Stellar Evolution through Breezes, Bangs and Blowouts

As we look up into the night sky we see many pinpoints of light. All the pinpoints are either stars or planets and the majority of the stars are found within our own galaxy. All the stars that we see are in different stages of life or evolution. If we look at how stars evolve, we will understand why stars are different colors. And we will also get a better understanding of how some of the deep sky objects, nebula, planetary nebula, and supernova remnants are all related through stellar evolution.

Interstellar Clouds

"Somewhere in our galaxy, in a far-off place, many thousands of light years away, a vast cloud of interstellar gas and dust drifts silently across the near-perfect vacuum. The wispy edges of the cloud stretch outward into the blackness for trillions of miles in all directions, as if to reach for the stars beyond. The cloud contains an enormous amount of matter which is composed mostly of hydrogen and helium. The cloud contains more than enough mass to create dozens upon dozens of stars like our sun. The cloud appears to be a "near prefect vacuum of interstellar space, roughly 10 atoms per cubic centimeter. Air we breathe, in comparison, contains 30 billion, billion atoms in each cubic centimeter. The majority of these atoms are hydrogen. For every 16 hydrogen atoms you will find a helium atom. It takes a great deal of searching to find atoms of the heavier elements, such as carbon, nitrogen, oxygen, and iron. The cloud is very cold, only 100 degrees above absolute zero" [1].

Dark Nebula

"As a spiral arm sweeps through the interstellar cloud, the widely spaced atoms are pushed together preventing star light from penetrating. The cloud has now become a dark nebula. The light from the distant stars no longer penetrates the compressed cloud to warm its gases. Temperature plummets toward absolute zero. As the temperature falls, the atoms move more slowly, so slowly that the weak force of gravity between each atom begins to dominate the nebula's internal structure. The nebula is no longer perfectly smooth and uniform. Some locations have more atoms than average and therefore a slightly stronger gravitational field. This force attracts other atoms and the number of atoms grows. The nebula begins to break up into lumps or globules. A typical globule may be several billion miles in diameter and contain an amount of matter a few times the mass of the sun" [1].

Globules

“A globule is unstable and cannot support its own weight. The globule shrinks, becoming smaller and smaller, squeezing the gases at the center of the contracting sphere to even higher pressures and densities. As pressure rises, so does the temperature. As temperature increases the gases deep inside the shrinking globule begin to glow. The globule has now become a protostar” [1].

Protostar

“The protostar cannot support its own weight, so it continues to contract pushing the temperature and pressure higher and higher. When the temperature at the center reaches approximately 10 million degrees, hydrogen burning begins. At this temperature the nuclei of the hydrogen atoms are moving so swiftly that when they collide they permanently stick together, producing helium. For every four hydrogen nuclei that are fused together a helium nucleus is created. The resulting helium nucleus weights slightly less than the four hydrogen nuclei from which it was created. The missing material has been converted to pure energy. This process is called a thermonuclear reaction. The enormous release of energy that accompanies hydrogen burning creates pressures that allow it to support its own weight, the contraction is halted. A star is born” [1] .

Stars

Stars come in all sizes and colors. Some of the stars are only about 1/20 the size of our sun, others are so big that if they replaced our sun they would encompass the orbits of Mercury, Venus, Earth and Mars. According to https://en.wikipedia.org/wiki/List_of_largest_stars, the largest star is UY Scuti with a radius of 7.94±0.9AU, and is so large that it would almost reach the orbit of Saturn. The temperature of the star's surface will decide the stars color. A relative cool star will be red and a hot star will be white or blue. A piece of metal as it is heated will also exhibit this change in color. When the metal is first heated it will glow red, as it becomes hotter the color will change to orange, yellow, then white and finally it will turn blue. Based on the surface temperature of the star, categories have been established for the stars. This is shown in table 1. Stars are also classified by their luminosity; this is shown in table 2. Our sun, for example, is classified as a G2V star.

Table 1. Stellar Categories (https://en.wikipedia.org/wiki/Stellar_classification)

Class	**Temperature** (°K)	**Color**	**Mass** (Mʘ)	**Radius** (Rʘ)	**% of Stars**

O	> 30,000	Blue	≥ 16	≥ 6.6	~ 0.00003
B	10,000 – 30,000	Blue White	2.1 – 16	1.8 – 6.6	0.13
A	7,500 – 10,000	White	1.4 – 2.1	1.4 – 1.8	0.6
F	6,000 – 7,500	White Yellow	1.04 – 1.4	1.15 – 1.4	3
G	5,200 – 6,000	Yellow	0.8 – 1.04	0.96 – 1.15	7.6
K	3,700 – 5,200	Orange	0.45 – 0.8	0.7 – 0.96	12.1
M	2,400 – 3,700	Red	0.08 – 0.45	≤ 0.7	76.45
Data valid for Main Sequence Stars only, ⊙ - Ratio caparison with the Sun					

Table 2. Stellar Luminosity Classification
(https://en.wikipedia.org/wiki/Stellar_classification)

Class	**Name**
0	Hyper Giants
Ia	Luminous Super Giants
Ib	Less Luminous Super Giants
II	Bright Giant
III	Giant
IV	Sub Giant
V	Dwarfs
sd	Sub Dwarfs
D	White Dwarfs

The surface temperature of a sun, and its color, are defined by the star mass. The length of a stars life, and also its fate, is also dependent on the star mass. The more mass a star has, the faster it burns its fuel, the shorter its lifespan and usually the hotter the surface temperature. According to https://www.e-education.psu.edu/astro801/Content/l7_P3.html, a star with 10 solar masses will last for only 32 million years. Our sun which has 1 solar mass will last about 10 billion years, and a star with one-tenth solar masses will last 3162 billion years. During this time the star is said to be a main sequence star, which means the star is in its middle life.

Stellar Winds and the Solar Corona

While a star is on the main sequence it is evolving by losing mass through stellar winds. "Breezes that blow over millions of years can actually carry away more matter than the abrupt bang of nebular ejection. But the significance of stellar winds varies a lot from star to star and changes during a star's lifetime"[2]. For our sun, "assuming that the solar wind will blow constantly over its lifetime, it is estimated that the mass of the sun will be decreased by 0.02 percent. The solar wind is carrying the lost mass at a speed of 300 mi/sec away from the sun" [6]. "The sun in this way continuously loses this matter, but the rate of loss, as can be seen is exceedingly small and has no important effect on the long term evolution of our sun. Besides, it is also gaining material from the other component of the interplanetary medium, the interplanetary dust" [5].

"The steady, continuous solar wind is the natural extension of what is called the solar corona. The corona of the sun is a very thin outer atmosphere that extends out to several times the solar radius from the surface of the sun. It is made up of exceedingly hot gas with temperatures as high as two million degrees, much hotter than the surface of our sun at 6000 degrees. The corona is produced by matter ejected from the surface of the sun, both by violent motions during the solar surface storms and by the general circulation called convection of the layers of the sun just beneath the surface" [5].

"Some of the very youngest stars in the Galaxy are also some of the most active in terms of mass loss through stellar winds. These are the O-type stars: the hottest and brightest of the main sequence stars, with surface temperatures exceeding 25,000 K and luminosities over 10,000 times that of the sun. The radiation pressure is so intense in the atmospheres of O-types stars that it can expel material at up to 1/10,000 solar masses per year. In extreme cases, heavy young stars can lose 10 solar masses from their atmospheres in less than a million years" [2].

"Even the cooler B and A-type stars experience mass loss through stellar winds, but the loss is significantly less than from the O-types"[2]. "Still further down the main sequence toward the cooler end, the evolutionary tracks of stars are virtually unaffected by "evaporation" in stellar winds" [2].

Stellar Death

During the time a star is on the main sequence undergoing thermonuclear reactions, helium is being produced as ash from the burning of the hydrogen fuel [1] (see Figure 1). To keep the star stable the energy liberated must counteract the contraction of the star. As the hydrogen is used up, the star must contract to raise the temperature causing the protons to fuse together more rapidly to provide enough pressure to keep the star from contracting. During the star's lifetime, the core of the sun continues to contract and also to grow hotter [7]. "As the amount of helium at the sun's core builds up, the hydrogen dwindles" [1]. "When the hydrogen is depleted at the sun's core, hydrogen burning at the core shuts off" [1]. This happens "because stars do not have very strong convective currents to circulate the unburned hydrogen in its outer layers down to its core” [3].

Now that hydrogen burning at the core has stopped, “the core becomes unstable against the influence of gravity and the star's helium-rich core begins to shrink” [1]. “The temperature begins to rise, finally the temperature surrounding the collapsing core rise high enough to ignite hydrogen burning in a thin shell around the core” [1]. “When the temperature reaches 100 million degrees at the helium core, the helium nuclei are traveling so fast and colliding so violently that they fuse together to form carbon and oxygen” [1]. The onset of this burning is called the “helium flash” [3]. “The helium flash liberates so much kinetic energy in such a short time that the core expands slightly. This in turn lowers the temperature and the rate of helium fusion, however, the reactions continue” [7]. “Because the rate of fusion reactions depends on the temperature, the star can for a brief time, liberate more kinetic energy per second than before. As the star does so, the increased amount of newly liberated kinetic energy pushes outward on the star's outer layers, expanding them to enormous proportions, increasing its volume a billion fold. The expansion cools the gases, and the star creates a cool, highly extended outer shell at the same time that it produces an extremely dense and hot central core” [7]. The star has “become a red giant” [7].

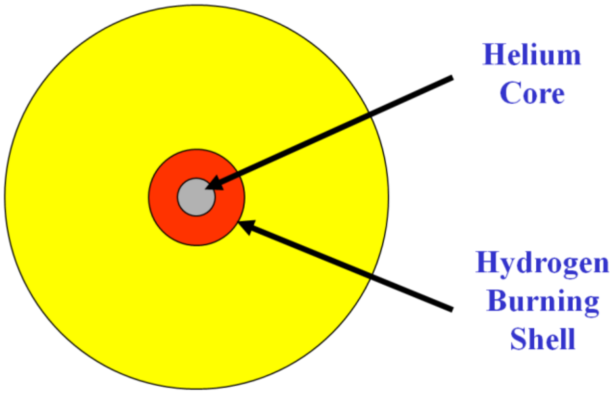

Fig. 1 As a star evolves a helium ash core is produced, but hydrogen burning continues in a shell outside the core [1]

Red Giants

As an example, “our sun's temperature is currently at about 6,000 degrees” [1]. When it becomes a red giant the temperature will “reduce to about 3000 degrees”[1] and the radius of the sun will grow to actually encompass the planets Mercury, Venus, Earth and possibly Mars. During this transition from main sequence to red giant the sun is “expected to lose its corona”[3]. The reason for this is “not completely understood” [3].

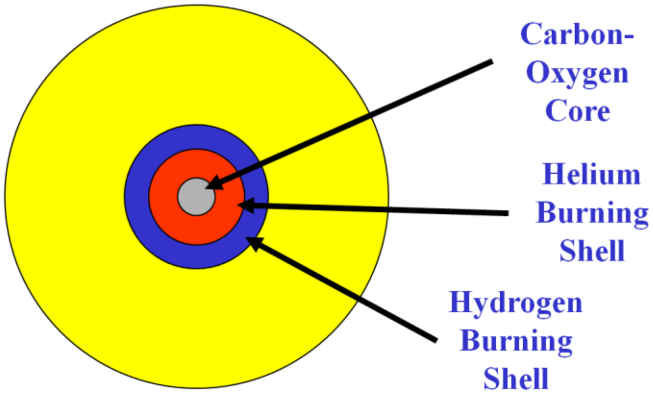

Fig. 2 As an old, low mass star nears death, helium burning produces a carbon-oxygen ash, but helium and hydrogen burning continues in shells outside the core.

“Red giants are particularly susceptible to mass loss through stellar winds following the disappearance of their coronas. Some red giants shed upwards of one solar mass over several million years" [2]. "For instance, much attention has focused on two stars with the names, Betelgeuse and Eta Carinae, for the simple reason that these colossal stars seem to be right on the verge of"[2] blowing themselves up. "Betelgeuse is blowing a stellar gale, losing a sun's worth of matter every 100,000 years" [2].

During the red giant stage, "carbon and oxygen are the ashes of helium burning" [1]. After a few million years "all of the helium at the star's center is used up. Helium burning shuts off at the core, once again the star becomes unstable and again begins to contract" [1]. When the temperature gets high enough, "helium burning begins in a second thin shell" [1] around the core. Now the star has "two thin shells of thermo-nuclear reactions, an inner helium burning shell and an outer hydrogen burning shell" [1] (see Figure 2).

If the mass of the star is not large enough, "the carbon-oxygen core remains inert as the hydrogen and helium burning shell creeps outward" [1]. "As the star evolves further and the helium burning continues, the carbon core becomes increasing smaller and hotter. This change is gradual in stars of moderate mass, and it results in an increase of the temperature of the surrounding helium-burning shell, and therefore an increase in the rate at which the helium fuses to form more carbon. This effect makes the star become larger and cooler at its surface. Finally the red giant star becomes so cool at its surface that the gas in the surface layers begins to become made up of neutral atoms. This is because the temperature is sufficiently low that the nuclei of the atoms can capture and hold the electrons. The temperature is so low that collisions between the particles making up the gas in the outer parts of these stars are so infrequent and so slow that they do not continuously dislodge electrons from the nucleus of atoms as has been the case throughout the lifetime of the star until this stage" [5].

Neutral Atoms

"Formation of neutral atoms in the envelope of a red giant star marks the beginning of the end for this stage. Neutral atoms when formed emit light waves, because of the change in the energy of the system when the electron is captured by the nucleus of the atom. A nucleus together with electrons forming a neutral atom has less total energy than a nucleus and electrons separately possess. This is because there is a certain amount of binding energy that holds the electrons to the nucleus in its neutral state. Whenever a nucleus captures an electron, it must give up some energy and this energy is emitted in the form of a photon of light. When the envelope of a red giant star begins to become neutral, many photons are thus emitted by the forming atoms. These photons are subsequently absorbed by surrounding material, thus slightly heating up the envelope. The heating in turn causes the envelope to expand to a larger size, and the expansion in turn leads to a cooling of the envelope that allows more neutral atoms to form and more photons to be emitted. This process continues in a cycle with the envelope getting progressively larger and cooler” [5]. “Thousands of years elapse between each” [1] cycle or pulse. “The envelope is in a tremendously dynamic state, its fate lying in the hands of two physical processes, convection and pulsation. Convection-"boiling" is a vital heat transfer mechanism in the atmosphere of both red giants and relatively low mass main sequence stars” [3]. These “pulsations may be what drive pulsation in the long period (1 year) variables (Mira type)” [3]. Finally, “at some point pulsations are likely to get so out of control” [3] that the envelope “completely leaves the star and becomes a separate entity - a ring of shell surrounding the star” [5]. This is called a “planetary nebula” [3,5].

Planetary Nebula and White Dwarfs

It is “suggested that perhaps 20 percent of the mass of a star like the sun could be gently ejected into space by this process” [5]. One astronomer calculated the “mass from 43 PN's and found they ranged from 1/1000 solar masses to 10 solar masses with an average of 1/5 solar mass” [3].

“The bare core of the star consists of the carbon-oxygen center and the thin helium-burning envelope. Because the envelope is very hot, the remaining part of the star will appear to be very blue. It is understood that the small bright planetaries are the most recently formed” [5]. “Expansion rates of 20-50 km/sec are observed” [3]. “The largest planetaries have diameters of about 1 parsec” [5]. “Planetary nebulas are short-lived phenomena in the universe” [1]. After only 50000-100000 years [1,3], the expanding envelope of gases has become so thinly dispersed that the nebulosity disappears from view. “About 1000 planetaries have been indentified in our galaxy” [3].

“The fact that even a thousand planetaries have been found indicates that many stars having 1 to 4 solar masses go through this stage” [3]. “Central stars of Planetary Nebulas have surface temperatures of 30,000 to 100,000K” [3]. “The observed numbers and ages of planetary nebulae indicate that a new planetary nebula is formed roughly once every two years in the Galaxy. This is about the rate at which stars above two solar masses are calculated to evolve through the red giant phase” [6].

After the central star has been exposed, following the ejection of the outer atmosphere, the stellar winds pick-up, increasing the mass loss of a star. “Meanwhile, the dead star gradually shrinks in size” [1] as it cools. “The star contracts until it is roughly the same size as the Earth. The star has become a White Dwarf” [1].

Degenerate Electron Pressure

"Most of the atom's mass is contained in the nucleus-protons/neutrons. Protons carry positive electric charge and neutrons are electrically neutral. Tiny lightweight electrons that orbit the nucleus are negatively charged. Normally the number of positively charged protons is exactly equal to an equal number of negatively charged electrons. Inside a dying low mass star, the atoms become packed so tightly that all the electrons are torn off their nuclei. The star's interior consists of nuclei floating in a sea of electrons. Finally when gravity has crushed the star down to the size of the earth, the electrons are crowded so closely that they produce a pressure that resists any further contraction. Any further contraction would cause the electrons to occupy the same place. This is forbidden by nature and the law is called the Pauli Exclusion Principle. This pressure is called degenerate electron pressure" [1].

"Degenerate electron pressure can support a stellar corpse that weighs as much as 1.4 solar masses. This limit is named the Chandrasekhar limit, after its discoverer, S. Chandrasekhar." [1]

Element Building

"If the star is massive, the carbon core will slowly continue to collapse towards the end of the red giant phase, eventually reaching exceedingly high temperatures. Calculations and experiments indicate that when 600 million degrees is reached, the carbon in the core will begin to fuse as did the helium and hydrogen before it" [5]. "After a short period however, the carbon of the core will be used up, and the core will once again begin to contract because there is no longer any source of outward pressure. When the core has contracted further and heated up to an even higher temperature other nuclear reactions" [5] occur. "When temperatures reach 1 billion degrees oxygen burning begins producing silicon" [1]. "At 3 billion degrees silicon burning begins producing ash of iron" [1] (see Figure 3). "This fusion then heats up the core still further, and the pressure produced by the energy generated temporarily stops the contraction of the core" [5]. "The process occurs relatively rapidly, and in only a few thousand years or less these steps finally come to a natural halt" [5].

"The reason for the eventual

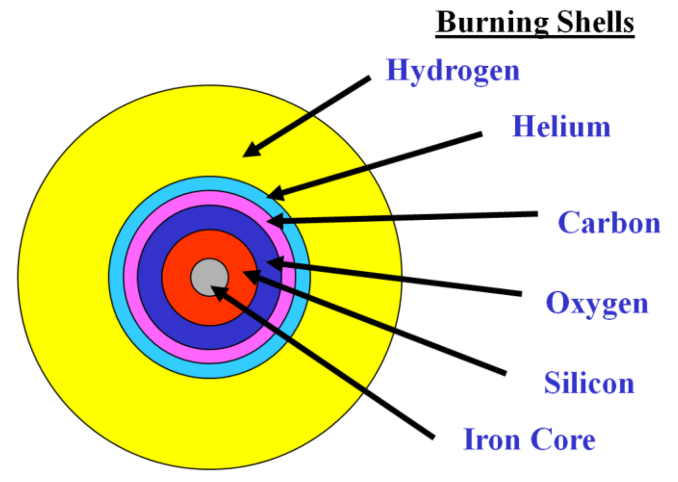

Fig. 3 As an old, high mass star nears death, multiple shell burnings occur around an iron rich core. At this stage in a star's life it is just about ready to become a supernova.

stoppage of element building is the very peculiar nature of the element iron" [5]. When all the silicon is burned up, the iron core will contract, but "because it takes energy to convert iron to a heavier nucleus, the con-traction is not halted by a new nuclear reaction. Rather it continues until it becomes energetically advantageous for the iron nuclei to break up into helium nuclei again. This reverse process absorbs energy with catastrophic results. As the kinetic energy of particles in the core provides the pressure supporting the star, the pressure suddenly drops when this energy is absorbed. In response the gravitational forces cause the core to contract event faster, hence driving the conversion of iron into helium faster and resulting in an ever greater loss of pressure. Such a process is called an implosion. The core collapses inward with ever increasing speed. Only if a new source of pressure develops can the collapse be stopped. Calculations show that at a certain density, degenerate neutron pressure begins to slow the collapse of the core" [6].

Degenerate Neutron Pressure and Neutron Stars

"Degenerate neutron pressure is when the densities are so great that the neutrons obey the Pauli Exclusion Principle. That means two identical neutrons cannot be forced to occupy the same place"[1]. "At this point the individual atoms nuclei are touching each other and cannot be pushed further together" [5], preventing the star from collapsing any further. The resulting core is made up of neutrons, or in other words, the "core becomes a neutron star" [7].

If the core weights less than 1.4 solar masses then the core will stop its collapse. "If the planet size core weighs more than the 1.4 solar masses then the core collapses in about 1/10,000 of a second to become a ball only 20 Km in diameter" [2].

Supernova

"In the meantime, the outer layers of the star also begin to collapse, being deprived of their base of support by the core collapse. By the time these layers reach the core, a neutron star has begun to form. The inrushing outer layers slam into the neutron-star core at velocities approaching the speed of light, heating the gas to 10^9 degrees or more and tremendously increasing its pressure. Hence the in falling gas encounters a huge pressure pulse which develops into an explosion. Matter in the outer layers of the star is hurled out into space in a flash that can be seen from distant galaxies" [6]. "These ejected gases glow and fluoresce as they crash headlong into the surrounding interstellar medium creating X-rays" [1]. This catastrophic event is call a supernova, and it is the material that is thus dispersed into space that eventually forms what is observed as a supernova remnant [5].

“The amount of energy liberated during the few brief moments of core collapse is as great as the total energy contained in all the light radiated from the star over the entire preceding course of its life” [1]. “During a supernova explosion, the star suddenly increases its brightness a hundred million fold. For a few days the star actually outshines the entire galaxy in which it lived” [1].

“Some astronomers estimate that three or four supernovas erupt in our Galaxy every century. Most of our Galaxy is hidden from view by vast quantities of interstellar gas and dust. The last nearby supernova occurred in 1604 in the constellation Serpens. Another one occurred in 1572 in the constellation Cassiopeia. We are overdue for a supernova to occur in our galaxy” [1]. However, in February 1987, supernova 1987A was discovered in the Large Magellanic Cloud, our closest galactic neighbor.

“The material from a super nova shock wave is flung into interstellar space at a tremendous speed of about 10,000 km per sec. After some 50,000 years, a typical remnant has created an enormous shock wave some 15 parsec in radius in the interstellar medium that sweeps up matter from a huge volume. Ultimately the heavy-element-rich supernova material becomes mixed with the interstellar medium, where it is later incorporated into new stars and planets. The mixing process appears to be very effective; at any one time there are few regions having large excesses of heavy elements from recent supernova explosions” [6].

“Exactly how much mass is blown off during a supernova event is unknown” [2]. “At one time, astronomers thought that up to 90% of the initial mass of heavyweight stars could be shed in a supernova blowout. Today estimates favor a value between 10% and 20%” [2].

If after a supernova event, the remaining “core exceeds about 3 solar masses”[2], then not even the neutrons can withstand the force of gravity. The neutron core simply collapses into a point or singularity creating a “Black Hole” [2]. The gravity of a black hole is so strong the nothing can escape, not even light. Essentially the black hole disappears from view. Although a black hole cannot be seen directly, the gravity from a black hole can influence the motion of any surrounding gas, and or dust. The gas and dust will be drawn towards the black hole, increasing its speed and therefore its temperature. When the temperature gets very high the gas and or dust starts to radiate with higher energies and eventually starts giving off x-rays. This gives a clue that a black hole resides in that area of space.

“An intermediate mass star's (4 to 10 solar masses) fate hangs in the balance throughout most of their lives” [2]. As mentioned before, “some red giants shed upwards of one solar mass over several million years” [2]. Or in a ‘Contact Binary’ star system, one star can steals material from the other star causes it to lose several solar masses over its life time. “In certain cases this might enable an otherwise supernova-doomed star to squeak under the minimum mass at which it would explode. Although it might not save a heavy star from going supernova, it could result in a lighter remnant object that ends its days as a neutron star rather than as a totally-collapsed black hole" [2].

Pulsars

"White dwarfs rotate rapidly and often have strong magnetic fields, but neutron stars rotate much more rapidly and have extraordinarily powerful magnetic fields"[1]. "Nearly every star you can see possesses a magnetic field. Typical strengths are fairly low. Our sun has a magnetic field about the same as the Earths, but if a star collapses down to a small size, the magnetic field increases dramatically. This increase occurs because the magnetic field, which originally had been spread over millions and millions of square miles of the stars surface, becomes concentrated onto a much smaller surface area. It is expected that neutron stars have magnetic fields a trillion times stronger than our sun's field" [1].

"In October 1967, astronomers at Mullard Radio Astronomy observatory in England began detecting pulses of radio waves from various locations in the sky. At first they thought the pulses were Navigation beacons from Little Green Men, but later they were determined to be pulsars. Pulsars are neutron stars that rotate very rapidly. When electrons on the neutron stars surface encounter the intense magnetic field at the star's north/south poles, the particles are rapidly accelerated and emit radio waves. These beams of radio waves sweep around the sky as the neutron star rotates. If the earth is located in its path we detect a pulse of radiation each time the star rotates" [1].

"Pulsars will eventually slow down after a few thousand years. The fastest pulsar rotates 30 times a second and the slowest 1 every four seconds with a typical period of about 1 second"[1]. "The fastest pulsar is the crab pulsar in Taurus, a supernova remnant that was observed on July 4, 1054 and recorded by the ancient Chinese historian Toktaga in part 9, Chapter 56 of Sung Shih or the History of the Sung dynasty: "On a chi-chhou day in the fifth month of the first year of Chih-Ho Reign-Period a 'guest star' appeared at the south-east of Thien-Kuan, measuring several inches. After more than a year, it faded away"" [1].

Stellar Evolution in a Binary Star System

Up to this point we have only discussed mass lost through single star systems. So now it is time to look at the way a star may lose mass in a binary star system and thereby produce an object called a nova.

Nova

"Novae are a phenomenon that occurs only in binary systems" [2]. "If two stars of different mass are members of a close binary pair, one will evolve more rapidly than the other and will be the first to become a red giant. The red giant star will eject its envelope, possibly as a planetary nebula, and then will collapse to form a white dwarf with a very hot surface. Later, the less massive member of the binary star will also become a red giant" [5]. When the red giant becomes so large that its "atmosphere is strongly influenced by the gravitational pull of the white dwarf, matter will be sucked from the bloated red giant star's atmosphere into a disk centered on the white dwarf" [2].

"Hydrogen rich material from the disk spirals down onto the white dwarf. As the hydrogen material impacts and accumulates on the white dwarf surface, the surface temperature of the dwarf gradually increases. At the same time, the heating gives rise to convection currents in the outer layers of the dwarf which circulate old carbon 'ashes' through the newly-acquired hydrogen. When the surface temperature hits 20 million degrees or slightly higher, hydrogen and carbon fusion reactions explosively begin" [2]. The result is a nova outburst with "surges to 10,000 to 1,000,000 times the pre-novae brightness" [2]. Although only a relatively small amount of mass is involved ("about 1/10,000 of a solar mass" [2]), its runaway fusion is enough to turn the white dwarf into a stellar celebrity for a few glorious days or weeks.

"So long as the bloated companion sheds material, the process may be repeated over and over again, giving rise to a recurrent nova. But not all of the captured material is necessarily regurgitated with each event. Gradually over time the white dwarfs mass increases. It may eventually reach the Chandrasekhar limit of 1.4 solar masses. Then a familiar pattern ensues. The white dwarf shrivels, in the twinkling of an eye, to become a neutron star. If sufficient energy is injected into the star's collapsing outer layers, a runaway thermonuclear reaction is triggered and the stellar envelope is launched space-ward at high speed" [2] creating a supernova remnant.

Contact Binaries

"Close binaries are fertile territory for events that knock stars from their original evolutionary courses. The components of binaries put a lot of gravitational stress on each other, and that stress manifest itself in its effect on the more loosely-held outer parts of a star. If the association is close enough and at least one of the components has an extended atmosphere, then conditions are ripe for the loss or transfer of mass" [2] .

“Some binary systems, the so-called contact binaries, are so close that their component stars actually touch. A sort of communal atmosphere envelopes both stars and there is continual and mutual exchange of matter. Other close binaries, the semi-detached variety, are more lopsided. In these, matter flows all one-way, typically from a giant star with a huge cool atmosphere to a more compact, parasitic companion” [2].

“Whatever the details of a particular close binary, though, one thing is clear. A star born in close association with another is likely to evolve very differently than if it were alone. In fact, the evolutionary effect from the mass that a star gains or losses because of a partner may outweigh all the other influences. If the star is initially a heavyweight, it may later have a good portion of its matter snatched away by its companion. On the other hand, it may begin life as the lighter component, only to put on weight at the expense of its mate and end its days as a neutron star or a black hole” [2].

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