STARS AND STELLAR EVOLUTION

Stars are balls of gas made incandescent by energy from nuclear reactions deep in their interiors. They come in a wide range of sizes and brightness, from faint dwarfs one percent the Suns diameter to dazzling supergiants hundreds of times the size of the Sun. They range in temperature from intensely hot blue-white stars to cool red stars. The Sun, which is a medium temperature yellow star, turns out to be pretty average in all respects.

Stars are born from massive clouds of gas and dust within our Galaxy. The clouds of gas and dust are not uniformly distributed in space, but contain denser knots - the seeds of future stars. If the knot is dense enough it begins to contract under the inward pull of its own gravity. As it gets smaller and denser it heats up, until conditions, until conditions of temperature(10,000^o K.) and pressure at the center of the shrinking blob become so extreme that nuclear reactions begin. The outward pressure of the very hot gases balances the inward pull of gravity. This balances is called *Hydrostatic Equilibrium*. The gas blob has "switched on" to become a true star, generating its own heat and light for millions of years.

Several star spawning clouds are well within reach of observation by amateurs. The most famous is the Orion Nebula. At the center of the Orion Nebula is a star called theta Orionis, which telescopes show consists of four component stars. Energy emitted the brightest of these four stars make the nebula shine. But behind the bright, visible part of the cloud is an even larger, still-dark area where stars are being born at this moment. The Orion Nebula is estimated to contain enough matter to produce 10,000 stars: it is a star cluster in the making. Another famous stellar birthplace is the Tarantula Nebula in the constellation Dorado, which dwarfs the Orion Nebula and is in fact the largest nebula known.

There are certain limits on the size of a star. A gas blob with less than 6% the Suns mass cannot become a star, because conditions in its interior will not become sufficiently extreme for nuclear reactions to begin. This 6% limit can be considered the dividing line between a planet and a star. If the planet Jupiter had been about 60 times more massive than it actually is, it would have become a small star.

A stars most vital statistic is its mass, for this factor affects everything else about it: its temperature, its brightness and its lifetime. The stars with the least mass are, not surprisingly, the coolest; they are known as ***red dwarfs***. A typical red dwarf such as Bernard's Star, the second closest star to the Sun, has a mass about a tenth that of the Sun and glows a dull red with a surface temperature of about 6000 degree Centigrade. Even though Bernard's Star is only 6 light years away, it is too faint to be seen naked eye. Surprisingly enough, stars with the lowest mass live the longest. Their nuclear fires burn so slowly that they can survive for as much as a trillion years, 100 times longer than the Sun. The Sun itself, which by definition is of one solar mass, has a surface temperature of 5500 degrees Centigrade and is expected to live for about 10,000 million years. It is currently in the prime of its life.

Moving up the scale, a star such as Sirius, which is twice the Sun's mass, can live for only about 1,000 million years, a tenth of the Sun's age. The surface temperature of Sirius is a blue-white 11,000 degree Centigrade. Larger and hotter still, the star Spica in the constellation Virgo has a mass of about 11 Suns and a surface temperature of 24,000 degree Centigrade. The lifetime of this intensely hot, highly luminous star is less than 1% of the lifetime of the Sun.

A stars color is a direct indicator of its temperature. The most precise way to measure a stars temperature is by studying the spectrum of its light, which is done by splitting the light up in a device known as a spectroscope. Stars are classified into a sequence of so called spectral types according to their temperature. Each spectral type is subdivided into 10 steps from 0 to 9; on this more precise scale, the Sun ranks as a G2 star.

The seemingly haphazard lettering sequence for the spectral types is the result of a previous classification scheme which was rearranged and shortened to produce the present system. The sequence of stellar spectral types is remembered by the mnemonic: '*Oh Be a Fine Girl, Kiss Me'.*

When the spectral type of stars is plotted on a graph against their actual luminosity or absolute magnitude(absolute magnitude is a measure of luminosity, if you could line up all the stars at the same distance from Earth- 10parsecs- you could see how they differ in intrinsic, or 'true' brightness) all stars that are in stable hydrogen-burning middle age lie in a well defined band across the graph known as the main sequence. You can think of a main sequence star as an adult star. In comparison to changes in protostars, evolution of a main sequence star is very slow. A star spends most of its life shinning steadily, with luminosity and temperature values found along the H-R Diagram. A star's position along the main sequence is fixed by its mass, with the least massive stars being at the bottom end and the most massive stars at the top end. Such a plot of star brightness against spectral type is known as a *Hertzsprung-Russell Diagram,* after the Danish astronomer Ejnar Hertzsprung, and the American Henry Norris Russell who devised it in 1911-13.

As we have seen, the Sun formed about 4.6 billion years ago and is about half way through its expected life span. In a few billion years, though, it will start to run out of hydrogen at its core. In search of more hydrogen to use as fuel, the nuclear reactions inside the Sun will start to move outwards, releasing more energy. Eventually when surrounded by a shell of burning hydrogen, even the helium in the Suns core will enter into nuclear reactions of its own, fusing together to form carbon. With all this extra energy being given off, the Sun will become much brighter than it is today and will swell alarmingly in size. But as the Suns outer layers expand they will also cool, becoming redden in color, so that the Sun turns into a red giant similar to the bright stars Aldebaran and Arcturus. At its largest, the red giant Sun will grow to 100 to 400 times its present diameter, engulfing the Earth within its distended outer layers. Needless to say, all life on our planet will long since have become extinct.

Stars spend only a few percent of their total lifetime is the red giant phase, which in the case of the Sun amounts to no more than a few hundred million years. A red giant is a star that has grown old and is about to die. Once a red giant has swollen to maximum size, its outer layers drift off into space, forming a stellar smoke ring of about 0.5 to 1 light year known as a **planetary nebula**, even though it has nothing to do with planets. The name was given in 1785 by William Herschel who said that they looked like the small, rounded disks of planets as seen through his telescope.

At the center of a planetary nebula, a core of carbon surrounded by a shell of burning helium, which was the core of the former red giant. Once the surrounding gases of the planetary nebula have dispersed, usually after thousands of years, the central star remains as a so-called **white dwarf.** A white dwarf is only about the size of the Earth, but it contains most of the matter of the original star; only about 10% of the stars mass is lost in the planetary nebula stage. White dwarfs are therefore exceptionally dense bodies. A teaspoon of white dwarf material would have a mass of thousands of pounds. Over billions of years, white dwarfs slowly cool off and fade into oblivion.

Our Sun, it seems, is destined to go through the stage of being a planetary nebula before fading out as a white dwarf. But stars with several times the Sun's mass, towards the top end of the main sequence, suffer a far more spectacular end. As we have seen, they first become dazzling supergiants rather than mere giants. They do not get a chance to reach the planetary nebula stage. So massive are they that the nuclear reactions at their centers continue in a runaway fashion until the star becomes unstable and explodes. Such an explosion is known as a **supernova.**

In a supernova eruption a stars brightness increases millions of times so that for a few days the star can rival the brilliance of an entire galaxy. The shattered outer layers of the star are thrown off into space at speeds of around 5,000 km per second. Astronomers figure that most of the energy released in the explosion is invisible. A great amount is carried away at the speed of light by high energy radiation and neutrinos ejected from the collapsing core. This energy holds clues to the causes of stellar explosions and the kinds and amounts of chemical elements manufactured and sprayed into space by supernovas. In 1054 astronomers on Earth saw a star erupt as a supernova in the constellation of Taurus. The star became brighter than Venus and was visible in the daylight for 3 weeks. It finally faded below naked-eye visibility more than a year after it had first appeared.

At the site of the explosion lies one of the most famous objects in the sky: the Crab Nebula, the shattered remains of the star that erupted as a supernova. The crab Nebula is visible as a smudgy patch in amateur scopes, but it is best seen on long exposure photographs taken with large instruments. Over the next 50,000 years or so the gases of the Crab Nebula will disperse into space, forming delicate traceries like those of the Veil Nebula in Cygnus itself the remains of a former supernova. Supernova 1987A, the first bright supernova in the sky since the telescope was invented, appeard in the LMC in 1987. It was visible from the southern hemisphere for months and is the best observed supernova to date. Neutrinos were detected exactly as theory predicted. The core temperature during the explosion must have been about 200 billion^o K. Now astronomers are using SN 1987A data to redefine and test theories of star death.

A star may not blow itself to bits in a supernova explosion. Sometimes the central core of the exploded star is left as an object even smaller and denser than a white dwarf, known as a **neutron star**. In a neutron star, the protons and elections of the stars atoms have been crushed by the tremendous forces of the supernova so that they combine to form particles known as neutrons. A typical neutron star is a mere 20 km in diameter, but contains as much mass as one or two Suns. Being so minute, neutron stars can spin very rapidly without flying apart. Each time they spin we see a flash of radiation emerging from the rotating star's magnetic poles as the sweep past Earth. Astronomers have detected radio pulses from several hundred such sources which they term **pulsars;** one lies at the center of the Crab Nebula. The Crab pulsar radiates 30 times per second; others pulse more slowly, down to once every four seconds.

If the core of the exploded star has a mass of more than three Suns, then even a neutron star is not the end for it. Instead, it becomes something still more bizarre: a **black hole.** No force can shore up a dead star weighing more than three solar masses against the inward pull of its own gravity. It continues to shrink, becoming even smaller and denser until its gravity becomes so great that nothing an escape from it, not even its own light. The surface of a black hole, or the boundary through which no light can get out, is called the *event horizon*.

The *Schwarzchild Radius* (R_S)is the critical radius at which a spherically synnetric body becomes a black hole. The equation is:

$$R_S = 2\ G\ M\ /\ c^2$$

where G is the gravitational constant, M is the mass of the body, and C is the speed of light. The Schwarzchild Radius for the Sun is about 3km(2 miles) while for the Earthit is about 1cm(0.4 inch).

Theory predicts that a star of over3 solar masses at its final collapse must cross its event horizon and disappear from view. No known force could stop further collapse, so the star may continue to shrink to a spot at the center called *.singularity.*

Professional astronomers have detected x-ray emissions from space which they believe are given off by hot gas plunging into the bottomless pit of black holes. The best known candidate for a black hole is Cygnus X-1; it lies near a visible 9th magnitude star in the constellation Cygnus. Cyg X-1 is an intense xray source over 800 light years distant. Discovered in 1966, it is an eclipsing binary star (see next section) whose unseen companion is the first black hole candidate. The visible primary star is a blue super giant that shows variations in spectral featuresfrom one night to the next. Possibly, when the unseen star sucks in the material gravitationally from the visible primary, the observed x-rays are emitted.

DOUBLE AND MULTIPLE STARS: A *binary star* is formed by a pair of stars that revolve around a common center of gravity as they travel through space together. The masses of the stars can be figured from the angular size and period of their orbits. Binary stars are classified by the way they are observed.

A *visual binary* can be resolved by a telescope so that two serarate stars can be seen. Over 70,000 visual binaries are known. *Mizar* in **Ursa Major** was the first binary star discovered, in 1650.

Many visible stars have companions that are too faint to be seen. An *astrometric binary* is a visible star with an unseen companion star. The presence of an unseen companion is inferred from variable proper motion of the visible star.

A *spectroscopic binary* cannot be resolved in a telescope. Its binary nature is revealed by its spectrum. A varying Doppler shift is apparent in the spectral lines as the stars approach and recede from Earth. Almost 1000 spectroscopic binaries have been analyzed.

An *eclipsing binary* is situated so that one star passes in front of its companion, cutting off the light from our view in regular intervals.

An *optical double* is a pair of stars that appear to be close together in the sky when viewed from Earth. Actually, one is much more distant that the other, and they have no physical relationship to one another.

Twins or triplets are most common among stars, but some stellar families can be much larger. One famous multiple star is the Double-Double, epsilon Lyrae. Amateur telescopes reveal that each star in itself a double, making a quadruple system. Even more remarkable is Castor, a system of six stars all linked by gravity.

VARIABLE STARS: Certain stars have a varying brightness and are known as variable stars. An observer estimates the brightness of the variable star by comparing it against nearby stars of known magnitude. The observations are plotted on a graph to form what is known as a *light curve,* which can reveal much about the nature of the star under study.

The usual cause of a star's variation is actual changes in its light output, but in some cases the star is a member of a binary system in which one star periodically eclipses the other. One eclipsing binary star, the first of its type to be noticed, is Algol in the constellation Perseus.

Of the stars that vary intrinsically in brightness, most do so because of changes in their size. These are known as **pulsating variables** (not to be confused with pulsars). Of particular importance to astronomers are the **Cepheid variables,** named after their prototype delta Cephei. Cepheid variables are yellow supergiants that go through one cycle of pulsations in periods ranging from about 2 - 40 days, varying in brightness by up to one magnitude as they do so.

Red giants and red supergiants are old stars that frequently turn out to be variable. The pulsate but not with anything like the same regularity at the types of stars mentioned above. The most abundant variables known are the **long period variables,** which have periods ranging from three months to two years.

Most spectacular of all variable stars are the **novae** which suddenly and unexpectedly erupt by perhaps 10 magnitudes or more (10,000 times or more in brightness), sometimes becoming visible to the naked eye where no star appeared before. According to current theory, novae are close double stars, one member of which is a white dwarf. Gas spilling from the companion star onto the white dwarf is thrown off in an eruption. The star does not disrupt itself in a nova outburst. In fact, some novae have undergone more than one recorded outburst, and perhaps all novae recur given time.