From our northerly latitude, there is a part of the heavens that we never see and a part that has such a low elevation when it rises in the South that we do not see it well. This region covers the heart of our Milky Way galaxy, containing many beautiful clusters and nebulae, our two nearest galactic neighbours, the Magellanic Clouds, a star that may well be the next nearby supernova, a pair of colliding galaxies, and a globular cluster containing “musical” stars. This lecture will aim to introduce you to this most beautiful part of the heavens.

Our Milky Way

On a dark night with transparent skies, we can see a band of light across the sky that we call the Milky Way. The light comes from the myriads of stars packed so closely together that our eyes fail to resolve them into individual points of light. This is our view of our own galaxy, called the Milky Way Galaxy or often “the Galaxy” for short. It shows considerable structure due to obscuration by intervening dust clouds. The band of light is not uniform; the brightness and extent is greatest towards the constellation Sagittarius suggesting that in that direction we are looking towards the Galactic Centre. However, due to the dust, we are only able to see about one tenth of the way towards it. In the opposite direction in the sky the Milky Way is less apparent, implying that we live out towards one side. Finally, the fact that we see a band of light tells us that the stars, gas and dust that make up the galaxy are in the form of a flat disc.

Stretching through Sagittarius and Scorpius, the central region of the Milky Way is a truly beautiful sight. We can see rich star fields crossed by intricate dust lanes and punctuated by bright nebulae and star clusters. The nebulae include the Lagoon and Trifid nebulae and the bright clusters include M6 and M7 in Sagittarius and the Northern Jewel Box in Scorpius. There are also “dark” nebulae such as the Pipe Nebula that lies on the boarders of Sagittarius and Scorpius and the Coal Sack in Crux.

The region of the Milky Way that cannot be observed from the UK extends from Scorpius along the Milky Way to Canis Major. The first prominent constellation moving in this direction is Centaurus, three of whose objects, Alpha Centauri, Omega Centauri and Centaurus A are discussed below. Somewhat hemmed in by Centaurus is one of the smallest constellations, Crux, often called the Southern Cross. It contains a beautiful open cluster, the Jewel Box, and one of the most prominent dark nebulae known as the Coal Sack. Next along the Milky way is Carina, home to an open cluster, called Mel 101, or the Southern Pleiades, along with the Eta Carina nebula in which lies the star Eta Carina. This is likely to be the next nearby supernova and is discussed below. Next is Vela, which harbours a supernova remnant at whose heart is a rotating neutron star, the Vela Pulsar, the sound of whose pulsations will have been played in the lecture and available on the web. Finally, crossing Puppis, we come to Canis Major.

The Heart of our Milky Way.

The Galactic Centre is the rotational centre of the Milky Way galaxy. It lies in the direction of the constellations Sagittarius, Ophiuchus, and Scorpius. When we look at images of the Milky Way we see extensive regions where the light is obscured by dark clouds of interstellar dust (containing much silicon and carbon) thus the Galactic Centre cannot be studied at visible, ultraviolet or soft X-ray wavelengths. We can, however, observe it at the extremes of the electromagnetic spectrum at gamma ray, hard X-ray, infrared, sub-millimetre and radio wavelengths. Its direction and distance were first found by Harlow Shapley who, around 1918, measured the distances to 100 of the globular clusters (spherical clusters of ~ 1 million stars dating from the formation of our galaxy) associated with our galaxy. He found that they formed a spherical distribution, whose centre should logically be the centre of the galaxy, and so deduced that the heart of the galaxy was ~28,000 light-years from our solar system. By observing the Sun’s motion relative to the globular clusters, we can calculate that the Sun is moving around the
centre of the galaxy at about 230 km/sec, taking ~ 220 million years to travel once around it.

The Galactic Centre contains thousands of stars. Many on these are old, red main sequence stars (still burning hydrogen to helium in their cores), but it is also rich in massive stars which appear to have been born a few million years ago in a burst of star formation. Currently, star formation does not seem to be occurring at the Galactic Centre but studies predict that in ~200 million years there will be a further “starburst” event there, with many stars evolving rapidly and producing supernovae at a rate one hundred times that observed now. It is thought that the Milky Way undergoes a starburst event of this sort every 500 million years or so.

On either side of the galactic centre is a bar, composed primarily of red stars, which is thought to be about 27,000 light-years long. It is inclined at an angle of ~44 degrees to the line between the Sun and the centre of the galaxy. The bar is surrounded by a ring in which most of the Milky Way’s star formation is concentrated. Many galaxies show such a ring and ours, as seen from the Andromeda Galaxy, would be the brightest single feature of the galaxy.

A Super-massive black hole at our Galaxy’s heart.

Whereas at optical wavelengths the centre of our galaxy is obscured by dust, at radio wavelengths we are able to peer deep into its heart and astronomers have discovered a very compact radio source called Sgr A* which we believe marks the position of a super-massive black-hole at the centre of our galaxy. How can we be sure that this exists? In the same way that we can calculate the mass of the Sun by knowledge of the orbital velocity of the Earth and its distance from the Sun, we can estimate the mass of Sgr A* by measuring the speeds of stars in orbit around it at very close distances. For example, one of the 8-m VLT telescopes at Paranal Observatory in Chile has observed a star in the infra-red as it passed just 17 light hours from the centre of the Milky Way (three times the distance of Pluto from the Sun). This convincingly showed that it was under the gravitational influence of an object that has enormous gravity and yet must be extremely compact - a super-massive black hole. Its mass is now thought to lie between 3.2 and 4 million solar masses confined within a volume one tenth the size of the Earth’s orbit.

The Constellation Centaurus

Alpha Centauri

Also known as Rigel Kent, it appears as a single star to the unaided eye and is the brightest star in the Constellation Centaurus (as one might well suspect from its Beyer designation Alpha Centauri) and the fourth brightest (at -0.01 magnitudes) star in the heavens. A telescope reveals that it is, in fact, a close binary system known as the "Alpha Centauri AB" system, often abbreviated to "a Cen AB". Alpha Centauri A is the more massive star of the system and is slightly larger and more luminous than our Sun. It is about 10% more massive than the Sun and about 23% larger and rotates once every 22 days - a very similar speed to our Sun. Its companion, Alpha Centauri B, is slightly smaller and less luminous than our Sun with a mass of 0.9 solar masses. Its magnitude is +1.3. There is a third component "a Cen C" that is located 2.18 degrees away in the sky. Together all three components make a triple star system, referred to as "a Cen AB-C". AlphaoCen C is normally called Proxima Centauri as it is the nearest star to our Sun at a distance of 4.2 light years, 0.21 light years closer than - Cen AB. Proxima Centauri is a red dwarf star shining at magnitude +11 (so can be observed in a small telescope) with a mass about one-eighth that of our Sun. As all three stars are moving in the same approximate direction through space, it is generally assumed to be gravitationally bound to - Cen AB, orbiting them with a period of several hundred thousand years, though it is possible that it is just passing - Cen AB on a hyperbolic trajectory.

From their position in space, our Sun would appear as a yellow +0.5 magnitude star in eastern Cassiopeia close to the 3.4 magnitude star - Cassiopeiae. This would add a 5th arm to the W shape we see, so that the \(\wedge\wedge\) of Cassiopeia would become \(\wedge\wedge\) as seen from Alpha Centauri. Sirius would become part of Orion and other stars near to us would shift in position too but more distant constellations such as Ursa Major would appear almost unchanged. Seen from Proxima Centauri, - Centauri AB would appear like two close, brilliantly bright, stars with the combined magnitude of -6.8. They would normally appear as a
double star to the unaided eye but occasionally for a short while as a single unresolved star.

**Omega Centauri**

Omega Centauri has long been regarded as a globular cluster - a compact spherical group of typically a million stars that dates from the formation of the galaxy. It had been listed as a star in Ptolemy's catalogue and, still thought to be a star, was given the designation, Centauri, by the German astronomer Johann Bayer in his 1603 star atlas, Uranometria. Bayer assigned a lower-case Greek letter, such as alpha (α), beta (β), gamma (γ), etc, to each star he catalogued, combined with a form of the Latin name of the star's parent constellation. Omega Centauri was first recognized as a globular cluster by the English astronomer John William Herschel in the 1830's and, if so, is both the brightest and the largest known globular cluster associated with our galaxy. We know of only one globular cluster, Mayall II in the Andromeda Galaxy, that is brighter and more massive. Omega Centauri is located about 15,800 light-years from Earth and contains several million stars. At its centre, the stars are so crowded that they are, on average, only 0.1 light years apart. It is though to date from the time when our Milky Way galaxy was formed, some 12 billion years ago and is one of the few globular clusters visible to the naked eye, appearing about as large as the full Moon. However, unlike other globular clusters, it contains several generations of stars and it is now thought that Omega Centauri may well be the core of a dwarf galaxy which was disrupted and absorbed by our Milky Way galaxy.

**A Central Black Hole?**

Perhaps giving further weight to this idea, in 2008 astronomers claimed to have found evidence of an intermediate-mass black hole at the centre of the cluster. The observations, made with NASA's Hubble Space Telescope and Gemini Observatory on Cerro Pachon in Chile, showed that the stars closer to the core are moving faster than the stars farther away (as one might expect). But the speed at which they orbit the centre implies the gravitational pull of an unseen massive, dense object - most probably a black hole. They predict a mass of ~40,000 solar masses for the black hole which lies between the masses of those resulting from the collapse of a massive stars such as Eta Carinae (several solar masses) and those found at the heart of large galaxies which can range from ~4 million solar masses at the centre of our Milky Way galaxy up to several billion solar masses within giant elliptical galaxies. As it is now thought that black holes are found at the core of all galaxies, this is further evidence of a galactic, rather than a cluster, origin.

**The Constellation Crux - The Southern Cross**

Alpha and Beta Centauri are often called the "pointers" as they direct one towards the small cross that makes up the constellation Crux - the smallest, but one of the most distinctive, of the 88 constellations in the heavens. It can be seen in April from northerly locations with latitudes less than +25 and, due to precession of the Earth's axis, will just be seen from southern England in about 10,000 years time! Three of the four stars making up the cross, Acrux, Mimosa, and Delta Crucis, are very young, hot, giant stars - about 10 to 20 million years old and part of the same moving star cluster. The principal star in the constellation is the binary system, Acrux or Alpha Crucis, with a combined visual magnitude 0.72. The pair of stars is 320 light years away from our Sun, and are each is approximately twice its size. The brightest star in Crux is actually Beta Crucis (Mimosa), a blue-white giant, five times the Sun's diameter, with a magnitude of 1.25. The star is ~580 light years away, and
8000 times more luminous than our Sun.

Very close to Beta Crucis is a beautiful cluster called the Jewel Box which contains about 100 visible stars and is about 10 million years old. It contains many highly luminous blue-white stars along with a central red supergiant that makes a beautiful colour contrast. It was named by Sir John Herschel who likened it to "a gorgeous piece of fancy jewellery!" Just to the south of the Jewel Box is a pear shaped region of obscuring, or dark, nebula 7 degrees long by 5 degrees wide. Called the Coal Sack, it is a dense region of dust and gas about 2000 light years from us that hides the light from more distant stars. Well seen in binoculars, it is the most prominent dark nebula along the plane of the Milky Way.

The Constellation Carina

Carina contains three objects well worthy of note:

Mel 101, the Southern Pleiades, is the name of a brilliant and striking open cluster whose appearance and great brightness makes it comparable to the well-known Pleiades cluster in Taurus. It is one of the brightest open clusters in the southern sky, lies at a distance of ~480 light years, has an overall magnitude of 1.9 and contains about 60 stars. It is thought to be about 50 million years old. Theta Carinae, at third magnitude, is the brightest star within the cluster with all other stars being of fifth magnitude or fainter.

The Eta Carina Nebula, also known as the Carina Nebula, this is a large bright nebula that surrounds several open clusters of stars which are significant in that they contain two of the most massive and luminous stars in our Milky Way galaxy, Eta Carinae and HD 93129A. The nebula lies at an estimated distance between 6,500 and 10,000 light years from Earth and contains many hot, blue O-type stars. It is one of the largest diffuse nebulae in our skies - four times as large, and brighter than the Orion Nebula! Within the nebula is a much smaller feature, known as the Homunculus Nebula (from the Latin meaning Little Man) which surrounds the star Eta Carina, and which is believed to have been ejected from that star during an enormous outburst in 1841 which briefly made Eta Carinae the second-brightest star in the sky as described below.

Eta Carinae

Eta Carinae is, perhaps, the most interesting single star in the southern hemisphere. It was first catalogued in 1677 by Edmond Halley when it was a 4th magnitude star. Lying at a distance of 7,500 light years it is a very massive variable star which is highly unstable and expected to explode in a supernova in the astronomically near future. Once though to be a giant single star Eta Carinae is now believed to be part of a system that contains at least two stars with a combines mass of 100 solar masses and about four million times brighter than our Sun. They orbit each other with a period of 5.52 years. Its brightness is highly variable and peaked at magnitude -0.8 mag in 1843, when it became the second brightest star in the sky (just brighter than Canopus at -0.7 and less than Sirius at -1.4). Currently it shines at 6.2 magnitudes. Such stars are quite rare with perhaps only a few dozen in a galaxy like ours.

Eta Carinae is surrounded by a huge, billowing pair of gas and dust clouds as shown in Hubble Telescope image above. These are 10 billion miles across, so about the size of our solar system, and were formed when Eta Carinae suffered a giant outburst about 160 years ago. Over a period of time it then released nearly as much visible light as a supernova explosion but survived! The two lobes produced in the explosion move outwards at about 1.5 million miles per hour. The reason for Eta Carinae's large outbursts is not yet known; the most likely possibility is that they are caused by a build-up of radiation pressure from the star's enormous luminosity. After the 1843 ourburst, Eta Carinae's brightness faded away, and between about 1900 and 1940 it was only about 8th magnitude so invisible to the naked eye. This was probably due to it being surrounded by the dust clouds that form the expanding lobes. Eta Carinae suddenly doubled its brightness in 1998-1999 and is now just visible to the unaided eye.

Eta Carinae is expected to explode as a supernova or hypernova some time within the next million years or so. As its current
age and evolutionary path are uncertain, it could explode within the next several millennia or even in the next few years. A similar outburst to that shown by Eta Carina in 1841-3 was observed during 2004 in the star SN 2006jc that lies some 77 million light years away in the constellation of Lynx. First though to be a supernova it, like Eta Carina, survived even though it lost about 0.01 solar masses of material into space - about 20 times Jupiter’s mass. However, it then exploded as a type Ib supernova on 9 October 2006 - just two years later! As a result some suggest that Eta Carinae could explode in our lifetime or even in the next few years. However, others say it is likely that Eta Carinae is at an earlier stage of evolution, and that the material in its core will still be able to support nuclear fusion (and hence prevent core collapse) for some time to come.

If Eta Carina were to become a hypernova it would probably eject gamma ray bursts aligned to the rotational axis of the resulting black hole. Happily, as seen in the Hubble Image, the rotation axis does not currently point toward the Earth, however, as part of a binary system, this axis could change and if it were pointing towards Earth at the time of the explosion, calculations show that the intercepted energy (in the form of gamma rays) would be equivalent to one kiloton of TNT per square kilometre over the entire hemisphere facing the star. Terrestrial life-forms will be protected by the atmosphere but gamma rays could destroy spacecraft or satellites and the ozone layer. In any event, it will probably be so bright that it could be seen in daylight and one would be able to read a book at night by its light!

**The Constellation Vela**

The most interesting object within Vela is the Vela Supernova Remnant. It is the result of a stellar explosion some 11,000-12,300 years ago at a distance of about 800 light years. In 1968 a neutron star in the form of a pulsar was associated with it and so was the first direct observational proof that supernovae form neutron stars. Pulsars are the spinning remnants of massive stars and have a typical mass of 1.4 solar masses. The intense gravitational forces have caused the protons and electrons to fuse to form neutrons so the star is very largely composed of neutrons to form what is called a **neutron star**. Stars rotate, our Sun once every ~ 25 days at its equator, so the core of a star will have angular momentum. As the core collapses to form the neutron star, much of this must be conserved (some is transferred to the surrounding material), so the neutron star that results will be spinning rapidly. The neutron star will also be expected to have a very intense magnetic field and it was Thomas Gold at Cornell University who suggested that this was the cause of pulsating radio signals that had been discovered coming from neutron stars. He surmised that the rotation, coupled with the expected intense magnetic field generates two steady beams of radio waves along the axis of the magnetic field lines, one beam above the north magnetic pole and one above the south magnetic pole. If (as in the case of the Earth) the magnetic field axis is not aligned with the neutron star's rotation axis these two beams would sweep around the sky rather like the beam from a lighthouse. If then, by chance, one of the two beams crossed our location in space, our radio telescopes would detect a sequence of regular pulses - just as had been observed - whose period was simply the rotation rate of the neutron star. They were quickly given the name Pulsars. Since their discovery in the late 1960’s, nearly 2000 pulsars have been discovered, the majority having periods between 0.25 and 2 seconds. It is thought that as the pulsar rotation rate slows the emission mechanism breaks down and the slowest pulsar detected has a period of 4.308 seconds.

The Vela Pulsar spins at a rate of one rotation every 89 milliseconds - 11 times a second - and as well as being a radio pulsar can also be observed in visible light and is the brightest persistent source of gamma rays in the sky. Pulsars are usually ejected at high speed from the exploding star and the Vela Pulsar is moving through space at about 1,200 km/s

**The Magellanic Clouds**
The two Magellanic Clouds are members of our Local Group of galaxies with the large Magellanic Cloud (LMC) being the fourth largest after (in order) the Andromeda Galaxy or M31, our own Milky Way galaxy and M33 in Triangulum. They are both classified as irregular dwarf galaxies, though the LMC has some characteristics of a barred spiral. They lie at distances of ~160,00 light years (LMC) and ~197,000 light years (SMC) and are separated by ~75,000 light years. Until recently, they were thought to be orbiting our Milky Way galaxy but new research seems to indicate that this is not the case and that they may be just "passing by" at a speed of 480 km/sec (300 mph). Only the Sagittarius Dwarf Elliptical Galaxy and the Canis Major Dwarf Galaxy lie closer to the Milky Way. The LMC was first recorded in 964 AD from a latitude of 12°15' north in Southern Arabia. The pair were later reported by Antonio Pigafetta during the circumnavigation by Ferdinand Magellan from 1519 to 1522 and, much later, named after him. They are visible as faint "clouds" in the southern night sky hence their name. Their makeup differs from our Galaxy in that a higher fraction of their mass comprises hydrogen and helium and so contain a lesser fraction of heavier elements. Their stars range from the very old to the very young, indicating a long history of stellar formation.

As seen from the Magellanic Clouds, the Milky Way would be a spectacular sight! The Milky Way would span about 36° across the sky - the width of over 70 full moons - with an integrated brightness of -2 magnitudes. Because they lie well above the Milky Way's galactic plane, any observers there would get an oblique view of the entire galaxy - far better than ours due to the interstellar dust that obscures our own view through its plane.

The Small Magellanic Cloud (SMC) is a dwarf irregular galaxy with a diameter of about 7,000 light-years. It contains several hundred million stars with a total mass of approximately 7 billion Solar masses. (Remember that our Sun is well above average in terms of stellar mass - there are few more massive stars than our Sun and many less massive.) Its declination is -73 degrees so it can only be viewed from the Southern Hemisphere and the lower latitudes of the Northern Hemisphere and appears as a hazy, light patch in the night sky about 3 degrees across in the constellation of Tucana. Due to its very low surface brightness, it can only really be seen from a dark sky location.

The SMC played a key role in setting up the "distance ladder" that enabled the distances of what were first called "white nebula" (galaxies) to be determined. In 1891, Harvard College Observatory opened an observing station at Arequipa, Peru whose 24-inch telescope was used to make a series of photographic plates of the Small Magellanic Cloud. Henrietta Swan Leavitt, of Harvard College Observatory, used these observations to study the variations in relative luminosity of its stars. Her results, published in 1908, showed that a type of variable star, now called "Cepheid Variables" (after the prototype star Delta Cephei) showed a relationship between the period of the star's brightness variations and the star's luminosity - the brighter the Cepheid Variable, the longer the period. This "period-luminosity relation" meant that the distance to any Cepheid variable seen in distant galaxies could be estimated in terms of the distance to the SMC. For example, say a Cepheid variable with a period of 100 days observed in a distant galaxy was seen to be 10,000 times fainter than one in the SMC, from the inverse square law it would be 100 times further away. Hence, given an accurate distance for the SMC, Cepheid variables could be used as a standard candle for measuring the distances to other galaxies. 1913 the distance to the SMC was first estimated by Ejnar Hertzsprung by relating the brightness of Cepheid variables in the SMC to some within our own galaxy. A problem is that Cepheids of different "metallicity" (the percentage of elements within the star that are not hydrogen or helium) have different period-luminosity relations. Unfortunately, the Cepheids in the Milky Way that he used to calibrate the period-luminosity relation are more "metal" rich than those found in the LMC. So his derived distance of 30,000 light years was ~1/6th of its now known distance. This is one reason why early estimates of the distances of more distant galaxies such as that made by Edwin Hubble of the Andromeda Galaxy of 750,000 light years were too low. Now these calibration problems have been overcome, it has been possible to measure the distances of remote galaxies with far greater precision and these data ("these" is not a spelling mistake) have been used in conjunction with their recession velocities to derive Hubble's Constant. The latest value from Hubble Space Telescope Observations is just over 74 km/s/Mpc - compared with Hubble's original value of ~500 km/s/Mpc! The inverse of this value gives the "Hubble Age" which is an approximate age of the Universe. Hubble got ~ 2000 million years whereas we now have ~ 14,000 million years - allowing time for the stars and galaxies to form and for life to evolve on our planet Earth!

The Large Magellanic Cloud (LMC)

The LMC has a mass of ~10 billion times Solar masses - about 1/10 the mass of the Milky Way, and a diameter of about 14,000 light-years. It contains a very prominent bar in its centre, suggesting that it may have previously been a barred spiral galaxy which has been distorted by tidal interactions with both the Milky Way and the SMC. The LMC, like many irregular galaxies, is rich in gas and dust, and contains the Tarantula Nebula, the most active star-forming region in our Local Group of galaxies. The Tarantula Nebula (also known as 30 Doradus) is an H II region (a region of hydrogen gas excited by the ultraviolet light from very
hot young stars) in the Large Magellanic Cloud. It was originally thought to be a star, hence the star name 30 Doradus, but in 1751 Nicolas Louis de Lacaille recognized its true nature. It has an apparent magnitude of +8, so easily seen in binoculars which, given its distance of about 170,000 light years, means that it is extremely luminous - so bright that if it were as close to Earth as the Orion Nebula (our nearest H II region) the Tarantula Nebula would cast shadows! It is, in fact, the largest (about 650 light years across) and most active region of star formation that we know of within our Local Group of galaxies. Most of the energy that excites the nebula comes from a compact (35 light years across and of 45,000 solar masses) star cluster at its heart.

**Supernova 1987A**

SN 1987A was a supernova that was first seen in the outskirts of the Tarantula Nebula on February 23, 1987. With a peak visual magnitude of -3, it was bright enough to be visible to the unaided eye and was the closest observed supernova since SN 1604, Kepler's Supernova, seen in the constellation Ophiuchus. Its brightness peaked in May and slowly declined in the following months giving modern astronomers their first chance to observe a near-by supernova - though sadly not from Jodrell Bank. It was first discovered by Ian Shelton and Oscar Duhalde at the Las Campanas Observatory in Chile on February 24 1987. Ian had processed the image he had taken immediately, but an earlier image (the first to show the supernova) taken by Albert Jones in New Zealand was not processed until the following morning so Ian became the discoverer!

The progenitor star was soon identified as Sanduleak -69° 202a, a blue supergiant - this was surprising as it was not then thought that a blue supergiant would produce such a supernova event. It is now thought that the progenitor star was in a binary system, whose stars merged about 20,000 years prior to the explosion, producing the blue supergiant. Most supernovas grow dimmer with the passage of time as they release their energy but, surprisingly, the X-ray and radio emissions from 1987A grew brighter with time as the shock wave from the explosion excited a dense cloud of gas and dust surrounding the star that had been ejected some time earlier.

**Neutrino emissions**

Perhaps surprising to you, three hours before the visible light from SN 1987A reached the Earth, a burst of (it is thought) antineutrinos was observed over a period of 13 seconds at three separate neutrino observatories: at 7:35am Universal time, Kamiokande II detected 11 antineutrinos, IMB detected 8 antineutrinos and Baksan detected 5 antineutrinos. The reason for the earlier arrival is that the neutrino emission occurred simultaneously with core collapse in the heart of the star, whereas light was only emitted when the shock wave reached the surface of the star - so the neutrinos had a head start. The neutrino count was well above the background level and was the first time neutrinos emitted from a supernova had been observed directly. Models of supernova explosions indicate that 99% of the energy of the explosion is radiated away in neutrinos. It is though that $\sim 10^{58}$ neutrinos were emitted with a total energy of $10^{46}$ joules! It was expected that SN 1987A would result in a neutron star but none has yet been observed: the neutron star may be enshrouded in dense dust clouds so that cannot be seen, a large amount of material could have fallen back onto the neutron star causing it to collapse into a black hole or that the collapsed core became a quark star. (Quarks are the constituents of protons and neutrons.)

**The distance to SN1987A**

Images of SN1987A now show three bright rings around it - material from the stellar wind of the progenitor that have been excited by the ultraviolet flash from the supernova explosion. These rings did not "turn on" until the UV light was able to reach them several months later, and so give us a measure of their radius in light days. The rings are large enough for their angular size to be measured accurately by the Hubble Space Telescope: with the inner ring being $\sim 0.8$ arc seconds in radius. Knowing the angular size and diameter of the inner ring enables its distance to be calculated by simple geometry giving about 168,000 light-years. These important observations have resulted in an estimate of the distance from Earth to the centre of the LMC of $52.0 \pm 1.3$ kpc. This has given a new value for the zero point of the Cepheid distance scale, which has greatly improved our knowledge of galactic distances and, as a consequence, the value of Hubble's constant - the scale factor of the universe.
The Globular Cluster 47 Tucanae

47 Tucanae, often just called 47 Tuc, is a globular cluster, 120 light years across, located at a distance of ~ 16,700 light years in the constellation Tucana. Having a magnitude of +4, it can be seen with the unaided eye very close (in direction) to the Small Magellanic Cloud. It was discovered by Nicolas Louis de Lacaille in 1751 and, under very dark skies, appears roughly the size of the full Moon. Assuming, as indicated above, that Omega Centauri is not a globular cluster it is the brightest globular cluster in the sky and is noted for having a very bright and dense core where the stars are very tightly packed.

Planets within 47 Tucanae

The Hubble Space Telescope has recently made a search for large, close-orbiting planets within 47 Tuc by searching for stellar occultations as their transits temporarily block some of the light of their parent stars. The HST observed ~ 34,000 stars but found no but no light curves that could be convincingly interpreted as due to planet occulting a star. Intriguingly, these observations showed that such “hot Jupiters” must be much less common (at least 10 times) in 47 Tuc than around stars in our own neighbourhood. It could well be that dense stellar environment is unhealthy for even such close planets, or that planet formation today is very different from the time ~ 12 billion years ago when 47 Tuc was formed.

Millisecond Pulsars in 47 Tucanae

47 Tuc is of very great interest to radio astronomers as it contains at least 23 so-called "millisecond pulsars". These are pulsars where the passage of a passing star has enabled the neutron star to "pull" material from the outer envelope of the passing star (or a companion in a binary orbit) onto itself. This also transfers angular momentum so spinning the pulsar up to give periods in the millisecond range - hence their name. The fastest known pulsar is spinning at just over 700 times per second - with a point on its equator moving at 20% of the speed of light and close the point where it is thought theoretically that the neutron star would break up!

The dense core of 47 Tuc is a perfect home for millisecond pulsars whose periods range from 8 down to 2 milliseconds, so the fastest are spinning on their axis around 500 times per second. If the pulse train derived from a single millisecond pulsar is amplified and applied to a loudspeaker cone, the periods are such that the sound appears as a tone rather than a sequence of regular pulses. One must, however, be cautious to note that it is not sound waves that are being received by our radio telescopes! The sounds played at the lecture may be found at: http://www.jb.man.ac.uk/research/pulsar/Education/Sounds/

Centaurus A

Centaurus A is a lenticular or elliptical galaxy with a superimposed dust lane about 11 million light-years away in the constellation Centaurus. The fifth brightest galaxy in the sky, it is exceedingly interesting as it appears to be the result of a merger between two smaller galaxies. First identified as a "peculiar galaxy" by John Herschell in 1847, it was included in the 1966 Atlas of Peculiar Galaxies as one of the best examples of a "disturbed" galaxy with dust absorption. The galactic bulge is comprised mainly of old red stars but over 100 star formation regions (like the Orion Nebula or the Tarantula Nebula in the Large Magellanic Cloud) have been identified in the disk giving rise to more recent star formation. It appears that Centaurus A is devouring a smaller spiral galaxy - a process that usually initiates an intense period of star formation.
These are galaxies where some processes going on within them make them stand out from the normal run of galaxies particularly in the amount of radio emission that they produce. It was mentioned earlier that, at the heart of our galaxy, lies a radio source called Sgr A*, one of the strongest radio sources in our galaxy. However this would be too weak to be seen if our Milky Way galaxy was at a great distance and our galaxy would therefore be termed a “normal” galaxy. However there are some galaxies that emit vastly more radio emission and shine like beacons across the universe. Because most of the excess emission lies in the radio part of the spectrum, these are called radio galaxies. (The name Centaurus A implies that it is the brightest radio galaxy in the constellation.) Other galaxies produce an excess of X-ray emission and, collectively, all are called active galaxies. Though relatively rare, there are obviously energetic processes going on within them that make them interesting objects for astronomers to study. Centaurus A is one of the closest radio galaxies to Earth so has been extensively studied by professional astronomers.

The Active Galactic Nucleus

We believe that the cause of their bright emissions lies right at their heart in what is called an Active Galactic Nucleus - or AGN. It was mentioned earlier that we believe that there is a super-massive black hole at the centre of our galaxy. We now believe that black holes, containing up to several billion solar masses, exist at the centre of all large elliptical and spiral galaxies. In the great majority of galaxies these are quiescent but in some, matter is currently falling into the black hole fuelling the processes that give rise to the X-ray and radio emission. A pair of relativistic jets that are responsible for the emissions at X-ray and radio wavelengths extract energy from the vicinity of the super-massive black hole at the centre of the galaxy. By taking radio observations of the jet separated by a decade, astronomers have determined that the inner parts of the jet are moving at about one half of the speed of light. X-rays are produced farther out as highly energetic particles are created as the jet collides with the gas in the outer parts of the galaxy. Centaurus A is the nearest galaxy to Earth that contains a super-massive black hole actively powering a jet. It is thought that the black hole at its heart has a mass of 100 million solar masses.

Let's consider what happens as a star begins to fall in towards the black hole. As one side will be closer to the black hole than the other, the gravitational pull on that side will be greater than on the further side. This exerts a force, called a tidal force, which increases as the star gets closer to the black hole. The final effect of this tidal force will be to break the star up into its constituent gas and dust. A second thing also happens as the material falls in. It is unlikely that a star would be falling in directly towards the black hole and would thus have some rotational motion - that is, it would be circling around the black hole as well as gradually falling in towards it. As the material gets closer it has to conserve angular momentum and so speeds up - just like an ice skater bringing her arms in toward herself. The result of the material rotating round in close proximity at differing speeds is to produce friction so generating heat that causes the material to reach temperatures of more than a million degrees. Such material gives off copious amounts of X-ray radiation which we can observe, but only if we can see in towards the black hole region. This is surrounded by a torus (or doughnut) of material called the accretion disc that contains so much dust that it is opaque. But if, by chance, this torus lies roughly at right angles to our line of sight then we can see in towards the black hole region and will observe the X-ray emission.

Nuclear fusion of hydrogen can convert just under 1% of its rest mass into energy. What is less obvious is that the act of falling into a gravitational potential well can also convert mass into energy. In the case of a super massive black hole energy equivalent to at least 10% of the mass can be released before it falls within the event horizon giving the most efficient source of energy that we know of! This energy release often results in the formation of two opposing jets of particles moving away from the black hole along its rotation axis. Moving at speeds close to that of light, these “bore” a hole through the gas surrounding the galaxy and in doing so the particles will be slowed down - or decelerated. They then produce radiation across the whole electromagnetic spectrum that allows us to observe the jets. If one of the jets happen to be pointing towards us, the observed emission can be very great and so these objects can be seen right across the universe.

©Professor Ian Morison, Gresham College 2010