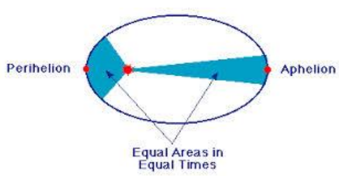
A Conceptual Guide to Astronomy
with very little math

- Laws
  - Kepler

Kepler's first law states that "Orbits are ellipses, with the sun at one focus". Ellipses are defined by their *eccentricity*, where an eccentricity of 0 being a perfectly circular orbit, with both foci at the center, and anything larger being an "eccentric" ellipse, with both foci set apart from the center at an equal distance. Eccentricities cannot exceed one because an eccentricity value equaling one would lead the object to come around the other in a hyperbolic motion, but it would not retain its orbit. The object would come in and fly off. The same goes with anything with an eccentricity of more than one. The path of orbit would be that of a hyperbola, and the object would come and gravity would not take hold to keep the object in orbit.

Kepler's second law states that "Objects move around equal areas of their orbits in equal times" This means that objects closer to the sun (perihelion) move faster than the same object when it is farther from the sun (aphelion). This is because when the object is closer to the sun, it has less area into the ellipse to sweep, so it sweeps out a larger path around the ellipse. Because it has to sweep along a larger part of the circumference of the ellipse, it ends up moving faster to keep with the "equal time". When the object is farther from the sun, it has more area into the ellipse it can sweep at one time, so it sweeps a smaller path around the ellipse. This smaller sweep creates a more narrow "pie piece" of the ellipse, where at the point closer to the sun, it takes a fatter "pie piece".



Kepler's third law states that "$P^2=a^3$". P is known as the Period, or the time it takes for an object to complete one full orbit around the sun, in years. a is the average distance of the object from the sun, in AU. One AU is equivalent to 149,597,871 km, or 93 million miles. It takes Jupiter 12 years to orbit the sun at a distance of 5.2AU. The distcance of $5.2^3=140.6$ and the period of $11.86^2=140.6$, so it holds true for $140.6=140.6$, or $P^2=a^3$.

  - Newton

Newton's first law states that "any object at rest will tend to stay at rest, and any object in motion will tend to stay in motion until an outside force acts upon that object". This means that if there is a pillow lying on a couch, that pillow is not going to roll off the couch of its own free will. Likewise, a bike tire is going to keep spinning and will not stop (excluding friction and air resistance). The pillow, however, will move if someone pushes it off the couch. This is an outside force that acts on an object at rest to get it moving. Likewise, if the spinning bike tire hits a rock, then the tire will stop, or at least slow down (again excluding friction and air resistance). This, too, is an outside force that acts on a moving object to get it to stop.

Newton's second law states that "Force is equal to mass times acceleration" In an equation, this looks like F=ma. If I have cars accelerating 30 miles per hour, and one is a smart car weighing one ton, and the other car is a minivan weighing three tons, then it is going to take more force to stop the minivan than the smart car, because the force would be dependent on the mass instead of the acceleration, because the acceleration is the same for both cars at 30 miles per hour. Likewise, if both cars are minivans, and one is accelerating to 60 miles per hour and the other one is accelerating to 30 miles per hour, it will take more force to stop the minivan accelerating to 60 miles per hour because the force is dependent on how much the car is accelerating, because the mass of the cars is the same for they are both minivans.

Newton's third law states that "for every action there is an equal and opposite reaction". This means that if there is a rubber band being stretched, there is an equal force pushing the rubber band outward as there is the force of the rubber band trying to contract back to its original state. The outward force stretching the rubber band and the contractive force the rubber band is giving are the same by Newton's third law. As well, if there is a stress ball being squished, then there is a squishing force on the ball. As well, the ball is pushing outward to stop being squished. Both of these forces, as well, are equal, due to Newton's third law.

Newton also "remade" Kepler's third law. Kepler's version of this law is $P^2=a^3$. This, however, only tells that the orbit will only be affected by distance, and that distance will only be affected by orbit length. However, Newton realized there is another component of this: the mass of the two bodies involved. Kepler's fixed law reads $P^2 = \frac{4\pi^2}{G(m_1+m_2)}a^3$. This incorporates both the Gravitational constant, showing that gravity is in play with orbits, as well as the masses of both objects in the orbit: sun and planet, planet and moon, or anything else.

Newton's law of gravitation is a general rule for the effects of gravity. It states $F_g = G\frac{m_1 m_2}{r^2}$. This, plainly, is that the Force of gravity is equal to the gravitational constant (6.67×10^{-11}) times the mass of both objects in a system divided by the square of the distance between the objects. This means that there will be a larger force of gravity when the distance between two objects is small, because r^2 will be smallest with a small number, and dividing by small numbers results in a larger number overall. Similarly, there will be a larger force of gravity when the objects in the system are more massive. This is because multiplying together two larger numbers results in a larger overall number in the numerator, which means it will be larger when divided by a number. Likewise, the force of gravity will be smallest with large distances and small objects.

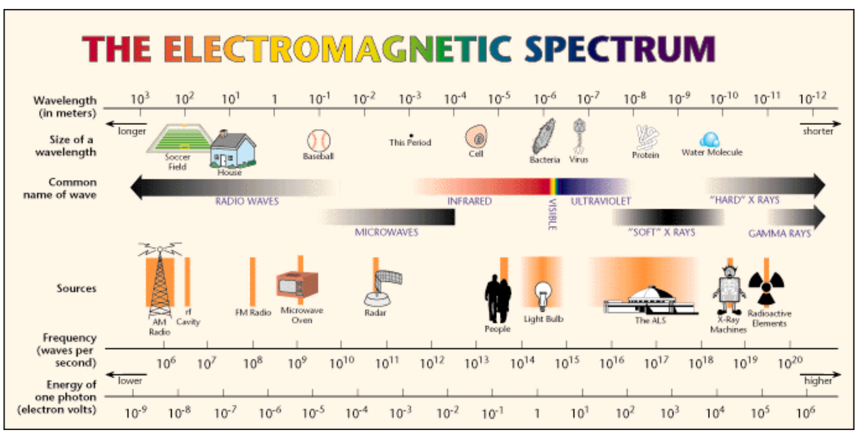
- Light

- Looking into the past

When we look at objects in the sky, we see them in the past. When we see the sun, we see the sun as it was eight minutes ago because it takes the light eight minutes to travel the 93 million miles between the Earth and the Sun. This is due to the fact that light, although going really fast (300000km/s or 186000 mi/s), it does not travel infinitely fast. This is more noticeable at longer distances, because the time light takes to reach you from the computer to read this takes only 9 billionths of a second. This is barely noticeable, and humans cannot notice it. However, take the Andromeda Galaxy. This resides 2.5 million light years away. That means that light emitted today from the Andromeda Galaxy will take it 2.5 million years to reach us. As well, the light we see from the Andromeda Galaxy is really light emitted 2.5 million years ago, and we are seeing the Galaxy in its past, 2.5 million years ago. This goes for any object. An object 10 million light years away is something we are seeing 10 million years in its past, and it will take another 10 million years to see it as it is today.

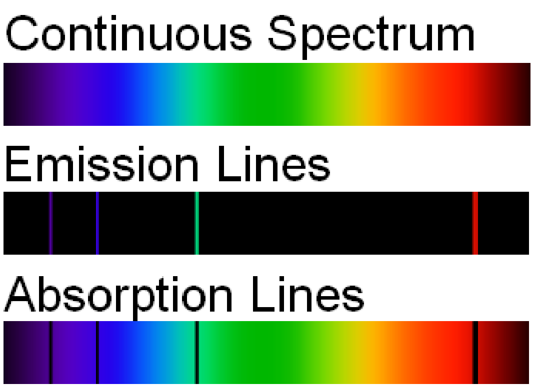
- The Electromagnetic Spectrum

The Electromagnetic Spectrum is the spectrum of light. It spans from Gamma Rays to Radio Waves. (Gamma, X Ray, ultraviolet, Visible-starting with violet, ending with Red, Infrared, Microwaves, and Radio Waves) Every particle of light is called a photon; it is a carrier of the electromagnetic force, hence the electromagnetic in the electromagnetic spectrum. Each particle of light has a specific Wavelength, Frequency and Energy. Gamma Rays have a very short Wavelength, and Radio Waves have a very long wavelength. Wavelength is quantified as the distance between two equal points in a wave, whether that is crest-crest, bottom-bottom, or sides after a crest. Likewise, Blue light has a shorter wavelength than Red light. The longer the wavelength, the less energy there is. This is because it is going up and down less often, and has less energy because it isn't oscillating as quickly. Frequency and Energy are the same in that Gamma Rays are the highest and Radio Waves are the lowest. Wavelength is opposite, Gamma Rays are the shortest and Radio Waves are the longest.



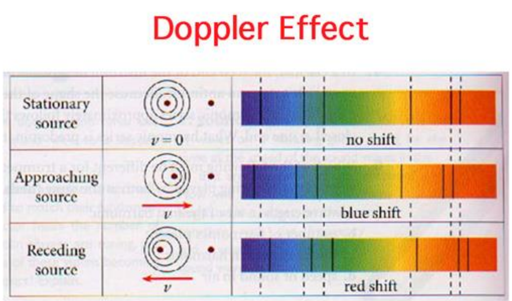
Light can do many things. It can absorb, reflect, or emit. Absorbing light means an object takes in those light photons at certain energies. This absorption is used to take elements electrons and move them up to higher levels. All electrons start at “ground state” in which they are all supposed to be in. When an element absorbs a specific wavelength of light, it really is the electrons absorbing the light. The electrons take the energy in the light and move up to different levels beyond the ground state. When the electron comes back to ground state (almost immediately), the electron will emit the same frequency light that it absorbed. Reflection is the opposite of absorbing. A rose reflects red light, making it look red. It absorbs all the other colors in a light spectrum. Similarly, the sky absorbs all the colors of light except blue, which is reflected. This is why the sky is blue. Emitting light is when the electrons that have absorbed light come back to ground state and they emit the same frequency light that they absorbed.

Scientists use light to tell the chemical composition of objects. They do this by taking a spectroscope and looking at the light. A spectroscope takes a small amount of light from a source and passes it through a prism. This prism takes the light and turns it into the continuous spectrum, like the album cover of Pink Floyds Dark Side of the Moon. This spectrum has three different “options”. The first thing that can happen in a spectrum is nothing. Nothing means that every color and frequency is shown up on a spectrum. This would mean that the source being looked at emits white light, like a light bulb. The second thing that could happen when looking at a spectrum is that there can be all black except for a few (or many) bright lines. This is the spectrum of something being emitted. These lines are the lines of a cloud of gas and the frequencies and colors of the light that the gas emits when its electrons come back to ground state. The ones in the picture are the emission lines of Hydrogen. If you heat up a tube of pure Hydrogen, you would see emission lines at those four points. Those four points are the amounts of energy the electron emits when coming back to ground state. Likewise, absorption lines are what are seen when there is a source of light behind the cloud of gas, and the gas absorbs the light frequencies it needs to get its electrons out of ground state. The picture, again, shows the absorption lines of Hydrogen. This would be like putting a light bulb behind the tube of Hydrogen and seeing what it absorbs to excite its electrons. Notice that the lines in both the emission and absorption lines are at the same place. It takes the same energy to move up from ground state as is does to leave back to ground state.



- Red and Blue shifting

  Nothing in the universe is static. Things move. Red shifting and blue shifting explain things that move away and towards us at noticeable speeds. The shifting is a manifestation of the Doppler Effect. The Doppler Effect is much more noticeable on Earth than Red/Blue shifting; the shift of stars is indiscernible to the human eye because it is only a few nanometers shift. To illustrate the Doppler Effect, think of a police car on a highway. When the police car is far away, the tone of the siren seems low, and then it gets higher and more frequent until it passes you. Once it passes you, the siren continues to get lower and less frequent. This is because when the car is coming towards you, the sound waves pile on top of one another, becoming more frequent and louder due to the fact that there are more of them there. Once the car passes you, the sound waves are no longer coming at you, so the sound gets quieter. The sound waves are thinning out and becoming less frequent, so it seems lower. The same happens with stars and the Earth. Instead of a cars siren, the Doppler Effect happens with light. Stars that move towards and away from the Earth have noticeable effects similar to the Doppler Effect. Pretend there are stars A, B, and C. All of them are the same distance away, the same temperature, color and type of star. Star A is stationary, Star B is moving towards us, and Star C is moving away from us. Star A, who is not moving, emits yellow light just like our sun. The spectral lines are where they should be to make up a star made up of mostly hydrogen. Star B, moving towards us, however, looks a little more green than yellow. The spectral lines have shifted just a little. They have shifted to the left, towards the blue end of the spectrum. Because this shift in the spectra goes towards the blue end of the spectrum, it is called a *blue shift*. Star C, moving away from us, looks slightly orange, rather than yellow. The spectral lines have shifted just a little towards the red end of the spectrum. Because the shift is towards the red end of the spectrum, it is called a *red shift*. This red and blue shifting works for an object that even has gone from ultraviolet to microwaves or from infrared to X rays. The former would still be a red shift, and the latter a blue shift.

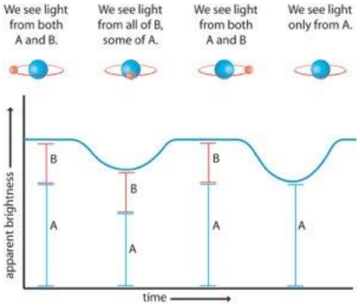


Measuring the relative velocities of stars by the Doppler shift.

- Binaries

  Binary systems are systems of stars that orbit one another. This orbit can be used to find the mass of the stars in the binary system. Scientists use Newton's version of Kepler's third law to do this. Since the mass can only be found with stars having something in orbit around them, binaries are the way to do that. There are three way scientists can determine if a system is a binary: eclipsing, visually, or with the use of a spectrograph.

- Eclipsing



Eclipsing binaries are binaries where one body in a system periodically eclipses the other. This type of binary is when there is a star orbiting another star. The system will be at its brightest when both stars are next to each other. This is due to the measurement of both stars' brightness. The largest dip in brightness is when the first star eclipses the larger star that seems stationary in the system. When the star gets eclipsed, all of the light from the first building is measured, but only the brightness not blocked from the second star. This is the larger of the two drops in brightness. The smaller dip is when the first star is behind the other one. This is a smaller dip because there is still all the light from the stationary star, but none from the smaller, orbiting star.

- Visual

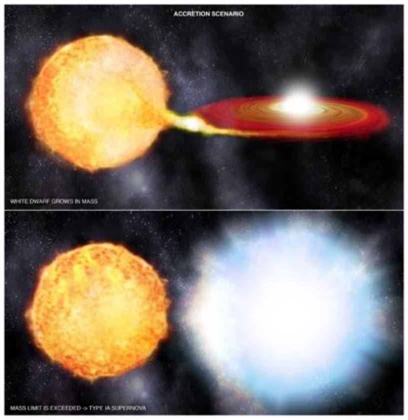
Visual binaries are binary systems that are seen with telescopes. These are the most rare type of binary systems because the stars may take so long to orbit one another that it is almost impossible to see a complete orbit occur to identify it as a binary, or the distance between the two stars is so small that it is impossible to tell them apart on a telescope, making them look like a single star. The latter is an issue of angular resolution, or the largest angle you can still see two things as separate entities before they merge into one. The Alpha Centauri system is composed of 3 stars, but humans see them as one single star due to our angular resolution. Most binary systems are close enough together and/or far enough away for us not to be able to tell if singular stars are one star or a binary system. When a visual binary is found it is possible to see one of the stars orbit the other.

- Spectroscopic

Spectroscopic binaries are found using the spectral line emitted from the orbiter in a binary. Since the orbiting star is seen coming towards and away from us as it orbits, the spectral lines of that star will be blue and red shifted, respectively. By waiting until the lines meet up at the same point they one orbit ago, scientists can find out how long it takes from the star to orbit.

- Supernovae
  - Type Ia

Type I supernovae are created by white dwarfs accreting more matter than they already have. This can be done in two main ways. The first way is called “single degenerate”. This is when a single white dwarf takes matter from a nearby star in a binary system. If the stars are close together or the white dwarf is “hungry” and absorbing a lot of matter, the next part will come quickly. If the stars are farther, or the white dwarf is not as “hungry” and absorbing matter as quickly, then the next part can take some time. The second way for a Type Ia supernova to occur is called “double degenerate”. Double degenerate systems occur when there are two white dwarfs in a binary system. They orbit one another until they collapse upon one another, leading to the next part. “The next part” is a supernova explosion. When the white dwarf becomes as heavy as 1.4 solar masses, the dwarf will explode in a supernova, just like the end of a massive star. Unlike the death of a massive star, after the Type Ia supernova, the white star will not end up as either a neutron star or a black hole. There is no stellar remnant after a Type Ia supernova. All that remains is a Supernova Remnant (SNR). A SNR is the gas and dust that is spit out during the explosion. A pressure wave that follows heats up and ionizes the gas, creating shock lines. Some white dwarfs have exploded past the point of 1.4 solar masses, but the Chandrasekhar Limit (named after the astrophysicist who found this limit, Subrahmanyan Chandrasekhar) mostly holds true.



- Type Ib

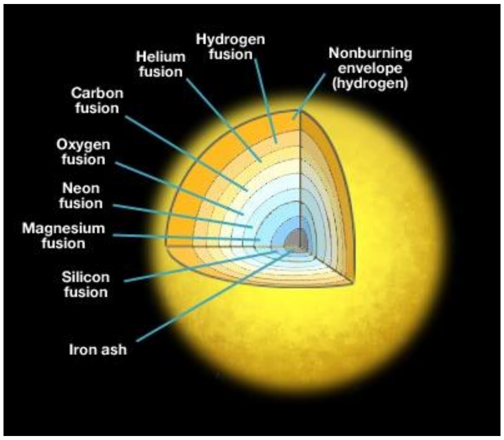
This type of supernova is created from the collapse of a massive, dying star. It is categorized as a Type I supernova because this type has lost its outer shell of Hydrogen. This can be for a few different reasons. One is due to interstellar winds, which blow away the hydrogen layer. Another cause can be that the partner in a binary system will consume the outer layer of Hydrogen, leaving the supernova without it.

- Type Ic

Type Ic supernovae are very similar to Type Ib supernovae. The main difference is that Type Ic supernovae have also lost the second shell of Helium, in addition to the outer shell of Hydrogen. The theories as to why this happen in Type Ib supernovae are the same for Type Ic supernovae. Either stellar winds strip the supernova of the outer two layers, or a binary partner consumes these layers for its own aggregation.

- Type II

Type II supernovae are created during the death of supermassive stars. Very large stars start with a core of Hydrogen that, over the course of many thousands of years, turns the core into Helium. When the core is turned almost totally into Helium, the star starts to contract because Helium is an inert gas that needs temperatures over 100000° to start the fusion process. Because the star is collapsing, it is increasing its pressure, and henceforth the temperature. The temperature will reach the 100000°, and the core will begin Helium fusion into Carbon. When this happens, the core is made of helium fusing into Carbon. Once enough Carbon has been formed, it takes the place of Helium as the innermost core. Outside the Carbon is Helium, and outside that is a shell of Hydrogen still fusing into Helium. This process continues up to all elements up until Iron. Before the star fuses Iron, there are many shells, each with a subsequently lighter element in an outer shell around the core. A star cannot fuse any element heavier than Iron because it takes more energy to fuse Iron into something heavier than the amount of energy that would be released from the reaction. Because of this, once the star has a core mainly consisting of Iron, the star contracts to try and speed up the fusion rates of the other shells. Similar to bouncing a tennis ball on top of a basketball, the outer parts of the star (tennis ball) rebound against the dense, large core (basketball). Just like the tennis ball is shot upwards with more energy than it originally had, the star shoots out its outer layers, exploding in a supernova. During the split second before and after the supernova explosion all the elements heavier than Iron up until Uranium are formed. Type II supernovae are similar to Type Ib and Ic, though Type II supernovae have both outer shells of Hydrogen and Helium. When the star explodes, it throws off massive amounts of matter that shine extremely bright for at least a month. After this, the remains of the dust and matter ejected during the explosion become a Supernova Remnant (SNR). One of the more famous ones is the Crab Nebula, formed when a star went supernova in 1054. The remains of the dead star either become a neutron star or a black hole. (See either for more information)



- Stellar Evolution

The way a star evolves is dependent upon its mass. Very large stars will consume their fuel much more quickly than a small star. A cooler star with a large surface area will emit more light than a very hot and small star because there is less surface area for the light to come out of.

All stars start in the same way. They form out of nebulae type gas and dust. The trigger for the gas and dust to collapse into a star is usually the shockwaves of a nearby supernova or other stellar interplay. Once the shockwave hits the blob of interstellar material for a star, the gas and dust will start collapsing into a star. This is called a *protostar*. The swirling mass of dust and gas forms together, slowly, into a ball of gas. It is not considered a star until it starts the process of fusion. Fusion of Hydrogen begins at about 10000°. After it becomes a star, the rest of its life is dictated by its size.

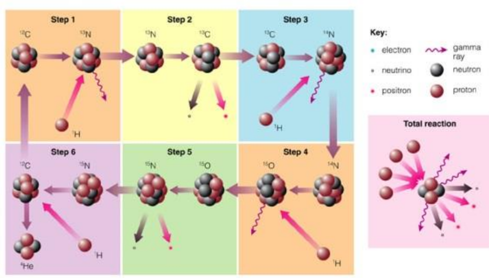
There are three parts to a full classification of a star. Our sun's full classification is a G2 V star. The G is part of the spectral type of star. The Spectral Sequence is OBAFGKM. The letter denotes the temperature of a star. O type stars are the hottest type of star, and M type stars are the coolest. An O type star will be around 40000°, and type M stars are around 3000°. The second part of a full classification is a number, 0-9. These numbers are sub-types of a spectral class. 0 is the hottest and brightest of a spectral class. Likewise, 9 is the coolest of a spectral class. a M0 is very close to a K9. Similarly, an O9 is similar to a B0. The last part to a full star classification is a Roman Numeral. The table has all of the Roman Numerals that a star can have. Our sun, based on its classification as a G2 V star is a yellowy star, on the higher end of the G spectrum, and is a Main Sequence Star.

Roman Numeral	Type of Star
I	Supergiant
II	Inbetween Giant and Supergiant
III	Giant
IV	Subgiant
V	Main Sequence

All stars start on the *Main Sequence*. The main sequence is when stars are converting Hydrogen into Helium via nuclear fusion. Nuclear fusion is the process of turning a light element into something heavier. The core of a star is the only place known in the universe where this process can occur safely due to the density of the core and the extreme pressure and temperature. There are two ways stars can undergo nuclear fusion. Small stars 1.3 Solar masses and below use what is called the proton-proton chain, and large stars above 1.3 Solar masses use the CNO cycle.

The proton-proton chain starts with two protons. They collide into one another and stick. One of the protons turns into a neutron, emitting a positron, antimatter particle of the electron, and an electron neutrino. This proton-neutron pair then is hit with another proton. This emits a gamma ray, and the nucleus contains two protons and a neutron. This has to happen twice to fuse Helium. The two proton-proton-neutron nuclei collide with each other and create Helium, two protons and two neutrons. The other two leftover protons fly away and will collide with other nuclei. In total, the proton-proton chain process of nuclear fusion needs four protons, and releases two positrons, two electron neutrinos, two gamma rays, two protons, and the all-important Helium.

The CNO cycle is the “Carbon, Nitrogen, Oxygen” cycle. It is called this because this is what nuclei interact with to become Helium. This is a much more efficient way of creating Helium, and goes much quicker than proton-proton fusion. Because it is more efficient and goes faster, this is part of the reason large stars go through their fuel much quicker than small stars. Only large stars can utilize the CNO cycle because small stars don’t have the heat capacity to fuse any element heavier than Carbon, so they would be missing the Nitrogen and Oxygen of the cycle. The first step in the CNO cycle is that one proton collides with a Carbon nuclei with six protons and six neutrons. This releases one gamma ray. The addition of the proton turns the Carbon into Nitrogen with Seven protons and six neutrons. This is not a stable element, so one proton decays into a neutron, making the Nitrogen back to Carbon, as well as emitting one electron neutrino and one positron. The Carbon now has six protons and seven neutrons. This Carbon nucleus is hit with another proton, emitting another gamma ray. This added proton makes Nitrogen with seven protons and seven neutrons. This Nitrogen is also hit with a proton, which also emits a gamma ray. The extra proton turns the Nitrogen into Oxygen with eight protons and seven neutrons. One of these protons decays into a neutron, emitting one positron and one electron neutrino. This turns the nuclei back to Nitrogen, but with seven protons and eight neutrons. This is hit with another proton, and a Helium nucleus is broken off from the Nitrogen. The Helium takes two protons and two neutrons, changing the Nitrogen back into Carbon with six protons and six neutrons, and the cycle starts over from there. Overall, there are four protons added to the cycle, and three gamma rays are emitted, two positrons, and two electron neutrinos. The extra gamma ray per cycle explains how the larger stars are more luminous; they have more light being emitted per one Helium nucleus fused.



Once a star starts do die, it will expand. The small stars that are less than eight solar masses will turn into giants, and the large stars greater than eight solar masses turn into supergiants. The core contracts in all the stars, creating hotter and denser conditions. If the temperature rises above 100000°, Helium fusion can start in the core, turning Helium into Carbon. The outer parts of the star start to expand, starting the giant or supergiant phase. The small stars cannot fuse anything heavier than Helium because they cannot create the temperatures necessary. The larger stars’ cores keep contracting, fusing more elements up to Iron. (see Type II supernovae for more information). Once the stars have exhausted all their fuel, they start to die.

Once the stars run out of fuel, it is time for them to die. Small stars under eight solar masses will shed their outer layers in a planetary nebula. The stellar wind takes the outer layers and sheds them while the core keeps shrinking. These phenomena don't last very long. After the planetary nebula, all that remains of the star is a white dwarf, a dense ball of carbon that was the core of the used to be star. (see white dwarfs for more information) Stars over eight stellar masses will continue to shrink and shrink. The outer layers collapse upon the Iron core, and, like a tennis ball on top of a basketball, rebound on the core and explode outward in a Type II supernova. (see Type II supernovae for more information)

- Dark Matter and Dark Energy
    - Dark Matter

      Dark Matter is a very unusual substance. Not very much is known about this substance because it interacts with normal matter very weakly. There are two currently prevailing theories as to what dark matter is. The first one is that dark matter is a WIMP, or a Weakly Interacting Massive Particle. This particle would be very heavy, which would explain why there is five times as much dark matter in the universe compared to ordinary matter we see. It would be weakly interacting as well, because it has escaped detectors for many years and still today there is no real conclusive evidence to the WIMPs existence. The other prevailing dark matter theory is that dark matter is found in MACHOs. MACHOs are Massive Astrophysical Compact Halo Object. These MACHOs are similar to nebulae; however they require very sensitive equipment to see them.
    - Dark Energy

      Thanks to Hubble, Astrophysicists know that the universe is expanding. However, it is expanding much more than previously thought. The extra energy in the universe that is not thought to be from the big bang's inflation is called dark energy because nothing is known about it except its existence. Astrophysicists found this energy when they realized that the faraway galaxies are receding from our own very quickly; faster than the inflationary energy predicted. Similar to dark matter, very little is known about the actual energy itself. It is theorized to be a sort of antigravity, though the exact ramifications of that are unknown. If the universe reaches a "critical mass" of weight of the whole universe, then theory goes that the universe will continue expanding forever, but will not always inflate like it is now with the dark energy. If this critical mass is met, the mass in the universe acts similar to brakes of a car; it slows it down but does not stop the universe (car). If the universe exceeds this critical mass, then at some point the universe will stop expanding and gravity will take over, leading to the "big crunch" scenario of the end of the universe. The universe will continually get smaller until who knows what. If the mass of the universe falls short of the critical mass, it is likely that the universe will continue to inflate at an exponential rate and at the end there will be nothing left because all the galaxies have been moved apart by the dark energy.
- Galaxies

Galaxies are clusters of stars orbiting all around a central black hole. There are three main classes of galaxies: lenticular, spiral, and elliptical. As well, there are irregular galaxies that aren't like anything else and, as their name states-are strange. There can be many reasons to classify a galaxy as irregular; be it shape, dust, or any other thing. They are strange and too broad of a group to explain below.

- Elliptical

Elliptical galaxies are elongated, flattened galaxies. They are classified on a scale of E0-E7, based on how far the galaxy is from being perfectly circular, called *eccentricity*. The E is the naming part of a galaxy, signifying that it is an elliptical galaxy. E0 is a perfectly circular galaxy, and E7 is the most elliptical galaxy out there. Elliptical galaxies are flat looking. They are mostly made of older stars. The stars in these galaxies formed relatively at the same time, and used up all the gas in the galaxy. Because of this, elliptical galaxies don't have, for the most part, star formation today. The stars that are in an elliptical galaxy are all on randomly oriented elliptical orbits around the galaxy, similar to the bulge of a spiral galaxy.

- Spiral

All spiral galaxies have the same main parts; a central bulge, and arms. The central bulge is the center of the galaxy, rising above the galactic plane in either direction. There are usually only two main arms in a spiral galaxy; however other smaller offshoots are common. The classification of spirals is denoted with an S, and an A for Ordinary and B for Barred. While forming a spiral galaxy, the halo stars form first, then the rest of the spiral. The halo stars are old and dim because there is no gas to support star formation. They also orbit the center in a highly randomized, elliptical orbit. The stars in the bulge of the galaxy are similar to those in the halo. They, too, are older stars that orbit in randomized, elliptical orbits. The stars in the disk are not all old. The disk has enough gas and dust to support ongoing star formation. This is why spiral arms sometimes seem blue, because of all the new stars that are being formed. These stars all orbit in circular orbits around the galactic center.

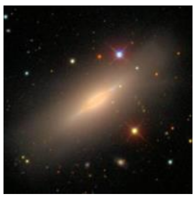
  - Barred

Barred spiral galaxies (SB) are galaxies that have the arms of the spiral going out of the bulge perpendicular to the center before curling away. There are subsets of these galaxies as well, SBa, SBb, and SBc. The difference between the a, b, and c of the classification is how tightly wound around the bulge the arms of the spiral are. A SBa has arms wound very close to a seemingly large central bulge, and a SBc has arms wound less tight from a seemingly smaller central bulge of the galaxy.

  - Ordinary

Ordinary spiral galaxies (SA) are galaxies that have the arms of the spiral going out of the bulge directly, curling around the central bulge. The subsets of these galaxies are SAa, SAb, and SAc. Like the Barred spirals, the a is where the arms are wound tightest to the seemingly larger central bulge, and the c is when the arms are wound least tight around the seemingly smaller central bulge.

- Lenticular



Lenticular galaxies are not quite spiral galaxies, but aren't quite elliptical either. This is because these galaxies have flat disks like elliptical galaxies, but have a central bulge like spiral galaxies. It may be possible that some elliptical galaxies are lenticular because we are seeing them face on so it is not possible to see the bulge that makes it lenticular.

- Nebulae
  - Emission

Emission nebulae are clouds of ionized gas. This ionized gas is being emitted in many different colors of the visible part of the electromagnetic spectrum. The colors we do see are caused by photons hitting the gas. The gas in a nebula is combined, like in H_2, where the two Hydrogen atoms are together. The photons sent out run into this H_2 and split it apart into two separate Hydrogen atoms. These separate atoms have more energy than before they split because the photon gave them some energy. However, the atoms don't want to be alone and they recombine into the two atom form. This time, however, they have more energy, and in order to get back to a normal, not too excited state, the atoms will radiate off energy in the form of a visible spectrum photon of light. Different elements radiate off different colors.

  - Reflection

Reflection nebulae are clouds of interstellar dust. Unlike emission nebulae, reflection nebulae do not emit any light of their own. Instead, they reflect the light of nearby stars. These types of nebulae are usually seen blue because they are star forming regions and there are some hot, young. Blue stars. These blue stars shine brighter than red stars, so they appear more blue than red. Some of these nebulae change in brightness. These are also known as variable nebulae. These nebulae vary in brightness because the star that supplies the light to be scattered changes its brightness. This change in brightness can be due to many things. It could be a variable star changing its brightness that

changes the brightness of the nebula. It could also be a dense interstellar dust clouds that sometimes cast shadows on the rest of the nebula, making them seem dimmer.

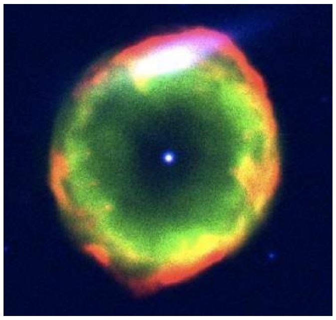
- Dark

Dark nebulae are only known because they obstruct the light of some other source. They are very dense clouds of interstellar dust that block out all light sources including stars, emission nebulae, and any reflection of other light sources. These nebulae are hot enough to allow for star formation. Stars do form in these nebulae;

however their clouds of interstellar dust are too dense even to allow that light to come in. These are different from black holes that do not allow light to come back into the universe because they are gravitationally pulled inwards; these nebulae are just too filled with stuff to let any light in. Imagine a really dirty window. It will be hard to see anything through a really dirty window, because all the dirt and grime covers the glass. This is very similar to how these nebulae work. The glass is whatever happens inside these nebulae. The interstellar dust is the dirt and grime on the window, obstructing our view. As much as humans cannot see into these nebulae, they still emit light. The light they emit just is not in a wavelength we can see. Usually we can see through the dust using infrared telescopes.

- Planetary

Planetary nebulae are a certain type of emission nebulae that are specifically



created while stars are in the deaths grasp. Trying to keep a hold onto equilibrium, the star throws out its outer layers of gas. These layers of gas are what make planetary nebulae. Different elements create different colors. This is due to the photons of the stars core hitting the different elements of the gas. The electrons get knocked out of ground state, and emit the light when they come back to ground state. The colors are different because the energy it takes a photon to return to ground state is different for each element. One thing unique to all planetary nebulae is the white dot in the center. The white dot is the core of the star that is dying; the soon to be white dwarf.

- Interstellar Objects
  - Black Holes

Black holes are the dense remains of a supernova explosion. They are points of extreme gravity, such that light itself cannot escape. The limit for light and all other matter passing into a black hole is called the *Event Horizon*. Any point after the event horizon is unknown to us; all matter is unable to come up through the mouth of the black hole to give us information. The event horizon is determined by the Schwarzschild radius. This radius is dependent upon the mass of the system before it becomes a black hole. Something like the sun, with one solar mass, would have to be packed into a sphere with a radius of only a few kilometers. The mass of all of humanity would have to be packed into the size of a sugar cube. Right before crossing the event horizon, matter is shooting off photons, for it is matters last ditch attempt in making communication with the outside world. This creates a glow like haze around the black hole.

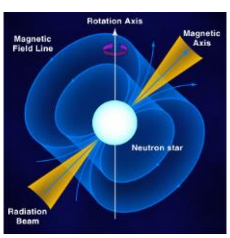
- Neutron Stars

Neutron stars, as well, are the other option for the remains of a massive star. Neutron stars are similar to white dwarfs in that they use the spin of quantum particles to keep their shape. This time, however, the density of a neutron star is so much that, when forming, the protons and electrons of the star combine to make neutrons, hence the name of neutron star. These stars, again, similar to white dwarfs, can accumulate matter from a partner in a binary system. When this happens with a neutron star, which cannot collapse to become itself again, it will collapse and become a black hole.

- White Dwarfs

White dwarfs are the remains of “normal” main sequence stars like our sun. This is a dense core of spinning electrons. The electrons don’t like to be in the same quantum state as one another, so when they get packed into a smaller area like the white dwarf stars, the particles spin faster to avoid being in the same state as other particles, and will move to higher energy states. These stars don’t actually shine, either. They shine because of the heat created by the immense pressure the “star” is under. This heat is leaked out and is what we perceive as it shining. These white dwarfs can also accumulate matter, and eventually will become Type Ia supernovae if they do. (See Type Ia supernovae for more information)

- Pulsars



Pulsars are very quickly rotating neutron stars. They can rotate many times per second. Pulsars are also highly magnetized. Because of the spinning and the magnetic fields in these objects, they emit beams of electromagnetic radiation. This radiation is moving very close to the speed of light and are easily identifiable here on Earth (and with satellites orbiting the Earth)

- Novae

Novae are associated with white dwarfs though they are not the same as supernovae. A nova is when the accretion disk around a white dwarf becomes hot enough to start Hydrogen fusion, or 10000°. Because all of this energy and light is not contained by the core of a star, it goes everywhere and is very bright. It can be bright enough to seem like there is a new star in the sky, though nowhere near as bright as a supernova. This process, unlike a supernova, can occur many times. Once the Hydrogen fusion has ended, the star can continue to accrete matter from its companion and turn nova many times over again as long as it doesn't pass the 1.4 solar mass limit.

- Close Binaries and Accretion Disks

Close binaries are binary systems that are closer together than usual, and their gravitational fields have very close tidal impacts on one another. Accretion disks occur when one star in the close binary has become a white dwarf, neutron star, or black hole with a massive gravitational field. The smaller star, usually still on the main sequence, can become locked in orbit with the other star, always showing the same side to the other star. If close enough, the white dwarf, neutron star, or black hole can suck matter from the star into its field. When this happens, the gas from the star forms an accretion disk around the object. The gas rotates very quickly and heats up. If the object is a white dwarf, it can form a nova if it heats up enough to start Hydrogen fusion. (see Novae for more information). If the object is a neutron star, the inwards spiraling matter eventually just hits the surface of the neutron star and emits light and radiation. There is no explosion or novae. If the object is a black hole, the accretion disks gas very close to the event horizon will be ripped apart and emit tons of x-rays before it is swallowed by the black hole.