perihelion - closest to center of orbit

aphelion - farthest away from center of orbit

Apollo missions - land on moon, Apollo 18 - space elevator mission

Coronae - huge ring shaped cracks in the surface, up to 100 km across

Novae - huge cracks and ridges shaped like stars

Arachnoids - web-like patterns that combine the two

Sun → G type star, 15×10^6 °C ^(core temp), 1.43856×10^8 km from Earth, all metallicity is based on this - ecliptical coordinate system

Starbirth - Nebulae

Nebulae - enormous collapsing clouds of gas and dust

They glow as the gas atoms are excited by radiation from newborn stars

Dark & dusty areas form huge columns that engulf stars & block out light from the background

Bok Globules, which are individual dark clouds, are found within these columns.

They collapse under their own gravity, pulling in more material from their surroundings.

They are made from "Pillars of Creation", which are the aforementioned huge columns of dust & gas. Each pillar is several light years long (really long!). The pillars gradually separate into ball-shaped masses, called Bok globules, each of which is a light year or more across. These things are the beginnings of new solar systems - as they collapse on themselves their centres eventually ignite as new stars.

Young Stars

Stars are born when the collapsing balls of gas within a nebula become hot and dense enough to trigger nuclear reactions in its core. Because it is surrounded by so much material, it remains unstable for a long time - often varying in brightness with unpredictable and violent results. It may throw off excess material as high-speed jets in line with its poles of rotation

Young Stars "Growing Pains"

The aforementioned jets are not the only effects of young stars. When the jets travel outwards from the star, it keeps going until it hits the original nebula(e). This causes a whole lot of dust and gas to billow out in flowing clouds. These are known as Herbig-Haro (HH) objects

Systems of Stars

More than half of all stars are members of binary/multiple systems. Essentially, these are stars that were born in the same nebulae and are eternally locked in orbits around each other.

Larger groups are called "clusters" and contain either very young or very old stars. There are few exceptions.

Unpredictable and young T-Tauri stars.

Open cluster - young

Globular cluster - old

In globular clusters stars are often extremely old. Theories state that massive black holes may have helped them keep together

In open clusters, the stars are held together simply because they are close to each other. In a few million years, most of them will drift apart, causing the cluster to disintegrate.

Note "old" means formed at approximately the same time as our very own Milky Way.

Pleiades (Seven Sisters) Found in Taurus

M45

440 ly away

43 ly in diameter

Features a rich store of massive blue-white stars

Seven stars are bright enough to see with the naked eye (hence the name)

Pleiades do not emit much infrared light

There are app. 1,000 stars total

The cluster is still surrounded by webs of ghostly gas - the remains of the mother nebula

Harvard Spectral Classification

Type	Temperature (K)	Colour	Hydrogen Lines
O	30,000 - 60,000	Blue	Weak
B	10,000 - 30,000	Blue-white	Medium
A	7,500 - 10,000	White	strong
F	6,000 - 7,5000	White	Medium
G	5,000 - 6,000	Yellow	weak
K	3,500 - 5,000	Yellow Orange	Very weak
M	2,000 - 3,5000	Red	Very weak

This is based on surface temperature, not core temperature. Generally, as temp increase, so does luminosity (but that is Yerkes Spectral Classification). Each one of the classes is also subdivided into 10 subdivisons (0-9).

Yerkes Spectral Classification

Type Ia : bright supergiants
Type Ib : normal supergiants
Type II : Bright giant
Type III : normal giant
Type IV : sub giants
Type V : main sequence (majority of stars)
Type VI : sub-dwarf
Type VII : white dwarf

Based on luminosity and temperature. Also known as luminosity classes

Galaxies

← spiral galaxy

Spiral Galaxies — look like spiral things

- Prominent spiral arms & central bulge
- Star formation mostly in spiral arms of galaxy → Very high rate
- Almost all spiral galaxies have a galactic halo around them
- Theorized to have massive black hole at center

Barred Spiral Galaxies

Like spiral galaxies, but have barred arms

-Central bar, then spiral arms

Elliptical Galaxies

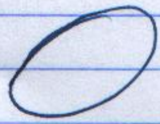
-These galaxies are elliptical / spherical

-Mostly Pop. II stars

- Barely any interstellar matter

-Very low rate of star formation

-rarest galaxy type in the Universe



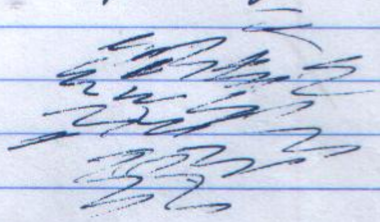
Irregular Galaxies

-No definite shape

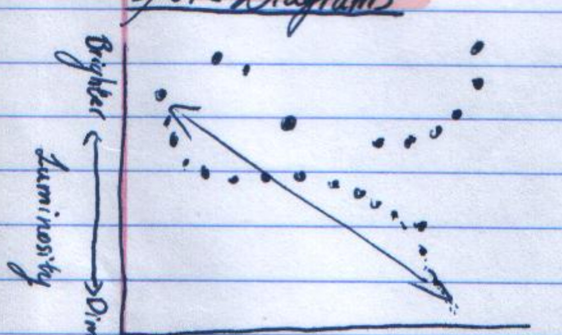
-Usually deformed spiral/elliptical galaxies (can be deformed by forces such as gravity)

- Contain a crapton of interstellar matter

-Extremely high star formation rate



HR Diagrams



-Comparison of temperature to luminosity

-Most stars fall along a diagonal stream called the "main sequence".

- The more massive a star is, the brighter it shines (in general)

-Red & yellow giants are exceptions, as are white dwarves

* Most of the Milky Way's stars are red dwarves. Funny, really...

Extrasolar ~~Pl~~ Planets

-There are a lot of solar systems out there. We're not unique here.

-Our system is unusually regular in orbits & stuff.

-We can really only detect these planets if they are the size of Jupiter

- first extrasolar planet to be photographed is 2M1207b
- PSR 1257+12 planetary system - orbits a burnt out pulsar - Really strong radio signals

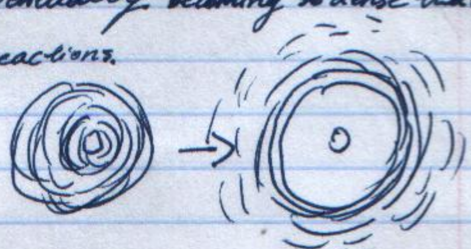
Strange Stars

- Stars usually vary because of changes in their internal structure or the way that they produce their energy.
- In violent cases, called novae, it is caused by the way that 2 stars in a binary system interact.

Monocerotis - a star with very strange action.
- Sudden flare-up followed by "light echoes"
- formed as light bounced off the sides of a tunnel of interstellar matter

- Nova outbursts are explosions on the surface of a dense white ~~star~~ dwarf star in a binary system. Stuff goes WHOOOM.

Possible scenario: companion star swells into red giant, pushing the outer layers into the dwarf's gravity. As the dwarf pulls material away, it piles on its own surface, eventually becoming so dense that it explodes in a burst of nuclear reactions.



Dying Stars

When a star exhausts the fuel in its core, it begins to burn the gas on its outer layers, which makes it unstable. This kind of star might shine more brightly than previously, but it also expands monumentally in size and the surface cools till it becomes a red giant.

Betelgeuse - red giant that can be seen from Earth, one of the largest stars that can be seen. Has a "hotspot". Will turn into Type II supernova. Average brilliance of 14,000 suns. App. **15** $M_\odot$. Offers detailed view of dying giant. So large it is unstable, fluctuating between 300 & 400 times the size of the Sun. Is a supergiant.
Beetle juice.

Radiation Laws

Wein's Law: $\lambda_{max} = b/T$

λ = maximum radiation in angstroms

b = Wein's constant (2,897,769 nmK)

T = temperature (in K)

Stefan-Boltzmann's Law: $L = 4\pi R^2 \sigma T^4$

σ = Stefan-Boltzmann's Constant ($5.6703 \times 10^{-8} \frac{watt}{m^2 K^4}$)

$4\pi R^2$ = surface area

T = temperature (in K)

ALTERNATIVELY:

$P = e \sigma A (T^4 - T_e^4)$

P = radiation rate

e = emissivity

A = area

T_c = Temperature of cooler surroundings

OR:

$P/A = \sigma T^4$ which simplifies to: (that first thing)

Apparently radiation is the same as luminosity here, so switch whatever

Luminosity Relations

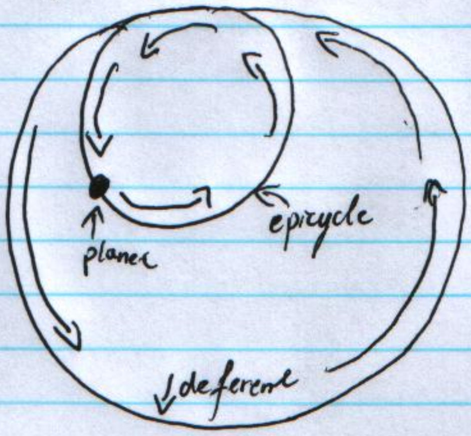
Inverse Square Law: $L = 1/r^2$

distance $= r^2$

L = luminosity

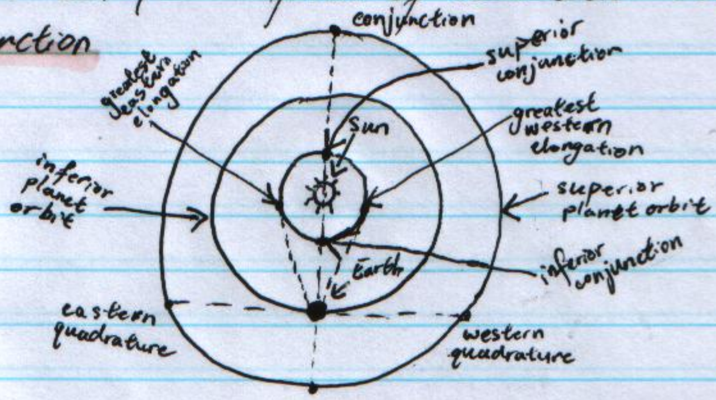
Retrograde Motion

- Some planets move across the sky, ~~east to~~ west to east, but then reverses direction for a bit before resuming its prior path. ↗ The very definition of backwards, or retrograde motion
- Greek scholars devised the theory of an epicycle that moved on a larger deferent. (Hipparchus)



Relative to Earth:

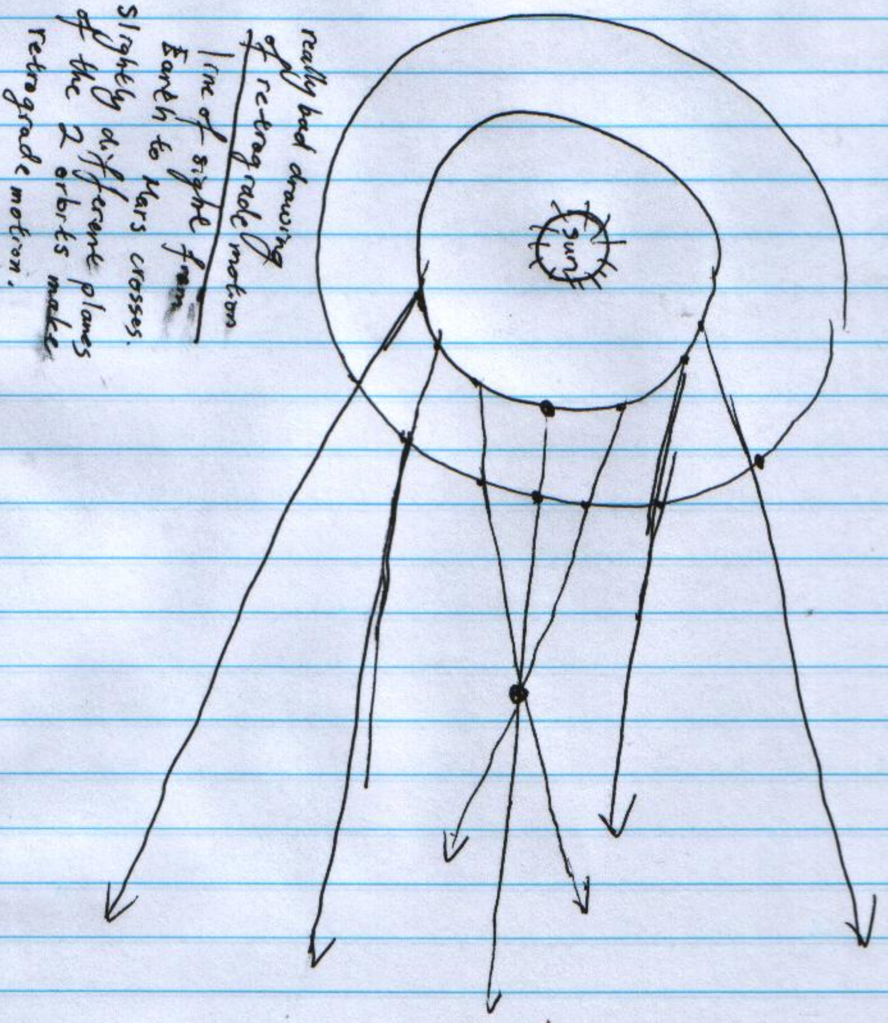
- Planets whose orbits are inside Earth are called inferior planets
- Maximum angular separation east or west of the Sun are known as greatest eastern elongation and greatest western elongation
- Superior planets can be seen 180° away from the Sun. This position is called opposition. Superior planets are outside Earth's orbit.
- inferior ~~Stars~~ planets can pass in front of solar disk - called inferior conjunction



- Time between oppositions is called synodic period (S).
- Time ~~between~~ to make 1 complete orbit relative to background stars is called sidereal perion (P).

$$\frac{1}{S} = \begin{cases} \frac{1}{P} - \frac{1}{P_{\oplus}} \\ \frac{1}{P_{\oplus}} - \frac{1}{P} \end{cases}$$

$P_{\oplus}$ is sidereal period of Earth (365.2563 days)



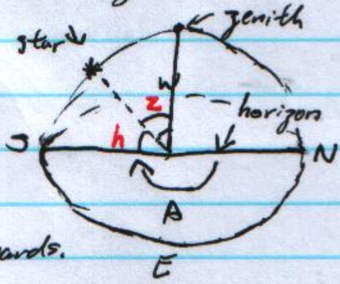
~~Hel~~ Heliocentric paradigm is born!

Coordinate Systems

Altitude-Azimuth System (also called ~~horiz~~ horizon system)

- h is defined as the angle measured from the horizon to the object in question
- z is defined as the angle measured from the zenith to the object in question

Therefore, $h + z = 90°$



- A, the azimuth, is the angle along the horizon measured from the north eastwards.

Completely based on observer's location; because of this, it is difficult to use in practise. The objects coordinates will change from day to day, minute to minutes, because of the motion of the Earth.

Equatorial System (Equatorial Coordinate System)

- Most popular
- right ascension and declination.
- Declination (denoted by δ) is the equivalent of latitude and is measured in degrees north or south of the celestial equator.
- Right ascension (denoted by RA or α) is equivalent of longitude and is measured eastward in hours.
  - 1 hour = 15°, 24h = 360°
- Measured based on J2000 epoch

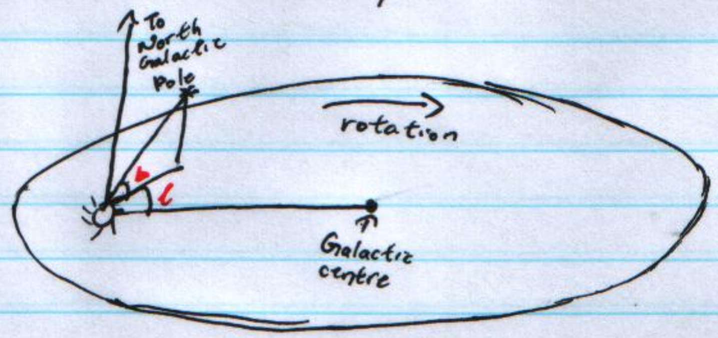
A Slight Side Note on J2000 epoch

- refers to Julian Calendar
- coordinates of an object are those of the objects position ~~on~~ at noon in Greenwich, England, on Jan. 1st, 2000

* NOT TO BE CONFUSED WITH JULIAN DATES

Galactic Coordinate System

- ~~Gl~~ Galactic midplane – plane that runs the the middle of the Milky Way
- It is not aligned with the celestial equator (it is actually inclined at a 62.87° angle to it)
- The galactic coordinate system uses the galactic midplane and disk.
- Galactic latitude (b) and galactic longitude (l) are defined relative to the Sun
- Both are measured in degrees.



Kepler's Laws of Planetary Motion

- Kepler was Tycho's student
- Tycho, fearful that Kepler would outshine him, gave him a very tedious task – mapping the orbit of Mars.
- Ironically, it was due to this that Kepler was able to formulate his laws of planetary motion.

Because Tycho's data was very precise, Kepler based his theories and analysis off that. When he found 2 points of discrepancy, he dismissed the idea that orbits were perfect circles, and instead hypothesized them to be ellipses.

This became Kepler's First Law.

Kepler's First Law:

A planet that orbits the Sun has a elliptical orbit, with the Sun at one focus of the ellipse.

Kepler's Second Law:

A line connecting a planet to the Sun sweeps out equal areas in equal time intervals.

- This law suggests that planets move faster when they are nearer to the Sun, and ~~farther~~ slower if they are farther away.

Kepler's Third Law (aka The Harmonic Law):

$P^2 = a^3$

where P = orbital period

a = distance (average) of the planet from the Sun in AU

(one AU is the distance from the Earth to the Sun (average).)

Newton's Laws of Motion and Universal Gravitation

Newton's First Law (The Law of Inertia)

An object at rest will remain at rest, and an object in motion will remain in motion in a straight line at a constant speed unless acted on by an ~~force~~ external force.

Newton's Second Law

The net force acting on an object is proportional to the object's mass and acceleration.

$F = ma$

Newton's Third Law

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

Law of Universal Gravitation

By combining Kepler's third law and his 3 laws of motion, Newton found the Law of Universal Gravitation.

$$F = G\frac{Mm}{r^2}$$

F = total force
G = Universal Gravitational Constant ($6.673 \times 10^{-11}\ Nm^2/kg^2$)
M = mass of larger object
m = mass of smaller object
r = distance between the two objects.

Parallax

- a technique of triangulation, measure angular position from 2 observation points separated by a known baseline. Using trig, the distance to the object can be measured.
- For astronomy, the baseline is the diametre of Earth's orbit around the Sun.
  - A star will exhibit a shift in position.
  - Using this we can find the parallax

  Then using:

$$d = 1/p$$

where d is in parsecs and p is in arcseconds

  we can find the distance.

  This is called trignometric parallax

* Be careful with your units! Most parallax is measured in mas, or milliarcseconds, so you will have to convert to arcseconds by dividing by 1000.

By this definition, when the parallax is 1 arcsecond, then the distance is 1 parsec (pc).

From Earth, trignometric parallax can only be used with objects up to 100 pc away. However, satellites such as Hipparcos, SIM PlanetQuest, and Gaia have been able to measure parallax angles with a precision of down to 4 mas.

Magnitude Scales

Apparent Magnitude

- how bright objects seem from Earth

The Greek astronomer Hipparchus developed the apparent magnitude system, assigning a value of 1 to the brightest stars and a value of 6 to the dimmest.

The scale is now a logarithmic scale, since the human eye is thought to respond to the difference of the logarithms of brightness. A star with a magnitude of 1, therefore, is exactly 100 times brighter than a star with a magnitude of 6. Therefore a difference of 5 magnitudes corresponds directly to brightness.

Flux & Luminosity

- "Brightness" of a star is actually radiant flux, or the total energy emitted from a star. that crosses a unit area. (# J/s m) J/s^m
- Luminosity: energy emitted per second

Related by:

$$F = \frac{L}{4\pi r^2} \quad \text{or as I prefer} \quad F = \frac{L}{2\tau r^2}$$

where: F = flux
L = luminosity
$4\pi r^2$ = area of a sphere

← Inverse Square Law

Absolute Magnitude

- how bright an object actually is (measured at 10pc)
- can be determined using Inverse Square Law
- Flux ratio of stars (actual distance & 10 pc) given by:

$$\frac{F_2}{F_1} = 100^{(m_1 - m_2)/5}$$

F_2 is flux at 10 pc
F_1 is flux at actual distance
m_1 is magnitude at actual distance
m_2 is magnitude at 10 pc.

The Distance Modulus

By combining the inverse square law and the absolute magnitude equation, we get:

$$100^{(m-M)/5} = \frac{F_{10}}{F} = \left(\frac{d}{10pc}\right)^2$$

Solving for d (the distance), we have

$$d = 10^{(m-M+5)/5} \text{ pc}$$

Therefore, m-M is a measure of distance as well, and the distance modulus is:

~~[illegible]~~

$$m-M = 5\log_{10} d - 5 = 5\log_{10}\left(\frac{d}{10pc}\right)$$

← Important equation

$$M = M_\odot - 2.5\log_{10}\left(\frac{L}{L_\odot}\right)$$

$$m = M_\odot - 2.5\log_{10}\left(\frac{F}{F_{10}}\right)$$

Light As a Wave

- denoted as c
- c = 2.99792458 × 10^8 m/s

$c = \lambda \nu$ OR as I prefer it, $c = \lambda f$

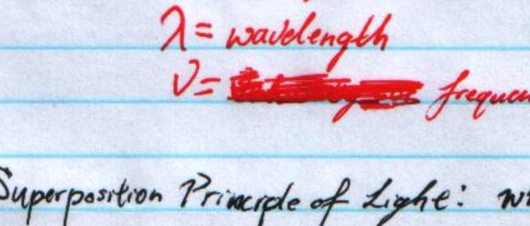
λ = wavelength

ν = ~~[illegible]~~ frequency (I prefer using f

Superposition Principle of Light: when two waves meet, they add algebraically

If a crest meets a crest, a bright fringe is produced.

If a crest meets a trough, a dark fringe is produced.



The Electromagnetic Spectrum

Radio	$10 < \lambda$
Microwave	$1mm < \lambda < 10cm$
Infrared	$700nm < \lambda < 1mm$
Visible	$400 nm < \lambda < 700 nm$
Ultraviolet	$10 nm < \lambda < 400 nm$
X-ray	$1 nm < \lambda < 10 nm$
Gamma ray	$\lambda < 1nm$

All of this is technically "light".

Blackbody Radiation *IMPORTANT SECTION

A perfect blackbody is a theoretical object that both absorbs and emits all energy. All energy in and all energy out.

- Stars and planets are rough black bodies.
- The hotter the star is, the smaller the wavelength within the EM spectrum is that it will peak at.
- This peak wavelength is known as λ_{max}
- It is given by Wien's Displacement Law:

$$\lambda_{max} = \frac{2.897 mm}{T_K}$$

2.897mm is Wien's constant

T_K is the temperature in Kelvin.

Stefan-Boltzmann Law

- As temperature of blackbody increases, it emits more energy per second at ALL wavelengths.

$$F = \sigma T^4$$

F = energy flux

σ = Stefan-Boltzmann constant ($5.67 \times 10^{8} \frac{W}{m^2 K^4}$)

T = temperature in Kelvin

MEMORISE THIS!

Learn it!
Live it!
Love it!
it's astro... you have to love it.

The Planck Function

- Derived from Rayleigh-Jeans Law and the opposing law

actually created an "ultraviolet catastrophe" → only worked if wavelengths were long (Rayleigh-Jeans Law) ; only worked if wavelengths were short (the opposing law)

The Planck Function!

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT}-1} \qquad B_\lambda T = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT}-1}$$ ← written prettier and better

B_λ = energy per unit time per unit volume

T = temperature in Kelvin

c = speed of light

λ = wavelength of light

k = Boltzmann constant (8.617×10^{-5} eV/K)

h = Planck's constant (6.626×10^{-34} Js)

Because "le" sounds cooler than "the"

Le Colour Index

- absolute and apparent magnitudes measured over all wavelengths, not just visible, are known as bolometric magnitude. It is denoted with a "bol" subscript.

BUT in practise, detectors can only measure radiant flux within a certain range, which varies with the instrument.

SO we have a system where we measure specific wavelengths and so measure the magnitude of the star at those wavelengths.

U for Ultraviolet. Filter of 365 nm with bandwidth of 68 nm.
B for Blue magnitude. Filter of 440 nm with bandwidth of 98 nm.
V for Visual magnitude. Filter of 550 nm with bandwidth of 89 nm.

Tada! The UBV system! (All standard, of course.) ← That says "all"

A star's U-B colour index is the difference between its UV and blue magnitudes.

more commonly seen, at least in astro → A star's B-V colour index is the difference between its blue and visible magnitudes

Stellar magnitudes decrease as the stars get brighter, so a star with a smaller BV index is bluer (and hotter, in both senses of the word) than a star with a larger one.

- The difference between a star's bolometric magnitude and its visual magnitude is called its **bolometric correction** ← bolometric correction

$$BC = m_{bol} - V = M_{bol} - M_V$$

BC = bolometric correction

m_{bol} = apparent bolometric magnitude

V = apparent magnitude, apparently (hehe, geddit)

M_{bol} = absolute bolometric magnitude

M_V = absolute magnitude (absolutely!)

The Special Relativity Theory

← we need not go in depth about this. That is for your physics classes.

Time Dilation: time goes slower if you are moving. Time will go fastest when observer or clock is at rest. Which is why a race seems so much longer to the runners than the spectators, I'm sure. The rate at which time passes at rest is called "proper time".

Length Contraction: The length of an object gets shorter as you move faster. At rest, its length is at its longest. This length is called the **proper length**.

This is used in the Doppler shift (the relativistic one).

You are an observer. There is an object moving at near the speed of light towards you. It appears... blue! This is said to be blueshifted. Then the object decides it doesn't want to come near you, and turns around and heads away at near the speed of light. It is now red! It is redshifted!

The Equation:

$$V_{obs} = V_{rest}\sqrt{\frac{1 \pm V_r/c}{1 \pm V_r/c}}$$

← I will explain how that is not 1!

V_{obs} = velocity observed

V_{rest} = velocity at rest

V_r = radial velocity

c = speed of light

For blue shift: $V_{obs} = V_{rest}\sqrt{\frac{1 - V_r/c}{1 + V_r/c}}$

For red shift: ~~[illegible]~~

$$V_{obs} = V_{rest}\sqrt{\frac{1 + V_r/c}{1 - V_r/c}}$$

See the difference in the signs? Don't get it mixed up.

Redshift is also how we know the universe is expanding - because everything is moving away from each other and therefore appears red.

Spectroscopy
← this is also important
You should pay attention to this

Kirchoff's laws (NOT the electrical ones)

- A hot, dense gas or hot solid object produces a continous spectrum with no dark lines.
- A hot, diffuse gas produces bright spectral lines, aka emission lines.
- A cool, diffuse gas produces dark spectral lines (aka absorption lines) when placed in front of a source of a continuous spectrum.

Applications!

- shift in spectral lines as result of the Doppler shift
- Therefore radial velocity (also called recessional velocity) can be calculated.

$$V_r = \frac{c(\Delta\lambda)}{\lambda_{rest}}$$

V_r = radial velocity
c = speed of light
$\Delta\lambda$ = change in wavelength ($\lambda_{obs} - \lambda_{rest}$)
λ_{rest} = wavelength at rest

← But this is also slightly outdated, though it's used in astro

Modern, classy astronomers use spectrographs. Starlight passes through a narrow slit, is reflected off a collimating mirror to a diffraction grating, and then bounces off that to a camera mirror and then to a detector.

Pauli Exclusion Principle

~~The~~ No two electrons (technically fermions) can share the same quantum state.

Also called: You can't have two people standing in the exact same space. Only fermions (matter) obey this rule. Bosons are exempt. The jumping of energy levels within an atom cause spectral lines. ~~The~~ Jumping down will create absorption lines, while jumping up will create emission lines.

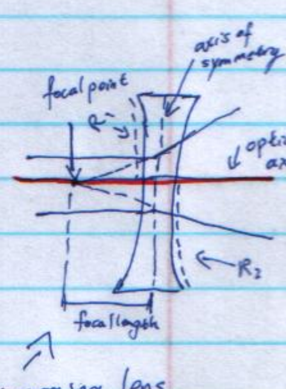
Telescopes

- Galileo created first telescope – refracting with lens
- Newton created reflecting telescope with mirrors

* lower IOR → higher IOR = bends towards normal & vice versa

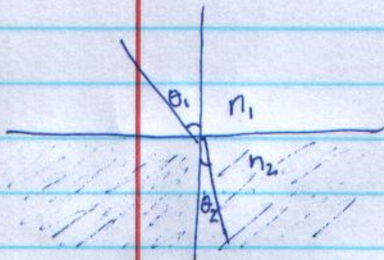
Refraction

- Path of light given by Snell's Law

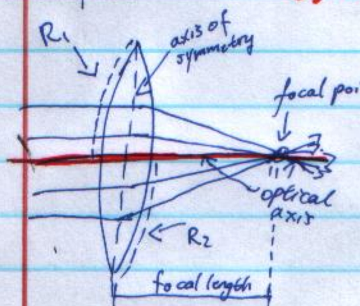


diverging lens

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



n_1 = index of refraction of medium 1
θ_1 = angle of incidence
n_2 = index of refraction of medium 2
θ_2 = angle of refraction



The focal length is given by the lensmaker formula.

↙ of very great use!

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

negative focal length denotes diverging, positive denotes converging.

the diagram of the diverging lens & converging lens

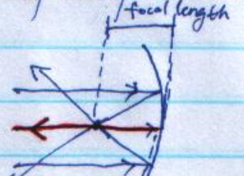
f = focal length
n = index of refraction
R_1 = radius of curvature of side 1
R_2 = radius of curvature of side 2

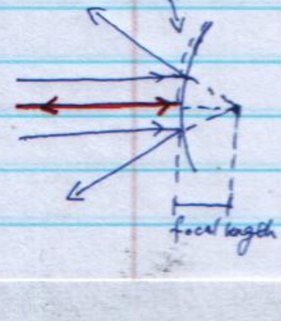
Reflection

Law of Reflection: $\angle I = \angle R$ angle of incidence = angle of reflection

$$f = R/2$$

f = focal length
R = radius of curvature





- Because objects in the sky are so far away, the rays of light they emit can be thought of as parallel to each other.
- Resolution in telescopes is limited — due to diffraction
- Rayleigh criterion — the point at which 2 objects are so close to each other as to be indistinguishable based on diffraction patterns.

Famous Observatories (on Earth)

Mauna Kea ~~Observatory~~ Observatories in Hawaii ← best seeing conditions of anywhere on Earth
Kitt Peak National Observatory in Arizona
Tenerife in the Canary Islands
La Palma in the Canary Islands
Cerro Tololo Inter-American observatory
Cerro La Silla
Cerro Paranal
Cerro Pachón

} Chilean Andes Mountains

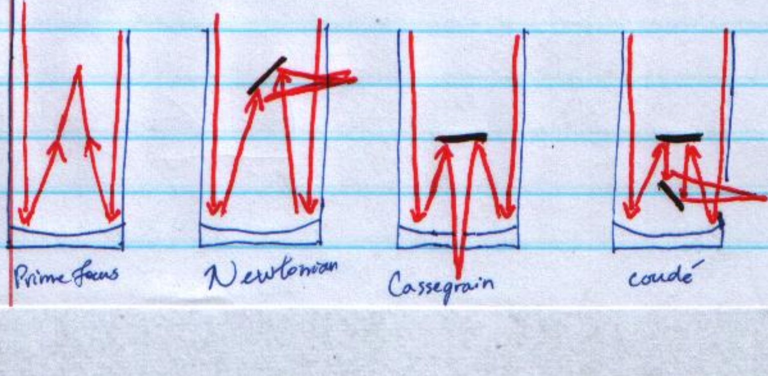
Aberrations (Image Distortions)

Chromatic aberration — distorted colour, only in refracting telescopes
Spherical aberration — light rays do not focus into single point. ← This was the problem with the Hubble Space Telescope
Coma — elongated images off the optical axis
Astigmatism — different parts of the lens/mirror converge at different locations
Curvature of field — focusing on a curve rather than a plane
Distortion of field — distance from the optical axis

Optical Telescopes

Reflecting/refracting types

Different optical systems (reflecting)



Two Types of Mounts: Equatorial Mounts | Altitude-Azimuth Mounts

Equatorial Mounts	Altitude-Azimuth Mounts
polar axis aligned to North Pole	continuous calculation of object's position
easy to adjust for RA/Dec	continuous rotation of image fields
* EXPENSIVE *	* can be compensated for by computers

Larger Aperture Telescopes = More objects that can be seen

* One of the largest in existence is the SALT, or Southern Africa Large Telescope, with an aperture of 11m

~~Adp~~ Adaptive Optics - make tiny changes in the shape of the mirror for best focus

Active Optics - relieves gravitational & thermal distortion by use of pressure pads

Space-Based Observatories

Not a complete list AT ALL ↓ just some important ones

- Hubble Space Telescope (HST)
- James Webb Space Telescope (JWST)
- Infrared Astronomy Satellite (IRAS)
- Infrared Space Observatory (ISO)
- Spitzer Space Telescope
- ~~Coln~~ Cosmic Background Explorer (COBE)
- International Ultraviolet Explorer
- Extreme Ultraviolet Explorer
- UHURU (SAS-1)
- High Energy Astrophysical Observatories
- Roentgen Satellite
- Advanced Satellite for Cosmology & Astrophysics
- *Chandra X-Ray Observatory*
- X-Ray Multi-Mirror Newton Observatory
- Compton Gamma Ray Observatory
- Hipparcos Space Astrometry Mission
- SIM PlanetQuest Mission
- Gaia (launch in fall 2013)
- SOHO

Radio Telescopes: need larger apertures because of longer wavelengths

Very Large Array: famous Earth-based radio telescopes

Earth's atmosphere blocks much of EM radiation, therefore giving the need for much higher observatories (such as Mauna Kea).

Otherwise, SPACE CAN BE USED! ←

* Chandra sponsors the Scioly Astronomy event. It would be an excellent idea to check out their website.

Virtual Observatories

Skyview - available to general public

Guide Star Catalogs & Digitized Sky Survey - available

Databases available on NSSDC (National Space Science Data Center)

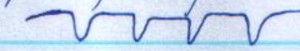
Hopes to create international Virtual Observatory

Binary Stars

Optical Double: stars that aren't really binaries, but only appear to be because they lie alone the same plane of sight.

Visual Binary: You can see both stars separately. Linear & angular separation can also be calculated.

Astrometric Binary: One star is significantly brighter than the other, so the ~~two~~ stars can't be seen separately. ~~I~~ These can be found by observing the oscillating motion of the star (the star wouldn't oscillate unless another force — the other star — is acting upon it.)

Eclipsing Binary — orbital planes are aligned along the line of sight of the observer, so one star will periodically pass in front of the other, eclipsing it. They have a distinctive light curve:  ← like that

Spectrum Binary — a system with 2 independent and discernable spectra. Because of the Doppler shift, as the stars rotate around each other, their spectra also shift. The spectra are often superimposed (on top of one another)

Spectroscopic Binary — Much like a spectrum binary, ~~ex~~ except one star is so bright that it covers up the other star's spectra. These are identified by the shifts in stellar spectra.

*Not mutually exclusive — a system can be more than one of these types. A system can be both an eclipsing binary and a spectroscopic binary, or it could be a visual binary AND a spectrum binary, etc.

You can determine mass with visual binaries with the following equation:

$$\frac{m_1}{m_2} = \frac{r_2}{r_1} = \frac{a_2}{a_1} = \frac{\alpha_2}{\alpha_1} \qquad \alpha = \frac{a}{d}$$

*distance is sort of trivial

m_1 & m_2 = masses of the stars

r_1 & r_2 = displacement vector

a_1 & a_2 = semimajor axes of the ellipse

α_1 & α_2 = angles subtended by semimajor axes

* Even if the distance to the stars isn't known, the mass ratio can still be determined.

$$\frac{m_1}{m_2} = \frac{v_2}{v_1}$$

m_1 & m_2 = masses

v_2 & v_1 = speed

Mass Lumosity Relation: the mass is directly proportional to the luminosity of the star (for the large majority of stars in the sky)

Eclipsing binaries can determine radii & temperature ratios, using relative velocities and an estimated value i.

Most analysis of data from binary stars is now done ~~from~~ on computers

Ex: masses, radii, temperatures, elongated star shapes (caused by the gravitational pulls of the other star), flux distribution, surface temperature variations, synthetic light curves

BINARY STARS ARE IMPORTANT SOURCES OF INFORMATION)

$m_1 + m_2 = \frac{s^3}{p^2}$

m_1 & m_2 = masses

s^3 = semimajor axis of orbital ellipse

p^2 = orbital period

Extrasolar Planets (or the search for such)

- First extrasolar planet discovered in October 1995 around 51 Pegasi
- They are detected by the following methods: radial velocity measurements, astrometric wobbles, eclipses, & gravitational lensing. Most popular is radial velocity
- The process used to determine the existence of extrasolar planets is much like what Sherlock Holmes says: Once you have eliminated the impossible, whatever remains, however improbable, must be the truth. All other possible sources of distortion must be eliminated before a planet can be found.
- Most of the planets discovered are rather huge because of limited observation techniques
- Measured in ~~Mg~~ M_J – the mass of Jupiter

Stellar Spectra

- First developed at Harvard by Edward C. Pickering.
  - Developed based on strength of hydrogen lines
  - Classes A – P
  - incorrectly assumed that the hotter the star, the stronger the hydrogen lines

THIS IS WRONG!!!

- Eventually arrived at OBAFGKMLT temperature sequence
  - Mnemonic "Oh Be A Fine Guy/Girl Kiss Me"
  - Decimal ~~subd~~ subdivisions (ex. B0 – B9)
  - B0 is called "early type" star, B9 is called "late type" star. (near beginning/end)
  - 200,000 stars were classified between 1911–1914 – collected into the Henry-Draper Catalogue (abbreviated as HD)
  - Therefore A stars have strongest hydrogen lines
  - ~~M~~ L & T are classifications of brown dwarfs

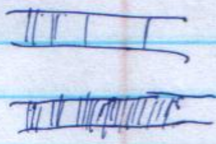
Spectral Type	Classification Characteristics
O	Hottest stars, fewest lines Strong He II lines Stronger He I lines
B	Hot Blue-White stars He I strongest lines Hydrogen lines getting strong
A	White stars Strongest hydrogen lines Ca II lines getting stronger
F	Yellow-white Stronger ~~Ca~~ Ca II lines Neutral metal lines are strong
G	Yellow stars (like our sun) Strong-ish Ca II lines Strong-ish neutral metal lines
K	cool orange Strong ~~a~~ Ca II H & K lines ~~Spectra dominated by molecular absorption bands~~ dominated by ~~[illegible]~~ neutral metal lines
M	cool red spectra dominated by molecular absorption bands neutral metal lines still strong
L&T	coolest more infrared than visible more molecular absorption lines

least spectral lines

For comparison:

O:

M:



* The hotter the star, the fewer the spectral lines

You should look up pictures of this. And graphs. I can't draw them, so I won't bother.
* technically I can, but it would be bad and not worth my time/effort.

most spectral lines

Spectral lines are created by atoms jumping electron levels

- if atoms jump down from a higher level, they create absorption lines
- if atoms leap up from a lower level, they create emission lines.
- pass through cold, diffuse gas = absorption spectrum
- pass through hot, diffuse gas = emission spectrum

} refer to Kirchoff's Laws, as stated earlier in this set of notes

* If you're really dedicated, you can go and look up the Saha Equation and the ~~Bta~~ Boltzmann equation; however, those aren't going to show up in astro, so they're not going to be put here

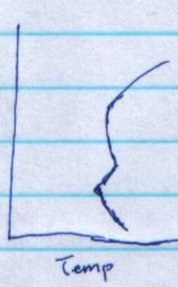
H-R Diagrams

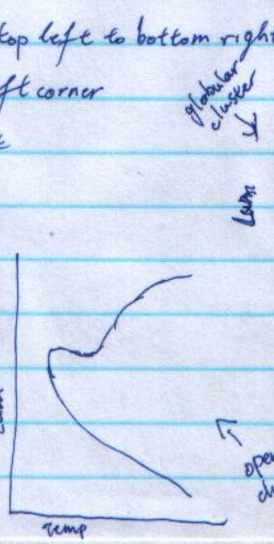
- Short for Hertzsprung-Russell Diagram ↙ I'm sorry, but hurrdurr NO DUH
- It was noticed that O-type stars were both brighter and hotter than M-type stars. They also tended to be larger.
- This guy called Ejnar Hertzsprung from Denmark discovered that stars of type G or later have a range of ~~of~~ absolute magnitudes, despite having the same spectral class. Bit of a shock for him.
- He also realised that the brighter a star is the larger it must be. So if two stars have the same temperature, then the brighter star must also be the larger one.
- At Princeton, this other dude called Henry ~~Norris~~ Norris Russell figured out the same thing. So now the H-R diagram carries both their names.
- The H-R diagram is plotted absolute magnitude against luminosity. Sometimes it is temperature against luminosity. (actually usually it is temperature, but the first H-R Diagram was abs. magnitude)

Important ↙

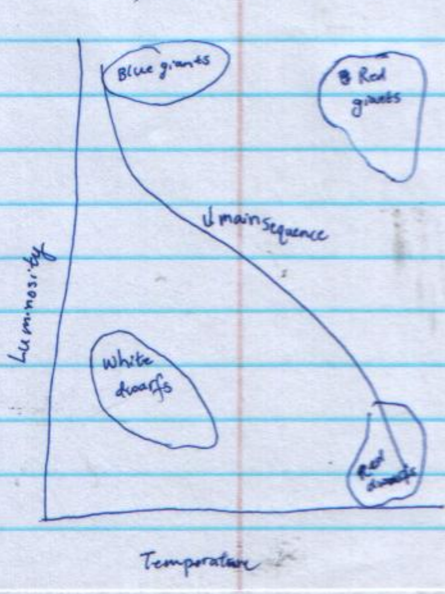
- A band reaches from the top left to bottom right - main sequence
- white dwarfs in bottom left corner
- Red dwarfs in bottom right
- Blue giants in upper left
- Red giants in upper right
- distinctive diagram for open & globular clusters

Supergiants in extreme upper right





Look up pics!



* If one star is 100 times more ~~lumin~~ luminous than another (assuming the temperature is the same), then the star is 10 times bigger.

- This relationship is determined by the star's mass. Most stars have the same density as water. Larger stars have a lower density.

Morgan-Keenan Luminosity Classes (also called 'Yerkes' Spectral Classification)

A luminosity class, which is in Roman numerals, is added after a star's spectral class.

Class	Type of Star
Ia-0	extreme, luminous supergiants
Ia	luminous supergiants
Ib	the other supergiants
II	Bright giants
III	normal giants
IV	subgiants
V	main sequence & dwarfs
VI	subdwarfs
D	white dwarfs

Ex: Sun is a G2V star

Stellar Atmospheres

* Need not go into much detail about this, go research it yourself if you want

- Spectral lines are produced because of how they pass through the stellar atmosphere
- Light, in addition to the atmosphere, can create a radiation pressure (photons can exert momentum)
- star aims to reach thermodynamic equilibrium within itself
- line profiles in stars because of broadening spectral lines
  - Natural broadening
  - Doppler broadening
  - Pressure (and collisional) broadening

* Most information on stellar atmospheres is highly technical and therefore need not to be bothered with.

Research can be done on your own. I encourage looking up the line profiles.

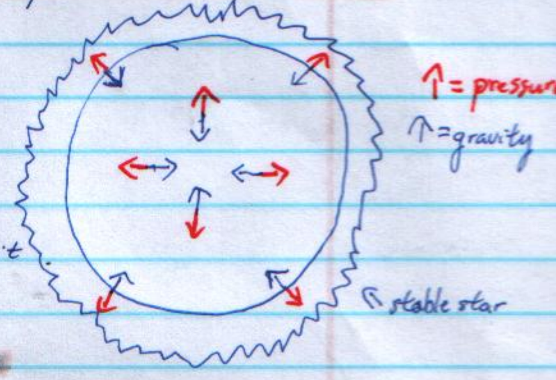
Also Pachelbel Canon is good music to study by.

Hydrostatic Equilibrium * VERY IMPORTANT CONCEPT

- A star is so large that it is always fighting gravity — gravity keeps pulling it into itself, trying to condense it more and more.
- There must be a force opposing that of gravity so that the star doesn't collapse in on itself
- This force is called pressure — different sorts, of course.

* Stellar evolution is a result of a star's constant war with gravity. — gravity pulls in and the star pushes out, but eventually the star's reserves are used up, and gravity inevitably wins.

- Hydrostatic equilibrium is achieved when the star's gravity and pressure balance each other out perfectly.
- The star spends 90% of its life in this state.

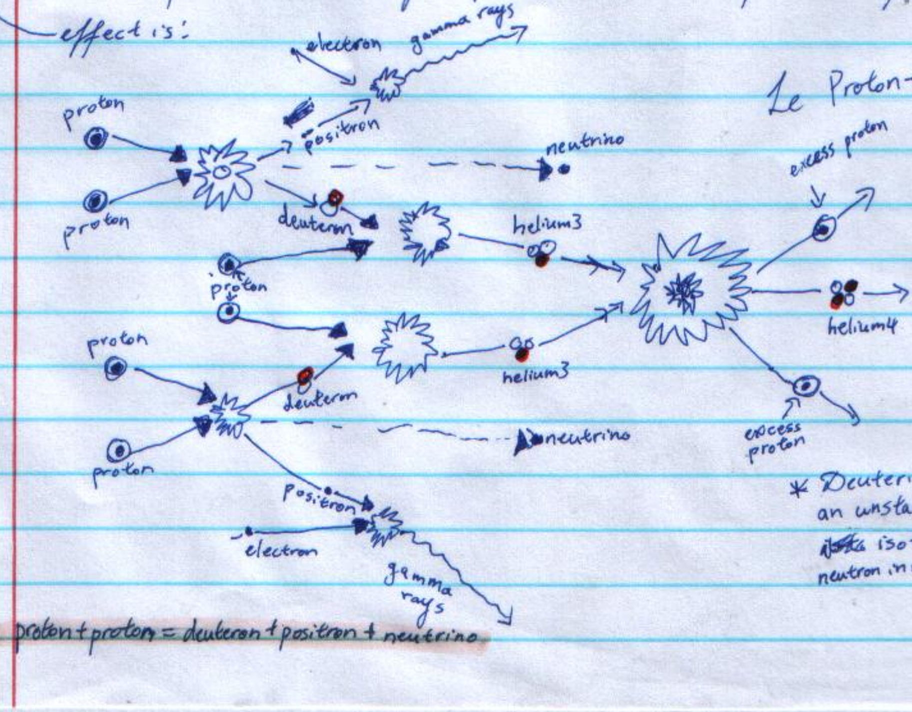


Stellar Energy Sources

- A star has to be powered by SOMETHING. Otherwise, it would just collapse.
- One source of energy is the gravitational potential energy.
- Another source is nuclear fusion — this is the main process that gives energy to a star.
- Hydrogen is fused into helium by the proton-proton chain « main source of energy
  - 4 hydrogen protons used to form 1 helium nucleus
  - a total of six are used during the process, but two are leftover. Therefore, the net effect is:

Le Proton-Proton Chain

(Bad drawing)



* The process by which one element is converted into another is called nucleosynthesis.

* Deuterium is an unstable hydrogen isotope — extra neutron in nucleus

proton + proton = deuteron + positron + neutrino

- strong nuclear force binds protons once they come within 10^{-15} m of each other, & fusion occurs

- Proton-proton chain can be chemically written as:

$^1_1H + ^1_1H \rightarrow ^2_1H + e^+ + \nu_e$ ⇐ This step involves decay

69% → $^2_1H + ^1_1H \rightarrow ^3_2He + \gamma$

repeat, then:

$^3_2H + ^3_2H \rightarrow ^4_2He + 2\,^1_1H$

^1_1H = hydrogen
^2_1H = deuterium
e^+ = positron
ν_e = neutrino
^3_2He = helium-3
γ = gamma rays
^4_2He = helium

There are TWO MORE proton-proton chains (I know, can you believe it?). The one so far is called the PPI chain (PP stands for proton-proton, and I is the Roman numeral one.)

PPII chain:

$^3_2He + ^4_2He \rightarrow ^7_4Be + \gamma$ Be = beryllium

31% → $^7_4Be + e^- \rightarrow ^7_3Li + \nu_e$ Li = Lithium

$^7_3Li + ^1_1H \rightarrow 2\,^4_2He$ for the rest, see above

PPIII chain:

$^3_2He + ^4_2He \rightarrow ^7_4Be + \gamma$

0.3% → $^7_4Be + ^1_1H \rightarrow ^8_5Be + \gamma$ See above

$^8_5Be \rightarrow ^8_4Be + e^+ + \nu_e$

$^8_4Be \rightarrow 2\,^4_2Be$

CNO Cycle

- Another way to produce helium
- Carbon (C), Nitrogen (N), and Oxygen (O) are used as catalysts

$^{12}_6C + ^1_1H \rightarrow ^{13}_7N + \gamma$ C = carbon

$^{13}_7N \rightarrow ^{13}_6C + e^+ + \nu_e$ N = nitrogen

$^{13}_6C + ^1_1H \rightarrow ^{14}_7N + \gamma$ O = oxygen

$^{14}_7N + ^1_1H \rightarrow ^{15}_8O + \gamma$ The rest can be found above

$^{15}_8O \rightarrow ^{15}_7N + e^+ + \nu_e$

$^{15}_7N + ^1_1H \rightarrow ^{12}_6C + ^4_2He$

Another CNO cycle does exist, but it only occurs 0.04% of the time, so really no need to put it here.

- When the star's hydrogen supply is used up, it must begin to fuse helium
- This is done by the triple-alpha process

$^4_2He + ^4_2He \rightleftharpoons ^8_4Be$ * the beryllium created is highly unstable and will rapidly decay back into helium if not acted on immediately.

$^8_4Be + ^4_2He \rightarrow ^{12}_6C + \gamma$

The triple alpha process is HIGHLY temperature dependent because of the decay rate of the beryllium. If the temperature is raised by 10%, then the energy output will be over 50 times as much.

Carbon and Oxygen Burning (because helium only goes so far)

$^{12}_6C + ^4_2He \rightarrow ^{16}_8O + \gamma$

$^{16}_8O + ^4_2He \rightarrow ^{20}_{10}Ne + \gamma$

.: and so on and so forth.

THIS IS IMPORTANT ALL THIS FUSION STUFF

Energy Transport Mechanisms

Radiation: energy carried away by photons – this is how we "see" stars

Convection: hot air goes up, cooler air goes down – cell  ← how energy gets around in a star

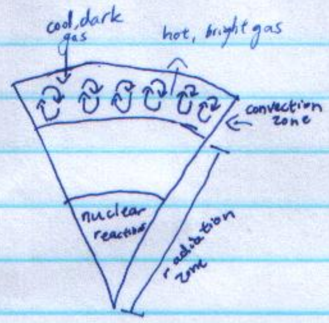
Conduction: transports heat through particle collisions – not particularly important

- Convection will occur when the stellar opacity is large (more gas), there is ionization taking place somewhere, and the temperature dependence is large.

- For smaller stars, the P-P chains will dominate, and for larger stars, the CNO cycle will.
- Lifetimes vary with mass – varies by a factor of $2.5 M_\odot$

Le Sun – The Closest Star

- G2V star
- 74% hydrogen
- 24% helium
- 0.02% other elements (referred to as "metals")
- 4.57×10^9 yrs old
- 5777K
- albedo: ratio of reflected to incident sunlight



The Sun and Its Neutrinos

- first detected in 1970
- There (was) a discrepancy between the ~~sol~~ solar model and how many neutrinos there actually were - or the observed neutrino counts — it is no longer a problem
- Cerenkov light - produced when neutrinos scatter electrons
- Mikheyev - Smirnov - Wolfenstein effect - neutrinos transform from one type to another - during time in the sun, they oscillate between neutrino types (electron neutrinos, tau neutrinos, and mu neutrinos.
- Since the Earth detectors could only detect electron neutrinos, the fluctuation and presence of the other two neutrino types accounted for the discrepancy.

The Solar Atmosphere

The layers are difficult to define - I mean, remember, this is a flaming ball of gas!

- Photosphere - the region where the observable photons originate - defining the base is a bit arbitrary
- Sun radiates light predominantly in visible & infrared parts of the spectrum
- ~~Sta~~ Solar Granulation - a patchwork of light and dark regions at the base of the photosphere. Caused by differing temperatures - dark spots are cooler than the bright ones.
- Chromosphere - layer above the photosphere. This is the part that we see
- Supergranulation - giant granules - exist here
- Spicules - Vertical filaments of hot gas that extend for 10,000 km up
- Transition Region - layer where temperature rises exponentially
- Corona - very faint layer above the transition region - no defined boundaries, simply reaches out into space
  - 3 parts: K corona, F corona, and E corona
  - forbidden transitions ~~can~~ can occur here.

- Solar wind – continuous stream of ions & electrons escaping from the Sun
- Coronal holes – regions of lesser x-ray emission
- Solar wind responsible for aurora borealis & australis (northern & southern lights)
  - Ions are trapped in Earth's magnetic field. When they bounce around the north & south pole, they create Van Allen ~~belts~~ radiation belts
- The Sun also loses mass in this way.
- The physical properties of the Sun's atmosphere and wind are pretty complicated. They include fancy concepts like hydrodynamic flow, magnetohydrodynamics, Alfvén waves, etc.

Sunspots

- Very well-known: dark regions on the surface of the Sun
- 11 year cycle
- Butterfly diagram – sunspot area in equal area latitude strips diagram (sunspot latitude with time)
- darkest part of sunspot called "umbra", surrounded by a slightly lighter penumbra
- can affect temperatures on Earth

Solar Flares

- eruptive events on the Sun's surface that releases a LOT of energy
- enormous events – reaching over 100,000 km in length
- charged particles expelled into outer space – some can disrupt Earth communications
- develop in sunspot groups – great magnetic field intensity
- several milliseconds to several hours.

Solar Prominences

- curtains of ionized gas that reach into the Sun's corona.
- can last for hours (eruptive) or weeks (quiescent)
- looks like a dark filament
- gas ejections

Coronal Mass Ejections

- bubble lifting off Sun's surface
- carries away Sun's mass
- averages one per day
- 400 km/s – 1000 km/s