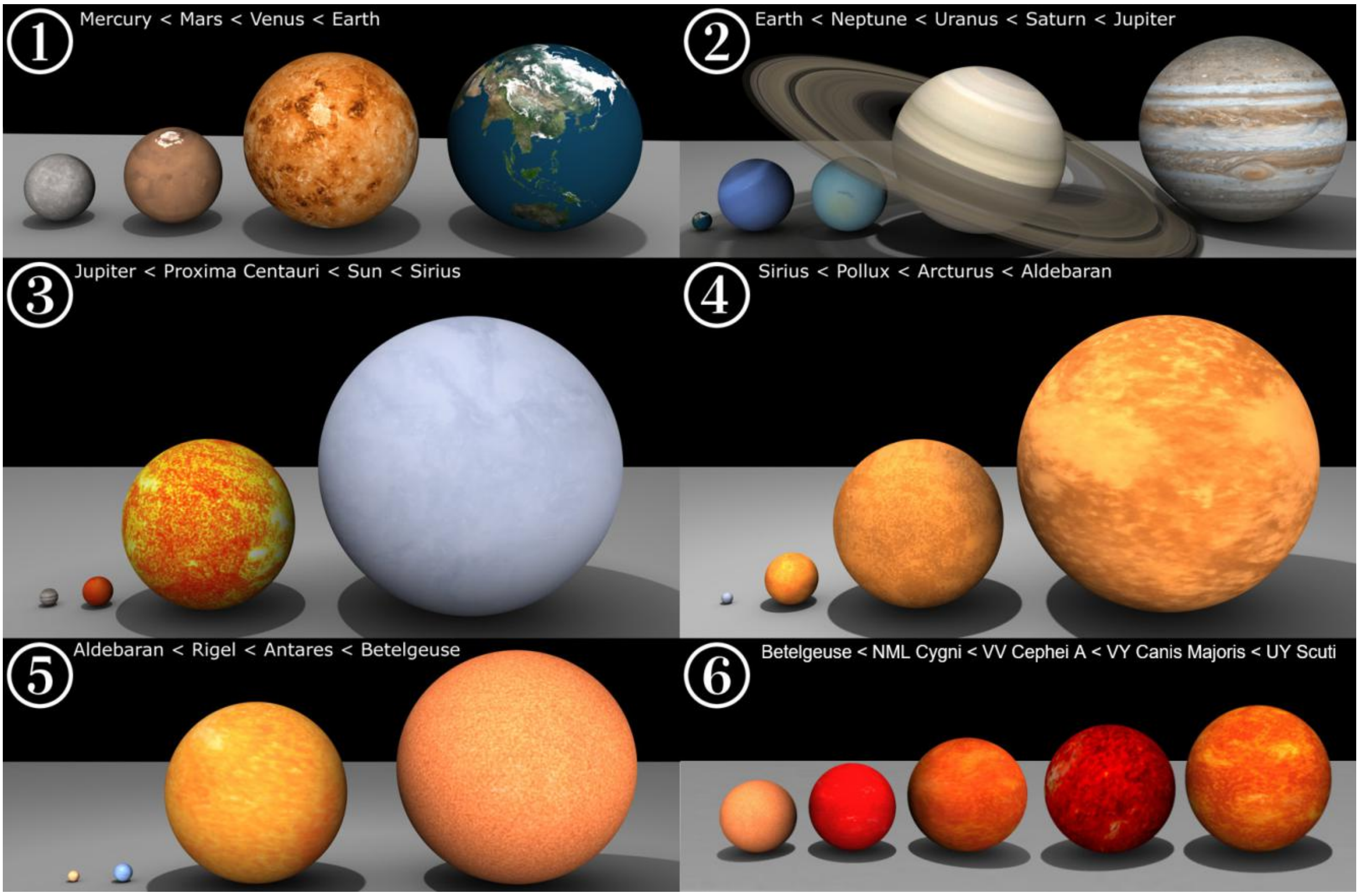
MIRA

2021.4
Number 113
Free to Members of the C&WAS
http://www.covastro.org.uk/
covwarksastro@yahoogroups.co.uk

The Journal of the
Coventry and Warwickshire Astronomical Society

The Betelgeuse Mystery



Comparative sizes of the main solar system planets compared with some well known stars. Betelgeuse is not the largest star known, but is getting to be near the largest.
The "Betelgeuse Mystery" of its sudden fade last year has been solved, but as explained in the story on page 2 it is still at an unknown distance.

Image, JoeyPknowsalotaboutthat

CONTENTS

Page 2 *Betelgeuse, and other Mysteries* By Ivor Clarke
Page 3 *The First Generation of Stars* By Paritosh Maulik
Page 7 *A Good Time to Observe Butterflies* By Geoffrey Johnstone
Page 8 *Expedition 3* A Lunar Si-Fi Story By Ivor Clarke

Betelgeuse, and other Mysteries

By Ivor Clarke

The bright red supergiant star Betelgeuse, α Alpha Orionis, at the top left of the main part of the Orion constellation has been in the news over the last year or so with its dramatic dimming last year to about magnitude +1.7 from its usual brightness of around -0.5. This dimming was one of the biggest drops in brightness for many years and may be the biggest drop in a century. It is thought it was caused by clouds of opaque dust and soot spreading out in our direction and absorbing its light, plus obscuring parts of its surface. Now it is nearly back to its "normal" brightness, which is about the same as Rigel at the opposite corner of the rectangle of Orion. Betelgeuse is the 11th brightest star in the night sky and is a M1-M2 red giant star near to the end of its life.

While its brightness can be measured very accurately it is quite surprising that its distance is unknown! For instance, if you check up its distance in all the astronomy books you have you will find the distance varies by quite a lot. Not only is its distance doubtful but its mass is not certain, with many different estimates from has high as 40M (40 times the Sun's mass) to 6M, with a best guess of about 15M. What happens to Betelgeuse in the future depends on its mass as the higher it is, the quicker it will burn through its supply of hydrogen and now it is in its helium burning stage. But as we don't know its mass we don't know how far along that is. Anything over around 7 - 9M will result in a supernova with a neutron star left afterwards.

In my copy of *The Constellations, An Enthusiast's Guide to the Night Sky*, by Lloyd Motz and Carol Nathanson printed in 1991, it is quoted as being at 590 light years, while receding at 13 miles a second. It says that it's the largest star visible to the naked eye, at 640 million miles in diameter, putting it well beyond Mars orbit if it was at the Sun's position in our solar system. Because of its size, it is 12,000 times as luminous as the Sun.

In my *Norton's 2000, Star Atlas and Reference Handbook,* by Ian Ridpath printed 1989, 1,400 ly, is given to the Orion cluster which is not the same as the distance to the star. Rigel too gets the same distance in my Norton's. I have a *Collins Encyclopaedia of the Universe,* which was printed in 2001 and the distance given is 427 ly, to Betelgeuse. This years *Philip's 2021 Stargazing handbook* by Heather Couper & Nigel Henbest, gives 720 ly to the star and states that it is 100,000 times brighter than the Sun. And not forgetting that font of all knowledge, Wikipedia gives its distance has 548 ly +90 -49 ly current best estimates 500 - 600 with a luminosity of 126,000 times the Sun. For such a famous bright star to have such a variation in its distance and brightness strikes me as strange. Why such a variation?

The distance to stars are measured by their parallax from each side of the Earth's orbit, (see MIRA 91, 93 & 102,), but unfortunately Betelgeuse is just too far to reliable measure with the very tiny angles giving its distance. Also before a trigonometric parallax can be determined of the star, the proper motion and of it in relation to the Earths motion must be taken into account. So if this star is outside the distance measurable from the surface, about 500 lys, and shows very small to no measurable angles because of atmosphere blearing, all is not lost today, as it should be measurable from space.

In the 1990's the European Space Agency launched the Hipparcos mission to measure the distance to thousands of stars. The mission got off to a poor start when it ended up in a highly elliptical orbit owing to a faulty stage misfire. However it did produce results giving the distance to Betelgeuse as 430 ly with an error of 20%, this gives us from 350 - 510 ly, a later reworking of the data gave a figure of 520 ly with an error of 450 - 590 ly. Other estimates have used the Very Large Array to give 640 ly with a range of 500 - 790 ly and a distance of 720 ly using the Merlin array in the UK and the ALMA telescopes in the Atacama Desert with a likely range of 570 - 830 ly. So it's getting further away now with each measurement and it means if we don't know its distance we don't know its true brightness.

One of the most distant stars you can see with the naked eye is Deneb, α Alpha Cygni, marking the tail of the Swan, the 20th brightest star in the sky. This is a A2 white supergiant star 1,500 ly away, 2,615 ly or 3230 ly in other books. It is 60,000, 195,000 or 250,000 times brighter than the sun. Probable the most distant star visible with the eye is ζ1, (Zeta) Scorpii which lies over 8,200 ly away and is magnitude +4.7 and is 850,000 times brighter than the sun! What could be the largest star that can be seen with the naked eye is Mu Cephei, a M2 red supergiant of +4 mag often called Herschel's Garnet Star, its red colour making it one of the reddest stars that can be seen. Its distance could be 5,400 ly, 3,000 ly or 2,400 ly and its size as extending well outside the orbit of Jupiter if it was in our solar system, with a brightness up to 340,000 times our Sun!

The Hipparcos mission data has now been replaced by the Gaia satellite and with this new data set should have resolved the mystery, but for one problem. Betelgeuse is too bright! Gaia can resolve stars down to +20 magnitude and any star brighter than +3 overloads its sensors, this was the same problem with the Hipparcos data. Gaia can be put into a special observing mode that requires non-standard data processing but this stops other more urgent work so may not be done until near the end of its mission in 3 - 4 years time. Another red supergiant star is Antares, α Alpha Scorpii, another M1 red giant which is properly at a distance of 520 ly, 640 ly or 550 ly, take your pick. Both of these red supergiants are near the end of their lives and could explode as a supernova anytime. Its lucky we are far enough away so we won't be wiped out with the blast of radiation from such an explosion.

I e-mailed Dr. Mark Kidger who wrote a paper in the BAA Journal, December 2020 about the dimming of Betelgeuse and its distance asking *"Would a solution to this problem be to use the New Horizons space craft, now about 4.5 billion miles away as one side of a very long base line to measure the parallax to these stars?"*. His reply was *"To measure parallax accurately requires a specially designed system with extreme accuracy, such as Gaia. Hipparcos made an estimate, but had such a problem with systematic errors that there is a lot of doubt about its estimate. New Horizons is distant enough to get good parallax, but not designed to get measurements with the necessary accuracy. Sooner or later a value will come from Gaia and it will be an extremely precise one, but reducing the data taken in the special observing mode is not a priority for the Gaia team as they are preparing the third complete release of their catalogue. When Gaia dies finally in about 3 years we should have the data but I for one am impatient!"*

He is not the only one!

The First Generation of Stars

by Paritosh Maulik

Fundamental particles like the proton, electron, neutron formed at the Big Bang, the birth of the Universe. When the temperature dropped the first element formed was hydrogen from these particles. This hydrogen cloud collapsed to form the very first generation of stars. No other elements were present. With time other elements were synthesised in the stars. These other elements got incorporate in the gas cloud, which formed the second generation of stars. Astronomers began to detect stars with very low concentration of elements other than hydrogen. They set their limit on iron content of the star. Can we find stars with zero iron content? Since the primordial gas is hydrogen, stars from this gas cloud should not contain any heavy element. Theoretically it is possible to find stirs with zero iron content, but so far we have found none. If we can find such stars, we would have a better understanding of the nature of the very first galaxies. So how did the very first stars form and where can we find these? Before we go into the formation of the very primordial group of stars, we shall have a quick look at the determination of the composition of the stars.

Composition of the Star

In 1841 Joseph von Fraunhofer invented the spectroscope, an apparatus to study the spectrum. It is a device based on a prism as used by Newton. It produced a very well resolved spectrum. With it he saw 574 dark lines in the solar spectrum. These are now called Fraunhofer Lines. Within the next couple of decades, Joseph Nicepheore Niepce and Louis Daguerre in France, developed photography. Soon the astronomers started taking photograph of the Sun and other astronomical objects. The advantage of photography is to record the image which can be analysed later in detail. Around 1860s Gustav Kirchhoff and Robert Bunsen heated various substances in the laboratory and recorded their spectrum. They noticed that these spectral lines correspond to fixed wave lengths and offer a means to identify different substances. They could reproduce some of the dark lines in the solar spectrum in the laboratory by heating various substances to a very high temperature. Sixty lines associated with iron were seen when iron was heated above its boiling point 2862°C. Apparently a printed copy of the solar spectrum was nearly 2.5 metre long. Thus Spectroscopy became a very powerful tool to identify elements and even in the astronomical objects.

In 1882 Edward Pickering in Harvard University, developed a method to record the spectrum of stars by placing a prism in front of the camera and recording the stellar spectrum for detailed analysis. In this laboratory Wiliamina Fleming was cataloguing the stellar spectra. She was born in Scotland and moved to the US. She is reported to have analysed over 200,000 plates. Fleming divided stellar spectrum into groups; A are the stars with most hydrogen lines and then in decreasing order to all the way to Q. In 1906, she was first American woman to receive the honorary membership of the Royal Astronomical Society.

Annie Jump Cannon took over from Fleming. Despite some physical disability, Cannon examined more stellar spectra and concluded that some of the Fleming's groups overlapped and shortened the original A – Q list to O, B, A, F, G, K, M.* This classification is still used today and is called Harvard Classification System. O class stars are young and blue in colour, the Sun is a yellow, G class and M class stars are red. In the meanwhile physicists developed the method to determine the temperature of the stars from its spectrum/ colour. There is another important parameter, the apparent magnitude of the star. An inherently bright star may not appear bright, if it is small compared to a star which is inherently less bright, but large.

Cecilia Payne Gaposchkin, a Cambridge, UK, graduate, started her PhD in the Harvard university on stellar spectroscopy. She applied the theory of ionisation of elements under heat and pressure, developed by Indian physicist Meghnath Saha, to the analysis of stellar spectra. Payne's thesis was:
The stars are mainly consist of hydrogen, with some helium
Unlike the Earth, only a very small amount of other elements are present in the Sun

In order to fully understand the stellar spectrum, we have to take into account of the temperature of the stars. O to M classification depends on the temperature of the star. This time period was in the 1920s.

Cecilia Payne Gaposchkin became the first woman professor of astronomy in Harvard and eventually the first woman to the chair of the department.

Her findings went against the perceived view at that time. Even Henry Russell of Hertzsprung-Russell diagram did not agree with Payne Gaposchkin's results, but eventually he accepted the results, without giving her the credit.

So we have methods available for the the determination of the composition of the stars. Colour of the star is not quite as straight forward as it may appear. Each observation method, unaided human eye, colour film and solid sate devices, all have in-built colour biases. Now there are methods to define the colour of the stars. Some introductory references are listed at the end.

The First Generation

Jan Oort, as early as 1926, noticed that the high velocity stars occur near the outer edges of Milky Way, where as stars close to the centre have lower velocity. Determination of the shape of the Milky Way owes much to the observations of Oort. Walter Badde also observed similar results with the Milky Way and with the stars in the Andromeda galaxy in 1944. Badde classified stars into two groups, young stars to be Type I, near the spiral arms and older stars as Type II near to the halo, the outer edges of the Galaxy. Nancy Roman found that stars with higher velocity are metal poor compared to the low velocity stars. By metals in the stars we mean elements higher than hydrogen and helium. Nancy Roman was the Chief of Astronomy, at NASA during the 1960s and 1970s and was a key figure in planning of Hubble Space Telescope.

Astronomers compare the iron content of a star to the iron content of the Sun. The iron content of the Sun is about 0.14%. Any star with lower iron content than the Sun is classed as a metal – poor star. In 1951 two stars $^{1}/_{10}{}^{th}$ of metallicity compared to the Sun were detected.

Over the years it became apparent that there are stars with still lower metal content. How did these stars form and how low the metal content can it get? Theories of star (and galaxy) formation have continued to improve. Computer simulation incorporating composition, magnetic field, gravitational forces of star and galaxy formation has become an in-disposable tool. Here is a short account of "metal-free" stars.

The Family Tree

Badde's original classification has been changed somewhat. Young stars with "high" metal content are called Population I stars. Population II stars have lower metal content than the Population I stars. Population II stars were born earlier and when some of these exploded as supernovae, their contents got mixed up in the star forming gas cloud. Population I stars formed from the gas cloud which contained metals produced by the Population II stars. When the Universe started from Big Bang, it produced hydrogen (H) and helium (He), (75% H nuclei (proton), 0.01% deuterium, ^{3}He, 25% ^{4}He); nothing heaver than helium was present, therefore stars formed from this primordial cloud should be metal free and we should find metal free stars out there. These are classified as Population III stars. This terminology may appear somewhat confusing; the the oldest generation, is called Population III stars and the youngest generation is called Population I stars. We may recall that Stellar nucleosynthesis process according to the B2FH (Hoyle and co-workers) theory produces elements up to iron in the stars and still higher elements are formed in the supernova explosions.

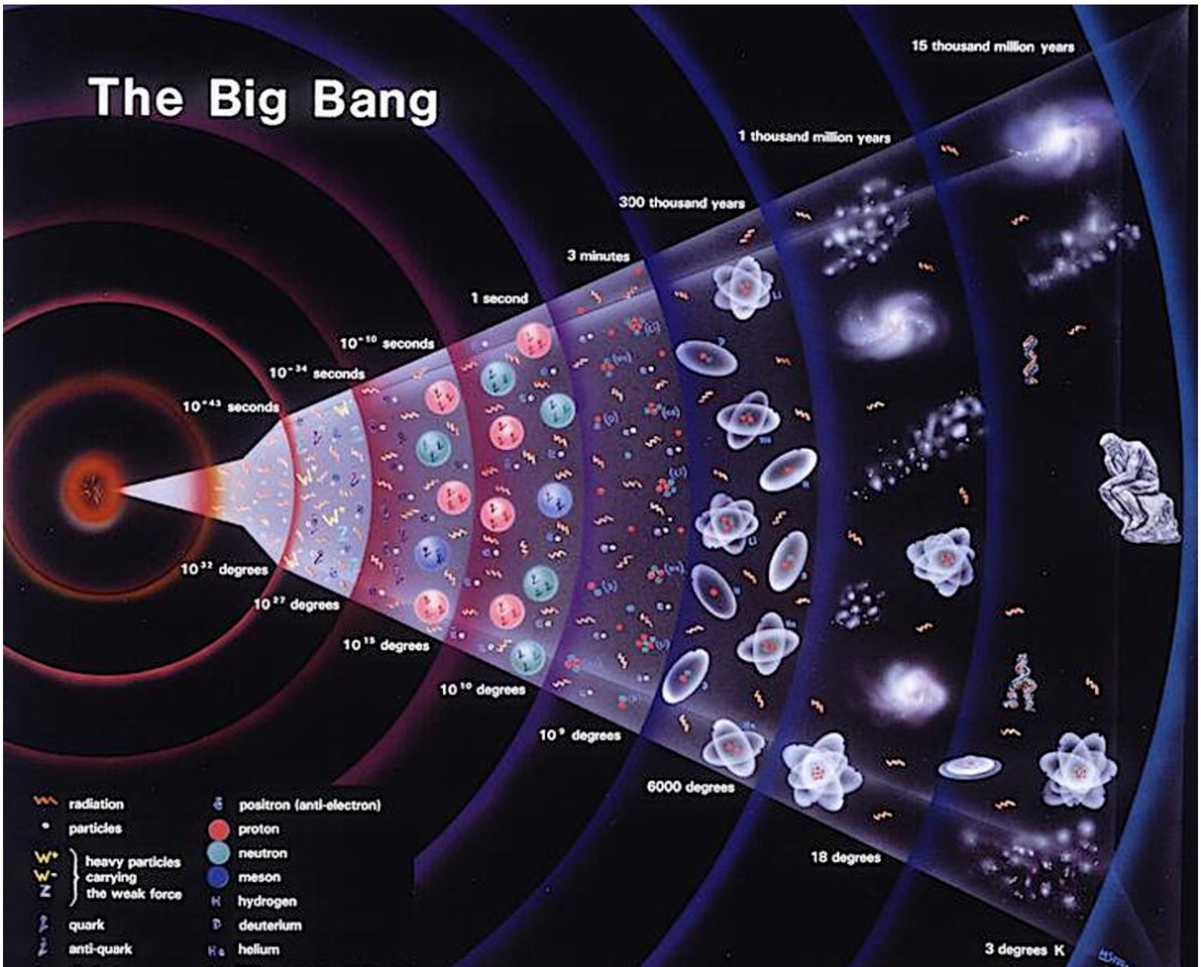
Formation of Metal Free Population III stars

Below is a pictorial presentation of the history of the Universe as we know today. *(Fig 1)*

Immediately after Big Bang everything is very hot. There were only primary particles like protons, neutrons, electrons and photons. Due to the intense heat, the positively charged protons and negatively charged electrons could not combine; all these sub-atomic particles created a thick fog of protons, electrons and neutrons. Within about three minutes of the origin of the Big Bang, the composition of the Universe was 75% hydrogen nuclei (proton), 0.01% deuterium, ^{3}helium, 25% ^{4}helium. ^{3}helium and ^{4}helium are isotopes of helium. Like hydrogen, helium was also in nuclei state, consisting of protons and neutrons; no electron. This 75% hydrogen eventually went on to produce all the stars. Photons generated in the Big Bang could not travel freely through the fog of these particles. This period is called the dark age of the Universe. With time the Universe is expanding and the temperature is cooling down. After about 380,000 years from the Big Bang, the temperature had sufficiently cooled down to about 3000°K, now protons can combine with electrons to form neutral hydrogen atoms (H). This combination of protons and electrons is called recombination. The prefix "re" is somewhat misleading, because, this is the first time combinations of protons and electrons has taken place.

The recombination process cleared the path for the photons. From now on the photons were free to move and were detected by Penzias and Wilson, as Cosmic Microwave Background radiation.

Gravity causes gas cloud to collapse. Temperature on the other hand, exerting an outward pressure, opposes the contraction of the gas cloud. British astronomer James Jeans correlated the collapsing due to gravity and expansion (outward pressure) due to temperature. The denser the mass, the closer particles are together. At lower temperature particles have less energy to flyaway from each other. The opposite case with a high temperature gas cloud. Hence denser mass and lower temperature promote collapse. The term Jeans mass tells us the mass of a system needed at a



given temperate that will collapse under gravity and can not expand.

In the very early Universe, when the very first stars were forming, the temperature was very high, the Jean mass is also high. Being hot, the gas cloud has tendency to expand; only gravity from a larger gas cloud can prevent expansion. The large collapsing cloud forms massive stars. Star formation starts when hydrogen fuses into helium. This scenario might suggests that only the very large isolated stars formed in the early universe. However when we obverse the star forming areas now in the infrared, we often see formation of more than one single star in the star forming cloud. Computer simulation also suggests that the star formation does not occurs in isolation. A cloud forms, it grows, breaks down into smaller clumps and eventually to protostars. When the smaller clumps reach Jean mass, these collapse into stars. Effect of rotation, rate of accretion etc. causes the fragmentation of the large cloud into smaller clumps. If the gas clouds fragments into smaller clumps, these clumps can also form stars. However, if the temperature of the cloud is reduced by some means, we can have lower Jeans mass and therefore collapsing mass, leading to the formation of smaller stars. Below is a mechanism for the lowering the temperature of the gas cloud by collision of two hydrogen atoms to form hydrogen molecule and release of a gamma ray.

H atom (1p + 1e) + 1e -> H anoin, negatively charged hydrogen atom (1p + 2e) + Υ gamma ray

H anoin, (negatively charged hydrogen atom; 1 p + 2 e) + H atom (1 p + 1 e) -> 1 hydrogen molecule, H2 (2 p + 2 e) + 1 electron

Release of the gamma ray Υ lowers the temperature of the gas cloud.
p proton; e electron

High temperature of the early massive Population III stars produced high energy gamma rays. Gamma rays split hydrogen molecules, H_2, into hydrogen atoms, H. This is the ionisation of hydrogen molecule. This phenomenon is called reionisation, and this is the state of the universe still today. Hydrogen is in the ionised state. Formation of molecular hydrogen produces cooling, but the break down of molecular hydrogen raises the temperature; collapsing slows down and the star formation eventually stops. These primordial stars have high surface temperature, in the order of 100° – 200° million K, compared to about 5,800°K of the Sun. High temperature also causes increase in fusion of hydrogen to helium and further fusion to carbon, beryllium, neon, oxygen and eventually to iron (B2FH process). The star is like an onion shell, different layers are rich in different elements. Synthesis of these heavier elements releases less energy. The star finds it difficult to hold up against the collapsing pressure. The energy needed to fuse iron is so high that it would destroy the elements. The star can not hold up against the collapsing gravitational pressure.b The star explodes as a supernova, scattering the heavier (than hydrogen and helium) elements in the surrounding environment.

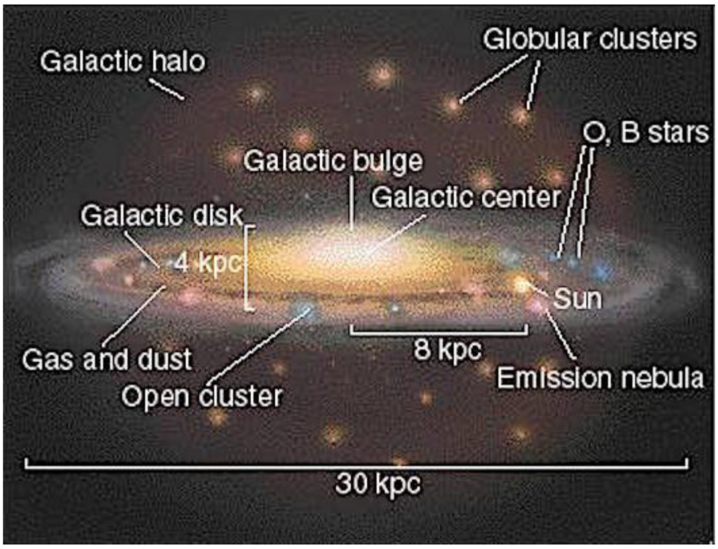
Massive stars die young. A star with 20 time mass of the Sun would live just over 10Myr, (10 million years), whereas a star of mass similar to the Sun could last over billions of years. By this time most of the hydrogen in the primordial stars have been fused to heavier elements. The majority of the Population III stars probably lasted for about 200Myr. The gas cloud is now "contaminated" with heaver elements and there is no more pristine hydrogen (and some helium) left. Star formation would continue as we discussed above, by the gravitational collapse of a gas cloud. These are the Population II stars; these would incorporate some heavier elements produced by the Population III stars. A gas cloud from the destruction of Population II would produce more heavier elements and eventually the star formation process would continue to form Population I metal rich stars of a mass comparable to the Sun. Presence of metals in the gas cloud also favours cooling; the Jean mass stays low and the stars formed are smaller.

Where to Look for the Metal Free Stars

Some of the Population III stars exploded as supernovae and seeded the gas cloud with heaver elements. Some might have formed massive black holes, which in tern merged to form super massive black holes. Depending on their mass, we can also expect the Population III remnants to form neutron stars, red dwarfs or white dwarfs. If we could find these remnants, we should not expect to find any elements heavier than helium.

There is also no reason that Population III stars can not exist as globular cluster or as individual stars.

Let us start nearer to home, a typical galaxy like Milky Way. The Milky Way has about 250 ± 150*10^9 (billion) stars. It has three main areas. *(FIG 2)* We could try to examine the composition of the stars in these areas. Some of the stars are very faint. So to study that many stars is not practicably possible; we have to be selective.



Bulge: It is spheroid in shape near the centre of the galaxy. Computer simulation indicate that it is the oldest area formed soon after the initial collapse. Being the oldest in age, we can expect metal-poor stars in this area. But being the oldest area, there have been many supernova explosions of the first born stars. These have created elements higher than helium and therefore the second generation (Population II) stars formed in this environment are likely to have incorporated metals in their atmosphere. Additionally dust created by the supernova explosions makes this area difficult to look for metal free stars.
Disc: The flat structure with spiral arms: It is breeding ground for the star formation. Materials are continuously being recycled. Hence the likelihood of finding very old metal free stars are almost impossible.
Halo: The nebulous area surrounding the outer edges of the disc. This area contains globular cluster and isolated stars. Stars in this region move faster. We have seen earlier that Roman has observed that stars with low metallicity move faster. However, there is no logical reason why metal-poor

stars would move faster. An explanation is that the very old primordial stars have move out to the halo area. The relative speed from our location to the halo region makes the stars appear to move faster. This is the ideal place to look out for the first generation metal free Group III stars.

Globular clusters are collection of gravitationally bound stars. Some observations have suggested that the stars in the globular clusters often metal – poor. Then there are dwarf galaxies. There is no cut off point when the small galaxies are small enough to be categorised as dwarf galaxies. These are very dim small galaxies. Some of these may appear as globular clusters. Dwarf galaxies have higher mass (including the dark mass) to luminosity ratio compared the globular clusters. Dwarf galaxies merge to larger galaxies we see today. Since these are old, we can expect the metal-free stars in the dwarf galaxies.

Stars with iron content $^{1}/_{10}{}^{th}$ of the Sun are not that uncommon. Astronomers are looking out for still metal-poor stars. But sadly still no metal-poor stars, which can be confidently classed as metal-free, has been observed. One star observed in 2012, was reported to have $^{1}/_{10,000,000}{}^{th}$ iron content of the Sun. There were presence elements of lithium, carbon, magnesium and calcium, but no iron. The origin of this spectrum could be explained as: a progenitor Population III star exploded as a supernova. The outer layer was expelled and formed the observed "iron free" Population II star; even if any iron formed, it stayed close to the black hole and hence did not take part in the star formation.

Another star with $^{1}/_{1,000,000}{}^{th}$ iron content compared to the Sun was observed. Its concentration of other metals was high enough for it not to be grouped as Population III star. It is a Population II star. The concept of Population III stars remains theoretical. It also has been suggested that dust from a supernova explosion can be accreted by a star; the dust cloud conceals the true identity of the star. Some figures have been quoted, but it is only a theoretical calculation.

Theoretical modelling suggests that Population III stars were of mass 60 – 300 times the solar mass. This figure is much higher than the majority of the stars, about 0.8 solar mass, we see today. So we are trying to look for a population of stars which are very low in number. Hence the Population III are difficult to track down. The fuel of these all high mass stars have been exhausted and perhaps only exists as remnants like black holes, neutron stars, white dwarfs etc. As we discussed earlier, star formation does not occur in isolation, some smaller stars also formed with along with the massive stars from the primordial metal free gas cloud. Some of these smaller stars perhaps could well have survived and may be detectable. Search is continuing to look for the nature of the Population III stars. This will help us to the better understanding of the evolution of the galaxies.

Reference

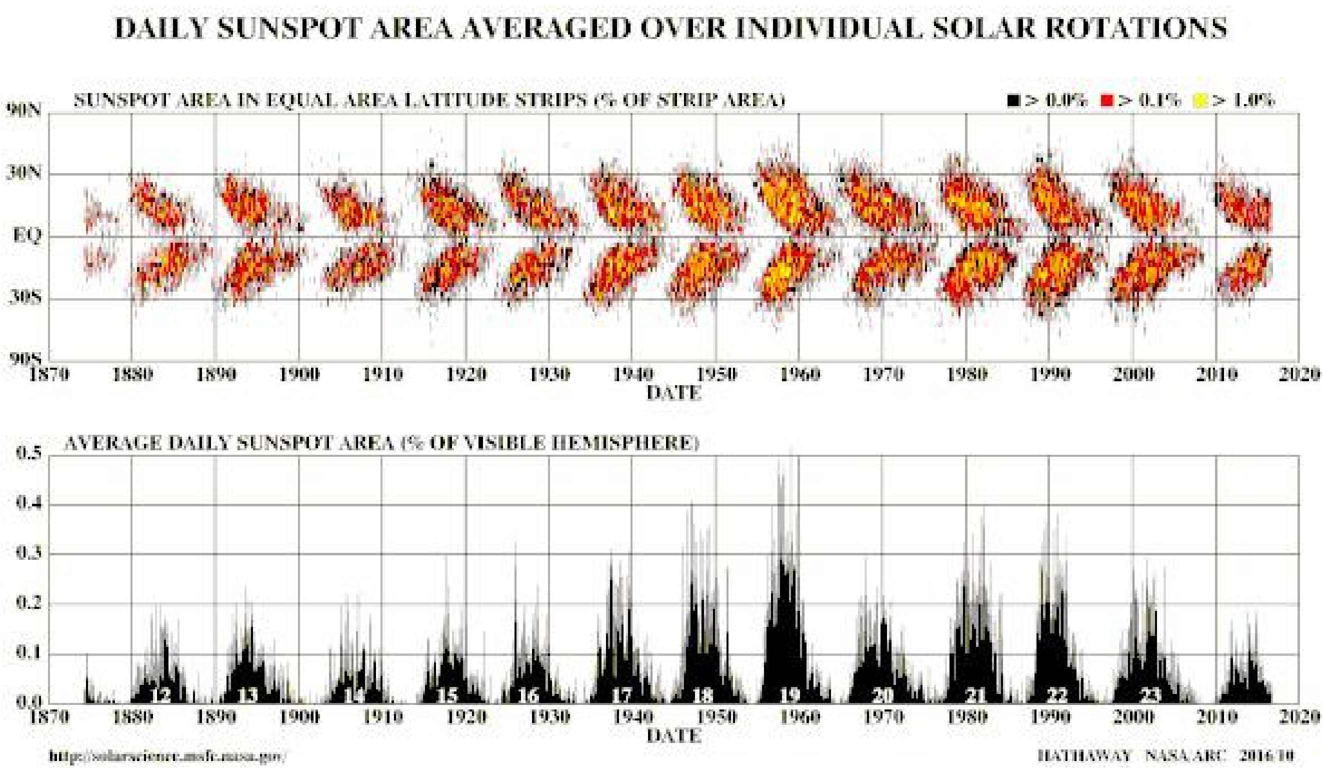
https://en.wikipedia.org/wiki/Metallicity
https://medium.com/predict/the-mystery-of-population-iii-2f6bc5521e29
https://astronomy.swin.edu.au/cosmos/P/Population+III
https://en.wikipedia.org/wiki/Stellar_population
https://www.astronomynotes.com/ismnotes/s9.htm
https://en.wikipedia.org/wiki/Recombination_(cosmology)

Colour, Spectrum, Temperature, Luminosity of stars

https://en.wikipedia.org/wiki/Color_index
https://www.astronomynotes.com/starprop/s5.htm)
https://www.atnf.csiro.au/outreach/education/senior/astrophysics/photometry_colour.html
https://en.wikipedia.org/wiki/Apparent_magnitude

First Light; Emma Chapman, 2020, Bloomsbury Sigma
Rebel Star; Colin Stuart, 2019, Michael O'Mara Books Limited

* To remember the order O, B, A, F, G, K, M. O. Be. A. Fine. Gal/Guy. Kiss. Me.



A Good Time to Observe Butterflies

By Geoffrey Johnstone

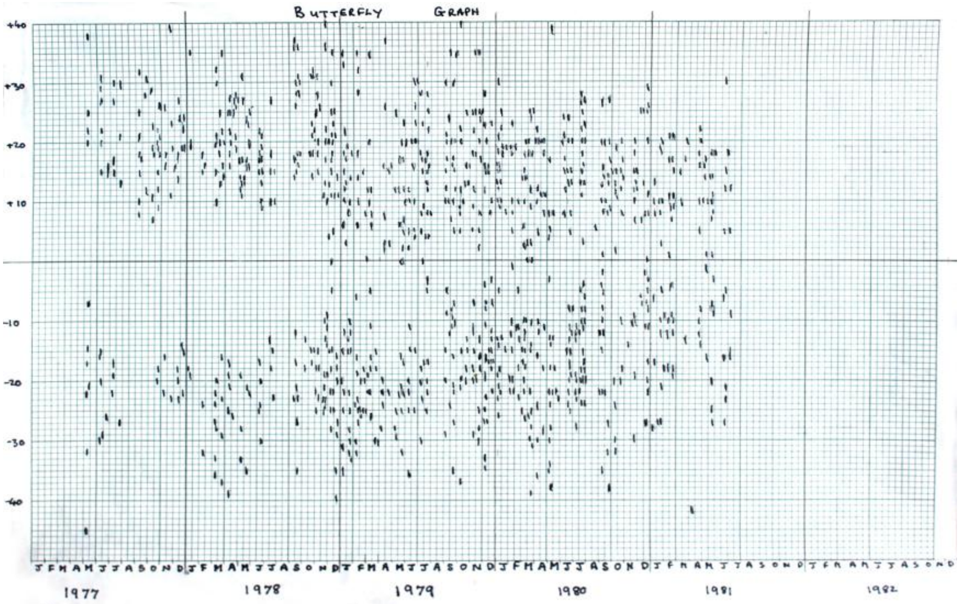
Edward Walter Maunder was born in 1851, in London. He took a job in a London bank to finance his studies and subsequently attended King's College London but never graduated. In 1873 Maunder obtained a post at the Royal Observatory, taking the position of a spectroscopic assistant. Shortly after, in 1875, he married and produced six children, 3 sons, 2 daughters and a son who died in infancy. His wife died in 1888, but in 1890 he met Annie Scott Dill Russell (later Annie Russell Maunder), a mathematician and astronomer educated at Girton College Cambridge, with whom he collaborated for the remainder of his life. She worked as a "lady computer" at the Observatory from 1890 to 1895.

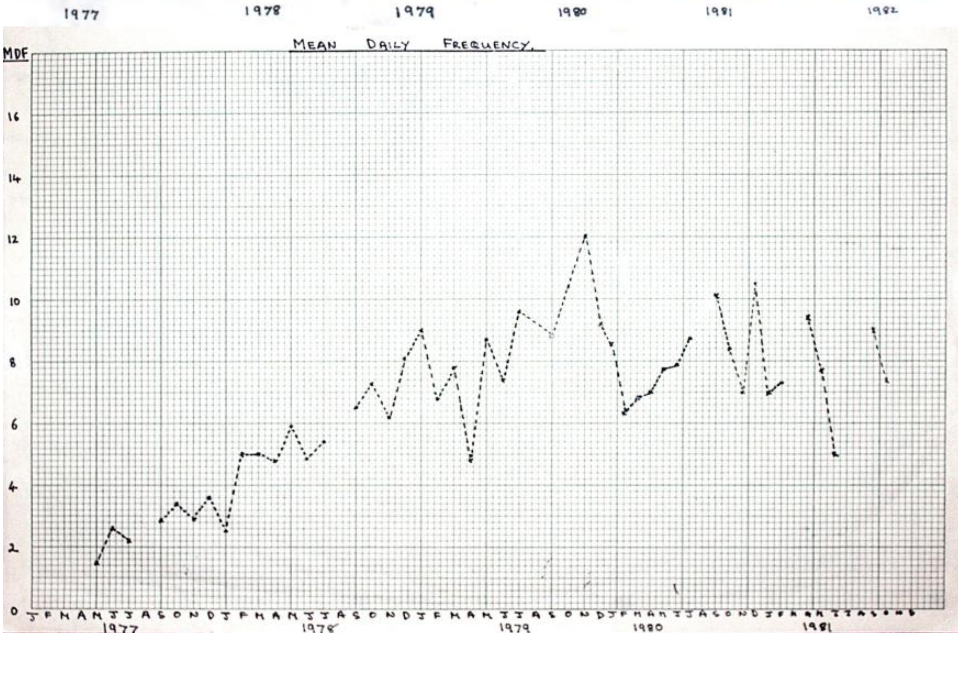
In 1895 Maunder and Russell married. In 1916 Annie Maunder became one of the first women accepted by the Royal Astronomical Society.

Part of Maunder's job involved photographing and measuring sunspots, and in doing so he observed that the latitudes of sunspots varied in a regular way over the course of the 11-year cycle. After 1891, he was assisted in his work by his wife Annie Maunder. In 1904, he published their results in the form of the "butterfly" diagram.

After studying the work of Gustav Spörer who examined old records from different observatory archives, looking for changes of the latitude of sunspots, Maunder presented a paper, on Spörer's conclusions in 1894 to the Royal Astronomical Society that showed the presence of a prolonged sunspot minimum in the 17-18th centuries. The period, recognised initially by Spörer, now bears the name The Maunder Minimum.

In 1890, Maunder was a driving force in the foundation of the British Astronomical Association. Although he had been a fellow of the Royal Astronomical Society since 1875, Maunder wanted an association of astronomers open to every person interested in astronomy, from every class of society, and especially open to women.





Maunder was the first editor of the Journal of the BAA, an office later taken by his wife; Annie Maunder. He was also director of its Mars Section 1892–1893, the Star Colour Section 1900–1901, President 1894-1896 and finally Solar Section director 1910–1925. His older brother, Thomas Maunder (1841–1935), was a co-founder and secretary of the Association for 38 years.

My feeble attempt to produce a Butterfly Diagram is shown left from observations I made between 1977 and 1981. I spent a good portion of the my summer holiday of 1982 measuring the latitudes of the sunspots recorded on my sunspot drawings and plotting them to see if a Butterfly pattern emerged, which it did to some extent. It must have been a wet summer because I remember doing the measuring in our caravan between trips to the beach with our young family. How I managed to fit in observing the Sun reasonably regularly to produces enough data amazes me. I was also holding down a full time teaching job at the same time. Incidentally Solar Cycle 21 began in 1976 and ended in 1983.

Maunder's Butterfly Diagram covered many solar cycles so produced a repeating pattern. I wonder how many amateurs have attempted this same exercise?

We are now just starting Solar Cycle 25 so now would be a good time to have a go yourselves.

Expedition 3

By Ivor Clarke

A Lunar Si-Fi Story

"No one ever said exploring the Moon was going to be easy," Alex said as we surveyed the damage to the right front wheel of the silver LSV.

"It's going to be embarrassing telling Control to bring a spare wheel again after last time." I agreed, when we got a rugby ball shaped rock stuck inside of the wire tyre. "But I don't think we can continue much further like it is, the damage will only get worse the further we drive. We should be able to get to the top OK and be on the level. We can move a lot of weight to the back to lighten the load on the front."

"Yes, but how long have we got before the solar storm hits the Moon, about 24 or 25 hours?" Alex asked.

"About that," I replied, "so we better get inside and get cracking."

"At least the hub motor is still OK, so it didn't hit the edge of the hole. And the way the tyre wires are bent, I think it will be easy to fix at the base workshop."

"Yeh, but it did go down with an almighty thump on what looked like a nice clean slope."

"Well, we better try to extricate ourselves from the hole and take another route up onto the plateau." Alex replied looking up the shallow slope to the top of the crater Wargentin.

It had all been a great 9 days of exploration after setting out from the South Pole International Station on the rim of Shackleton, a 21km diameter crater right at the lunar South Pole. Now one of the main lunar bases for research and astronomy into the far infrared. All of this area is part of the South Pole-Aitken basin, one of the oldest and largest formations on the Moon at 2,600km in diameter and with a depression of about 6km below the average surface. In the century since the first lunar base was established, the south pole region has opened up the exploration of the Moon with even tourists (if they have the money) visiting and enjoying themselves in the low lunar gravity and visiting some of the more touristy views and famous craters, along with the first swimming pool on the Moon at SPIS.

When it was discovered that the floor of Shackleton is deep in water ice and other minerals, frozen down to near minus 200° degrees in the regolith, it marked a turning point in the history of the exploration of the Moon. This was because the Suns light had not shone into its interior in over three and a half billion years; for almost all its history the Moon had spun in a nearly upright position as it had orbited the Earth. Today it only tilts at just 5 degrees from the ecliptic. At first it was close, just after its formation the Moon orbited Earth in just a couple of days as it coalesced from the impact debris after the Earth was hit a glancing blow by a Mars size planet. Now it is 380,000km distance taking 27.3 days.

The nearby high mountain Malapert and a couple of others are almost forever in sunlight and provided power to the base and have a direct line of sight to Earth. This icy discovery and other mineral deposits in other nearby craters like Shoemaker, de Gerlache and Sverdrup which also have substantial supplies of water ice in their interiors helped. Soon the extraction of oxygen and hydrogen began for use as air and fuel as the main requirement of the base.

The lunar regolith in the Shackleton crater proved easy to mine and a metre or so fused together would provide excellent protection from almost all radiation, even highly energetic cosmic rays. So a large base was built in just a few years, just alongside the crater on the flattest area, dug well in underground with the expanding science and engineering labs covering the research needed to live on the Moon without getting major supplies from Earth. After a few false starts all the food needed for the rapidly expanding bases was grown locally.

As the terrain around the south pole was not very smooth to say the least, consisting of many large craters overlapping each other with high walls and deep dark interiors, it had been decided to build the Southern Lunar Exploration Base near to the large crater Clavius, a 225km wide crater with an unusual string of six craters curving across its floor with each one smaller than the previous starting with the largest in the southern wall nearest to the pole called Rutherfurd. This crater was the main lunar base in an ancient old movie film *'2001'*, made even before the first landings!

After an early start Alex and I met at the smaller of the the two loading bays were two other teams had assembled to fly to the SLEB for their 14 day tours. We knew most of the other teams and asked one another what was their goal was this time and had a few laughs as we climbed into the cramped flyer with all our gear, computers, cameras, favourite food and clothes for the next fortnight. This would be our last trip together as we were due to fly back to Earth next month after our six month stay.

"Everyone buckled up?" asked the pilot, "Then I'll pressurise the Vehicle and ask permission for the airlock to unlock."

The bay's airlock door opened and the flyer was pushed into the airlock tunnel along a track, we halted and the inner door closed and locked behind us.

"Four minutes to depressurise." The second pilot said as the air was sucked out back into storage tanks so as not to waste too much with every coming and going. Through the front window we could see the outer door opening onto the surface with the landing and takeoff area lit with light. The flyer was pushed forward onto the takeoff pad. A few words with Control and all clear was given for liftoff.

And then with a far off whooshing sound we lifted off and rose above the base with the sudden a burst of bright light made some gasp as we cleared the top of the nearby mountains and burst into sunlight.

Looking out of the side window I caught a glimpse of the Far Infer-Red Facility and the mining area over 4km below on the floor of Shackleton as the flyer banked and headed north over the towering walls of the polar craters towards the SLEB and the start of our exploration tour.

The flyer dropped us and the other teams off at the SLEB, a quick 30 minute ride from the large SPIS base at Shackleton. A flexible air lock locked onto the side door and we walked into the base. In a few years time the monorail connecting both bases should be complete and saving the fuel used on these trips. The Sun was just coming up over the horizon in the east and from Earth the Moon was a day after first quarter. Both Alex and I had been on the Moon for over five months already and were used to each others company. We had met during the long training required for lunar exploration work and had become firm friends. Both of us were working on our University papers into the Moon's history, mineralogy and geology and we helped each other with the analysis of the complex samples we had collected back in the labs during the lunar night.

We all filed into the Base hanger were three Lunar Surveying Vehicles stood, lined up behind each other waiting for us. They are quite large silver machines with four large All Wheel Drive wheels made of a springy wire woven into complex patterns lifting the cabin over a metre above the ground, these are the same as the ones used on Mars, but they have toughened up wheels and suspension for the higher gravity. All the wheels can be steered so giving the machine great manoeuvrability around rocky areas and with an armoured underside was a great "Off-Road" drive. The cabin could hold four at a push or half a dozen in an emergency, but was great for two to spend a fortnight in. Inside the LSV the floor was covered in a grippy material which made walking feel a bit more like Earth and helped to stop you banging your head on the roof if you jumped out of the seat too quickly. At the front was the two driving and control positions, behind was the kitchen and food store set along the right hand wall, opposite was the vehicle control, computer and comms systems. At the rear near the air locks was the "RestRoom" as the Americans like to call the loo and wash cubical; and a couple of gym equipment, bike and rowing machine, stowed into the wall. The rear wall contained the four EVA suits which are entered through the backpack opening swinging away for access. After climbing into a suit the backpack folds back and seals the suit with enough air and water for up to 18 hours, then the aperture is filled with a sealing door and the outside airlock is then able to open. This arrangement keeps all the lunar dust in the rear airlock so none gets into the living area. The roof of the cabin was domed with the beds fitted just below the roof which contained the hundreds of litres of water for radiation protection, for drinking, washing and to provided the fuel for the electric fuel cell power generator. On the top was the comms aerials and an array of solar cells covering the roof. The LSV could stay away from the base for up to a month. But it was not recommended to drive around at night as it was best to be able to see what was in front of you further than the vehicles lights could show. . .

"We're in the end one I think," I told Alex, "Let's collect our gear and stow it in the lockers." The Base Vehicle Manager came up to us checking her pad.

"You'll be taking LSV3 "Moondog." The BVM told us, "It's all fuelled up, been checked and serviced, so have a good trip. I'll be in touch to check up on your progress from time to time so . . ." she trailed off. We both knew what she meant, remembering the rock stuck in the tyre last trip, letting a couple of university types loose on the Moon in a 10 million bucks machine even if they were top of the class and had completed all the arduous driving tests, EVA's and safety training in a six month training course. Our route was mapped out visiting three interesting craters in the south west region two days drive away and logged along with the sampling points and core drilling areas. She knew where we were going and when.

"Don't worry. We'll bring it back in one piece, this will be our third trip in one of these," replied Alex. "See you in 13 days time." We said goodbye to the other teams going off in their Lunar Surveying Vehicles further north.

The Lunar Surveying Vehicle 3 would be our home for the next two weeks so we understood why the BVM was weary of a couple of rookies taking off into the unknown. She was the one who would have to come and get us if it all went pear shaped. The large four wheel vehicle had an airlock door at the side for loading and could be used with a flexible airlock attached in a vacuum. The cabin bulged at the front so as to leave it free for observation with large windows and for the two manipulation arms. In the base we boarded by the side door to store all our equipment, some which we had left at the base lockers for future use. After half an hour we were ready to go, all the comms systems working fine and checking with the other two teams confirmed they were also ready.

"All systems on green, we are ready to go. All doors locked and we're airtight." I told Control. "Confirmed," they replied. The alarm sounded and the hanger emptied of people and the air was sucked out. The green light over the main door changed to red and it opened up onto the lunar surface.

"Expedition 3 is off an' rollin'." Said Alex in a best broadcasting voice. "The Teams are off exploring unknown destinations and wonders." We both laughed at that.

We followed the two other LSV's out into the morning sunlight and they turned north and we followed them for several kilometres. The Sun was over the eastern horizon and to the west, Jupiter could just be seen shining brightly and in the north, the Earth low in the sky 5 days off new, four times larger than the Moon looks from Earth. After a couple of hours we turned left to head round the northern side of Clavius.

The first day was a driving day, taking two hour driving turns we threading a way between the crater Clavius and the 145km crater Longomontanus. While the lunar surface looks very mountainous and rough when you look through a telescope to areas near to the terminator, when you are on the surface its mostly 10 - 20 degree slopes covered in small rocks and craters. And if anyone has been there before you, you can follow in their tracks. Nowadays you can't get lost with the small constellation of lunar satellites orbiting overhead marking your position. Next day after a 8 hour rest stop and sleep near Longomontanus we continued for that day threading our way between a series of large craters to get closer to the first interesting crater stop on our tour, a visit to the very elongated crater Schiller, 180km long but only 70km at its widest. This lay at the eastern side of the Pre-Nectarian Schiller-Zucchius formation which was well over 4.2 billion years old. The crater we were heading into was at least 500 million years younger. At the southern end there is a gap in the crater walls caused much later by an impact right on the rim gouging out an opening, so we were headed for that and a rest stop.

Next day we drove into Schiller through the gap and stopped to photograph the view with the Sun just coming up over the eastern walls and illuminating the left hand western wall, the long flat floor of the crater disappearing over the horizon.

"What a view." I said, "You think how lucky we are to be able to see views like this. Some of the old Moon mappers wouldn't believe how magnificent it looks."

"Yes, 'Magnificent desolation'." Alex agreed quoting the second man on the Moon words.

We spent the rest of the day exploring in Schiller travelling up its floor northwards with sampling stops and a few core extracts before a rest stop. Next day we set off early to reach the far end of Schiller heading towards the low hills in the crater where it narrowed.

"The objects which formed this must have come in at a very low angle indeed to gouge out this formation." Alex mused as we sighted the low central ridges at the far end.

"Well the interior mare looks continuous all the way along so far, so it must have flooded in one surge." I remarked.

We stopped near a small interior crater Schiller T, to photograph a large 9 meter bolder which had rolled down hill leaving a trail for nearly a kilometre some time in the last 100 million years!.

That evening as we ate dinner we had a progress check with the LSEB Vehicle Manager, "How's it going guys?" She asked, "I've got a report from the Space Weather Bureau about an active area just coming round onto our side of the Sun. No problems expected, but I'll keep you informed."

"That could really screw up a nice day out here if the worst happens," I said to Alex. "Let's have look at the Space Weather feed and see what they think."

It looked just like a couple of small spots which could fade away at anytime. "Nothing to get excited about," was Alex's verdict.

Next day we drove up the wall at the end of Schiller where there had been a wall collapse spreading material into the interior, this made a slope that wasn't too steep and then onto a flatter area for the days drive to our next target Schickard, an ancient vast flooded plain 227km in diameter about 200km away.

Getting into Schickard was best done by driving into Schickard E, a 30km crater in the southern rim. From the south east there are a couple of easy descents onto E's floor and a gap in the hilly ridge to the north west onto Schickard's interior mare. Schickard itself is one of the oldest formations on the Moon, formed about the same time as the South Pole-Aitken basin which is mostly on the far side of the Moon. The floor of the crater has been flooded with larva at least three or more times and has no central uplifted mountain range and as we entered we turned right and a few kilometres away was the last area to flood covering an area of hundreds of square kilometres. Even looking at a photograph of the crater you can see this is a recent flood in lunar history by the lack of secondary craters on this dark area of floor. Why this occurred a billion years after the first flood of mare basalt which covered the entire crater floor was for us to discover (hopefully).

Next day we made our way northwards up the inside of Schickard to the northern end with a larger and older re-flooded area. The Earth was by now a thin crescent still low in the north with the Sun about to sail past well under the Earth at midday local lunar time. On the Moon the Earth more or less stands still in the sky, (on the near side) with the Sun and planets swinging around it in 27 days, of which half are in sunlight or in darkness. You get use to it after a while as the Sun slowly makes its way across the black sky by about 13° degrees a day, stars can't be seen when the Sun is above the horizon. But once the Sun has set and the Earth is not full most of the bright stars and the planets are visible. As we moved north we left behind the the darker flooded mare and reached the oldest light coloured mare area. This mare flooding covered all of the interior at one time, but now it is visible over most of the central area and is the most heavily secondary cratered of all. Our route was up the east side past one of the largest interior craters, Schickard B, a 12km crater near the east rim were there are two fresh overlapping impacts in the rim wall.

After another rest period we soon arrived at the second re-flooded area in the north of the crater, this has more pits and small craters across its surface than the southern end, so is older. We made our way up to the top northern end of Schickard where a ribbon of larva must have run from a volcano like feature located in the walls of a crater called Lehmann, 53km in diameter, cutting a grove before flooding onto the plane of Schickard. It would have been great to try to get to the source of the larva channel but it was too risky to drive 50 or 60km along a twisting larva channel up hill. Sometimes you can't take the risk and we only had 4 days left.

And then we had the warning from Control to all the exploration teams, "Sorry guys but it looks like that sunspot group is starting to kick off, several Class 3 - 4 flares have been reported. A Coronal Mass Ejection is very likely within the next couple of days and it could come our way. You may all have to come back a day or two sooner I'm afraid."

"That's all we need." I said gloomily to Alex. "On our last trip too."

"If we did an overnight driving stint and get to the south end and through the rough stuff and up the wall we can still finish off the trip as we planned."

"On top of the world, eh?" I replied. "OK, it's our last expedition. Let's make it a good-un."

The western side of Schickard is a nightmare of jumbled craters caused by the splash of the Early Imbrian Epoch impact, the Orientale multi-ring basin, 900km in diameter lying just over the western side of the Moon about 3.8 billion years ago. This caused wide spread secondary cratering over a large area including the whole side of Schickard where we were heading to. Near the southern end not far from the point we had entered the crater at, we turned due west and headed for our final destination, the strange crater Wargentin. This is the only crater of its type on the Moon, a large crater 84km in diameter filled to its rim with basaltic larva forming a raised plateau about 600m above the surrounding area. Where had all this larva come from? Why had the larva filled it to its brim and then not drained away, but stayed and solidified is a mystery. The plateau has a few small craters and a couple of wrinkle ridges, but is otherwise flat and undamaged. At the northern end we were heading to, it seems to have overflowed the tops of the surrounding walls and smoothed out its side walls and should make it an easy ascent up its side onto the plateau. That was why we were trying, what we hoped we could be, the first to drive on its roof!

We were parked up for the rest period a few kilometres from the crater when Control sent out the warning message of the coronal-mass ejection which was heading towards Earth, "In about 32 hours we expect the CME to hit Earth and the Moon, all personal **MUST** be inside the bases and **NOT** taking refuge in a LSV or any other area with out proper radiation protection. This is a Class Y VI flare, nearly as powerful as the old 1859 event. All Earth orbiting satellites are being put into safe standby mode, so comms may go down for a bit. The good news is it is travelling fast, nearly 1,000kps, so will be clear and past in a couple of hours. If it's not possible to return to a Base within 30 hours, inform Control immediately to arrange collection by air. All Lunar Surveying Vehicles left outside of a Base must be put into a parking standby mode fully powered down to protect the electronics and computer systems."

"Sounds pretty serious, there is no way we can get back to the SLEB in 30 hours so someone will have to come and pick us up," I said.

"Well, I think as we're so close, we could drive up onto the top and do a couple of quick cores and samples. Then start to head to base ASAP." Agreed Alex. "We can get within a half hour flying time in the 30 hour time frame."

So off we set to find the smoothest way up onto the Wargentin plateau. We soon cleared the rough cratered area between Schickard and the flanks of Wargentin and could see a possible smooth way up the side of the crater from the north. The slope was well within the design capability of the LSV and it was fairly smooth with only a few large rocks to dodge and groove like channels.

After climbing around 300 meters we had the accident. The LSV suddenly dropped forward with a crash as the right front wheel disappeared in a cloud of dust. This being on the Moon, dust and gravel drops away in seconds to reveal the wheel over a large hole which had not been there a couple of seconds earlier.

"Where the hell did that come from?" Exclaimed Alex. "It looked like a perfectly even slope!"

"It's a good job we record everything with the cameras, so we can show the Base we were not fooling about." I said. "We better get out and have a look to see if there is any damage."

After photographing the wheel and the hole for the record, we had a good look at the large hole that had appeared.

"It looks like a thin slab of material has slid down the slope and covered the hole and its never been hit by a meteorite to cave it in." I said. "Let's move as many sample containers as we can to the rear lockers to lighten the front." After that we retreated to the rear airlock of the LSV and climbed aboard closing the outer airlock door before backing up to the spacesuit docking stations and locking the seals around the backpacks. "Seals complete," the AI announced, "you may enter the vehicle now." We both said thank you to the AI and with a hiss the backpacks swung aside and we pulled ourselves out of the rear of the EVA suits easily in the one sixth gravity. After also pumping as much water as possible from the front roof tanks into the rear containers and moved some equipment to the back, we were ready to move again.

"I'll go outside and guide you out so we don't do anymore damage to the wheel." I said.

"Good idea, I'll take it real slow. Have a good look which side of that hole we need to avoid." Alex replied.

There was an ample supply of air in my EVA suit, so in five minutes I was outside again by the front wheel.

"OK, start to back out real slow." I radioed Alex as I stood a couple of meters away recording the event.

The LSV started to move slowly backwards when suddenly the front wheel spun and disturbed a cloud of dust and gravelly material, more of the edge of the slope dropped into the hole. Alex kept going back and in seconds had all four wheels back on the slope.

"Great, we're out." I called. "Just a second, let me get a lamp from the tool locker to have a look at what this is."

The Sun was shining a little way into the hole but with the lamp I could see much further and deeper into the hill side. The now much larger hole went out of sight into the mountain glistening with a glass like sheen.

"Hoy, we've discovered a larva tunnel into the crater." I told Alex.

"No kidding. How far can you see?" Came the reply.

"I can't tell. If I clamber over the rubble, I reckon we both could walk in there easily. The floor looks pretty smooth and slopes downward and I can't see any end. Come and have a look."

Alex got into a suit and joined me at the entrance to the tunnel which disappeared into the mountain.

"Wow, what a discovery, and on our last trip too. This will finish off our adventure in a grand style. I bet they may even forgive us the damage with this find." I said.

We walked into the tunnel, down the slight slope, the larva tunnel was fairly straight and smooth with the walls a glass like finish similar to ones we had seen on Earth. But this one was nearly four billion years old! After ten minutes we stopped. "Do you realise we have about 500 metres of solid rock over us. This must be the safest place on the Moon when the CME storm hits." I remarked.

"Let's get back and talk to Control. We can stay here safely so there's no panic for us to get back to base." Alex agreed. "We can unload all the computers into this tunnel for safety, And wait here for the two or three hours when the storm hits and then they can pop over with a new wheel without any time pressure."

"We can lay down some of the radiation meters near the entrance and then back here and work out the thickness of the overlaying rock."

"Good idea," Alex agreed, "we'ed better find out how long the storm will last here, as a lot of the radiation flux will come down the Earth's magnetotail and give us a double whammy. We are only just past new Earth, so a lot of the radiation will flow down onto the Moon causing problems."

In the LSV we called Control and told them our situation and that we had discovered a larva tube that would enable us to sit out the solar storm safely without any danger. They could not believe our good luck with that, but they weren't too happy about the wheel damage when we showed them the pictures of the wheel. "Cut off the ends of the bits sticking out of the tyre and if you take it steady you should get back OK. The tyres are stronger than you think and a couple of broken wires are no problem." Was their verdict which was a relief to us. We could make it back ourselves, without help!

We still had a full day to explore before the CME hit, so we drove up onto the top of the Wargentin plateau which is nearly 80km across and with no craters larger than 2 - 3km, but with loads of smaller pits showing its great age.

"To think this surface is about four billion years old and in all that time nothing larger than about 15 meters has landed here is quite remarkable." Wondered Alex, "But were did all this larva come from and why didn't it drain away? Perhaps it's over a Lunar Hot Spot." I agreed it was a mystery, it was here well before the Orientale impact covered much of this section of the Moon in debris and secondary cratering. We travelled a few kilometres across the plateau collecting samples and cores before retracing our steps and travelling back to the edge we had climbed.

"If we have an early rest period now, now we're on the level, we can go back to the tunnel tomorrow and unload the computers after giving the suits time to fully charge for the EVA into the tunnel." I thought.

"Good idea, sounds sensible." Agreed Alex.

We watched a newscast about the chaos and panic the approaching CME was causing back on Earth with all space flights grounded and telecommunications satellites and others being shutdown. While no-one of Earth would be harmed, the forecast for some wonderful aurora sounded promising.

We called Control next day for an update and got to hear of the panic the CME was causing in the Lunar bases and the other teams trying to get back in plenty of time.

"Great to hear you will be quite safe as you are the furthest team away at the moment. We don't know if you will be able to hear us if you are deep into that tube. Try putting a repeater near the entrance and see if that helps. We think the storm will last 4 - 5 hours max as it's moving rapidly, so see you after the storm. Good luck."

"Well they feel confident we will be fine down the tube. But I reckon we'll be in the EVA suits for over eight hours, so if you want to scratch your nose you had better do it now." Joked Alex.

"You're right, it will be the longest we've spent in a EVA suit, so we had better have a good meal before hand." I agreed.

After parking the LSV by the larva tunnel, we loaded all the equipment and computers we could into boxes then got into our EVA suits, de-pressurised the LSV so we could open the side door to get the gear out and into the tunnel.

"How far do you reckon we need to carry this stuff down here, 100 meters?" Asked Alex.

"I should think that's more than enough." I replied.

"Hello, Control, we've got the LSV in standby and all the sensitive stuff in boxes in the tunnel so it should be safe." I told Base.

"Looks like the first bit of the storm will be here in about 75 minutes so good job guys. Enjoy the tube. Will call in 5 hours, shutting down now." And with that the line went dead.

"I think we may be better off here than in the panic at the base." I said to Alex. "Lets get a couple of spare lamps and have a walk down the tube with the laser scanner so we'll have an accurate map, as we can't do anything else."

Off we set, down the long larva tunnel recording it in detail. It remained about the same width but varied in height, the walls smooth and glass like. Some sections were a lot steeper, but still safe to walk down in the light gravity. After an hour Alex asked, "How far do you reckon we have walked?"

"About 3 or 4k I should think," I replied, "How much further does this tube go? 40k to the centre of Wargentin?"

"Well, we can't get lost as we haven't seen any branch-offs. Let's go another couple of k's and if it's still a tunnel it will need a proper expedition to explore." Alex remarked.

"OK, the storm should be washing over the Moon by now, but my radiation counter is more or less on zero. so let's press on." I agreed.

On we went for another four or five hundred meters and then we got the surprise of our lives. The larva tube started to widened and the roof extended upwards, the floor of the tunnel suddenly seemed to stop and all we could see was blackness. Our eyes by now were used to the darkness, but this was a black hole. We switched on all the lamps and pointed them into the blackness. We could see the floor of the tunnel running down steeply into the blackness beyond the reach of the lamps.

"Well this is as far as we can go." Said Alex in disbelief.

"You know what I'm thinking." I gasped at the blackness. "This is a gigantic empty larva chamber, under the roof of the crater. It's been here for billions of years because no rocks big enough to crack the roof has landed in all that time. It's incredible, who would have thought it possible? The crater must have filled up with larva not long after forming and the top started to solidify with the interior staying molten for millions of years and then. . ." I suddenly had an idea. "The Orientale basin impact would have shock up everything around here and maybe opened up the bottom of the crater with cracks and faults and the liquid larva that was left, just drained away leaving this."

"Well it sounds plausible." Thought Alex. "It could be were the larva went that flooded into south Schickard. Let's see if we can get an image with the camera on a time exposure with the lamps on."

We set up the camera on a long exposure setting and shone the lamps into the blackness. Slowly an image appeared on the screen of a vast cavern tens of kilometres across and two or three high. "This is the most incredible space I have ever seen." I exclaimed, "Only here in this low gravity could it hold itself up, and when you think how old this is and the roof hasn't collapsed. . ." I trailed off, dumbstruck for words. "We are going to be quite famous for this find." I added. "If they ever get round to building a city on the Moon, this is the place. . ."

"What are we going to call this. . . this space. . . chamber. . . cave. . . cavern?" Alex wondered.

"Well: as we're the only girl exploration team on the Moon, so how about 'The Wargentin Ladies Room'." I laughed.