SCI 238 — Introduction to Astronomy

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1 Chapter 1 – Our Place in the Universe

1.1 Overview

A naive look at the sky, which seems to rotate around us, implies we live in a **geocentric** Universe, ie. that everything orbits around the Earth. We know now that this is untrue, but the path to this knowledge was a long one.

We can refer to our place in the Universe as our **cosmic address**, this is our **solar system**; which consists of the Sun and all objects that orbit it including rocky **asteroids** and icy **comets**. Our solar system, and all the stars we can see, make up a small portion of the **Milky Way** galaxy.

A **galaxy** is an island of stars in space containing anywhere between a few hundred million to trillions of stars. The Milky Way is a relatively large one, with 100 billion stars. We are located about halfway from the center of the Milky Way (the **galactic center**) to the edge of the **galactic disk**.

In summary: the Earth is a planet in the solar system, which is a collection of objects orbiting a star, which is in the milky way galaxy, which is a part of the **local group** of galaxies, which is part of the **local supercluster** of groups, which is somewhere in the **Universe**.

The local group contains about 40 galaxies, and is one of what we call **galactic clusters** – groups of galaxies with more than a few members. Superclusters are essentially clusters of galactic clusters, as the Universe seems to be arranged ingiant chains and sheets with large divides between them. The local group is on the edge of the local supercluster.

1.2 The Big Bang and the Expanding Universe

We have observed that the Universe seems to be *expanding*, that is, the distance between galaxies is increasing. By extrapolating backwards, we imagine that all matter must ahve existed at the same point in the past and exploded outward in a **Big Bang**. Based on the rate of expansion, we believe this happened approximately 14 billion years ago.

Note that though the distance between galaxies is increasing, the distances between objects within galaxies is *not*.

Most galaxies, including our own, formed within a few billion years of the Big Bang.

1.3 The Birth of Stars

A star is **born** when gravity compresses the material in a cloud of gas and dust until it is dense and hot enough to generate energy through **nuclear fusion**. The star lives so long as it has useable material to fuel its fusion and dies once it runs out.

A star **dies** by blowing much of its remaining content back into space in a **supernova**. This matter eventually becomes new stars and planets.

1.4 Modelling the Universe

1.4.1 Distance

We can imagine our solar system shrunk down to a manageable size. On the **Voyage** scale (a model solar system in Washington, D.C. where sizes are one billionth of the actual size), the Sun is roughly the size of a grapefruit, Jupiter the size of a marble, Earth the size of a pinhead. Obviously the Sun is far larger than any planet, in fact, it has more than 1000 times as much mass as all the planets in our system combined. Note that the planets also vary in size to a large extent: the "permanent" storm on Jupiter known as the **Giant Red Spot** is larger than the Earth.

We can also use this model to describe the distances between objects. On the same scale, the Earth is 15m from the Sun and the distance from the Sun to pluto is 600m. To have enough space for the orbit of each object in the system, we would need a grid of 300 football fields centered around the Sun.

The closest star (Alpha Centauri) is incredibly far away, on this scale it would be the difference between Washington, D.C. and California.

If we reduce this scale by another factor of one billion, we can start thinking about the size of the galaxy. On this scale, each light year is roughly a millimeter and the Milky Way is about the size of a football field. The distance between our star system and Alpha Centauri is smaller than the width of our pinky.

1.4.2 Time

We can also model the time between events by creating a **cosmic calendar**. If we set the Big Bang as January 1^{st} and the present day as Decembre 31^{st}, we can place each major event on specific days. By the age of the universe, each month represents just over a billion years.

On this scale, the Milky Way was formed sometime in February. Our solar system, though was, only formed in September – life on Earth flourished by the end of that month. Recognizeable animals only appeared in mid-December. Dinosaurs first appeared the day after Christmas and died off yesterday. Around 9PM today, early hominids began to walk upright.

The entire history of human civilization, then, occurred in the last half-minute of January 31^{st}.The Egyptians built the pyramids in 11 seconds, Galileo proved the Earth orbited the Sun one second ago, and the average college student was born 0.05 seconds ago.

1.5 Motion of the Universe

The Earth has a daily rotation (its **spin**) and a yearly **orbit** (or **revolution**) around the Sun.

The Earth rotates each day around its **axis**, the imaginary line from the North to the South pole. It rotates from West to East – counter-clockwise when viewed from above the North pole. The speed is substantial; anywhere other than near the axes, an object whirls around the Earth at a speed greater than 1000km/h.

The Earth's average orbital distance is one **Astronomical Unit** (AU), which is approximately 150 million kilometers. At times, we race around the Sun in excess of one hundred thousand kilometers per hour.

Earth's orbital path defines the **eliptic plane**, and its axis is tilted by 23.5 degrees from a line perpendicular to this plane. The **axis tilt** happens to align our north pole with Polaris, the North Star.

Note that the Earth orbits the Sun in the same direction as it spins around its axis since it was formed from a spinning disk and both of these rotations are a remnant of this.

We also move relative to nearby stars at a rate of $70,000$ kilometers per hour. We rotate around the Milky Way's galactic center once every 230 million years, which implies speeds of (on average) $800,000$ kilometers per hour.

1.6 Dark Matter and Dark Energy

Since stars at different distance from the galactic center orbit at different speeds, we can learn how mass is distributed in the galaxy by measuring the differing speeds. Studies show that the mass of the stars in the galactic disk form only a small percentage of the total mass of the galaxy. Most of the galactic mass, then, seems to be located outside of the visible disk in the galaxy's **halo**. We call this mass **dark matter**, since we have not observed light being emitted from it. Similarly, we find that the bulk of the energy in the universe is **dark energy**. This seems to be the case in all observable galaxies.

1.7 Relative Galactic Movements

Within the local group, some galaxies move toward us and some move away. Outside of the local group, though, this changes; virtually every galaxy outside of the local group seems to be racing away from us at a speed proportional to its distance from us. This is the basis of our theory that of an **expanding universe**: that the space between galaxies is increasing.

Note that we observe this motion by measuring **Doppler shifts**, as detecting any difference in celestial position within our lifetimes is impossible.

2 Chapter 2 – Discovering the Universe

2.1 The Motion of the Stars

Stars appear to move across the sky from east to west. This is not, as the ancients believed, because everything revolves around the Earth, but because the Earth is rotating. This rotation is not perfect though, because the Earth is tilted.

Some stars (those near the celestial north pole) do not rise or set; they remain above the horizon and make daily counter-clockwise circles around the pole. These stars are called **circumpolar**

stars. Other stars (those near the celestial south pole) never rise at all. All other stars appear to rise and set each day.

2.2 Constellations

Although we have a colloquial definition of constellations, astronomers more precisely declare **constellations** to be regions of the sky with well-defined borders. The patterns of stars which "form" constellations simply help us to locate them.

There are 88 official constellations which cover the night sky, as determined by a 1928 summit including members of the International Astronomical Union. Every part of the sky is located within one of these constellations.

Though the stars are very far away, the ancient Greeks believed they were all "painted" on a **celestial sphere** centered around the Earth. We use this today to help us map out space:

- the **north celestial pole** is directly above the north pole, and
- the **south celestial pole** is directly above the south pole, and
- the **celestial equator** mirrors the real equator, and
- the **ecliptic** is the path the Sun takes as it appears to circle around the celestial sphere yearly. It crosses the celestial equator at a 23.5 degree angle

The **Milky Way** traces a complete circle around the celestial sphere, moving through many constellations. It is almost, but not quite, repesentative of the Milky Way *Galaxy*: it traces our galaxy's disk of stars as it appears from our location in the outskirts of the galaxy. The Milky Way appears somewhat wider as we look through Sagittarius since this is the direction of the galactic center.

Note that when looking above you at the **local sky**, you can (obviously) only see one hemisphere of the celestial sphere at a time. We define the Earth-sky boundary as the **horizon**, the point directly overhead as the **zenith**, and an imaginary semi-circle passing along the sphere from due north to due south through the zenith as the **meridian**.

We can locate any object by its direction along the horizon and its altitude above the horizon. We also sometimes use the **azimuth** – the angular distance clockwise from due north.

We can define the **angular size** of an object as the angle it appears to span within our field of view. Since this depends on distance, it does not give us a clear idea of an object's true size; for example, the angular size of both the Sun and the Moon is half a degree despite the Sun being about 400 times larger (since the Sun is 400 times farther away).

The **angular distance** between two objects is the number of degrees which appears to separate them. The distance between the pointer stars in the big dipper is roughly 5 degrees. We further divide each degree into 60 **arcminutes** – and then each of those into 60 **arcseconds** – for precision.

2.2.1 Variance

Constellations vary with both our north-south location on Earth as well as the time of year.

Latitude affects the constellations by changing the locations of the horizon and zenith of our local sky. In effect, by moving to the north or south we can change which portion of the celestial sphere is visible. We can also use this effect to prove that *the altitude of the celestial pole in your sky is equal to your latitude.*

The constellations vary over the course of the year due to Earth's changing position around the Sun. As we orbit, the Sun appears to move across the eliptic such that different stars are behind it at different times of the year. The constellations along this eliptic make up the **zodiac**, the thirteen most widely known constellations (traditionally, there are twelve zodiacs; however, Ophiuchus is also present in the eliptic).

2.3 Seasons

The seasons are caused by the tilt of the Earth's axis. In effect, the axis remains pointing at a specific direction in space at all times. This, of course, means it is pointing at different points relative to the Sun throughout the year. The Northern Hemisphere is tipped toward the sun in their summer (June), and vice-versa. This causes the Sun's rays to hit the "closer" hemisphere for a longer time each day during their summer, as well as concentrating its rays, thus making it warmer.

Note that the common assumption is the summer occurs when the Earth is closer to the Sun than it is during winter. This is incorrect; in fact, the orbital distance between the Earth and the Sun *does* vary, but only by approximately 3%. This difference does not cause noticeable temperature changes.

2.3.1 Solstices

We mark the special celestial events each year as the **solstices** and **equinoxes**:

- the **summer (June) solstice** occurs around June 21^{st}. It is the moment in which the Norther Hemisphere is tipped most directly toward the Sun.
- the **winter solstice** occurs around December 21^{st} and is precisely the opposite of the summer solstice.
- the **spring equinox** occurs around March 21^{st} and is the moment at which the Northern Hemisphere switchees from being slightly tipped away from the Sun to slightly toward the Sun.
- the **fall equinox** occurs around September 22^{nd} and is precisely the opposite of the spring equinox.

The exact dates vary each year by no more than a few days in either direction. In fact, our leap year system is designed precisely to ensure this is true.

The equinoxes are the only days of the year in which the Sun rises and sets exactly due East and West, as well as being the only days in which an equal amount of sunlight falls on both Hemispheres. The Sun rises and sets farther to the North on the Summer solstice side of the equinoxes, and farther South on the Winter solstice side.

We usually consider the solstices and equinoxes as the first day of the new season, despite the summer solstice, for example, being the longest day of the year – ie. the midpoint of summer? This is generally due to weather patterns; the solstices and equinoxes match the beginning of the new season's weather patterns. We also find the it takes some time to match the temperature of the Earth to the Sun's location, thus making us feel a lag behind what the Sun implies our temperature should be.

Note that te solstices are named opposite to the seasons in the Southern Hemisphere. For the equator, we find that the rainy seasons occur at the equinoxes and the dry seasons occur at the solstices.

2.4 Precession

Precession is a slow wobble of the Earth's tilt which affects our orientation in space. Each precession cycle takes approximately $26,000$ years and slowly changes where our poles point to in space. Today, our axis points toward Polaris, which we call the North Star. In approximately $13,000$ years, Vega will be in this location (ie. a bright star very near the pole's zenith). Most of the time, there is no North Star.

Precession, though, does not change the amount of tilt we have relative to the eliptic; we always have a 23.5 degree tilt, and so our seasons are not affected by precession.

Precession is caused by the effect of gravity on a rotating object which is not a perfect sphere. For the Earth, precession is caused by the competing effects of gravity from the Sun and the Moon attempting to "straighten out" our bulging equator.

2.5 The Moon

The Moon orbits the Earth once every $27.\bar{3}$ days. We can see that the Moon appears to move across the sky at half a degree (it's angular size) per hour. As it moves across the sky, its appearance and rising / setting times change according to its **lunar phase**, which is based on its position relative to the Sun as it orbits the Earth.

The change of appearance is based on the direction the Sun casts its light from. When the Moon, Earth, and Sun form a right-angle, the Sun casts its light in such a way that only half of the Moon is illuminated from the Earth's perspective. The lunar cycle takes 29.5 days to complete.

The Moon appears to fill in illumination starting from the right, then lose illumination from the same direction. We refer to completely dark Moons as **New Moons** and completely illuminated ones as **Full Moons**. **Crescent Moons** and **Gibbous Moons** (barely illuminated and almost fully illuminated, respectively) are refered to as **waxing** or **waning** depending on whether it is between a New Moon and a Full Moon or vice-versa. Half-illuminated Moons are referred to as the **First and Third Quarter Moons**.

Moon Phases & Time of Day

Moon Phase	Name	Direction (From Sun)	Rising (Eastern Sky)	Meridian (Highest point)	Setting (Western Sky)
	New	0° away (in front)	6 AM	12 PM	6 PM
	First Quarter	90° East (6 hrs behind)	12 PM	6 PM	12 AM
	Full	180° away (opposite)	6 PM	12 AM	6 AM
	Third Quarter	90° West (6 hrs ahead)	12 AM	6 AM	12 PM

2.5.1 Eclipses

Eclipses occur when the Sun, Moon, and Earth are aligned. A **lunar eclipse** occurs when the Earth lies between the other two, such that the Earth's shadow falls on and blacks out the Moon. A **solar eclipse** occurs when the Moon lies between the Sun and the Earth, so that the Moon block's our view of the Sun (ie. its shadow falls on us).

Since the Moon's orbit is slightly (5 degrees) inclined, eclipses do not happen each month. Eclipses, then, only occur when the Moon passes through the ecliptic; the two locations in which it does are referred to as the **nodes** of its orbit. These times are called **eclipse seasons**, and occur twice per year.

A lunar eclipse occurs when a full moon occurs near a node, a solar eclipse occurs when a new moon occurs near a node.

Since the Moon's shadow has both an **umbra** – the central area which completely blocks sunlight – and a **penumbra** – which only partially blocks sunlight – these eclipse can look extremely different. If the three objects line up perfectly, we can have a **total lunar eclipse**, in which the Moon is completely blocked during the period of **totality**. More likely is a **partial eclipse**, which only hides a portion of the Moon. Finally, we have **penumbral lunar eclipses**, which shade the Moon but do not completely blot it out.

During totality, the Moon is completely dark for typically less than an hour, save for the red ring around it formed because Earth's atmosphere bends some of the Sun's light toward the Moon (and, to a far lesser extent, due to **gravitational lensing**).

Similarly, we have total and partial solar eclipses based on whether you are within the Moon's umbra or penumbra. When the Moon is too far away for its umbra to even reach the Earth, we see an **annular eclipse**: a ring of sunlight surrounding the Moon when we are directly behind the umbra; otherwise, we see a partial eclipse.

Since the umbra moves across the Earth at a speed of $1,700$ km/h, an eclipse can last no more than a few minutes for any given location on Earth.

The location of the nodes in the Moon's orbit slowly change over time. This gives us an eclipse cycle of 18 years 11.3 days; we call this the **Saros Cycle**. Of course, this only tells us when eclipses will occur, not where they will be visible from on Earth or whether they will be total or

partial.

2.6 Planets

We can see five planets with the naked eye: Mercury, Venus, Mars, Jupiter, and Saturn. Mercury is rarely visiable, and only near sunrise or sunset. Venus can often be seen shining brightly in the evening (in the West) or before dawn (in the East). Jupiter, when visible, is the brightest star at night. Mars is often recognizeable by its red hue. Saturn has no distinguishing features, but can be identified with star charts.

Planets have different paths of motion that do stars, which is why the word for planet in Greek means "wandering star". The planets usually move Eastward through constellations, but sometimes go through periods of **apparent retrograde motion** for anywhere between a few weeks and a few months. This retrograde motion occurs when the Earth "passes" the other planet, ie. when their orbits are in line with the Sun.

Stellar parallax is the phenomenon of stars appearing to move at different rates given different angles; given the extremely great distances between us and the stars, this is not detectable by the human eye – though it can be detected by telescopes.

3 Chapter 3 – Ancient Astronomy

3.1 Ancient Roots of Science

Other lunar calendars remain roughly synchronized with solar calendars by taking advantage of an interesting coincidence: 19 years on a solar calendar is almost precisely 235 months on a lunar calendar. As a result, the lunar phases repeat on the same dates about every 19 years (a pattern known as the Metonic cycle).

The study of ancient structures in search of astronomical connections is called **archaeoastronomy**

3.2 Ancient Greek Science

Greek - To account for the fact that the Sun and Moon each move gradually eastward through the constellations, the Greeks added separate spheres for them, with these spheres turning at different rates from the sphere of the stars. The planets also move relative to the stars, so the Greeks added additional spheres for each planet. The **difficulty** with this model was that it made it hard to explain the apparent retrograde motion of the planets.

The **Ptolemaic model** - Each planet moves on a small circle whose center moves around the Earth. A planet following this circle-upon-circle motion traces a loop as seen from Earth, with the backward portion of the loop mimicking apparent retrograde motion. Despite its complexity, the Ptolemaic model proved remarkably successful: It could correctly forecast future planetary positions to within a few degrees of arc.

3.3 The Copernican Revolution

Copernicus - Discovered simple geometric relationships that allowed him to calculate each planets orbital period around the Sun and its relative distance from the Sun in terms of EarthSun distance. The models success in providing a geometric layout for the solar system further convinced him that the Sun-centered idea must be correct.

Keplers key discovery was that planetary orbits are not circles but instead are a special type of oval called an ellipse. The locations of the two tacks are called the foci (singular, focus) of the ellipse. The long axis of the ellipse is called its major axis, each half is called the semimajor axis. A circle is an ellipse with zero eccentricity, and greater eccentricity means a more elongated ellipse.

Kepler's first law - The orbit of each planet about the sun is an elipse with the sun at one focus. It is closest at **perihelion** and farthest at the point called the **aphelion**.

Kepler's Second Law - As a planets moves around its orbit it sweeps out equal areas in equal times. This means the planet moves a greater distance when it is near perihelion than it does in the same amount of time near aphelion. That is, the planet travels faster when it is nearer to the Sun and slower when it is farther from the Sun.

Kepler's Third Law - More distant planets orbit the sun at slower average speeds. $p^2 = a^3$ p is the orbital period in years, and a is the distance from the sun. We can use the law to calculate a planets average orbital speed.

Galileo - observed four moons clearly orbiting Jupiter, not Earth. Soon thereafter, he observed that Venus goes through phases in a way that proved that it must orbit the Sun and not Earth.

Galileos experiments and telescopic observations overcame remaining objections to the Copernican idea of Earth Venus as a planet orbiting the Sun. Although not everyone accepted his results immediately, in hindsight we see that Galileo sealed the case for the Sun-centered solar system.

Science generally exhibits three hallmarks: (1) Modern science seeks explanations for observed phenomena that rely solely on natural causes. (2) Science progresses through the creation and testing of models of nature that explain the observations as simply as possible. (3) A scientific model must make testable predictions about natural phenomena that would force us to revise or abandon the model if the predictions do not agree with observations.

A **scientific theory** is a simple yet powerful model that explains a wide variety of observations using just a few general principles, and that has survived repeated and varied testing.

4 Chapter 4 – Motion, Energy, and Gravity

velocity speed with respect to a direction

acceleration rate of change in velocity

the acceleration of gravity $g = 9.8\frac{m}{s^2}$

momentum $p = mv$

net force net force acting on an object dictates changes in its momentum

mass amount of matter in object

weight force that a mass exerts on the ground (due to gravity and other forces, like elevators)

freefall state of falling without any resistance to slow you down. Since there is no ground for your mass to exert force upon, you seem weightless. Object x in orbit of object y is in a constant state of freefall toward y

Newton's Laws

1. If net force is zero, objects maintain velocity
2. Force is mass times acceleration
3. Forces have equal and opposite reaction forces

- Conservation of Angular Momentum
  - total angular momentum can never change
  - an object's angular momentum must transfer to or from another object
  - angular momentum of an object = radius of the orbit * velocity around the orbit * mass
  - this explains
    1. why Earth needs no fuel or push to continue orbiting the sun
    2. why Earth's velocity around the sun must be faster when it is closer to the sun (Kepler's Law)
  - The same is true for Earth rotating on its axis, though it is slowly transerring this rotational angular momentum to the Moon
- Conservation of Energy
  - energy also cannot change, only transferred and converted
    - kinetic: movement
    - radiative: carried by light (visible or otherwise)
    - potential: stored in some form (eg gravitational potential)
    - thermal: subcategory of kinetic, sum movement of particles within (measured in Kelvin)
    - mass: a type of potential energy (energy = mass * speed of light^2)
- Universal Law of Gravitation
  - every mass attracts every other mass in the universe
  - $G = 6.67 * 10^{-11} \frac{m^3}{kg*s^2}$
  - d = distance between object 1 and 2
  - $F = \frac{G*m_1*m_2}{d^2}$

bound orbits an object goes around another object over and over again (planets, satellites, moons)

unbound orbits paths that bring an object close to another object just once (some outer comets)

- Newton's Version of Kepler's Third Law
  - orginally $p^2 = a^3$
  - a = average orbital radius
  - p = orbital period
  - Newton: $p^2 = a^3 * \frac{4\pi^2}{G(m_1+m_2)}$
  - note: if m1 ¿¿ m2, you may be able to ignore m2 for an approximate answer (easier expression manipulation)

Orbital Energy the sum of an object's gravitational potential and kinetic energy. this value remains constant

Gravitational Encounter two objects pass near enough so that each can feel the effects of the others gravity. Note: gravitational encounters are the basis for slingshot maneuvers in spacecraft

- Atmospheric Drag
  - low-orbiting objects (few hundred km) experience slight drag
  - causing it to slow, converting to thermal enegry
  - as it slows its orbit becomes smaller, eventually crashing to the surface
- Escape Velocity
  - if an object in bound orbit gains velocity (eg thrust) its orbit increases average altitude
  - an object with velocity of 11000 m/s (on surface) will escape Earth's gravity
  - this velocity does not depend on mass
  - since gravity weakens with distance, starting higher requires less energy
- Tides
  - the moon can pull the water on the surface towards it
  - strongest on the side of Earth facing the moon, causing a bulge
  - weakest on far side of Earth, causing another bulge
  - Sun also has an effect on tides, but is too far away to be as noticeable (little under half of moon's)
  - spring tides (sun and moon work together) and neap tides (sun and moon fight)
  - moon's synchronous rotation caused by tidal friction
  - used to rotate faster, tidal bulges in its mass
  - tidal forces cause the axial rotation to slow (and orbit radii to increase)

5 Chapter 5 – Light

- light spectrum
  - the range of visible light we see as we pass it through a prism
  - can be detailed enough to show us individual black bands representing missing colors
- electromagnetic spectrum: the complete version of all light forms. visible light is only tiny fraction
- wave properties
  - a wave is something that can transmit energy without having to carry material with it
  - wavelength: the distance between adjacent peaks (measured in m)
  - frequency: the number of cycles per second (measured in Hz)
  - since light can affect both charged particles and magnets, we refer to it as an electromagnetic wave
- All light travels at the same speed: $3 * 10^8 m/s$
- particle properties
  - comes in pieces called photons
- gamma — x-ray — ultraviolet — visible — infrared — microwave — radio
- atomic structure
  - protons, neutrons, electrons
  - some really obvious shit
  - strong nuclear force holds protons and neutrons together at the nucleus
  - electrons in an atom a cloud that surrounds the nucleus and gives the atom its apparent size
  - it is impossible to pinpoint their positions
  - isotopes: atoms with varying numbers of neutrons
- light and matter interact in four ways
  1. emission: matter creates light (eg thermal, electrical potential)
  2. absorption: light's energy is absorbed into matter (typically as thermal)
  3. transmission: matter allowing light to pass through
  4. reflection: light bouncing (scattering is reflecting randomly)
- transparent: material allows light to pass through
- opaque: material absorbs all light

- some materials treat certain light differently (eg red glass allows red light through, grass reflects green light)
- types of spectrum
  - continuous: broad range of wavelengths without interruption
  - emission line: light composed of individual bands (dependant on composition and temperature)
  - absorption line: broad range with individual bands missing
- electrons can only have particular amount of energy and not levels inbetween (measured in eV)
- 1 electron Volt $= 1.60 * 10^{-19}$ Joule

These values are unique to every atom, ion, and molecule. Example:

```
A hydrogen atom has states:
    level 1: 0 eV   ground
          2: 10.2
          3: 12.1
          4: 12.8
 ionization: 13.6   escape
```

- an electron rising or falling between levls are called energy level transitions
- can only occur when an election gains or loses the specific amount of energy separating the two levels
- electrons will not accept energy in quantities that do not correspond with an energy level (except escape, can go over)
- each possible downward energy level transition (eg 3 to 1) corresponds to a release of energy in the form of photons
- the more energy released, the shorter the photon wavelength
- some of these transitions create photons with wavelengths that fall in the visible light spectrum (many won't be visible)
- the exact possible emissions are unique to each atom, so we can use emission lines to identify compositions of light sources
- electrons will not rest at high energy levels, they will fall back down quickly (fraction of a second)
- energy exchanges typically caused by atoms colliding
- most just bump away, a few transfer exactly the right amount of energy to an electron
- collisions only keep happening while the gas is relatively hot
- energy can also be recieved in these exact quantities by other photons

- this causes absorption lines, since the photons that get absorbed then released will be in random directions
- the photons that do not get absorbed travel straight through the material to us
- most objects (eg rocks, plants, people) are complex enough that they absorb light from a very broad range
- light cannot easily pass through, light emitted cannot easily escape

Consider an idealized case, an object absorbs all photons and does not allow photons inside it to escape easily. Photons bounce randomly around inside the object, constantly exchanging energy with its atoms or molecules. When photons finally escape the object, their radiative energies have become randomized so that they are spread over a wide range of wavelengths. This wide range explains why the spectrum of light from such an object is continuous, like a pure rainbow without any absorption or emission lines

- this all depends on the temperature of the object (the average kinetic energy of the atoms)
- that's why this type of light is called thermal radiation
- no real object emits a perfect thermal radiaton spectrum, but all objects emit light that approximates it
- two laws of thermal radiation:
  1. each square meter of a hotter objects surface emits more light at all wavelengths
     - each square meter on a hotter star emits more light at every wavelength than a cooler star
     - hotter star emits light at some ultraviolet wavelengths that the cooler star does not emit at all
     - T = temperature (in Kelvin)
     - $o = 5.7 * 10^{-8} \frac{W}{m^2 K^4}$
     - emitted power per square meter of surface = oT^4
  2. hotter objects emit photons with a higher average energy
     - shorter average wavelength
     - explains why peak wavelength is shorter in hotter objects
     - Lambda Peak = $2.9 * 10^6 \frac{1}{T}$
- Doppler effect
  - the velocity of the light source have an effect on the apparent wavelength of the photons
  - travelling away: wavelengths appear longer, become redshifted
  - travelling towards: wavelengths appear shorter, become blueshifted
  - v = velocity of source (in radial direction, so only net away from us. negative means towards)

  - c = speed of light ($3 * 10^8 m/s$)
  - Lambda Shift = observed wavelengths from source
  - Lambda Rest = lab recorded wavelengths of source's composition
  - v/c = (shift - rest) / rest
- telescopes have two properties
  1. light collecting area - total light telescope can collect at a time
  2. angular resolution - smallest angle we can determine two stars are distinct
- arcminute: 1/60th of a degree
- arcsecond: 1/60th of an arcminute
- human eye has angular resolution of 1 arc minute (objects se)
- basic telescope designs
  1. refracting telescopes
     - operates like eye, uses transparent glass lenses to collect and focus light
     - earliest telescopes built by Galileo
     - worlds largest has 1m lens, 19.5m tube, completed 1897
  2. reflecting telescopes
     - use large curved primary mirrors to gather light, small secondary mirror to reflect to a focus
     - majority of modern telescopes, size typically restricted by weight of primary mirrors
     - 5m Hale telescope on Mt. Palomar, San Diego (1948)
     - 8m Gemini telescope on Mauna Kea, Hawaii
     - 10m Keck telescopes in Hawaii
     - plans for 30m telescope in 2018
- Telescopes can be specially designed to recieve non-visible light
  - radio waves have large wavelengths, telescopes need to be large to get decent resolution
  - 305m Arecibo radio dish in Puerto Rico has only 1 arc minute
  - collecting high energy rays straight on will punch straight through the lens, possibly damaging it
  - need to catch them at a slight angle and deflect them into the focus
- Putting telescopes in space dodges atmospheric interference but is extremely expensive
  - bright day skys, light pollution, weather, air turbulence (causes eye-visible twinkling)
  - lower energy wavelengths are barely affected by atmosphere and can be built lower

  - most high energy wavelengths cant even reach the ground
- adaptive optics: computers control the telescopes, making minute adjustments to the shape of the mirrors many times a second to eliminate atmospheric distortion
- interferometry: using multiple telescopes simultaneously to combine their images to achieve higher resolution

6 Chapter 6 – Formation of Planetary Solar Systems

6.1 Overview

This chapter is about the nature of our solar system and current scientific ideas about its birth. We will also examine characteristics about our solar system that are key clues about how it formed. Finally it will talk about how astronomers have discovered other planets around other stars and how those planetary systems are helping us understand our own.

6.2 Clues to the formation of the Solar System

The Solar System's layout and composition offer 4 clues as to how it was born.

1. **Large bodies in the solar system have orderly motions**.
   - All planets have nearly circular orbits going in the same direction in nearly the same plane.
   - All planets **orbit** the Sun in the same direction: **counterclockwise** as viewed from high above Earths North Pole.
   - Most planets rotate in the same direction in which they orbit, with fairly small axis tilts. The Sun also rotates in this direction.
   - Most of the solar systems large moons exhibit similar properties in their orbits around their planets, such as orbiting in their plane
2. **Planets fall into two major categories**
   (a) **Terrestrial planets**
      - Small in mass and size
      - Close to the sun
      - Made of metal and rock
      - Few moons and no rings

   (b) **Jovian planets**
      - Large in mass and size
      - Far from the Sun

- Made from H, He and hydrogen compounds
- rings and many moons

3. **Swarms of asteroids and comets populate the solar system**. Vast numbers of rocky asteroids and icy comets are found throughout the solar system, but are concentrated in 3 distinct regions
   - Most **asteroids** orbit in the **asteroid belt** between Mars and Jupiter
   - Many **comets** are found in the **Kuiper Belt** beyond Neptune's orbit
   - Even more **comets** orbit the sun in the distant spherical region called the **Oort Cloud** and only a rare few ever plunge into the inner solar system. May contain a trillion comets.
4. **Several notable exceptions to these trends stand out**
   - **Uranus's odd tilt** Uranus rotates nearly on its side compared to its orbit and its rings and major moons share this sideways orientation.
   - **Earth's relatively large moon** Our moon is much larger in size than most other moons in comparison to their planets
   - Venus' backwards rotation

6.3 The Sun

The **sun contains more than 99.8% of the solar systems total mass**. (1000 times more massive than the rest of the solar system combined). The surface is a sea of rolling hot (5800K) Hydrogen and Helium gas. The sun is gaseous throughout and temperture and pressure both increase with depth. In addition, charged particles moving outward (**Solar wind**) help shape planetary magnetic fields and can influence planetary atmospheres.

6.4 Mercury

A desolate, cratered world with no active volcanoes, no wind, no rain, and no life. It is a world of both **hot and cold extremes**. The combination of rotation and orbit gives Mercury days and nights that last about 3 Earth months each. Mercurys **surface is heavily cratered** But it also shows evidence of past geological activity, such as plains created by ancient lava flows and tall, steep cliffs that run hundreds of kilometers in length. Mercurys **high density** indicates that it has a very large iron core.

6.5 Venus

Venus is nearly identical in size to Earth. It **rotates on its axis very slowly and in the opposite direction of Earth**, so days and nights are very long. An **extreme greenhouse effect** bakes Venuss surface to an incredible 470C. Day and night. Venus has **mountains, valleys, and**

craters, and shows many signs of past or present volcanic activity. But Venus also has geological features unlike any on Earth, and we see no evidence of Earth-like plate tectonics.

6.6 Earth

Only planet in our solar system with oxygen to breathe, ozone to shield the surface from deadly solar radiation, and abundant surface water to nurture life. Temperatures are pleasant because Earths atmosphere contains just enough carbon dioxide and water vapor to maintain a moderate greenhouse effect.

6.7 Mars

Mars has ancient volcanoes. The presence of dried-up riverbeds, rock-strewn floodplains, and minerals that form in water offers clear evidence that Mars had at least some warm and wet periods in the past. Major flows of liquid water probably ceased at least 3 billion years ago. More than a dozen spacecraft have flown past, orbited, or landed on Mars.

6.8 Jupiter

Most famous feature: long-lived storm called the Great Pluto. **Made primarily of hydrogen and helium and has no solid surface**. Increasing gas pressure would crush us long before we ever reached its core. Jupiter reigns over dozens of moons and a thin set of rings (too faint to be seen in most photographs).

6.9 Saturn

Saturn is made mostly of hydrogen and helium and has no solid surface. The rings may look solid from a distance, but in reality they are made of countless small particles, each of which orbits Saturn. Titan, the only moon in the solar system with a thick atmosphere. Saturn and its moons are so far from the Sun that Titans surface temperature is a frigid -180C.

6.10 Uranus

It is made largely of hydrogen, helium, and hydrogen compounds such as water (H 2 O), ammonia (NH3), and methane (CH4). Uranus lacks a solid surface. The entire Uranus systemplanet, rings, and moon orbitsis tipped on its side compared to the rest of the planets and it gives Uranus the most extreme seasonal variations of any planet in our solar system.

6.11 Neptune

Neptune looks nearly like a twin of Uranus, although it is more strikingly blue. Smaller than Uranus but more massive due to higher density (even though they have similar composition. Triton is the only large moon in the solar system that orbits its planet backwardthat is, in a direction opposite to the direction in which Neptune rotates. This backward orbit makes it a near certainty that Triton once orbited the Sun independently before somehow being captured into Neptunes orbit.

6.12 Pluto (and other dwarf planets)

Pluto is much smaller and less massive than any of the other planets, and its orbit is much more eccentric and inclined to the ecliptic plane. Its composition of ice and rock is also quite different from that of any of those planets, although it is virtually identical to that of many known comets. Pluto is not even the largest of Kuiper belt objects, Eris, is slightly larger than Pluto.

6.13 Where did the solar system come from?

The **nebular theory** begins with the idea that our solar system was born from a cloud of gas, called the solar nebula, that collapsed under its own gravity. As the solar nebula shrank in size, three important processes altered its density, temperature, and shape, changing it from a large, diffuse (spread-out) cloud to a much smaller spinning disk: **heating, spinning, flattening**. As it collapsed, it heated up, spun faster and flattened into a disk.

6.13.1 The Formation of the planets

In the center of the collapsing solar nebula, gravity drew together enough material to form the Sun. Because hydrogen and helium gas made up 98% of the solar nebulas mass and did not condense, the vast majority of the nebula remained gaseous at all times. However, other materials could condense wherever the temperature allowed.

The solid metal and rock in the inner solar system ultimately grew into the terrestrial planets we see today, but these planets ended up relatively small in size because rock and metal made up such a small amount of the material in the solar nebula. **Accretion** The process in which small "seeds" grow into planets.

The leading model for jovian planet formation holds that these planets formed as gravity drew gas around ice-rich "boulders" much more massive than Earth. Their large masses had gravity strong enough to capture some of the hydrogen and helium gas that made up the vast majority of the surrounding solar nebula. Ultimately, the jovian planets accreted so much gas that they bore little resemblance to the icy seeds from which they started.

The young Sun had a strong solar windstrong enough to have swept huge quantities of gas out of the solar system, sealing the compositional fate of the planets.

Asteroids and comets are leftover and are less common than earlier in the solar systems life. Although impacts occasionally still occur, the vast majority of these collisions occurred in the first few hundred million years of our solar systems history, during the period we call the **heavy bombardment**. These impacts did more than just batter the planets. They also brought materials from other regions of the solar system. (Potentially bringing water to Earth)

6.13.2 How do we explain the exceptions to rules?

Our moon - The giant impact hypothesis holds that a Mars-size object hit Earth at a speed and angle that blasted Earths outer layers into space. Strong support for this comes from two features of the moon's composition.

1. The composition of the moon is similar to Earth's outer layers
2. The Moon has a much smaller proportion of easily vaporized ingredients (such as water) than Earth. This fact supports the hypothesis because the heat of the impact would have vaporized these ingredients.

Other Exceptions

- Mercurys surprisingly high density may be the result of a giant impact that blasted away its outer, lower-density layers.
- Giant impacts could have also been responsible for tilting the axes of many planets (including Earth) and perhaps for tipping Uranus on its side
- Venuss slow and backward rotation could also be the result of a giant impact

Nebular Theory accounts for **all FOUR** of the major features of the solar system.

6.13.3 When did the Planet's form?

The planets begin to form just over **4.5 billion years ago**

6.13.4 Other Planetary Systems

We can detect planets in other stars directly (pictures) or indirectly (measurements of a stars properties).

Indirect Methods:

- **Astrometric Technique** - we make very precise measurements of stellar positions in the sky. If a star wobbles gradually around its average position (the center of mass), we must be observing the influence of unseen planets.
- **Doppler technique** searches for a stars orbital movement around the center of mass by looking for changing Doppler shifts in a stars spectrum. Used for the majority of planet discoveries to date

- **Transits and Eclipses** searching for slight changes in a stars brightness that occur when a planet passes in front of or behind it. The transit method can also be used to search simultaneously for planets around vast numbers of stars and to detect much smaller planets than is possible with the Doppler technique.

6.13.5 Comparing Extrasolar planets

Orbits

- Most of the planets orbit very close to their host star
- many of the orbits are elliptical instead of nearly circular like the orbits of planets in our own solar system

Masses

Most of the known extrasolar planets are more massive than Jupiter, smallest is twice the mass of Earth

7 Chapter 18 – Life in the Universe

- Reasons why life likely might exist elsewhere
  - Life arose quite quickly on Earth, so why not on other planets too
  - Chemicals on young Earth combined readily into complex organic compounds. This may also be true on other exoplanets.
  - We have discovered microorganisms that could survive on other planets in our solar system
- Timeline of development of life on Earth:

Years ago	Event
4.5 billion	Earth and moon form
3.85 billion	Carbon isotope evidence of life
3.5 billion	Oldest microfossil evidence of life
2.5 billion	earliest evidence of oxygen in the atmosphere
410 million	animals colonize land
230 million	mammals and dinosaurs appear

- Requirements for life (on Earth)
  - A source of nutrients
  - Energy to fuel the activities of life
  - Liquid water (* this is the only one that is difficult to achieve)

- Microbes living in extreme conditions (volcanic vents, deserts) imply that if not for a need for water life could exist almost anywhere
- Only likely candidates to have liquid water in our solar system are Mars and some jovian moons (e.g. Europa)
- What properties must a star system have to contain life
  - It must be older than several million years (that's how long life took to form after Earth's formation)
  - The star must not be much bigger than our Sun, because it would die off before life formed (still leaves about 99% of stars)
  - Planets must have stable orbits (far less likely in binary star systems, but not impossible)
  - Bigger star means larger habitable zone (the zone where liquid water could exist)
- A planet's spectra can give us the atmospheric makeup, allows us to look for water vapour, ozone, methane, etc.
- Rare-Earth hypothesis
  - The galaxy has a habitable zone, just like our solar system
  - Star systems further out contain far less non-hydrogen/helium elements, which almost completely compose terrestrial planets
  - Inner systems are subject to far more high supernovae, which would likely irradiate life
  - Leaves only about 10% of solar systems habitable
  - Impact rate in our solar system dropped off quickly, is the same true everywhere? In our solar system this was due to jovian planets ejecting small objects from the inner solar system
  - Our atmosphere has been relatively stable due to plate tectonics (which might be rare on other planets) regulating the carbon dioxide, and our large moon regulates our axial tilt
- Counter-arguments include
  - Earth is very small and wouldn't need a high abundance of heavy elements to form (relative to the mass of the star)
  - We don't know if a supernova would be harmful to life
  - If the Earth rotated faster it would also regulate our axial tilt without the Moon
  - Large moons could exist other places, ours isn't that rare
  - Life could adapt to a changing axial tilt
- Drake equation: Number of civilizations = $N_{\mathrm{HP}} * f_{\mathrm{life}} * f_{\mathrm{civ}} * f_{\mathrm{now}}$

  $N_{\mathbf{HP}}$ number of habitable planets in the galaxy that *could* have life

$f_{\mathbf{life}}$ fraction of habitable planets that actually have life

$f_{\mathbf{civ}}$ fraction of life-bearing planets upon which a civilization capable of interstellar communication *has at some time* arisen

$f_{\mathbf{now}}$ fraction of civilization-bearing planets that currently have such a civilization

- Fermi paradox: If it's so likely that other civilizations exist than there are some millions of years ahead of us technologically. So where are they? Options: "we're alone", "every other civilization destroyed itself before it could settle the galaxy" or "they haven't revealed themselves to us yet"

8 Assignments

8.1 Assignment 1

Distance from Earth (furthest to closest): Andromeda, far side of the milky way, near side of the milky way, orion nebula, Alpha Centauri, Pluto, The Sun

If an object is 10 light-years away, then we see it as it was 10 years ago, but if it is 20 light-years away, we see it as it was 20 years ago. In other words, more distant objects have aged more since their light left on its way to Earth.

Timeline: Universe begins to expand, Elements such as carbon and Oxygen first form, nuclear fusion begins in the Sun, Earliest life on Earth

Our cosmic address: Earth, solar system, Milky Way Galaxy, Local Group, Local Supercluster, universe

We cannot See a Universe that is 20 billion years away because it is not in our observable universe

8.2 Assignment 2

The **Tilt of a planet is responsible for seasons**. Jupiter (3*) has almost no seasons compared to Uranus (97*). Earth and Mars have a similar tilt.

Time of Year	Earth-Sun Distance
March (Northern Spring Equinox)	149.0 million km
June (Northern Summer Solstice)	152.0 million km
September (Northern Fall Equinox	150.2 million km
December (Northern Winter Solstice)	147.2 million km

Earth is actually farthest from the Sun when it is summer in the Northern Hemisphere. We conclude that variations in the Earth-Sun distance from are not the major cause of our seasons.

The **Moons orbit about Earth is tilted** (by about 5) with respect to Earths orbit about the Sun. As a result, the actual number of solar eclipses that occur each year is approximately 2 (instead of one each month)

Apparent **retrograde motion can be observed by noticing changes in Mars's position among the constellations**. Note that a complete period of apparent retrograde motion unfolds while Earth moves a significant fraction of its orbit, which means it takes several months. Apparent retrograde motion occurs as Earth "laps" Mars in their respective orbits around the Sun. The middle of a period of apparent retrograde motion occurs when Mars is closest to Earth in its orbit and in a full phase as viewed from Earth, which is why it is brightest in our sky at that time. It is also directly opposite the Sun in the sky at that time, which is why it crosses the meridian at midnight.

The **Greeks explained retrograde motion by imagining that planets moved around small circles that in turn moved around larger circles around Earth**. Because this model made reasonably accurate predictions of planetary positions and fit with other philosophical ideas that they held, the Greeks had no compelling reason to reject it,

Random: How frequently does the Galactic Center (in the constellation Sagittarius) and the Sun align, that is, appear in the same constellation? Once A year

Neutrinos rarely interact with anything on Earth (faulty premise of movie 2012)

8.3 Assignment 3

Kepler's second law tells us that as an object moves around its orbit, it sweeps out equal areas in equal times

Venus is full whenever it is on the opposite side of the Sun from Earth, although we cannot see the full Venus because it is close to the Sun in the sky. For Venus to be high in the sky at midnight, it would have to be on the opposite side of our sky from the Sun. But that never occurs, because Venus is closer than Earth to the Sun.

Falsifiable: (could be proven false)

True Statements belong in Sun centered and "Both" models

Earth Centered Model Only

- A planet beyond Saturn rises in east and sets in West

Sun Centered Only

- Positions of nearby stars shift back and forth slightly each year
- Mercury goes thorough a full cycle of phases

Both Models

- Moon rises in east and sets in west
- A distant galaxy rises in the east and sets in the west
- stars circle daily around north and south celestial pole

Neither Model

- We sometimes see a crescent Jupiter

An object must come between Earth and the Sun for us to see it in a crescent phase, which is why we see crescents only for Mercury, Venus, and the Moon.

Greek geocentric model, the retrograde motion of a planet occurs when the planet actually goes **backward in its orbit around Earth**

Random: Copernicus's Sun-centered model did not make significantly better predictions of planetary positions in our sky. (not an advantage of it)

Tides:

- Any particular location on Earth has two high tides and two low tides each day.
- Tides also affect land, although not as much
- One tide bulge faces the moon, the other is away from
- The second tidal bulge arises because gravity weakens with distance, essentially stretching Earth along the Earth-Moon line.
- High tides are highest at both full moon and new moon
- Low tides are lowest at both full moon and new moon.
- Moon is larger factor than the sun because gravitational attraction between Earth and the Moon varies more across Earth than does the gravitational attraction between Earth and the Sun

8.4 Assignment 4

- The Sun emits all colors of visible light, but cooler gasses on the Sun's surface absorb some of these colors.
- The most intense color in an absorption spectrum can tell us the temperature of an object.
- **Wien's Law**: thermal radiation from a higher object peaks at a shorter wavelength.
- Electrons lose energy exactly equal to the proportion of distance between "rings" they jump, regardless of which rings they traverse.
- Visible light and radio waves reach the Earth's surface, infrared light reaches mountain tops, UV light reaches the upper atmosphere, and X-rays don't enter the atmosphere.
- The light-carrying area of a telescope varies at a rate double its diameter.
- The Hubble Telescope has a resolution of less than 0.1 arcseconds.

8.5 Assignment 5

Jovian planets _____ than terrestrial planets:

- Are more massive
- Are lower in average density

- Are bigger
- Orbit the Sun farther
- Have more moons
- Have rings

How are Pluto and Eris different from other planets:

- Smaller
- More elliptical orbits
- Less massive
- Similar composition to comets (ice and rock)

Characteristics of planets in our solar system:

- Large bodies have orderly motions
- There are exceptions to most trends
  - Venus spins backwards
  - Uranus rotates on its side (axial tilt $\approx 90°$)
  - The moon is about $\frac{1}{4}$ the size of Earth
- Planets orbit the Sun in the same plane
- Planets closer to the Sun move around their orbits at higher speed than planets farther from the Sun
- All the planet (not counting Pluto) have nearly circular orbits

Small bodies:

- Rocky = asteroids
  - Found in the asteroid belt
- Icy = comets
  - Found in the Kuiper belt (starts around Neptune, extends past Pluto) and Oort cloud (sphere around the solar system, far beyond Pluto)

Detecting extrasolar planets

- Planets are very dim compared to their star, it makes it very hard to image them visually. The angular separation from Earth is also very small.
- We can detect planets by watching how their star "wobbles" due to their gravity (Doppler technique). This technique can only give us the **minimum** mass of the planet (unless it's on the same plane as the Earth)
- Smaller orbital radius of planet results in higher max speed of the star and shorter period of rotation

- Mass of the planets only affects the max speed of the star in its "wobble"
- If the planets orbital plane lie between the Earth and the star we can see eclipses — a slight dip in the stars luminosity
- As of 2008, the most extrasolar planets have been discovered by the Doppler technique
- The Kepler mission mostly looked for eclipses
- Transit technique has the best chance of finding Earth-like planets
- The astrometric technique uses careful measurements of positions of celestial bodies to find planets

Properties of extrasolar planets (discovered so far):

- Some jovian planets have been found closer to their star than Mercury is to the Sun (hot Jupiters)
- Many are on very eccentric orbits
- Jovian planets migrate closer to their star from their original orbits
- Most are larger than Jupiter

Four process that shape planetary surfaces:

- Impact cratering
  - number of impacts per square area about the same for all planets
  - Mostly occurs in the first few hundred million years after formation
  - Primary factor for craters still being visible is if they've been erased, because they were definitely there at some point
- Volcanism
  - Outgassing explains how terrestrial planets got their atmospheres
- Tectonics
  - Happens beneath the *lithosphere*, the rigid layer of rock at the surface of a planet
  - Compression causes mountain ranges
  - Extension (stretching) causes cracks and valleys
  - Earth is the only planet where the lithosphere has been broken into plates
  - Lots of tectonic activity means lots of volcanic activity
  - Can only occur if the interior of the planet is liquid (hot!)
  - Big planets take longer to cool than small ones, so they have tectonic activity for longer
- Erosion
  - Occurs due to surface liquids, ices and gases
  - Liquid water is the best, causes much more pronounced features

- Canyons (formed by glaciers), dunes, rock formations
- Planet must be warm enough to have liquids, and big enough to capture an atmosphere

9 Definitions

9.1 Basic Astronomical Objects

star is a large, glowing ball of gas that generates heat and light through nuclear fusion in its core. Our Sun is a star.

planet is a moderately large object that orbits a star and shines primarily by reflecting light from its star. According to a definition approved in 2006, an object can be considered a planet only if it (1) orbits a star; (2) is large enough for its own gravity to make it round; and (3) has cleared most other objects from its orbital path. An object that meets the first two criteria but has not cleared its orbital path, like Pluto, is designated a dwarf planet.

moon (or satellite) is an object that orbits a planet. The term satellite can refer to any object orbiting another object. asteroid A relatively small and rocky object that orbits a star.

comet is a relatively small and ice-rich object that orbits a star.

extrasolar planet is a planet that orbits a star that is not our Sun.

9.2 Collections of Astronomical Objects

solar system is the Sun and all the material that orbits it, including the planets, dwarf planets, and small solar system bodies. Although the term solar system technically refers only to our own star system (solar means of the Sun), it is often applied to other star systems as well.

star system is a star (sometimes more than one star) and any planets and other materials that orbit it.

galaxy is a great island of stars in space, containing from a few hundred million to a trillion or more stars, all held together by gravity and orbiting a common center.

cluster (or group) of galaxies is a collection of galaxies bound together by gravity. Small collections (up to a few dozen galaxies) are generally called groups, while larger collections are called clusters.

supercluster is a gigantic region of space where many individual galaxies and many groups and clusters of galaxies are packed more closely together than elsewhere in the universe.

universe (or cosmos) are the sum total of all matter and energy – that is, all galaxies and everything between them. observable universe The portion of the entire universe that can be seen from Earth, at least in principle. The observable universe is probably only a tiny portion of the entire universe.

9.3 Astronomical Distance Units

astronomical unit (AU) is the average distance between Earth and the Sun, which is about 150 million kilometers. More technically, 1 AU is the length of the semimajor axis of Earths orbit.

light-year is the distance that light can travel in 1 year, which is about 9.46 trillion kilometers.

9.4 Terms Relating to Motion

rotation is the spinning of an object around its axis. For example, Earth rotates once each day around its axis, which is an imaginary line connecting the North Pole to the South Pole.

orbit (revolution) is the orbital motion of one object around another. For example, Earth orbits around the Sun once each year.

expansion (of the universe) is the increase in the average distance between galaxies as time progresses. Note that while the universe as a whole is expanding, individual galaxies and galaxy clusters do not expand.

Doppler shift light is **bluer** if the object is moving **towards** the Earth, it is **redder** if the object is moving **away** from the Earth. The intensity of the light is related to the speed at which the object is moving toward / away from the Earth.

9.5 Telescopes

Diffraction limit The angular resolution before interference of light itself causes problems

10 Formulae and Values

Our solar system was formed 4.5 billion years ago, when about 2% of the galaxy's original Hydrogen and Helium had been converted to heavier elements. Thus the cloud which formed our galaxy was roughly 98% Hydrogen and Helium. The 2% of other materials form the core of the rocky planets in our systems, ie. the Earth.

The **Andromeda galaxy** is roughly 2.5 million light-years away and about $100,000$ light-years in diameter. **Sirius**, the brightest star visible in the night sky, is 8 light-years away. **Alpha Centauri**, the closest star system to our own (a three star system), is 4.4 light-years away.

- $E_k = \frac{1}{2}mv^2$
- $v = \lambda f$
- Energy $= hf = \frac{hc}{\lambda}$
- $v_{\text{radial}} = \frac{\Delta\lambda}{\lambda}\ c$
- $F = G\frac{m_1 m_2}{r^2}$

- $p^2 = \frac{4\pi^2}{(M_1+M_2)*G}\ a^3$ (in our solar system years^2 = A.U.^{3})
- $L = 4\pi^2 R^2 \sigma_{SB} T^4$
- Angular separation (rad) = $\frac{\text{semi-major axis (AU)}}{\text{distance parsecs}}$
- $r_{\text{planet}} \approx r_{\text{star}} * \sqrt{\text{fraction of light blocked}}$
- Eccentricity of an ellipse: $e = \frac{f}{a}$ where f is the distance from the center to a focus
- momentum = mass $*$ velocity
- $\text{SA}_{\text{sphere}} = 4\pi r^2$
- $\lambda_{\text{peak}} T = 2.898 * 10^{-3} m \cdot K$
- Time dilation: $t' = t * \sqrt{1 - \left(\frac{v}{c}\right)^2}$
- Length contraction: $l' = l * \sqrt{1 - \left(\frac{v}{c}\right)^2}$
- Mass increase: $m' = \dfrac{m}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$
- Angular size, physical size, and distance are related as $\frac{l_{angular}}{360} = \frac{l_{physical}}{2\pi d}$

11 Data

Speed of light $2.998 * 10^8 m/s$

Light year $9.461 * 10^{15}$ m = 63 241 AU

Observable Universe Boundary $14 * 10^9$ ly

Average Earth-Moon distance 385 000 km

Average Earth-Sun distance (1 AU) $1.4959 * 10^{11}$ m

Diameter of the Sun $1.391 * 10^6$ km

Planck's constant (h) $6.626 * 10^{-34} J \cdot s = 4.136 * 10^{-15} eV \cdot s$

StefanBoltzmann constant $5.67 * 10^{-8} \frac{W}{m^2 K^4}$

Gravitational constant $6.673 * 10^{-11} N \cdot (m/kg)^2$

	Mercury	Venus	Earth	Moon	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Mass (10^{24} kg)	0.330	4.87	5.97	0.073	0.642	1898	568	86.8	102	0.0131
Diameter (km)	4879	12,104	12,756	3475	6792	142,984	120,536	51,118	49,528	2390
Density (kg/m^3)	5427	5243	5514	3340	3933	1326	687	1271	1638	1830
Gravity (m/s^2)	3.7	8.9	9.8	1.6	3.7	23.1	9.0	8.7	11.0	0.6
Escape Velocity (km/s)	4.3	10.4	11.2	2.4	5.0	59.5	35.5	21.3	23.5	1.1
Rotation Period (hours)	1407.6	-5832.5	23.9	655.7	24.6	9.9	10.7	-17.2	16.1	-153.3
Length of Day (hours)	4222.6	2802.0	24.0	708.7	24.7	9.9	10.7	17.2	16.1	153.3
Distance from Sun (10^6 km)	57.9	108.2	149.6	0.384*	227.9	778.6	1433.5	2872.5	4495.1	5870.0
Perihelion (10^6 km)	46.0	107.5	147.1	0.363*	206.6	740.5	1352.6	2741.3	4444.5	4435.0
Aphelion (10^6 km)	69.8	108.9	152.1	0.406*	249.2	816.6	1514.5	3003.6	4545.7	7304.3
Orbital Period (days)	88.0	224.7	365.2	27.3	687.0	4331	10,747	30,589	59,800	90,588
Orbital Velocity (km/s)	47.4	35.0	29.8	1.0	24.1	13.1	9.7	6.8	5.4	4.7
Orbital Inclination (degrees)	7.0	3.4	0.0	5.1	1.9	1.3	2.5	0.8	1.8	17.2
Orbital Eccentricity	0.205	0.007	0.017	0.055	0.094	0.049	0.057	0.046	0.011	0.244
Axial Tilt (degrees)	0.01	177.4	23.4	6.7	25.2	3.1	26.7	97.8	28.3	122.5
Mean Temperature (C)	167	464**	15	-20	-65	-110	-140	-195	-200	-225
Surface Pressure (bars)	0	92	1	0	0.01	Unknown	Unknown	Unknown	Unknown	0
Number of Moons	0	0	1	0	2	67	62	27	14	5
Ring System?	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Global Magnetic Field?	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Unknown

* From the Earth

** Due to intense greenhouse effect of thick atmosphere

12 Lecture Slides

12.1 Scale of the Universe

12.1.1 Objects in the Universe

- Star: A large, glowing ball of gas that generates heat and light through nuclear fusion
- Planet: A moderately large object that orbits a star; it shines by reflected light. Planets may be rocky, icy, or gaseous in composition.
- Moon: An object that orbits a planet
- Asteroid: A relatively small and rocky object that orbits a star
- Comet: A relatively small and icy object that orbits a star
- Solar System: A star and all the material that orbits it, including its planets and moons
- Nebular: An interstellar cloud of gas and/or dust
- Galaxy: A great island of stars in space, all held together by gravity and orbiting a common center
- Universe: The sum total of all matter and energy; that is, everything within and between all galaxies

12.1.2 Light Travels

Light travels at a finite speed (3000,000 km/s) so the farther away we look the farther back in time we look. Light years are distance light travels in a year (9,460,000,000,000 km).

Destination	**Light travel time**
Moon	1s
Sun	8s
Sirius	8 years
Andromeda	2.5 million light years

12.1.3 The Universe is Big

We can't see a galaxy 15 billion light years away (universe is 14 billion years old) because looking 15 billion light-years away means looking to a time before the universe existed.

If we reduce the size of the solar system by a factor of 10 billion the sun is the size of a grapefruit and earth is the size of a ball point (15m from the sun)and alpha centauri is 2500 miles away

The milky way galaxy has about 100 billion stars. There are around 100 billion galaxies in universe. There are more stars in the universe than grains of sand on earth. It would take more than 3000 years to count the stars in the Milky Way Galaxy at a rate of one per second, and they are spread across 100,000 light-years.

The matter in our bodies came from the Big Bang, which produced hydrogen and helium. All other elements were constructed from H and He in stars and then recycled into new star systems, including our solar system. On a cosmic calendar that compresses the history of the universe into 1 year, human civilization is just a few seconds old, and a human lifetime is a fraction of a second.

12.1.4 Earth Moves Through Space

Earth orbits the sun at an average distance of 1AU = 150 million kilometers (at 107,000 km/h) and tilted by 23.5 ° rotating clockwise.

The sun moves 70,000 km/h and orbits the galaxy every 230 million years.

Galaxies in our Local Group are moving away from us and the farther a galaxy is the faster it is moving, which implies that we live in an expanding universe.

12.2 Discovering the Universe for Yourself

12.2.1 View from Earth

With the naked eye we can see $>$ 2000 stars as well as the milky way. Some of these stars are sorted into 88 constellations. These lie on the celestial sphere (all stars lie on celestial sphere).

- the **ecliptic** is the sun's apparent path through celestial sphere
- **north celestial pole** is directly above earth's north pole
- **celestial equator** is projection of earth's equator on celestial sphere

The milky way is a band of light making a circle around the celestial sphere (just our view into the plane of our galaxy).

12.2.2 Local Sky

An object's altitude (above horizon) and direction (along horizon) specify its location in your local sky.

- **meridian**: line throuh zenith and connecting N and S points on horizon
- **zenith**: point directly overhead
- **horizon**: all points 90 degress from zenith

12.2.3 Measurements

Angular size of sun	0.5 degrees
Angular size of moon	0.5 degrees
Width of finger	1 degree
Width of hand	20 degrees
Width of fist	10 degrees

Arcminutes (denoted ') are 1/60 of a degree and arcseconds are 1/60 of arcminutes (denoted ").

$$\text{angular size} = \text{physical size} \times \frac{360\,^\circ}{2\pi \times \text{distance}}$$

12.2.4 Star Rise

Earth rotates west to east so starts appear to move east to west. Stars near the north pole are circumpolar and never set. Starts near south pole are not seen. What constellations we see depends on latitude (but not longitude) because position on Earth determines which constellations remain below the horizon, and time of year because Earth's orbit changes the apparent location of the Sun among the stars.

The altitude of the celestial pole equals your latitude (ex if Polaris is $50\,^\circ$ above the horizon due north you are at latitude $50\,^\circ$N). All constellations move counter clockwise around Polaris.

12.2.5 Seasons

Direct sunlight heats more so in the summer we are angled toward the sun so we get more direct sunlight. Sun's position varies by season (summer has is higher). Earth's distance from Sun varies by at most 3% so it cannot effect the temperature as much as the axis tilt can.

- Summer solstice: highest path (rise and set at most extreme north)
- Winter solstice: lowest path (rise and set at most extreme south) for this half of the year the sun's angle at north pole is less than 0
- Spring/Fall equinox: middle path (rise and set at exactly east and west) here the angle of sun at noon on north pole is earth's axis tilt.

Earth's axis rotates once every 26,000 years

12.2.6 The Moon

Moon's phases:

- new (6am to 6pm)
- waxing crescent (glowey bit on the right) (9am to 9pm)
- first quarter (noon to midnight)
- waxing gibbous (3pm to 3am)

- full (6pm to 6am)
- waning gibbous (9pm to 9am)
- last quarter (midnight to noon)
- waning crescent (glowey bit on the left) (3am to 3pm)

A lunar eclipse occurs when earth casts a shadown across the moon. **Penumbra** is a glowing ring around (due to light refraction) **umbra** which is strict shadow.

- full lunar eclipse - moon passes through umbra
- partial lunar eclipse - moon partially passes through umbra
- penumbral lunar eclipse - moon passes through penumbra

Eclipses only occur wiht a full moon at night.

A solar eclipse only occurs at new moon during the day.

The Moon's orbit is tilted 5 to ecliptic plane. So we have about two eclipse seasons each year, with a lunar eclipse at new moon and solar eclipse at full moon.Eclipses recur with the 18-year, 11 1/3-day saros cycle, but type (e.g., partial, total) and location may vary.

12.2.7 Ancient Planets

- Mercury
  - difficult to see; always close to Sun in sky
- Venus
  - very bright when visible, morning or evening "star"
- Mars
  - noticeably red
- Jupiter
  - very bright
- Saturn
  - moderately bright

Ancients saw planets that moved eastward relative to the starts but occasionally went backwards (called **retrograde**). Impossible to explain with geocentric universe. The greeks rejected the heliocentric universe because they couldn't observe the stellar paralax (difference in position of a star as seen from earth) because the change in distance was too small to be measured.

12.3 Science of Astronomy

The seven days of the week were named after the sun, moon, and five visible planets (tues-mars, wed-mercury, thurs-jupiter, fri-venus, sat-saturn).

Some ancient time peices:

- Stonehenge
- Templo Mayor (mexico)
- Sun dagger marks solstice(US)
- Macchu Picu
- Polynesia were good celestial navigators
- China first to record supernovas

12.3.1 Ancient Greeks

Greeks were the first people known to make models of nature. They tried to explain patterns in nature without resorting to myth or the supernatural.

Eratosthenes measured the size of earth in 240BC: Distance between two cities (Syene and Alexandria) was 5000 stadia, using a stick in a hole he could see that when the sun was directly overhead of alexandria it was off by 7 degrees in Syene. 7/360 * (circumference of earth) = 5000 stadia. Was only off by 2000km.

Greeks used geocentric model(heaves must be perfect with everything being perfect spheres and circles). This couldnt explain retrograde motion. Ptolemy came up with the most sphisticated geocentric model and it was accurate enough to be in use for 1500 years. He explained retrograde motion by having planets make little circles occasionally in their larger orbit of earth.

Which of the following is NOT a fundamental difference between the geocentric and Sun-centered models of the solar system?

1. Earth is stationary in the geocentric model but moves around Sun in Sun-centered model.
2. Retrograde motion is real (planets really go backward) in geocentric model but only apparent (planets don't really turn around) in Sun-centered model.
3. Stellar parallax is expected in the Sun-centered model but not in the Earth-centered model.
4. **F** The geocentric model is useless for predicting planetary positions in the sky, while even the earliest Sun-centered models worked almost perfectly.

Greek knowledge was preserved through:

- The Muslim world preserved and enhanced the knowledge they received from the Greeks.
- Al-Mamun's House of Wisdom in Baghdad was a great center of learning around A.D. 800.
- With the fall of Constantinople (Istanbul) in 1453, Eastern scholars headed west to Europe, carrying knowledge that helped ignite the European Renaissance.

12.3.2 Copernican Revolution

Copernicus:

- Proposed a Sun-centered model (published 1543)
- Used model to determine layout of solar system (planetary distances in AU) But . . .
- The model was no more accurate than the Ptolemaic model in predicting planetary positions, because it still used perfect circles.

Tycho Brahe:

- Compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.
- Still could not detect stellar parallax, and thus still thought Earth must be at center of solar system (but recognized that other planets go around Sun).
- Hired Kepler, who used Tycho's observations to discover the truth about planetary motion.

Johannes Kepler:

- Kepler first tried to match Tycho's observations with circular orbits
- But an 8-arcminute discrepancy led him eventually to ellipses.

Kepler's laws:

1. The orbit of each planet around the Sun is an ellipse with the Sun at one focus
2. As a planet moves around its orbit, it sweeps out equal areas in equal times (means that a planet travels faster when it is nearer to the sun)
3. More distant planets orbit the Sun at slower average speeds, obeying the relationship: $p^2 = a^3$ where p = orbital period in years and a = avg. distance from Sun in AU

Gelileo fixed some flaws in Compernican revolution:

- Earth could not be moving because objects in air would be left behind.
  - Galileo's experiments showed that objects in air would stay with Earth as it moves, showed that objects will stay in motion unless a force acts to slow them down
- Non-circular orbits are not "perfect" as heavens should be.
  - Tycho's observations of comet and supernova already challenged this idea.
  - Galileo used telescope to spot imperfections (sunspots, and craters on the moon)
- If Earth were really orbiting Sun, we'd detect stellar parallax.
  - Galileo showed stars must be much farther than Tycho thought in part by using his telescope to see the Milky Way is countless individual stars. If stars were much farther away, then lack of detectable parallax was no longer so troubling.

He also saw Jupiter's moons so not everything was orbiting earth. Proved Venus' orbit of the sun and used it to explain retrograde motion.

12.3.3 Scientific Theory

Science Hallarks:

- Modern science seeks explanations for observed phenomena that rely solely on natural causes.(A scientific model cannot include divine intervention)
- Science progresses through the creation and testing of models of nature that explain the observations as simply as possible. (Simplicity = "Occam's razor")
- A scientific model must make testable predictions about natural phenomena that would force us to revise or abandon the model if the predictions do not agree with observations

A scientific theory must:

- Explain a wide variety of observations with a few simple principles
- Must be supported by a large, compelling body of evidence
- Must NOT have failed any crucial test of its validity

12.3.4 Astrology

Astronomy is a science focused on learning about how stars, planets, and other celestial objects work. Astrology is a search for hidden influences on human lives based on the positions of planets and stars in the sky.

12.4 Making Sense of the Universe: Understanding Motion, Energy, and Gravity

Momentum = mass X velocity.

Angular momentum = mass x velocity x radius

Remember that force is based on acceleration not speed.

Remember that weight force and mass is matter

Newtons Laws:

- An object moves at constant velocity unless a net force acts to change its speed or direction.
- Force = mass x acceleration
- For every force, there is always an equal andopposite reaction force

Conservation Laws:

- conservation if momentum
  - The total momentum of interacting objects cannot change unless an external force is acting on them.
  - Interacting objects exchange momentum through equal and opposite forces.

- conservation of angular momentum
  - The angular momentum of an object cannot change unless an external twisting force (torque) is acting on it.
  - Earth experiences no twisting force as it orbits the Sun, so its rotation and orbit will continue indefinitely.

Types of energy:

- Kinetic (motion)
- Radiative (light)
- Potential (stored)
- Thermal: The collective kinetic energy of many particles
  - Temperature is the average kinetic energy of the many particles in a substance
- Gravitational Potential
  - In space, an object or gas cloud has more gravitational energy when it is spread out than when it contracts. A contracting cloud converts gravitational potential energy to thermal energy
  - $F_g = G\frac{M_1 M_2}{d^2}$
  - items orbit around their center of mass (usually close to the big thing they are orbiting)
- Mass: $E = mc^2$
  - A small amount of mass can release a great deal of energy (for example, an H-bomb).
  - Concentrated energy can spontaneously turn into particles (for example, in particle accelerators).

We combine Newton's law of gravity and Keplers orbital law:

$$p^2 = \frac{4\pi^2}{G(M_1+M_2)}a^3$$
p = orbital period
a = average orbital distance
M = object masses

The total orbital energy is the sum of gravitational and kinetic and remains the same (which is why we go faster closer). This means its very hard to change an orbit.

Earth's escape velocity is 11km/s (40000km/h)

Tides:

- caused by moon being closer to one side
- depends on phase because of sun's position
- tidal friction slows earths rotation, making moon get farther from Earth

12.5 Light and Matter: Reading Messages from the Cosmos

How do light and matter interact?

- emission/absorption (determines brightness)
- transmission
- reflection (determines color)

12.5.1 Waves

Speed of light = wavelength x frequency
Photon energy = (6.626*1010$^-$34) plancks constant * frequency

Polarization is the direction a light wave is vibrating

12.5.2 Matter

Vocabulary:

- Atomic number = # of protons in nucleus
- Atomic mass number = # of protons + neutrons
- Isotope: same # of protons but different # of neutrons
- Ionization: stripping of electrons, changing atoms into plasma
- Dissociation: breaking of molecules into atoms
- Evaporation: breaking of flexible chemical bonds, changing liquid into solid
- Melting: breaking of rigid chemical bonds, changing solid into liquid

12.5.3 Light

Three types of spectra: emission line (specific elements emit light at certain wavelengths due to electrons jumping), continuous, absorption line (a cloud in between absorbes some light).

12.5.4 Thermal Radiation

Hotter objects emit more light at all frequencies per unit area. Hotter objects emit photons with a higher average energy.

Wein's law approximates starts to blackbody radiators (absorbs all kinds of radiation and emits energy regardless). Peak wavelength times the temperature is a constant (Plank radiation constant): $\lambda_{peak}T = 2.898 \times 10^3$. This also means that stars of shorter wavelength (blue) are hotter.

Interpretting Spectrum:

- look for parts of the visible spectrum that have lower intensity (low intensity blue light means it looks red and vice versa)
- look for a spike in the infrared to indicate tempurature
- look for absorbtion lines for the content of the atmosphere
- look for emission lines to describe the upper atmosphere

12.5.5 Doppler effect

As something moves towards us its spectrum gets shifted

1. measure spectrum of stars composition in lab (heat gases)
2. measure spectrum of star
3. compare placement of lines
4. if wavelength of star is longer than lab (it shifted right/red) its moving away
5. $f_{star} = \sqrt{\frac{c-v}{c+v}} \times f_{lab}$

When an object is rotating the width of its spectral lines can tell us how fast its spinning.

12.6 Telescopes Portals of Discovery

Two most important properties of telescopes:

- Light-collecting area: Telescopes with a larger collecting area can gather a greater amount of light in a shorter time.
  - $A = \pi r^2$
- Angular resolution: Telescopes that are larger are capable of taking images with greater detail.
  - minimum angular separation the telescope can distinguish, diffraction limit is caused by interference of light waves in telescope (larger = less interference)

Two basic designs:

- refracting: focus light with lenses
  - need to be long and large with heavy lenses
- reflecting: focus light with mirrors
  - larger diameters
  - most common

Uses of telescopes:

- imaging: pictures

  - record only one color at a time
  - use color to represent invisible light
- spectroscopy: breaking up light spectra
- time monitoring: watching how light output of object varies with time

Problems:

- twinkling: turbulence in earths atmosphere distorts veiw and causes stars to twinkle (can be fixed by rapidly changing the shape of the mirror)
- light pollution
- certain wavelengths cannot pierce atmosphere
  - gamma rays - 10km, balloons
  - x rays - 100km, rockets
  - ultraviolet - some reach earth but some require rockets
  - visible - reaches ground
  - infrared - 5km, some mountains, planes
  - radio - reaches ground

Telescopes:

- radio: giant mirror that reflects radio waves to focus point
- infrared and ultraviolet: like visible telescopes but need to be above the atmosphere
- x-ray: also need to be above atmosphere, mirrors arranged to focus x-ray photons through grazing bounces off of mirrors
- gamma-ray: also need to be above atmosphere, fucking hard to focus gamma rays

Multiple telescopes (Inferometry) increase the angular resolution of a single large image

12.7 Our Planetary System

What does the solar system look like?

- There are eight major planets with nearly circular orbits.
- Dwarf planets are smaller than the major planets and some have quite elliptical orbits.
- Planets all orbit in same direction and nearly in same plane.

Comparative Planetology (find patterns among planets)

- Planets are very tiny compared to distances between them.
- All large bodies in the solar system orbit in the same direction and in nearly the same plane and most rotate in the same direction

- two planet types
  - terrestrial
  - jovian
- Many rocky asteroids and icy comets populate the solar system.

Exceptions:

- Uranus spins sideways
- earth has a large moon
- venus rotates backwards

Objects:

- sun
  - Over 99.9% of solar system's mass
  - Made mostly of H/He gas (plasma)
  - Converts 4 million tons of mass into energy each second
- mercury
  - Made of metal and rock; large iron core
  - Desolate, cratered; long, tall, steep cliffs
  - Very hot, very cold: 425C (day), 170C (night)
- venus
  - Nearly identical in size to Earth; surface hidden by clouds
  - Hellish conditions due to an extreme greenhouse effect
  - Even hotter than Mercury: 470C, day and night
- earth
  - An oasis of life
  - The only surface liquid water in the solar system
  - A surprisingly large moon
- mars
  - Looks almost Earth-like, but don't go without a spacesuit!
  - Giant volcanoes, a huge canyon, polar caps, more
  - Water flowed in distant past; could there have been life?
- jupiter
  - Much farther from Sun than inner planets

  - Mostly H/He; no solid surface
  - 300 times more massive than Earth
  - Many moons, rings
    * Io (shown here): active volcanoes all over
    * Europa: possible subsurface ocean
    * Ganymede: largest moon in solar system
    * Callisto: a large, cratered "ice ball
- saturn
  - Giant and gaseous like Jupiter
  - Spectacular rings:Rings are NOT solid; they are made of countless small chunks of ice and rock, each orbiting like a tiny moon.
  - Many moons, including cloudy Titan
- uranus
  - Smaller than Jupiter/Saturn; much larger than Earth
  - Made of H/He gas and hydrogen compounds(H2O, NH3, CH4)
  - Extreme axis tilt
  - Moons and rings
- neptune
  - Similar to Uranus (except for axis tilt)
  - Many moons (including Triton)
- dwarf planets
  - Much smaller than major planets
  - Icy, comet-like composition
  - Pluto's main moon (Charon) is of similar size

Planet	Relative Size	Average Distance from Sun (AU)	Average Equatorial Radius (km)	Mass (Earth = 1)	Average Density (g/cm^3)	Orbital Period	Rotation Period	Axis Tilt	Average Surface (or Cloud-Top) Temperature[b]	Composition	Known Moons (2012)	Rings?
Mercury		0.387	2440	0.055	5.43	87.9 days	58.6 days	0.0°	700 K (day) 100 K (night)	Rocks, metals	0	No
Venus		0.723	6051	0.82	5.24	225 days	243 days	177.3°	740 K	Rocks, metals	0	No
Earth		1.00	6378	1.00	5.52	1.00 year	23.93 hours	23.5°	290 K	Rocks, metals	1	No
Mars		1.52	3397	0.11	3.93	1.88 years	24.6 hours	25.2°	220 K	Rocks, metals	2	No
Jupiter		5.20	71,492	318	1.33	11.9 years	9.93 hours	3.1°	125 K	H, He, hydrogen compounds[c]	67	Yes
Saturn		9.54	60,268	95.2	0.70	29.5 years	10.6 hours	26.7°	95 K	H, He, hydrogen compounds[c]	62	Yes
Uranus		19.2	25,559	14.5	1.32	83.8 years	17.2 hours	97.9°	60 K	H, He, hydrogen compounds[c]	27	Yes
Neptune		30.1	24,764	17.1	1.64	165 years	16.1 hours	29.6°	60 K	H, He, hydrogen compounds[c]	13	Yes
Pluto		39.5	1160	0.0022	2.0	248 years	6.39 days	112.5°	44 K	Ices, rock	5	No
Eris		67.7	1200	0.0028	2.3	557 years	1.08 days	78°	43 K	Ices, rock	1	No

12.7.1 Spacecraft Exploration

Flyby: flys past a planet (usually a slingshot type path), cheapest but gathers less data

Orbiters: go into orbit around object, more time to gather data

Probes and Landers: land on surface, most expensive

Combination: an orbiter drops a lander and continues its orbit

12.8 Other Planetary Systems: The New Science of Distant Worlds

Its hard to learn about extrasolar planets because planets are too close to their star and too dark to easily see.

Planet Detection:

- Direct: pictures or spectra of the planets themselves
- Indirect: measurements of stellar properties revealing the effects of orbiting planets

Stars wobble back and forth a bit because they are also pulled by their planets' gravity which we can use to reveal the mass (this is a lower limit since we would need to know its tilt to be accurate) and orbit of planets. These changes are very hard to see and we need to use doppler technique to measure them (accurate to 1m/s of movement).

The first extrasolar planet was discovered around 51 Pegasi when a 4 day orbital cycle was found. This means that the planet is very close to the star (it also has a mass similar to jupiter)

If you see a star with a wobble of greater than 1 year it has a planet closer than 1AU.

We can also watch for changes in brightness when a planet passes infront of the star called a transit. We use this to tell the planet's radius. The Kepler mission was launched to look for these tiny changes in brightness.

We can also use gravitational lensing to see how a planet's mass bends the light of a star and dust disks to see gaps in disks of dust and gas around stars where planets are.

We can also monitor the change in spectrum during a planet's transit across its star to know about its atmosphere composition. Similarly we can measure the surface tempertaure of the planet by seeing how the temperature of the star changes as the planet passes it.

Most detected planets have orbits smaller than Jupiter's but this is because planets at a farther distance are harder to detect. Some extrasolar planets have more eliptical orbits and tend to have greater mass than Jupiter (this is also because smaller mass planets are harder to detect).

Extrasolar planet suprprises:

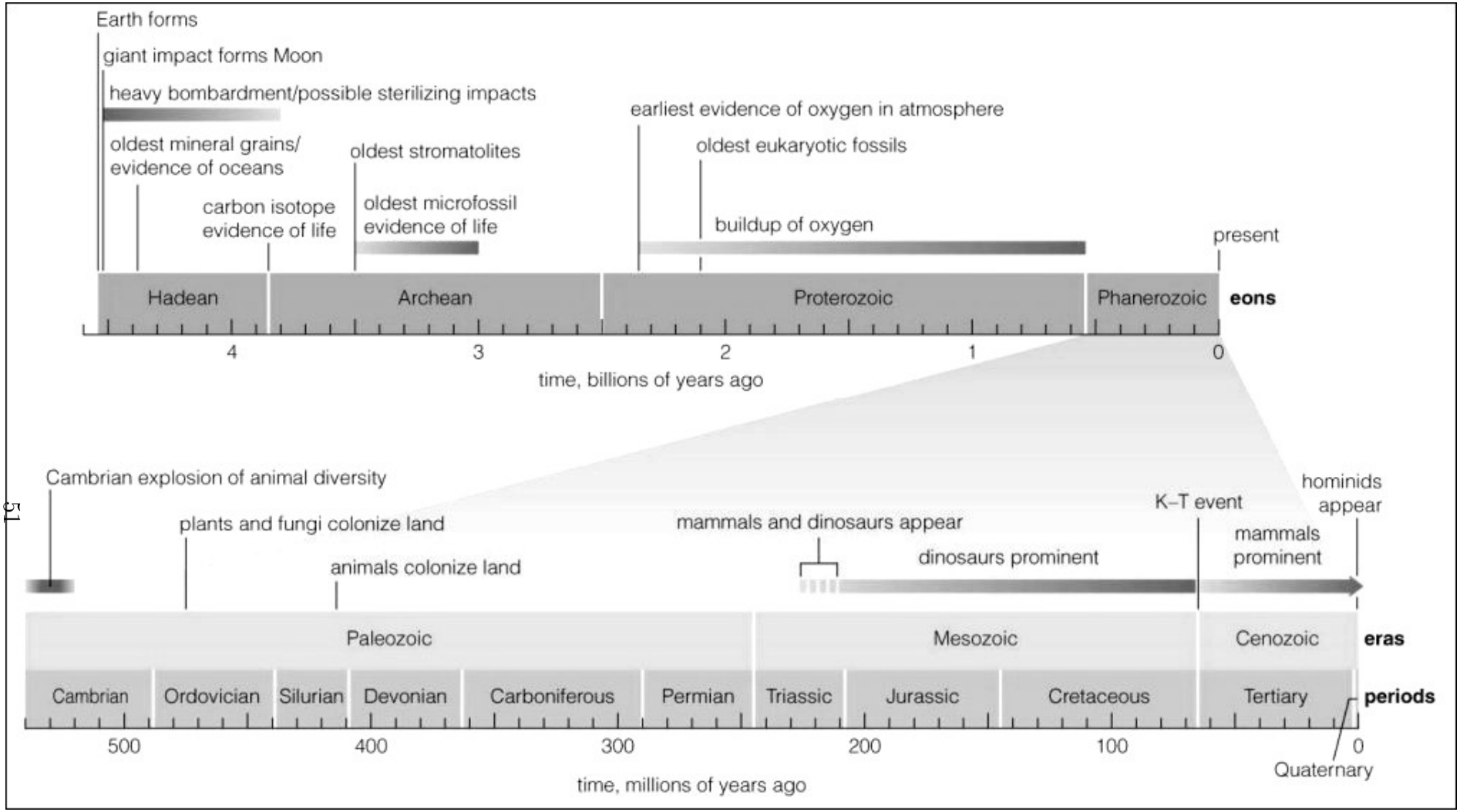
- highly elliptical orbits
- huge diversity of size and density
- massive planets very close to their start (hot Jupiters)
  - Nebular theory predicts that massive planets cannot form inside of frost line ($<<$ 5AU)

- may be explained by planetary migration or gravitational encounters
    - **planetary migration**: young planets spin very quickly and can form disks which can tug the planet's orbit inward
    - **gravitational encounters**: two massive planets getting two close to each other can result in one getting ejected into a highly elliptical orbit, multiple ones can cause a inward migration, this is due to one planet transfering energy and angular momentum to the other

The above weirdness caused a reevaluation of Nebular Theory

12.9 Life in the Universe

Life on earth started 3.85 billion years ago shortly after a heavy bombardment as fossils and carbon dating imply. Fossiles tend to be found in sedimentary rock.


Earth forms
giant impact forms Moon
heavy bombardment/possible sterilizing impacts
oldest mineral grains/
evidence of oceans
carbon isotope
evidence of life
oldest stromatolites
oldest microfossil
evidence of life
earliest evidence of oxygen in atmosphere
oldest eukaryotic fossils
buildup of oxygen
present
Hadean
Archean
Proterozoic
Phanerozoic
eons
4
3
2
1
0
time, billions of years ago
Cambrian explosion of animal diversity
plants and fungi colonize land
animals colonize land
mammals and dinosaurs appear
dinosaurs prominent
K–T event
mammals
prominent
hominids
appear
Paleozoic
Mesozoic
Cenozoic
eras
Cambrian
Ordovician
Silurian
Devonian
Carboniferous
Permian
Triassic
Jurassic
Cretaceous
Tertiary
periods
500
400
300
200
100
0
Quaternary
time, millions of years ago

We all know that life came about through evolution. Genetics builds a tree of life through relationships that implies a common ancestor for all life probably similar to bacteria found deep in the ocean near volcanic vents. We still dont know how that common ancestor came to be. The Miller-Urey experiment (among others) shows that the building blocks of life can arise spontaneously under the conditions of early earth.

Chemicals to Life:

1. Naturally forming organic molecules are building blocks of life
2. Clay minerals catalyze production of RNA and membranes that form pre-cells
3. Molecular natrual selection favors efficient self-replicating RNA molecules
4. True living cells with RNA genome give rise to RNA world
5. DNA evolves from RNA and biological evolution continues

One idea is that live could have come from another planet (Venus, Earth, and Mars exchanged tones of rock and some microbes can survive for years in space).

Brief History of life:

- 4.4 billion years - early oceans form
- 3.5 billion years - cyanobacteria start releasing oxygen
- 2.0 billion years - oxygen begins building up in atmosphere
- 540500 million years - Cambrian Explosion
- 22565 million years - dinosaurs and small mammals (dinosaurs ruled)
- Few million years - earliest hominids

Oxygen didn't always exist so readily on earth. The evolution of **cyanobacteria** kicked it off by releasing oxygen to the atmosphere using photosynthesis.

(Bear)Necessity of Life:

- nutrient source
- energy
- liquid water

12.9.1 Life on Other Planets

Erosion lines on mars imply that it had liquid water in its distant past, there is still subsurface ice would could result in near surface water near its volcanoes. The Curiosity rover landed on mars to investigate the habitability of the planet.

Another potential is the moon **Europa** which we think has a layer of liquid water or warm convecting ice. Two other Jupiter moons, **Ganymede** and **Callisto** also show evidence of subsurface oceans. Very little energy reaches these moons, but life may be possible.

The moon **Titan** is much too cold for liquid water (there may be some deep under the surface) but it does have lakes of liquid methane.

Encelandus has ice foundations that suggest it may have a subsurface ocean.

12.9.2 Life Outside our Solar System

Habitable Solar System:

- old enough to allow time for evolution (no high mass stars, too young, 1% of systems)
- need to have stable orbits (might rule out multistar systems, 50% of systems)
- must have habitable zone (place where planets of the right size could have liquid water), larger stars have larger zones

There are billions of stars in the milky way alone that fulfill the above constraints.

It is very hard to spot a earth like planet due to their size and distance from their star (see previous section on finding extrasolar planets for a better explanation). We launched Kepler specifically to look at 100,000 stars for habitable planets and future inferometers may be precise enough to see earth-sized planets.

We can also use spectrometry to see the composition of planets to determine if they have the elements necessary for life.

12.9.3 Earth-like Planets

Some scientists argue that the proportions of heavy elements need to be just right for the formation of habitable planets. If so, then Earth-like planets are restricted to a galactic habitable zone.

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Some scientists argue that plate tectonics and/or a large moon are necessary to keep the climate of an Earth-like planet stable enough for life.

We dont know how important the above concerns are so its very hard to make a guess as to how common earth-like planets are and how many would be habitable.

12.9.4 The Search for Extraterrestrial Intelligence

The drake equation tries to calculate how many civilization we could communicate with exist

$$N_{HP} \times f_{life} \times f_{civ} \times f_{now}$$

N_{HP} = total number of habitable planets in galaxy = probably billions
f_{life} = fraction of habitable planets with life = hard to say (near 0 or 1)
f_{civ} = fraction of life-bearing planets with civilization at some time = took 4 billion years on earth
f_{now} = fraction of civilizations around now = depends on if civilizations survive long-term

Humans are not very exceptional (not too far from a line of best fit) in our brain mass to body mass ratio.

SETI is designed to look for deliberate signals from extraterrestrial civilizations and even to send some messages of our own.

12.9.5 Interstellar Travel and Communications

Current spacecrafts travel at one ten thousandth of the speed of light which means it would take a ridiculous amount of time to get to the nearest stars. We sent a message out with Voyager in hopes of reaching one someday.

Problems with space travel:

- Far more efficient engines are needed.
- Energy requirements are enormous.
- Ordinary interstellar particles become like cosmic rays.
- Social complications of time dilation.

Fermi's paradox suggests that civilizations should be very common in our galaxy so why haven't we found any.

Explanations:

- life/civilization is much rarer than we might have guessed
- Civilizations are common, but interstellar travel is not
  - interstellar travel is more difficult than we think.
  - the desire to explore is rare.
  - civilizations destroy themselves before achieving interstellar travel.
- we just haven't met them yet

12.10 Space and Time

Einstein's Theories of Relativity:

- Special Relativity: usual ideas of space and time change as we approach the speed of light ($E = mc^2$)
  - no object can travel faster than light
  - observing a object near the speed of light:
    - time slows down
    - length contracts in direction of motion
    - mass increases

  - simultaneousness changes based on your frame of reference

- General Relativity: new views of gravity

Motion is relative. Usually how fast your percieve something is based on your velocity compared to it. The exception is light which always is seen at the same speed (called **absolute relativity**)

Postulates of special relativity:

- laws of nature are the same for everyone
- speed of light is the same for everyone

Time Dilation:

$$t_1 = t_0\sqrt{1 - \left(\frac{v^2}{c^2}\right)}$$

Length Contraction:

$$l_1 = l_0\sqrt{1 - \left(\frac{v^2}{c^2}\right)}$$

Mass Increase:

$$m_1 = \frac{m_0}{\sqrt{1-\left(\frac{v^2}{c^2}\right)}}$$

Since no information can be transfered faster than the speed of light objects traveling near the speed of light will perceived information at different rates since the information is moving much more slowly relative to their speed.

12.10.1 Tests for Relativity

Michelson-Morley experiment found evidence for the absoluteness of the speed of light in 18887.

Time dilation occurs often to subatomic particles in accelerators.

Time dilation discovered with airplanes and very precise clocks.

$E = mc^2$ verified by measurements taken of the sun.

If the speed of light were not absolute light coming from a car moving towards you would travel at 100km/hr + c and a car moving parallel to you would be see at 100 km/hr so witnessing their collision would look very odd.

12.11 Searching the Stars

12.11.1 Brightness

The brightness of a star depends on both distance and luminosity (amount of power a star radiates in energy per second, ie. Watts). The apparent brightness is the amount of starlight that reaches

Earth in energy per second per square meter.

In concentric spheres, the amount of luminsoty through each sphere is identical, ie. we can divide luminosity by area to find brightness ($b = \frac{l}{2\pi d^2}$).

The brightness at a distance three times farther, then, is, one-ninth as much.

Given the parallax angle p in arcseconds, the distance in parsecs is the inverse of p and the distance in light-years is $d = 3.26 * \frac{1}{p}$.

We define magnitude m and apparent magnitude M as and ratio in luminosity is equal to $(100^{\frac{1}{5}})^{M_1 - M_2}$ and the ratio in apparent brightness is $(100^{\frac{1}{5}})^{m_1 - m_2}$. Thus, the birghter a star is, the lower its magnitude. We can think of magnitude as a "ranking" of stars by brightness.

12.11.2 Star Spectrums

Absorption lines in a star's spectrum tell us its ionization level. These lines also correspond to a spectral type which revels its temperature (from hottest to coolest: O B A F G K M).

12.11.3 Thermal Radiation

Hotter objects emit more thermal radiation at all frequencies.

The hottests stars are approximately $50,000K$, the coolest are $3,000K$. Ours is roughly $5,800K$. Note that these are surface temperatures: our Sun's core has a temperature of roughly ten million Kelvin.

Note that the mass of these suns range from 0.08 to 100 timex the mass of our Sun.

The life expectancy of our star is 10 billion years. A star ten times more massive uses 10^4 times as much fuel, so lasts only 10 million years.

12.11.4 Binary Systems

About half of all stars are in binary systems.

12.12 Patterns Among Stars

An H-R diagram plots the luminosity and temperature of stars. Most stars fall on its main sequence.

Detailed modeling of the oldest global clusters reveal they are about 13 billion years old.

12.13 Stellar Nurseries

Stars form in dark clouds of dusty gas in interstellar space. The gas between stars is called the **interstellar medium**.

The molecular clouds – which contain the bulk of matter in interstellar space – have a temperature of ten to thirty Kelvin and densities of approx 300 molecules per cubic cm.

Long wavelength light such as infrared light passes through these clouds more easily than visible light; this is why we can see the center of the Milky Way only with infrared light.

Gravity can create stars only if it can overcome the force of thermal pressure within the cloud. A typical cloud must contain at least a few hundred solar masses to overcome this pressure.

Gravity within a contracting gas cloud becomes smaller as the gas becomes denser; thus it can cause the cloud to break apart into fragments which may each form a star.

As contraction packs molecules closer, it becomes difficult for infrared and radio photons to escape. Thermal energy and pressure then build up. This slows down contractions, and the center of the cloud fragment becomes a **protostar**.

Protostars *must* be rotating in order to form planets.

More low-mass stars tend to form than high-mass ones.