Physics of Star Life

Anne Wilhelmi

Ali Sahami

Gerald Ericksen

Steven Benjamin

Evan Cantor

Gabriel Crowley

Salt Lake Community College

Abstract

Existence as we know started from a cataclysmic explosion that occurred approximately 13.798 billion years ago, setting in motion a chain of events that created our universe, galaxy, solar system, planet, and even the substances that we are made of. Everything in our existence has been derived in one way or another from a star. Stars are born through interactions between masses, they produce energy, condense upon themselves, explode, and die. Energy can never be created nor destroyed and because of this the death of a star only contributes to the chain reaction of the birth of another star, galaxy, planet, or being. So we owe our existence to an event known as the big bang. In a sense the big bang is responsible for all life and conscious thinking as well as understanding. Physics is one of the oldest fundamental principles studied over the millennia. It is the study of matter, motion, energy and force. All of which were created due to the big bang. These interactions between stars follow strict rules that we understand under the principles of physics.

Accretion and The Birth of Stars

The origin of our universe is been debated for centuries. Astronomers believe that through calculation and reversing the timeline of the universe they can find the exact moment it was created. One of these theories is involves a massive explosion, called the big bang. The force from this explosion accelerated debris and energy in every direction. The universe dramatically expanded, heated and cooled. As a result of this explosion the universe is still expanding at an exponential rate. The energy from the big bang was then converted into subatomic particles which combined into Hydrogen and other atomic gases. The remnants of the big bang created molecular clouds called nebulae and led to the formation of stars from dense stellar nurseries.

The slow birth of stars begins in nebula with the slow accumulation of dust, gas, and other materials left over from the universe's creation in a process known as accretion. This matter will continue to accumulate until a gravitational disturbance, like the pass of a star or other large body interferes with the materials collapse. There are several variations of these gradually accumulating clouds including dark nebula, planetary nebula, supernova remnant, and diffuse molecular nebula. Dark nebula are usually so dense that they obscure light. Planetary nebula are stellar remnant clouds which contain glowing shells of ionized gases. Supernova remnant clouds are the remains from the explosion of dying stars. Stars are most commonly formed from nebula called diffuse molecular clouds. Many of the clouds previously described can range from just a few light years to several hundred light years in diameter. A light year is determined by the distance light can travel in a vacuum in one Julian year which is approximately 9.4605284×10^{15} meters (Whitlock). The physics of molecular clouds is poorly understood and the general concepts of gravitational condensing has been suggested over many centuries even by Isaac Newton. Advancing technology has allowed for observations of clouds and star formation, which are made possible by using radio and infrared waves.

Stars are formed from gravitational collapse of a molecular cloud found at the the center or in spiral arms of galaxies. The dust and elements of the cloud clump together into molecular cores, which become some of the densest matter of a nebula. Areas of overly dense matter have a greater gravitational potential than that of the surrounding atomic gas causing what is known as gravitational instability. Gravitational potential is defined by:

$$U = -\frac{Gm_1 m_2}{r}$$

where G is the gravitational constant, m is the mass and r the radius.

As the gravitational force of the core increases it draws more of the surrounding particles inward and in addition increases in mass. An object becomes more dense by increasing its mass compared to its volume. The cores continue to collapse and become increasingly more dense. As the pressure of collapse increases particles become energized and heat is produced. The energized particles push outward against the gravitational pull. Pressure is force per unit of area, and force is an influence used to perform work. The work exerted in gravitational collapse causes the atoms to vibrate at a higher rate, resulting in the release of energy.

In order for star formation to occur, many factors must be overcome. One such factor is inversely related to the increasing pressure of collapse. Thermal pressure is the outward force of energized particles and is an important force counteracting against gravity. Thermal pressure also sets the minimum mass that a cloud core must exceed in order to collapse under its own gravity. The minimum mass requirement is calculated using Jean's mass:

$$\frac{dp}{dr} = -\frac{G\rho(r)M_{enc}(r)}{r^2},$$

Where G is equal to the gravitational constant, r is the radius, p is pressure p (r) is the pressure of gas at r (Larson 2003).

Another factor that must be overcome are forces made by galactic tides. Tidal force is directly influenced by Newton’s law of universal gravitation which states:

> "Every point mass in the universe attracts every other point mass with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them," (Hewitt, P. 2010).

$$\frac{I_1}{I_2} = \frac{{D_2}^2}{{D_1}^2}$$

Where I is equal to intensity and D is equal to distance. Tidal force depends upon the pull of one mass compared to that of the second mass and the distortion that occurs to each body. These tidal forces may be greater than that of the force of gravitational collapse acting upon the core, which will cause interference and can stop star formation.

Molecular clouds have complex internal motions known as turbulence, which is another major source that can counteract star formation. Turbulence in space is a random diffusion of material traveling at supersonic speeds that can exceed $.2km^{-1}$. It is speculated that turbulence plays a major role in the formation of molecular clouds. There is strong evidence that although this force appears random, the velocity dispersion as viewed from infrared data suggests that it follows Kolmogoroff's Law, which is the probability of whether an event will occur (Larson 2003). This random variation of velocity and pressure works against the gravitational force of collapse. Density fluctuations of stars can be influenced by these supersonic movements and by the energized particles. These fluctuations in density lead to limitations on star size and provides evidence that turbulent motions effect star growth (Puiu, T 2012). Although magnetic fields are not able to completely counter the force of gravity alone, they are speculated to have some influence on star formation. Unfortunately there is not enough data to properly understand the importance of magnetic fields in countering the gravitational forces. They may however damper rotational forces (Jsureshcfa 2011).

There are some timescales that are important to understand about the formation of a star. Free fall time, which is the amount of time it takes for the star to collapse due to its own gravitational force. Free fall time is dependent upon the mass of the object. This is the amount of time that a contradicting force would need to exert an influence on the collapse in order to disrupt formation. Another time scale to understand is the Kelvin-Helmholtz timescale. This is scale is the measure of how long a cloud of a specific luminosity would need to collapse if all gravitational energy was radiated away. This energy timescale is important in the collapse of stars in early life by setting the time it takes for a protostar to collapse, and later in its life by setting the timescale that it takes for other stars to evolve into giants.

A protostar, the result of a nebula that has collapsed under Jean's Mass, continues to accumulate as gravity increases, pressure builds, and heat increases (Mihos). The time before a protostar reaches it's main sequence and begins producing energy is known as the pre-main sequence. This sequence is the slow contraction of the star, which actually decreases the stars luminosity until the surface temperature increases to the point where the surface becomes more opaque and the energy beneath the surface starts to filter out (Mihos). When the core temperature reaches 10,000,000 degrees Kelvin, fusion reactions will begin, the star will begin producing its own light and the solar wind that is produced will push away the remaining debris. A star then becomes a hot ball of gas, with hydrogen fusing into helium at its core (Mihos).

Middle Age, The Main Sequence

A star is not the result of gravitational compression, but the conversion of the star’s mass into energy through a process known as fusion. In stars comparable in mass to our sun, this is a reaction involving the Proton-Proton chain. It requires temperatures upward of 13 million Kelvin and a density of at least 100 gm/cc (University of Northern Iowa). The star’s available elements create energy and leave a byproduct of helium. Smaller particles such as neutrinos and photons are also spewed out during the process. It starts with 4 protons and results in a helium nucleus (University of Northern Iowa).

Stars typically spend most of their lives actually fusing the hydrogen. The bigger the star the more heavy the elements it can fuse this into. This is where most of these heavy elements of the universe are created, right in the middle of a star (Oracle Foundation). The equilibrium of this whole process is the battle of the gravity and the gas pressure, this battle between the two is a big part of how stars live and die (Montana State University). The main phase of a stars life is called the “main sequence”, once they achieve nuclear fusion, the star begins to shed light into the universe for billions of years to try and make up for the heat and light energy that it has lost (Oracle Foundation). While this is occurring, the star is gaining density, pressure and heat, and the temperature of the core of the star slowly increases, as it also is contracting because the battle of gas pressure and gravity is occurring throughout the entire life of the star (Oracle Foundation).

The life of a star is somewhat like the life of a human in the sense that a human begins to die once its body can’t stay at what biologist call homeostasis. And so the main purpose of a stars life and what keeps it alive is dependent on how long the star can maintain its equilibrium (Montana State University). So obviously, if the star is smaller, then it isn’t going to have the components to keep itself at equilibrium for as long as a bigger star which will be able to hold itself at equilibrium for very long time. But when it says that the star has to stay at equilibrium, it doesn’t mean that there aren’t any changes in the star, because they are changes occurring all the time, it just means that there is no “net overall change”, which means that the gravity pulling atoms into the star must be equal to the gas pressure pushing out from the middle of the star, and when those are equal, then the star is technically at equilibrium (Montana State University). It takes some time for the star to hit the point of equilibrium, but once it does hit that point, the star will begin to burn, a star will normally burn hydrogen for the duration of its life (Montana State University).

The Death of a Star

After the main sequence phase of a star hits, it then becomes a star of old age and eventually dies. But how long it takes a star to die is completely up to the stars initial mass, for example, a smaller star such as our sun, can easily burn for billions of years, but then once the star cannot get hot enough to keep the carbon fused it will then die (NASA). Although this may come as a surprise, the stars with the larger masses actually will live much shorter lives than a smaller star, the bigger stars only end up living millions of years before they develop “dead iron cores” and explode into a supernova which may end up creating what we know as a black hole (NASA). But the outermost parts of the star will actually return back to the interstellar medium from which it had come (NASA). The bigger stars may obtain more atoms, but the process of the fusion reaction actually goes faster than in a smaller star, so in this case bigger is not better.

Stars are sustained by the nuclear fusion reactions taking place in their cores. For stars on the main sequence, such as our own Sun, which combines hydrogen to form helium, the energy that these reactions produce is enough to support their mass against its own gravity. As a star runs out of fuel it can expand and will begin to form heavier elements such as carbon and iron. Once it finally exhausts all of its fuel it will begin to collapse and turn into black holes or receive other fates that dying stars get. Our own sun will collapse until it becomes a white dwarf. At this point, quantum mechanics of Pauli exclusion principle states, “no two identical fermions or particles with half-integer spin can occupy the same quantum state at the same time,” because two electrons cannot be in the same energy level at the same time, the star resists further collapse. This energy is called electron degeneracy. Basically hydrogen in the core of the star is gone, and the star needs increased temperature in the core to re-ignite the fusion. The star is forced to burn helium in an effort to maintain stability. The star takes $10x10^7$ K to initiate the burning of the helium, but it only takes a temperature of $2x10^7$ to get the hydrogen to burn (Gerhardt). Helium burns inside of the stars core, but the rapid hydrogen reaction occurs faster in the shell of the star. As the temperature in the shell of the star increases, the outer layers of the shell actually expand. The outer layer of the star shell expands in an attempt to maintain the heat produced in the core from escaping into the space. Once the star reaches this point, the fusion process throughout the star will begin to cease.

Towards the end of a star's life, the temperature near the core rises and this causes the star to expand. Stars convert hydrogen to helium which produces light and other radiation. As time progresses, the heavier helium sinks to the center of the star, leaving a shell of hydrogen to surround the helium core. The hydrogen is depleted so it no longer generates enough energy to support the outer layers of the star. There are several stages a star can enter after it has run out of hydrogen to convert to helium, beyond the possibility of a red giant. If a star has only half the mass of our sun, electron degeneracy pressure will prevent the star from collapsing in on itself. What could theoretically result (the universe isn't old enough for one of these to have been observed yet) is a white dwarf, a mostly inert ball of hot gas. A white dwarf is formed when a star has burned all of its original hydrogen and helium fuel to elements such as carbon, nitrogen and oxygen (Nave 2013).

When electrons are packed together, as they are in a white dwarf, the number of available low energy states is too small and many electrons are forced into high energy states. When this happens the electrons are said to be degenerated. These high energy electrons make a significant contribution to the pressure. Because the pressure arises from this quantum mechanical effect, it is insensitive to temperature; the pressure doesn't go down as the star cools. A black dwarf is a white dwarf that has cooled down enough that it no longer emits light. If the star doesn't have enough mass, or pressure at its center is too low, and the elements of the core can not fuel a reaction, the star will be unable to produce further heat. The star however, is still hot from the early burning stages, and will remain glowing until it cools down. It takes tens to hundreds of billions of years for a star to cool down entirely. Unfortunately, the universe is not that old and the oldest stars that have been discovered are between 10 and 20 billion years old (Mattson 2004).

As a white dwarf ages, it is also possible for some fusion to continue in the core, resulting in a slow expansion that will eventually transform the dwarf into a red giant. In the early stages of a red dwarf, the pressure and temperature rise until it is high enough for helium to combine into carbon. To radiate the energy produced by the helium burning, the star expands. A red giant will slowly fuse helium to form carbon and oxygen. Eventually this process would exhaust itself and leave a black dwarf.

If a star is 1.4 times the mass of our sun it is over the Chandraskhar Limit (3×10^{30} kg) , which is the mass a star must exceed in order to avoid becoming a white dwarf, it will become a neutron star (Stein, 2012). A neutron star has three main layers, the core is solid, it possesses a liquid mantle, and a shallow, solid crust. Neutron stars contain a very tiny atmosphere, but in most cases this contributes very little to the function of a star. The crust usually is very thin and can range to be just a few kilometers deep. The mantle and core combined, on the other hand, are approximately ten kilometers. A neutron star also has two axes, the first being a magnetic one and the second is an axis of rotation. The axes of a neutron star's magnetic axis is similar to that of earth where they do not line up with the geographic poles. Pulsars are like neutrons but include one very important difference, A pulsar emits two very high-energy beams into space. These beams are emitted along the magnetic axis of the star.

> "The beams are made of material usually stolen from a companion star, and the particles are accelerated to speeds as great as 20% that of light...Pulsars and neutron stars spin very rapidly as seen from Earth, most at about once every second. The record for the fastest is at 642 rotations per second, and the record for the slowest is one spin every 4.308 seconds," (Neutron Stars).

Due to the law of conservation of angular momentum the star spins rapidly. This law has a direct effect on the stars rotation because the speed at which it spins leads to the star shrinking without losing mass and in turn causes an increase in the rate of rotation.

Pulsars do eventually slow down and stop spinning. Ripples are sent out into space as a result to the energy lost from this decrease in momentum. This phenomenon is also called gravitational waves, that emanate from all moving massive objects. After this event the pulsar shows the characteristics of an ordinary neutron star because if the light emitted from the beams no longer reach Earth, the star will no longer be seen as pulsing. If a star is over five times the mass of our sun, it will become a supernova when the fusing of hydrogen stops. What material isn't expelled in the creation of the supernova will eventually condense into a black hole.

Light, Star Classification and the Photon's Random Walk

From a stars main sequence onward, it will emit a great deal of light. The color of this light, as we on earth perceive it, is determined by the amount of energy produced by the star (Wikimedia Foundation). The hottest stars emit high intensity, short wavelengths of light that appear on the blue end of our visible light spectrum, while cooler stars emit light that falls closer to red in our spectrum of visible light. Therefore, by examining the distribution of frequencies given off by stars and looking at the shifts in and dominant frequencies of this light, scientist can make determinations about the star's temperature and type. There are 7 color categories of stars, O, B, A, F, G, K and M, with O types being the hottest and bluest with temperatures ranging from 25,000 - 50,000 degrees Kelvin to less than 3,500 K in M class stars (University of Nebraska-Lincoln).

While stars emit some light at all frequencies along this continuous spectra of color, not all of that light will make it to us to be observed (Ventrudo). The light emitted will pass through thin layers of gas that surround the star and possibly other clouds of gas on its way to an observer, so the color spectrum observed when it reaches us isn't a continuous spectrum, like the unfiltered white light from a light bulb, but an absorption spectrum that is characterized by short dark gaps along the color distribution from blue to red. An example of this type of wavelength absorption is our blue sky. If you looked at our sun from space, free from the interference of our atmosphere, it would appear to be white, but because blue light is reflected and scattered by our atmosphere, the light emitted by our sun that makes it to us is mostly red and yellow in appearance (Ventrudo).

The basic unit, or quanta, of light is the photon, a massless, chargeless particle that moves at 299,792,458 m / s. Photons begin their life as high energy gammas produced by the stars powerful fusion reaction (University of Northern Iowa). The force that these gamma rays emit actually fights the gravitational contraction of the star, keeping stars at a consistent size. Stars are incredibly dense, so when these high energy photons are produced in the star's core, they just don't fly off into space, first they have to take a long walk. The photons journey from the stars core to the surface is referred to as the Random Walk (University of Northern Iowa). We think of light as moving in a straight line, but in a star photons are constantly being produced in the form of gamma-rays and are colliding with other particles, often electrons, that are being cast off by fusion processes. It can take about 200,000 years for photons to escape what is referred to as the Radiative Zone of a star, the areas outside of where these primary energy producing reactions are taking. This zone slowly transports the particles to what is known as the Convective Zone, a less dense area of hot gas where the radioactive processes that drove the photons out of the

Radiative Zone are less important. Here the photons, no longer gamma-rays after exhausting so much energy in their escape, can radiate into space as visible light. This light will begin to travel in a straight line, but can be bent to an extent by the influence of gravity (University of Northern Iowa).

Stars, The Equivalence Principle and Bending Light

It might sound counter-intuitive to say that light is affected by the stars gravity because photons are massless, but this can be understood by reviewing some of Einstein's theories on the effect that a great deal of mass can have on the space around it. Basically, Einstein proposed that things that were once thought of as separate properties, like mass, energy, space, and time, were all actually linked (Possel). One such link is something called the equivalence principle. With this principle, Einstein proposes that inertial forces, the forces that act on you as you are accelerating freely through space, can be equated to the forces felt when you are stationary on Earth subject to the acceleration of Earth's gravity. He imagines a thought experiment in which a person is placed in a windowless elevator. Once inside, the elevator will either remain stationary on Earth, subject to Earth's gravity or will be sent accelerating into the void of space. Einstein proposes that a person inside the elevator would not be able to distinguish between the Earths gravity or the gravity-like inertial effects felt by the person because of the elevators consistent velocity, which is equivalent to that of gravity. This same equivalence would exist on the elevator in the opposite situation, one in which the effects of gravity are not being felt at all. If the elevator was in freefall, both the person inside and the floor would be moving at the same rate, thus causing an experience of weightlessness. The same sensation would be felt, however, if the elevator was in an area totally free from the forces of gravity. Again, the person inside would not be able to tell difference between free fall and total freedom from any gravitational forces (Possel).

In the next part of the thought experiment, two holes are drilled across from each other on the elevator horizontally. The elevator is then rigged to fall the instant light from a flashlight enters one of the holes. This flashlight is special in that the light emitted from it moves slowly enough that we are able to observe its motion. To someone in the elevator, the light entering as the descent begins will appear to move in a straight line through the first hole and then out the other. Someone on the outside observing this fall would only be able to agree with the person in the elevator on one thing: that the light entered one hole and left the other. The path of the light to the observer outside of the elevator wouldn’t observe the light traveling in a straight line, but as a curve that had to bend its path to exit the second hole. Because of the equivalence of gravity and acceleration, Einstein concluded that gravity must also be able to have this sort of effect on light, that gravity can deflect it (University of Oregon Online).

For a star with the mass of our sun, it’s ability to bend light (called gravitational lensing) is small, but observable. In the case of a black hole, however, Einstein's principles become more evident. Scientist have been eager to observe an area of space that is less subject to normal physical laws for decades and in October of 2012 they got their chance with the discovery of small star, S0 - 102, which orbits a black hole (Kaufman). Here a star in its main sequence is trapped by a star, the remnants of a long dead star serving as an example of Einstein's theories. In Special Relativity, massive bodies can actually bend the shape of space. With S0-102, scientist may be able to delve into a better understanding of the actual geometry of space and of the complex physics that guide the life of stars (Kaufman).

Conclusion

Through the lives of stars, beginning with their slow accretion in nebulae and their transformation from fusion factories of photons in the main sequence to theoretical objects like white dwarfs or obscure black holes, we can see how a host of complex physical laws converge to form something powerful.

References

Cain, F. (2005, February 4). Upper Limit on Star Mass. Retrieved March 31, 2013 from the world wide web <http://www.universetoday.com/10247/upper-limit-on-star-mass/>.

Gerhardt, Amy. The Life Cycle of Stars. Retrieved March 31, 2013, from the world wide web <http://www2.hesston.edu/Physics/StarsAmy/starspaper.htm>.

Hewitt, P. (2010). Conceptual Physics 11-ed. Illinois, Glenview. Pearson Education Inc.

Jsureshcfa, Magnetic Fields and Gravitational Collapse. (2011, Feb 11). Retrieved from world wide web <http://astrobites.org/2011/02/07/magnetic-fields-and-gravitational-collapse-2/>

Kaufman, Marc. "Speedy Star Found Near Black Hole May Test Einstein Theory." National Geographic. National Geographic Society, 04 Oct. 2012. Web. 29 Mar. 2013. Retrieved March 31, 2013, from world wide web <http://news.nationalgeographic.com/news/2012/10/121004-black-hole-milky-way-stars-space-science-einstein/>.

Larson, R. The Physics of Star Formation. (2003, Sept. 10). Retrieved March 31, 2013, from world wide web <http://iopscience.iop.org/0034-4885/66/10/R03/>

"Life Cycle of a Star." *ThinkQuest*. Oracle Foundation, n.d. Web. 01 Apr. 2013. <http://library.thinkquest.org/26220/stars/formation.html>.

Mattson, B. How do we measure the size and the age of the universe. (2004, Sept. 27).

Retrieved March 31, 2013, from world wide web <http://imagine.gsfc.nasa.gov/docs/science/mysteries_l1/age.html>.

McKee, Christopher F, and Ostriker, Eve C. “Theory of Star Formation,” in Annual Review of Astronomy and Astrophysics, vol. 45. Palo Alto: Annual Reviews, 2007: 565–687.

Millis, J.P.Binary Stars. Retrieved March 31, 2013 from the world wide web <http://space.about.com/od/stars/a/Binary-Stars.htm>.

Molecular Cloud Collapse. (2008, Feb 18) Retrieved from world wide web <http://www.astrophysicsspectator.com/topics/milkyway/MolecularCloudCollapse.html>

Nave, C.R. Electron Degeneracy. (2013). Retrieved March 31, 2013. Retrieved from the world wide web <http://hyperphysics.phy-astr.gsu.edu/hbase/astro/whdwar.html>.

Neuron Stars. Retrieved March 31 2013, from the world wide web <http://burro.astr.cwru.edu/stu/stars_neutron.html>

Phillips, C. & Priwer, S. (No Publishing Date Included). Stellar Lives. Retrieved March 31, 2013, from the world wide web <http://www.netplaces.com/astronomy/a-star-is-born/stellar-lives.htm>.

Pössel, M. "The Elevator, the Rocket, and Gravity: The Equivalence Principle." — Einstein Online. N.p., n.d. Web. 29 Mar. 2013. Retrieved from world wide web <http://www.einstein-online.info/spotlights/equivalence_principle>.

Puiu, T. Turbulence “Space confirmed and measured for the first time”. (2012, Dec. 18) Retrieved from world wide web

<http://www.zmescience.com/space/space-turbulence-measured-and-confirmed-for-first-time-423432/>

"Photon." *Wikipedia*. — Wikimedia Foundation, 31 Mar. 2013. Web. 01 Apr. 2013. <http://en.wikipedia.org/wiki/Photon>.

"Relativity." — University of Oregon Online. N.p., n.d. Web. 29 Mar. 2013. Retrieved March 31, 2013, Retrieved March 31, 2013, from world wide <http://abyss.uoregon.edu/~js/21st_century_science/lectures/lec07.html>.

"Stars - NASA Science." *Stars - NASA Science*. NASA, n.d. Web. 01 Apr. 2013. <http://science.nasa.gov/astrophysics/focus-areas/how-do-stars-form-and-evolve/>.

"Scientific Background for Life Cycle of Stars." — Montana State University, n.d. Web. 01 Apr. 2013. <http://btc.montana.edu/ceres/html/LifeCycle/starsbackground.htm>.

"Spectral Types of Stars." - Eclipsing Binary Stars. — University of Nebraska-Lincoln N.p., n.d. Web. 29 Mar. 2013. Retrieved March 31, 2013, from world wide web <http://astro.unl.edu/naap/ebs/spectraltype.html>.

"Stellar Birth and Middle Age." Stellar Birth and Main Sequence Life. — University of Northern Iowa Website N.p., n.d. Web. 29 Mar. 2013. Retrieved March 31, 2013, from world wide web March 31, 2013, <http://www.uni.edu/morgans/astro/course/Notes/section2/new7.html>.

Stein, J. The Chandrasekhar Limit: The Threshold That Makes Life Possible. (2012, Jan 19), Retrieved March 31, 2013, from the world wide web <http://www.pbs.org/wgbh/nova/physics/blog/2012/01/the-chandrasekhar-limit-the-threshold-that-makes-life-possible/>.

University of Arizona, Notes on Spherical Collapse. (2010, Fall) Retrieved March 31, 2013, from world wide web <http://sancerre.as.arizona.edu/~fan/Home/AST541_files/SphericalCollapse.pdf>.

University of Colorado. A Star is Born. Retrieved March 31, 2013, from world wide web <http://lasp.colorado.edu/education/outerplanets/solsys_star.php>.

Ventrudo, Brian “Star Colors Explained | One-Minute Astronomer." OneMinute Astronomer. N.p., n.d. Web. 29 Mar. 2013. Retrieved March 31, 2013, from world wide web <http://www.oneminuteastronomer.com/708/star-colors-explained/>.

Whitlock. K, What is a Lightyear and how is it used. Retrieved April 1, 2013, from the world wide web <http://starchild.gsfc.nasa.gov/docs/StarChild/questions/question19.html>