild radii – black holes do not “suck in” material any more than an extended mass would
  + To a distant observer:
    - Spacecraft accelerates toward event horizon
    - As it gets closer it appears to slow and redden
  + At horizon, time dilation becomes infinite and the spacecraft appears to freeze whilst rapidly fading from view
  + Free falling observer, if small enough, could pass through event horizon with no trouble and without realising
    - In reality you would get ripped apart by the tidal forces
* Black holes
  + Is there really a singularity at the centre of a black hole?
    - No one knows, of course; present theory predicts that the mass collapses until its radius is zero and its density infinite; this is unlikely to be what actually happens
  + Need a theory of quantum gravity
    - Does not consist and/or is inconsistent
    - Best alternative is string theory
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Chapter 14: The Milky Way Galaxy

* Overview
  + Our galaxy
  + Measuring the milky way
  + Galactic structure
  + Formation of the milky way
  + Galactic spiral arms
  + The mass of the milky way
  + The galactic center
* Our galaxy
  + From earth, we see few stars when looking out of galaxy, many looking in milky way is how our galaxy appears in the night sky
  + Our galaxy is a spiral galaxy
* Measuring the milky way
  + One of the first attempts to map and measure the milky way was done by Herschel using visible stars
    - Unfortunately, he was not aware that most…
  + Variable stars
    - Cataclysmic variables: Novae, supernovae, and related phenomena
    - Intrinsic variables: Stars whose luminosity varies in a regular way. Two classes: RR Lyrae stars and Cepheids
    - The variability of the stars comes from a dynamic balance between gravity and pressure – they have large oscillations around stability
  + The upper plot is for an RR Lyrae star. All such stars have essentially the same luminosity curve, with periods from 0.5 to 1
  + The lower plot is a Cepheid variable; Cepheid period ranges from 1 to 100 days
  + The utility of these stars comes from their period – luminosity relationship
    - This allows us to measure the distances to the stars
    - Longer the period, the brighter the star
  + Many RR Lyrae stars around in globular clusters. These clusters are not all in the plane of the galaxy, so they are not obscured by dust and can be measured
  + This yields a much more accurate picture of the extent of our galaxy and our place within it
* Structure of the milky way
  + This artist’s conception shows the various parts of our galaxy, and the position of our sun
  + Globular clusters are the oldest objects in the universe
* Galactic structure
  + The galactic halo and globular clusters formed very early; the halo is essentially spherical. All the stars in the halo are very old, and there is no gas or dust
  + Infrared is not as much absorbed by gas and dust as visible light
  + Stellar orbits in the disk are in a plane and in the same direction; orbits in the halo and bulge are much more random
* Formation of the milky way
  + Any theory of galaxy formation should be able to account for the properties of the different components
  + The formation of the galaxy is believed to involve the merging of sub-clumps with rotation playing an important role
    - Still an active area of investigation
* Galactic spiral arms
  + Measurement of the position and motion of gas clouds shows that the Milky Way has a (barred) spiral structure
  + The spiral arms cannot rotate along with the galaxy; they would “curl up”
* Looking for MACHOs – Micro Lensing
  + The bending of spacetime can allow a large mass to act as a gravitational lens
  + Observation of such events suggests that low-mass white dwarfs could account for about half of the dark matter needed
    - Rest is still unknown
* The galactic center
  + The view toward the galactic center, in visible light
  + The two arrows in the IR inset indicate the location of the center

Chapter 15: Normal & Active Galaxies

* Overview
  + Hubble’s law
* Hubble’s galaxy classification
* Measuring the distribution of galaxies
  + Need “standard candles”
  + Cepheid variables allow measurement of galaxies up to 25 Mpc away
  + However, most galaxies are farther away than 25 Mpc away
    - New distance measures are needed
  + Tully-Fisher relation correlates a galaxy’s rotation speed to its luminosity
  + Type I supernovae
  + Blue shifted lines move to higher frequencies, and red shift goes to lower
* Extending the distance scale
  + Tulley-Fisher allows us to extend the cosmic ladder to about 1 Gpc
    - 1 Gpc = A billion parsecs
* The local group of galaxies
  + Galaxies can be gravitationally bound together
* Galaxy clusters
  + Most (>50%) galaxies reside in groups or clusters
    - Clusters are about 3 – 5 entities
  + Virgo cluster contains about 3500 galaxies
* Hubble’s law
  + All galaxies (with a few nearby exceptions) seem to be moving away from us, with the redshift of their motion correlated with their distance
    - Conclusion is that the universe is expanding
  + There is a linear relationship between distance and recession velocity
    - Recession velocity = H0 x distance
    - Hubble’s constant, H0 = 70km/s/Mpc
      * For each Mpc you go out, the galaxy recedes by 70km/s
        + 2Mpc = 140km/s
        + 3Mpc = 210km/s
* Active galaxies
  + About 20 – 25 percent of galaxies don’t fit the Hubble scheme – they are far too luminous and have a peculiar course
    - These galaxies emit a different radiation from normal galaxies
  + You can distinguish an active galaxy from a normal galaxy using black body curve
  + Classified into three types: Seyfert, radio, and quasars
    - Seyfert: Resemble normal spiral galaxies but have a core that is thousands of times more luminous
      * Also have rapid variations in the luminosity, indicating that the core is compacted
    - Radio: Emit very strongly in the radio portion of the spectrum.
      * May have enormous lobes, invisible to optical telescopes
      * Very dusty galaxy
      * May also be core dominated
    - Core-dominated and radio-lobe galaxies are probably the same phenomenon viewed from different angles
    - Many active galaxies have jets and most show signs of interactions with other galaxies
      * These jets extend right down to a central source
    - Quasars: OR QSOs – quasi-stellar objects – are star like in appearance, but have very unusual spectral lines
      * Eventually realized that quasar spectra were normal, but enormously red shifted, z ≈ 0.16
        + 16% the speed of light; high velocity
    - Solving the spectral problem introduced a new problem – quasars must be among the most luminous objects in the universe, to be visible over such enormous distances
* The central engine of an active galaxy
  + AGN have some or all of the following properties
    - High luminosity
    - Non-stellar energy emission
    - Variable energy output, indicating small nucleus
    - Jets and other signs of explosive activity
    - Broad emission lines, indicating rapid rotation
    - Often involve galaxy interactions
* Model of AGN central engine
  + Black hole, surrounded by an accretion disk
  + The strong magnetic field lines around the black hole channel particles into jets perpendicular to the magnetic axis (≈109 Solar Masses black hole)
  + Accretion disk of gas and dust; may radiate 10 – 20% of mass
* Synchrotron radiation
  + Particles will emit synchrotron radiation as they spiral along the magnetic field lines; this radiation is non-thermal and can be strongly beamed
    - Charged particles emit radiation

Chapter 16: Galaxies & Dark Matter

* Overview
  + Dark matter in the universe
  + Galaxy collisions
  + Galaxy formation and evolution
  + Black holes in galaxies
  + The universe on a very large scales
* Dark matter in the universe
  + The milky way is a spiral galaxy with a well defined disk, and the centrifugal is stable
    - With this knowledge we can find the dark matter
  + Other spiral galaxies have rotation curves similar to ours, allowing measurement of their mass
  + Another way to measure the average mass of galaxies in a cluster is to calculate how much mass is required to keep the cluster gravitationally bound or the binary in orbit
    - Motions are just big enough to prevent the clusters collapsing inward
  + Galaxies need between 3 and 10 times more mass than can be observed to explain their rotation curves
  + The discrepancy is even larger in galaxy clusters, which need 10 to 100 times more mass
  + The total needed is more than the sum of the dark matter associated with each galaxy
  + There is evidence for intracluster superhot gas (about 10 million K) through clusters, densest in the center
    - Likely primordial + smattering of heavier elements
* Galaxy collisions
  + In a group or cluster, separation between galaxies is usually not large compared to the size of the galaxies themselves, and galactic collisions are frequent
    - The chance of galaxies hitting each other is very high
      * The antennae galaxies (the mice) collided fairly recently, sparking stellar formation
* Galaxy formation and evolution
  + Galaxies are believed to have formed from mergers of smaller, and more irregular galaxies and star clusters
  + Image (c) shows large star clusters found some 5000 Mpc away
  + Collisions were very common in the earlier, denser universe
  + Each of these starburst galaxies exhibits massive star formation in the wake of a galactic collision. The collision of two galaxies can be clearly seen
    - Galactic cannibalism
  + Interaction of two similar spirals 🡪 Destroy disc 🡪 Starburst 🡪 Eject remaining gas 🡪 Elliptical
* Quasars and AGN
  + Most quasars are found at high redshift (>10 Gyr ago) believed to be an early, active stage of galaxy formation when large amounts of gas can be fed to a massive black hole
  + Doppler shifts of emissions from the core of this galaxy show enormous speeds very close to a massive object – a black hole.
* Black holes in galaxies
  + Careful measurements show that the mass of the central black hole is correlated with the size of the bulge
  + Many large galaxies contain a central black hole
  + Bright QSOs consume around a thousand star masses a year
* Galactic evolution
  + This figure shows how galaxies may have evolved, from early irregulars through active galaxies, to the normal ecliptics and spirals we see today
  + It is unknown how a massive black hole starts in the center
* The universe on a very large scale
  + Galaxy clusters join in larger groupings, called super-clusters. This is a 3D map of the super-clusters nearest us; we are part of the Virgo cluster
  + Mapping out the universe has revealed that there is structure in the universe (walls and voids)
  + The decreasing density of galaxies at the farthest distances is due to the difficulty of observing them
  + Quasars are very distant, and the light coming to us from them has gone through many interesting regions.
* Gravitational lensing
  + Bending of light around a celestial
    - Einstein cross
* Mapping dark matter
  + Background sources are slightly distorted by foreground cluster
  + Dark matter is very noisy

Chapter 17: Cosmology

* Overview
  + The universe on the largest scales
  + The expanding universe
  + Cosmic dynamics and the geometry of space
  + Our universe
  + The early universe
  + Formation of nuclei atoms
  + Cosmic inflation
  + Formation of large-scale structure in the universe =
  + Fine tuning in the universe
* The universe on the largest scales
  + The largest known structure: the Sloan Great Wall. No structure larger than ≈300 Mpc is seen
  + The universe is homogenous on scales >≈ 300 Mpc and isotropic
    - Cosmological principle
  + The milky way doesn’t occupy some special space in the universe
* Olbers’ Paradox
  + If the universe is homogenous, isotropic, infinite, and unchanging, the entire sky should be as bright as the surface of the sun
    - In fact, it should be infinitely brighter
* The expanding universe
  + Thinking about the meaning of Hubble’s law:
    - Recession velocity = H0 x distance
  + In the past, galaxies were closer together; at some point in the past, at this rate of expansion, galaxies would all have been at the same place
    - This is the big bang
  + How long ago?
    - T = distance/velocity = 1/H0
    - For H0 = 70km/s/Mpc, T ≈ 14 Gyr
      * The universe is 14 billion years old
  + This doesn’t mean that the big bang happened at a particular place
* A 2-D expanding universe
  + Imagine a balloon with coins (galaxies) stuck to it. As we blow up the balloon, the coins all move farther and farther apart. There is, on the surface of the balloon, no “center” of expansion
* Cosmological redshift
  + The same balloon analogy can be used to explain the cosmological redshift. As the balloon gets bigger, so does the imaginary grid and waves.
  + The photons are red-shifted
* The expanding universe
  + Does the expansion rate change, and what is the ultimate fate of the universe?
    - A self consistent description requires general relativity but many aspects can be understood in Newtonian terms
  + If the only force determining the dynamics is gravity, there are two types of behaviour depending on the mean density of the universe
  + A low density universe will expand forever
  + A high density universe will collapse
* The geometry of space
  + Density determines gravity which determines both curvature of space and dynamics
  + 1. Critical density, pcrit: Flat (Euclidean) space; infinite; expands forever. Pcrit ≈ 9x10-27 kg/m3; n = 5 x 106 /cm3
  + 2. p < pcrit: open universe; negatively curved space; infinite; expands forever
  + 3. p > pcrit: closed universe; positively curbed space; finite; re-collapses
* Our universe
  + What kind of universe do we inhabit? Must measure the average density
  + Measurements of luminous matter suggest that the density is only a few percent of the critical density
  + But – we know there is a large amount of dark matter
  + Best estimates from clusters and gravitational lensing, however;
  + Can try to measure change of expansion rate directly by looking at recession of distant galaxies. Use type I supernovae as standard candles
  + If the expansion of the universe is decelerating, as it would if gravity were the only force acting, the farthest galaxies would have had a more rapid recession speed in the past, and would appear as though they
  + Gravity is not the only force acting
* Age of the universe
  + Universe cannot be younger than its contents
  + We can date the age of many globular clusters to 13 Gyc
* The early universe
  + The cosmic microwave background was discovered fortuitously in 1964, as two researchers tried to get rid of the last bit of “noise” in their microwave antenna
    - Instead they found that the “noise” came from all directions and at all times, and was always the same. They were detecting photons left over from the Big Bang
  + When these photons were created, it was only one second after the Big Bang, and they were highly energetic. The expansion of the universe has red-shifted their wavelengths so that now they are in the radio spectrum, with a blackbody curve corresponding to about 3K
  + Since then, the cosmic background spectrum has been measured with great accuracy. Precise blackbody: T = 2.73 K
  + The total energy of the universe consists of radiation and matter
  + As the universe cooled, it went from being radiation-dominated to being matter-dominated
  + Dark energy becomes more important as the universe expands
  + As the universe expands, the frequency goes down
  + Expansion of universe is starting to accelerate
* Primordial Nucleo-synthesis
  + At about 1 minute, the universe contained radiation and elementary particles including protons and neutrons
  + For a few minutes, conditions were favorable to form He
  + Most deuterium fused into helium as soon as it was formed, but some did not
  + Deuterium is not formed in stars, so any deuterium we see today must be primordial
  + Amount formed is sensitive to density of ordinary matter during nucleosynthesis. Only consistent with universe containing ~4% ordinary matter…
* Recombination
  + The time during which nuclei and electrons combined to form atoms is referred to as the decoupling or recombination epoch. This is where the cosmic background radiation we observe originated
  + You can’t see the early universe because the atoms are ionized
    - Due to it being very hot. Atoms are scattered
* Problems with the standard model
  + The horizon problem: Cosmic background radiation appears the same in diametrically opposite directions from Earth, even though there hasn’t been enough time since the Big Bang for these regions to be in thermal contact
* The flatness problem
  + In order for the universe to have survived this long, its density in the early stages must have differed from that producing a flat universe by no more than 1 part in 1015. How was this fine tuning achieved?
* Cosmic inflation
  + Between 10-35 s and 10-32 s after the Big Bang, some parts of the universe may have found themselves in an extreme period of inflation, as shown on the graph. Between 10-35 s and 10-32 s, the size of this part of…
  + Inflation solves both the horizon and the flatness problems
  + Similarly, horizon problem: entire presently observable universe originated from a very small part of casually-connected space that inflated
* Formation of structure in the universe
  + Structure grew from small in-homogeneities in matter distribution which grew under self gravity
  + Before decoupling, background radiation kept clumps from forming in baryons
  + Variations in the density of matter before decoupling lead to small variations in the cosmic microwave background
* CMB Anisotropies
  + Measurement of the scale of fluctuations provides an independent measure of cosmological parameters
  + Micro-kelvin is 10-6
* Formation of large-scale structures
  + Stimulating the growth of fluctuations with the characteristic spectrum of the CMB leads to the kind of large-scale structure now observed in the universe
* Fine tuning in the universe
  + A small number of fundamental constants/numbers turn out to be highly “tuned” to allow life to exist. Why/how?
    - 1. Ratio of electromagnetic force to gravity 1036
      * Gravity stronger 🡪 Earlier, denser structure; insect-size organism
    - 2. Fine structure constant ≈ 0.007
      * < 0.006 deuterium unstable; 0.008 protons can fuse
      * Cannot be to big, and cannot be to small
        + Must be 0.007
    - 3. Mean density of the universe ≈ 0.3 critical
      * Smaller; expands before structure forms
      * Larger; universe recollaspes
    - 4. Cosmological constant ≈ 0.7
      * Larger 🡪 universe accelerates before structure forms
    - 5. Fluctuation
    - 6. Number of spatial dimensions = 3
      * If it is less than 3 than you have no stable orbits; And if it’s more than 3, than you have no networks. Also knots, string theory
  + Is it just a coincidence that our universe has the properties to support life?
    - Creator?
    - Multiverse?
    - Many possibilities, each universe has its own set of constants – we live in one which can support the development of life
* Cosmological Redshift
  + The same balloon analogy can be used to explain the cosmological redshift

Chapter 18: Life In The Universe

* Overview
  + Cosmic evolution
  + Life in the solar system
  + Intelligent life in the galaxy
  + The search for extra terrestrial intelligence
* What is life?
  + Difficult to define but there are some generally agreed-upon characteristics that any life-form should have:
    - Ability to react to environment
    - Ability to grow by taking in nourishment and processing it into energy
    - Ability to reproduce, with offspring having characteristics of parent
    - Ability to evolve
* Cosmic evolution
  + The history of the universe is one of increasing complexity marked by several stages leading eventually to intelligent life
  + Stars are critical for life to survive and thrive
    - i.e. Our sun creates heat, provides energy, light, etc.
  + Must live around the star, in a sustainable zone
  + Chemistry of the habitable planet is specific
  + We have very little information about the first billion years of Earth’s existence; Earth was simply to active at that time
  + It is believed that there were many volcanoes and an atmosphere of hydrogen, nitrogen, and carbon compounds
  + As earth cooled, methane, ammonia, carbon dioxide, and water formed
  + Earth was subject to volcanoes, lightning, radioactivity, ultraviolet radiation, and asteroid impacts
    - Radioactivity is important because it allows mutations and evolution
* Miller-Urey 1953
  + Over ~Gyr, amino acids and nucleotide bases, the basis of DNA formed. The process by which this happens has been recreated in the laboratory
* Evolution of Cell-like objects
  + (l) Protein-like droplets created from clusters of billions of amino acid molecules. These droplets can grow, and can spilt into smaller droplets
  + (r) Fossilized remains of single-celled…
  + …

18 questions

2 hours

If you write too much, you will get marks deducted

Write only what is required

Homework questions are good practice

Thinking questions

Why is solar day longer than sidereal day?

The dagger means learn that shit real good

Difference between sidereal and synodic months

Kepler’s laws

Doppler shift

Exoplanets – discovery techniques and limitations

Why are stars stable? What is imbalance? Know Equilibrium

Know where parsec comes from, draw a diagram

Be able to draw an HR diagram with axis and groupings of stars

How do stars evolve and move thru the HR diagram?

Why do we end up with different end points like black holes

What is degeneracy pressure?

Special relativity: Know the larence contraction and time dilation and simultaneity

Main components of the Milky Way

Evidence for dark matter in galaxy and clusters

Hubble’s law: Very important. Know what is Mpc. Relate recessional velocity to distance

of velocity. It tells us that universe is expanding

Active galaxies: Know characteristics and classification

Gravitational lensing: Multiple image quasers!

Olber’s paradox!!!

Redshift!!! Be careful when you think about redshift. Relationship between velocity and

redshift. Forget about V/C for redshift b/c nothing is faster than light.

Fate of universe and what’s gonna happen?

Practical limitations of searches for life. It makes no sense to search for life in other

galaxies. Concerned with the strength of communication and speed of light. i.e.

Andromeda is far far away and communication would take 6 million years

Atmospheric windows

Crater history

Discovery of Neptune/Uranus

Distance modulus

Know proper motion

How do we find the masses of stars?

With massive stars you can burn heavier elements up to Fe

Know what happens at the end of a star

What are pulsars?

Evidence for black holes?

Different colors of nebulae

Stars are formed from interstellar medium

Understand principle of equivalence and curvature of space time

How to test for general relativity

Measure the mass of milky way

Hubble’s tuning fork diagram

Tulley-Fisher relation and rotation curve

Spiral galaxies collide to form elliptical

Know cosmological principle

Age of universe and how it all fits together

Problem of horizon and flatness problems

Idea of multiverse

Search for extraterrestrial intelligence

Stages of life and how life is formed

Drake equation and its implications. There is a probability of life present in the galaxies. These other civilizations are more advanced than us. It is better to listen than speak…

Know Kepler’s laws: His third law is mathematical

Know when to apply kepler’s laws and in which form. i.e. Only works for planets orbiting sun, and not moon orbiting earth

Newton’s F=ma and the G = m1m2…

Black body constant

Resolving power of telescopes

Inverse square law in terms of brightness or flux!!!

Luminosity of star and mass relation

Lorrentz factor and special relativity

Hubble’s law

Be comfortable with ratios

You can cancel constants

You don’t need to remember the value of G, C, etc. Just know how many kilometers in a meter and shit

Know arc-seconds and how to convert to degrees

Question 1 of midterm

Question 2 of midterm

Question 4B

Question 5

Question 6

Question 7: Kirchoff’s laws: Understand that shit real good and why they are as they are

Question 9: Know limits of exoplanets

EXAM

Dark Matter

Know how to draw HR diagram

Remember main features and components of milky way