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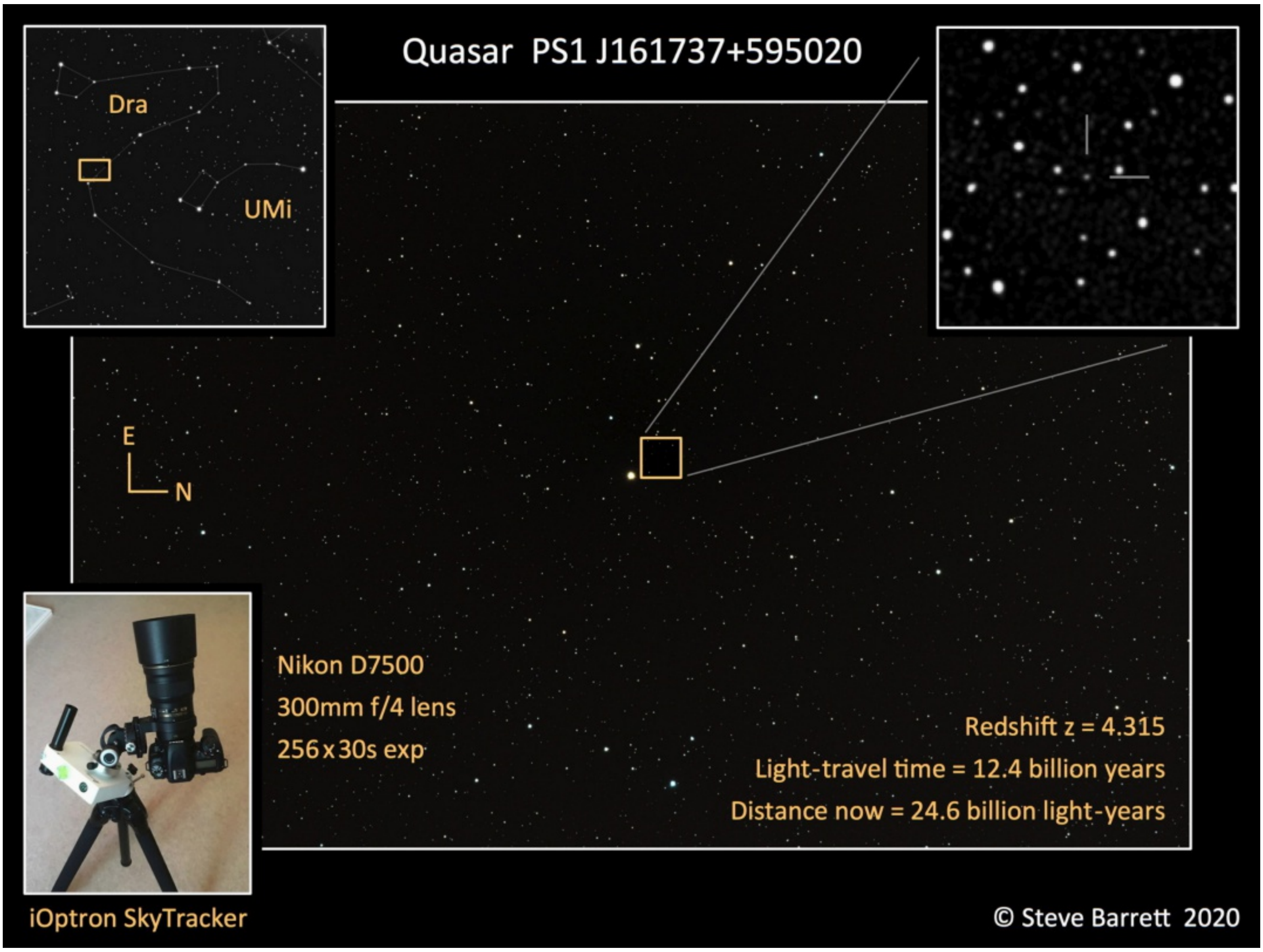
Ancient Light

The original of this article was in the Journal of the British Astronomical Association. 2021 April. Vol. 131, No 2. Please refer to the full version of the article that gives more details of the redshift and the expansion of the Universe at:
https://www.liverpool.ac.uk/~sdb/Astro/Ancient-Light-JBAA.pdf



The bottom left inset shows the camera and 300mm telephoto lens on a star tracker (the white box). The rectangle in the top left inset shows the field of view of the lens in the constellation of Draco. The main image is a two-hour exposure (256 x 30s exposures) that shows the fifth-magnitude star AT Dra at the centre. Zooming in to the area near the centre, the top right inset shows the quasar identified by the two grey lines. At a distance of 25 billion light-years, the quasar is barely one pixel in the image.

CONTENTS

Ancient Light

By Dr Steve Barrett

The Universe is vast and ancient. Large telescopes such as the Hubble Space Telescope have imaged galaxies that are billions of light-years distant. It is easy to assume that any instrument that is capable of detecting the light from such distant galaxies must be very sophisticated and very expensive, with a price tag as astronomical as the distances involved. In this article I show that this is not so by demonstrating that an ordinary camera designed to take photographs in daylight can be used to capture the light from a galaxy that is so distant from us that the light it emitted had been travelling for most of the age of the Universe to reach us.

During the pandemic of 2020 I recalled Stephen Hawking's words "Remember to look up at the stars and not down at your feet" and set myself a lockdown challenge – not just to look up, but to look up as far as possible. What is the most distant object that I can photograph with my camera without using a telescope?

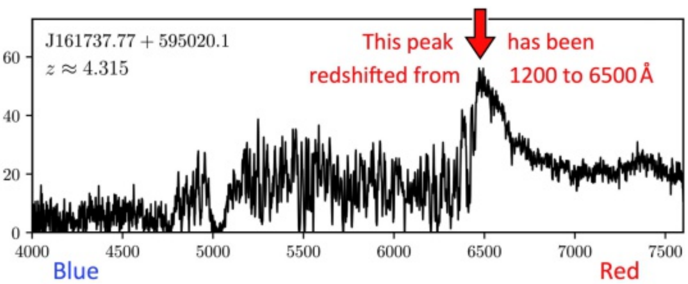
I looked up a research paper **[1]** cataloguing very distant galaxies (quasars) that emit a huge amount of energy and picked the most distant one that is high in the sky as seen from the UK during the summer months. Having identified the target quasar **[2]** the first opportunity to try to image it came on the night of 20 July. My camera equipment comprises a Nikon D7500 digital SLR camera with a 300mm f/4 telephoto lens – the equipment that I use for normal daylight photography, not 'customised' or 'modified' in any way for astrophotography. I set up the camera on a small star tracker that rotates the camera at 1 revolution/day to follow the stars, as shown in the bottom left inset on page 1. The quasar is located in the constellation of Draco (top left inset, page 1) which is high in the sky during the darkest part of the night in the UK spring/summer.

Not knowing how long an exposure was necessary, I exposed for as long as the short summer night allowed. Rather than take a single very long exposure, I took a continuous series of shorter 30-second exposures over a period of about an hour either side of midnight. After discarding some of the images that were spoiled by passing clouds, the remaining exposures were added together to produce a resultant image that was equivalent to taking a single two-hour-long exposure. The final image, the result of adding together 256 exposures of 30 seconds each, is shown in the main panel of the Figure. Zooming in to the area near the centre, the top right inset of the Figure shows the quasar identified by the two grey lines.

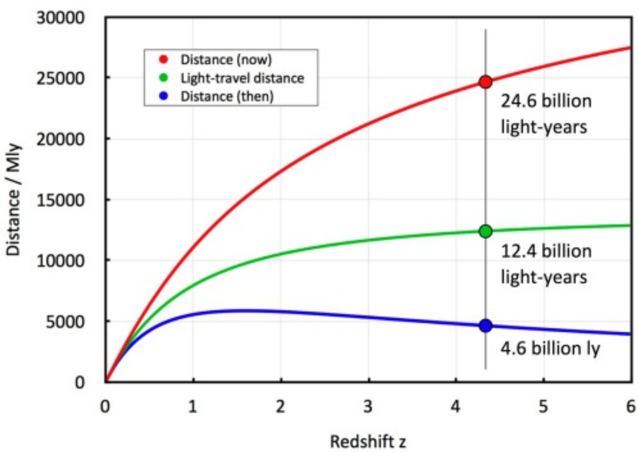
Having shown that it is possible to capture the light from this quasar using a digital SLR camera, the big question is... just how far away is it? If the quasar is just a tiny dot, even in a large telescope, how can its distance be determined? We have to remind ourselves that the distance to the quasar cannot be measured. The length of time that the light has been travelling to reach us also cannot be measured. The key to determining distances on cosmological scales is the one thing that can be measured – the spectrum, from which we can calculate the redshift that results when an object is receding from us. Reference 1 determined that this quasar has a redshift of z = 4.3.

Determining the distance to the quasar is complicated by the fact that the Universe is expanding at a rate that changes with time. This means that we can only calculate the distance to a remote object if we have some understanding of how the Universe is expanding, and in particular how the Universe has expanded over the time interval between the time when the light left the object (perhaps billions of years ago) up to the time when it arrived here on Earth (now). The so-called concordance model of the Universe is based on the currently accepted 'best guess' of the parameters that determine the way that the Universe expands and evolves **[3]**. Using these parameters it is possible to convert measurements of redshift into distances. For our quasar with a redshift of z = 4.3 we find that (i) the quasar was about 5 billion light-years away when the light was emitted; (ii) the light from the quasar has been travelling for over 12 billion years; and (iii) while the light was travelling the Universe continued to expand and so the quasar is now about 25 billion light-years away. The light-travel time, also known as the look-back time, of over 12 billion years is absolutely mind-boggling. Bearing in mind that no telescope, no matter how powerful, can look back further than 13.8 billion years (the age of the Universe) it is remarkable to realise that a camera can 'see' light that has been travelling for 90% of the age of the Universe.

A quick back-of-the-envelope calculation using the distances quoted above leads to a very interesting conclusion. The distance to the quasar increased by 20 billion light-years during the light-travel time of 12 billion years, so that corresponds to the quasar receding from us at a speed that is



The spectrum of the quasar from wavelengths of 4000Å (blue) to 7000Å (red). The large peak has been redshifted from 1200Å, beyond the left end of this spectrum, to 6500Å as a result of the quasar receding from us faster than the speed of light.



Converting redshift to distance depends on models of how we think the Universe has expanded over the billions of years that the light has taken to reach us. The distance to the object when the light was emitted (blue), the distance that the light has travelled to reach us (green) and the distance to the object now (red) are shown as a function of redshift z. The values are given for the quasar at z = 4.3.

faster than the speed of light. At first sight this seems wrong, but actually this does not contradict any laws of physics. The quasar is not moving through space at this speed, but the Universe is expanding at this rate and the quasar is 'along for the ride'. A more detailed calculation tells us that when the light was emitted, the quasar was receding from us at a little more than twice the speed of light.

When looking at the image of the quasar, I think about the incredible journey that the ancient light has taken to form the image, with the narrative as seen from the perspective of the light...

The light was emitted by the quasar 1.4 billion years after the Universe was created in the Big Bang. It had already been travelling for nearly 8 billion years when the Sun and the Earth were born. The light continued on its journey through the void for another 4.5 billion years. Life evolved on Earth. The light travelled on. Dinosaurs came and went. The light travelled on. In the last million years of its journey it arrived at the edge of our Milky Way galaxy, crossed a few spiral arms, and entered the Solar System. In its last few hours it finally arrived at Earth, travelled through the atmosphere in a fraction of a second, hurtled towards England, dodged a few clouds, entered the lens and hit the camera sensor.

Just a pixel in the image... but what a journey!

References

[1] J–T Schindler et al, *'Extremely Luminous Quasar Survey in the Pan-STARRS 1 Footprint (PS-ELQS)'*, Astrophys. J. Suppl. S., 243, 5 (2019), https://doi.org/10.3847/1538-4365/ab20d0

[2] Quasar PS1 J161737+595020, magnitude 17.4, redshift z = 4.315

[3] Matter density = 0.3, Dark Energy density = 0.7, Hubble constant H_0 = 70 km/s/Mpc

The Life of Fred Hoyle Astronomer Extraordinaire

Part 2 By Geoffrey Johnstone

The first part of this life story of Fred Hoyle appeared in MIRA 108

It is hard to believe at this time of his life that Fred Hoyle was going to become the most well known astronomer of his generation, by both professional astronomers and by many of the general public.

Fred returned to Cambridge after obtaining his degree with little knowledge of what he was going to study, whether mathematics, physics or astronomy. His first task was to obtain funding so he applied for two research grants. He was successful with both. One provided him with £250 per annum, with free board and lodging at St Johns College, while the other grant was for £500 for two years. Together they made up a considerable sum which enabled him to buy himself a car.

As so often happens in life, his line of research came about virtually by accident, following a chance remark to someone who would have a big influence on his life from then on, in fact it was more of an insult on Fred's part that brought them together. His name was Raymond Lyttleton, an astronomer. So in 1939 Fred Hoyle was now researching problems in astronomy and it was in this year that another accidental meeting was to change his life further. He went to meet a teacher friend who had brought two young ladies. One was studying at Homerton College and the other, her sister, had come for an interview at Girton College. Fred, obviously taken with the younger of the two girls, subsequently visited her at her school and contrived to invite her to have a holiday with him in the Lake District. Even in our modern rather free society his behaviour seems quite extraordinary. She did wonder though, why he walked in shoes with holes in them! It wasn't long after this with war imminent they decided to marry. They turned out to have a long and successful marriage.

Before even the war started Hoyle was a research fellow, married, and in a very sound financial position. Not all these good fortunes were due to last, as war was to see to that. By 1940 many of the Cambridge staff had already been called to war work and it wasn't long before Fred was called to a meeting and given a job with less than half his current income in the very hush-hush new field of RADAR or RDF as it was known in those days, something that Fred knew absolutely nothing about.

He spent much of the war near Chichester with the Royal Navy, researching early warning systems and countermeasures to help the navy thwart aerial attack, to which he made a considerable contribution. He eventually obtained accommodation so that his wife and young family could join him. His evenings were spent researching astronomical problems and writing papers with Raymond Littleton. Towards the end of the war it was suggested that he went to America to attend a scientific meeting on the latest developments in RADAR, so he went by sea along with 7800 American GI's hoping that the ship wouldn't be torpedoed. While in the USA he bought an 'old banger' and toured all the important observatories and met the great and well-known astronomers of the day. He visited Henry Norris Russell at Princeton. That is the Russell of the Hertzsprung-Russell diagram fame. From there it was on to see Walter Adams at Pasadena where the Mount Wilson Observatory is. He spent time at Mount Wilson with Walter Baade who was using the great telescope for the weekend. Baade was famous for his discovery of the populations of stars. In the morning he walked the seven miles down the mountain which is twice the height of Mount Snowdon. By the time he got to the bottom his shoes had fallen apart again, just like the old days. Hoyle' s next stop with the great and good of astronomy was at Harvard College Observatory where he met Shapley whose most important contribution to astronomical knowledge was the determination of the dimensions of our galaxy and the location of its centre. In Boston Hoyle met up with an old friend, Maurice Pryce who was working on the atom bomb and told Hoyle that the British had made advances in the measurement of the energy levels of atomic nuclei. He had discussed Supernovae with Baade and atomic physics with Pryce and wondered if there was a connection in their researches.

Cecilia Payne-Gaposchkin, English born American astronomer, suggested in her 1925 doctorial thesis that the Sun was mainly composed of Hydrogen. Yet while Hoyle was studying at university it was generally accepted that the Sun was mostly iron since that was the predominant spectral line. Nobody really had a clue how the Sun worked or how the elements were produced although Hans Bethe in 1937 had started the ball rolling by proposing the Proton-Proton chain reaction in which Hydrogen nuclei could fuse to form Helium. To get much further the temperature of stars has to rise, but current understanding of the temperatures was very incomplete and inaccurate.

In 1939 Hoyle and Littleton had proposed accretion to overcome the way stars could become hotter. Their suggestion was that they accrete matter as they pass through clouds of interstellar gas and so their temperature would rise. They went on to develop the same theory to explain ice ages and all manner of other phenomena. They had quite a battle to get their theories published in war time with difficulty in finding suitable referees for the papers and a shortage of paper for printing. Accretion now is a popular theory to explain how galaxies, and stars form, it explains how white dwarfs can rob matter from companion stars to produce novae and type 2 supernovae, and many other phenomena beside.

The war came to an end in 1945, when briefly, Hoyle was sent to Germany in May with a British contingent to discover if there was anything to learn from the Germany's RADAR system, but came back empty-handed as there was too much devastation to learn anything. After a holiday with his family he returned to Cambridge to the Faculty of Mathematics, but found his circumstances very different from the beginning of the war, when he was comparatively well-off with a car, now he was struggling quite a bit. The prices of property had gone from affordable in 1939 to unaffordable in 1946. So he had to rent a house well out of town.

He developed a knack for teaching and his lectures became very popular with the lecture halls full. The authorities were inclined to add extra lecture programmes as he was very popular, so his teaching load became excessive, as there were supervisions, marking and research to take on board also. Unfortunately he had a poor reputation for punctuality and was often late or failed to turn up. Regarding supervisions he often requested the students to come back at another time.

It was known at this time that all the galaxies were flying apart. Rolling back time would bring all the galaxies closer together. George Gamaw had already suggested the distribution of the chemical elements were caused by the break up of some super dense object. Hoyle and Tommy Gold wondered what would happen to the universe in the future. Would space become empty and along with Hermann Bondi the three of them thought that maybe if there was a mechanism for creating particles the universe could go on for ever. So the universe would exist in a steady state. Tommy Gold worked their calculations in a paper which was published by the Royal Astronomical Society (RAS). Hoyle also wrote a paper for the RAS on steady state, but his calculations were made from a different view-point. Nevertheless this is where the steady state theory started, and Hoyle never let it go while eventually all other astronomers discarded it. It subsequently made him into a bit of an eccentric along with some of his later theories. Much brilliant research was yet to appear.

At this time Hoyle would attend conferences and symposia, rushing from lecture to lecture asking searching questions and generally making a nuisance of himself. Apart from his lecture commitments with the university he was dashing off a paper a week on all sorts of topics, so much so one of the astronomers was heard to say. *"If he goes on like this there will be no field left to the rest of us."*

In 1948 his impecunious state was soon to improve when the university was asked to provide someone who would give two lectures on BBC radio for a fee of 15 guineas each, worth about £150 in today's money. Following this he was asked by the Turkish section to answer written questions sent in, at one guinea a time. The success of this led to a series of lectures to be read on the 'wireless'. His lecture course turned out to be a sensation, the most memorable part of which was when he described the creation of the universe as *"the Big Bang"* which he did as a derogatory term believing only in the *"Steady State"*. Along with the lectures he produced an accompanying book which sold like hotcakes. As a result of lectures and books he became a very well known person. His lecture courses on the BBC ran until February 1950 when he rather spoiled things a bit in his final lecture by introducing his anti-religious views, which subsequently got him into trouble with the establishment, apart from which the *"Big Bang"* hypothesis itself suggests a time of creation which Hoyle was very much against.

During the 1940's and 50's nobody had much of a clue how stars worked, even though the classes of stars and their evolutionary pathway was well established. The Hertzsprung-Russell diagram was established around 1910 yet the chemistry of the changes and how they produced their energy lay in the future, and turned out to be hellishly complicated.

Cecilia Payne-Gaposchkin, an English born American astronomer, suggested in her 1925 doctorial thesis that the Sun was mainly composed of Hydrogen yet while Hoyle was studying at university it was generally accepted that the Sun was mostly iron since that was the predominant spectral line. Nobody really had a clue how the sun worked or how the elements were produced. Before Fred Hoyle became involved we have to go back to the 30's when suddenly the door was slightly opened by the discovery of the neutron by James Chadwick at Cambridge. The neutron was a particle with the same mass as a proton, but with no charge. It turned out that the neutron had an identity crisis, because it was inherently unstable. After about 15 minutes on its own it decayed into a proton, an electron and an anti-neutrino. What was also discovered in the 1930's was that a proton could tunnel into the nucleus of a hydrogen atom and fuse with it releasing energy in the process. Because of its lack of charge it was even easier for a neutron to fuse with a proton in the nucleus and release energy. Without going into details this meant that it was possible for hydrogen nuclei to fuse to form helium in so doing release huge amounts of energy. So the proton-proton chain reaction was born. A second process could also produce helium and release energy, but involved instead carbon and became known as the carbon cycle.

Arthur Eddington comes into the picture because he had done much to understand the workings of stars. He was famous for confirming Einstein's prediction that starlight could be bent by gravity. He did this in 1919 from observations of a total eclipse of the Sun. He also held the Plumian Chair of Astronomy at Cambridge. This was a post that Hoyle would eventually hold a few years into the future. Eddington could only envisage temperatures in the centres of stars reaching 10 million degrees at the most, which became totally inadequate for the reactions necessary for synthesis of the heavier elements.

Hoyle was aware that it was theoretically possible to build up elements by slamming together lighter elements. The heavier elements could only be manufactured by the addition of neutrons. The problem was that there was not an adequate supply of neutrons since neutrons had such a short existence. Then, purely by chance, he was asked to referee a paper by Alastair Cameron. The first two referees had recommended rejection, yet the magazine's editor felt there was some merit in the paper. Without going into details Cameron had found a process in which neutrons were left over after a series of reactions, which would make them available to building elements.

In 1954 Margaret and Geoffrey Burbidge came to Cambridge. Geoffrey gave a talk describing the research that he and his wife had been doing on the abundances of elements in stars. In the audience was Willy Fowler from the Kellogg Radiation Laboratory, California. Fred Hoyle suggested they work together, since the Burbidges could provide the experimental evidence from their spectroscopy and Fowler had access to atom smashing equipment which would be equally useful in providing evidence. The result of their collaboration was a paper in the *"Reviews of Modern Physics"*. The paper ran to 104 pages and described how all the elements were forged in stars including all the heavy elements including uranium and gold. The paper Burbidge, Burbidge, Fowler and Hoyle became known as B2FH. Fowler was subsequently awarded the Nobel Prize for Physics partly on the strength of B2FH. Some have presumed that Fowler was the leader of the group because the writing and submission for publication were done at Caltech, but Geoffrey Burbidge has stated that this is a misconception. Fowler, though an accomplished nuclear physicist, was still learning Hoyle's theory in 1955 and later stated that Hoyle was the intellectual leader. The Burbidges also learnt Hoyle's theory during 1954 and 1955 in Cambridge. *"There was no leader in the group,"* Geoffrey Burbidge wrote in 2008, *"we all made substantial contributions"*.

Here is one of the pathways for producing elements in stars.

1. Carbon plus helium produces oxygen.
2. Oxygen plus helium produces neon.
3. Neon plus helium produces magnesium.
4. Magnesium plus helium produces silicon.
5. Silicon plus helium produces sulphur.
6. Sulphur plus helium produces argon.
7. Argon plus helium produces calcium.
8. Calcium plus helium produces titanium.
9. Titanium plus helium produces chromium.
10. Chromium plus helium produces iron.

Other fusion pathways create the elements with odd numbers of protons. Iron has such a tightly bound nucleus that there isn't further fusion once that point is reached.

The rate at which stars fuse hydrogen to helium varies according to the mass of the star. The more massive the star the shorter their life span. In the case of the Sun, which is classed as a yellow dwarf, the lifespan is 4.6 billion years and is about half way though its fuel. It currently fuses 600 million tons of hydrogen into helium every second, converting 4 million tons of matter to energy every second.

Without the heat of fusion, the star collapses and explodes in a shockwave. Physicist Lawrence Krauss notes that it takes 100,000 years for the carbon to burn into oxygen, 10,000 years for the oxygen to burn into silicon, and one day for the silicon to burn into iron and herald the collapse of the star.

A History of the Jodrell Bank Observatory

Part 2: Project Able to Arboretum, 1957 - 1973

By Mark Edwards

The first part of this was in MIRA 111

In the spring of 1958 Bernard Lovell received an intriguing message from the Government's Joint Intelligence Bureau that he should go to Goostrey Railway Station the following morning and on a local train at a certain time there would be, in plain clothes, a Colonel 'L' from the United States Air Force.

Sure enough Colonel 'L' was there the following day and Lovell drove him to his office near the newly completed 250ft telescope (now called the Mk I), where behind closed doors he was told that the Americans had just completed their Atlas intercontinental ballistic missile and they were going to send a probe on it to the Moon, before the Russians. Unfortunately, they had no means to track the rocket and wanted permission to use the Mk I.

Lovell agreed, so long as it was within the framework of the International Geophysical Year (an international scientific project that ran from July 1957 to December 1958). In return he was told that he had to keep everything top secret.

So he was shocked when one day in July a large trailer full of equipment arrived at Jodrell emblazoned with the sign: "Jodrell Bank, U. S. Air Force, Project Able". The next day, 25th July the Manchester Guardian ran the headline "Jodrell Bank joins in journey to Moon"!

The rocket itself was launched on 17th August (Lovell was actually in Russia at the time), but exploded 74 seconds into the flight. This was followed by another attempt on 11th October (now called Pioneer 1) and its telemetry was received on 108MHz ten minutes after launch. However, when it reached an altitude of 77,000 miles it fell back to Earth due to a third stage failure. The next one, Pioneer 2, was launched on 8th November, but that failed in the same way.

These may have been failures for the USAF, but each one was a source of income and welcome publicity for the telescope.

Two months later on 2nd January 1959 the Russians indeed made their first attempt when Luna 1 was launched

Mk I with the USAF trailer next to the control building. Copyright William D. Young

surface of the Moon. The Americans were sceptical that the Russians had succeeded where they had failed, but they could not dispute the Jodrell Doppler measurements which had also given the rough area of the crash site.

30 years later Lovell happened to meet one of the Russians who had worked on the project and he revealed that, as with the Americans, they had no means of tracking the probes and had had to rely on Jodrell to do it instead.

Just three weeks later on 4th October 1959 Luna 3 was launched and again from information that the Russians sent, Jodrell heard signals (on 39.986MHz and 183.6MHz) from it less than ten hours after launch. The probe flew past the Moon three days later and on 26th October the Russians released the first pictures of its far side. Although the narrow bandwidth used on the receivers at Jodrell meant that the transmission of these was missed.

towards the Moon, but missed its target and was not detected at Jodrell. However, on Saturday 12th September just as Lovell was setting off from home to play in the local cricket match (he was captain of the Chelford cricket team) he received a phone call from Jodrell to say that the Russians had launched Luna 2 towards the Moon. He apologised, but said that he could do nothing until that evening as he had a cricket match to go to.

At 6:30pm when he arrived back at Jodrell he found that the Americans there were being harassed by their masters in Washington to do something about tracking the probe. Going into his office Lovell was surprised to find that a large length of paper had poured out of the telex machine on to the floor. That was a telex from Moscow detailing the frequencies (19.992MHz and 183.6MHz) that Luna 2 would be using, the time of its impact on the Moon (10pm that evening) and the positions of the telescope to receive the signal from the probe.

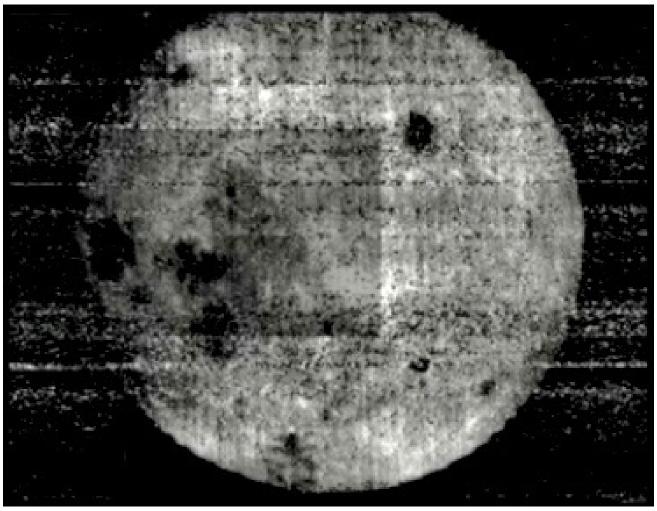
He and John Grant Davies (who had joined Jodrell in 1947) went to the swinging laboratory, located under the bowl of the Mk I, with a receiver and immediately they plugged it into the aerial they heard the beep-beep of the probe.

The word had got out, so the following day the control room was full of the press. Davies had had the idea of measuring the Doppler shift of the probe's signal so that they would be able to know when it was accelerating to its doom. Just before 10pm the Doppler shift changed dramatically then suddenly the beeps stopped, Luna 2 had crashed into the

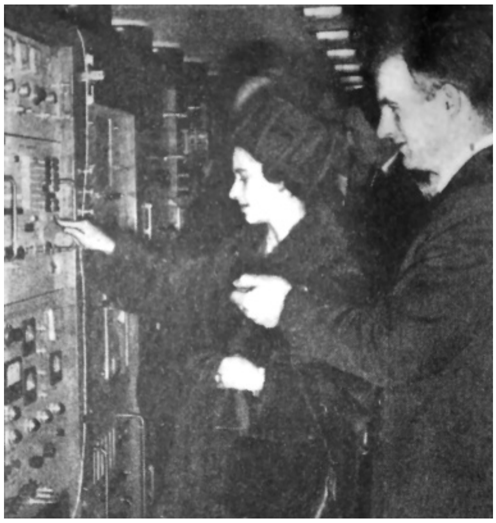
Up to his time Jodrell had always had a passive role in tracking space probes, but that was to change with the launch of the American's Pioneer V on 11th March 1960. This was a probe into deep space between Venus and Earth and as the Mk I telescope was the only one in the world capable of transmitting over the vast distances involved to communicate with the probe, Jodrell was required to issue commands to it.

One of these commands was sent by Princess Margaret on 18th March when she was on an official visit to the observatory on that day. Jodrell continued to command the probe until its batteries died on 26th June, when at a distance of 22,462,000 miles. Pioneer V is to this day still in a 312 day orbit around the Sun.

At that time Jodrell did not have a dedicated public relations or press officer so Lovell was constantly on the phone answering queries from the press. Wearily answering the phone not long after the launch of Pioneer V, to his astonishment it was not from yet another reporter but Lord Nuffield who offered to pay off the remaining debt of the telescope. When he tried to thank him Lord Nuffield just replied *"That's all right, my boy, you haven't done too badly!"*



Luna 3's view of the far side of the Moon



Princess Margaret commanding Pioneer V

The Mk II telescope

The Mk III telescope

Despite these collaborations with the Americans and the Russians this was the time of the cold war so it was no surprise that the Air Ministry had eyes on the Mk I telescope as it had been used a number of times for radar observations of the later Sputniks and their carrier rockets. This came to a head in October 1960 when, because of strike delays to the installation of an early warning system at Fylingdales, the RAF had radar equipment installed at Jodrell.

This intended use of the telescope had somehow leaked to the press, as on 5th September the Daily Express headline read "Jodrell is ready for Khrushchev - Telescope Called Up to Beat Rockets". It remained in a position to be activated by a "state of military vigilance" until late 1963 when finally Fylingdales took over.

Surprisingly, from 25th June to 15th July that year Lovell made another visit to Russia, part of which was a tour of their deep space tracking centre at Eupatoria in the Crimea about which nothing was known at that time in the west. It was rumoured that he had been poisoned by radiation during the trip as he became ill on his return with a mysterious illness. It was only after a later holiday in Ireland that he again felt fully recovered.

Venus radar

Meanwhile, back in the astronomy research world an attempt was made at the close approach of Venus in September 1959 to measure both an accurate distance to the planet and its rotation rate and direction. Because of the large amount of power needed for a usable echo to be received they used a klystron transmitter that previously had been used in a linear accelerator at the university.

The radar pulses were sent for five to six minutes and then the receiver was switched on for an equal period, this was repeated for 59 hours of observations, but they barely saw any increase above the receiver noise. However, the distance to Venus seemed to match that obtained by MIT in 1958, so the results were published. Unfortunately, the results were spurious as shown when they repeated the experiment in April 1961 with more sensitive equipment.

Lovell never recovered from this blemish on his reputation and insisted thereafter that any desire for priority or publicity had to take second place to accuracy in any papers subsequently published by Jodrell.

From the 1961 measurements of the distance to Venus, along with those made in America and Russia, they established an average value of 149,600,000km for the Astronomical Unit and although it differed from optical measurements by 60,000km was eventually accepted as the basis for the value of the solar parallax.

That left the problem of the rotation, which was finally resolved years later by a joint experiment with the Russians, who on 9th January 1966 transmitted from Eupatoria to the planet with the echo received at Jodrell. This revealed that Venus had a retrograde rotation taking 243 days. However, they had been beaten to this result by the Americans using the Arecibo telescope.

These experiments marked the end of active radar researches at Jodrell as it became increasingly difficult to run an establishment where high power transmitters were operating next to highly sensitive receivers. For a few years they had used a synchronised pulse cabled around the site so that the receivers were turned off during the period of radar transmissions, but this had become increasingly inconvenient for the type of research being undertaken. So regretfully, the wartime equipment that had been used at the start was collected by the scrap merchants - the last relics of mud and leaking cabins.

Large Telescopes

Not satisfied with the size of the Mk I, on 21st January 1960 Lovell wrote that he had the backing of the Vice-Chancellor and the university to request funds from the DSIR committee for astronomy to build a telescope perhaps ten times larger, even if it had to be restricted in the area of sky that it could be steered to. These ideas evolved to become the Mk IV telescope and on 31st May the DSIR made a provisional award of £5,000 for a design study.

Lovell showed a sketch of the Mk IV on 28th June to Husband, which showed a huge dish 1,500ft to 15,000ft wide with a height limited to 500ft. This would have a gain 20 to 100 times that of the Mk I. By the time that a meeting had been held between Lovell, Husband, the Ministry of Works and the DSIR on 5th January 1961, the plans had changed from one to three new telescopes.

The new idea was to build an elliptical telescope 125ft by 83ft and focal length 40ft that could be scaled up for the Mk IV. The elliptical design was to help avoid constructional problems and to avoid the effects of differential wind loading with height. Such a prototype telescope would have the advantage that it would be more accurate than the Mk I and would allow the use of the rapidly developing high frequency amplifiers. It could also be used to make a sensitive interferometer with the Mk I telescope. In addition if it was successful a mobile version could be made to extend the

Model of the 400 ft diameter Mark V telescope, April 1967

baseline further.

These two telescopes become known at the Mk II and Mk III respectively and at a meeting on 6th March the DSIR granted £192,000 for the Mk II and £129,000 for the Mk III (Lovell had been advised not to mention that they were prototypes for fear of the grant being withheld). By the summer of 1964 the Mk II was working, but the Mk III was delayed with the contracts being signed in April 1964 and completed in October 1966.

The Mk II was constructed on the site of the original 218ft telescope and it was the first telescope in the world to be controlled by a computer, the Ferranti Argus 100 (which used discrete germanium transistors). Two years later the computer was moved to the Mk I control room where it replaced the existing electro-mechanical analogue computer. At the same time two new Argus 400 computers (using DTL integrated circuits) were acquired. One took over control and data acquisition for the Mk II, the other was installed in the Mk I's observing room for data acquisition and analysis.

From the earliest days of operation of the Mk I Lovell had the desire to have it modified so that it would work more efficiently at the higher frequencies then being investigated, so much so that on 23rd January 1963 he made an application to the DSIR for a £4,000 grant for the "Investigation of deflection and ancillary problems of the Mk I radio telescope". This grant was duly made on 3rd December and in April 1964 Husband proposed that two new bicycle wheels should be built under the bowl along with an extra railway track and bogies to support the structure and prevent it from flexing.

Nothing was done to implement these proposals until in September 1967 fatigue cracks were found in the steel cones that carried the whole load of the bowl. This meant that repairs became critical to maintaining the integrity of the structure and on 8th July 1968 the SRC announced that a grant of £400,000 had been made.

To balance the weight of the new steelwork Husband suggested that a new shallower reflecting surface be built above the old one. This would also increase the focal ratio to 0.31 and make it easier to feed, but in the process would require a higher focus tower to be built.

These modifications started on 24th September 1968 with pile driving for the foundations of the new railway track and continued in three phases. Eventually they were finished on 14th November 1971 when the telescope was finally handed back to the university. Once again the cost had risen. This time to £664,000, more than the cost of its initial construction.

While these alterations were being made, Lovell still had ambitions to build an even larger instrument. After seeing that the Government would not fund the Mk IV telescope he turned his attention to a new concept, the Mk V. Originally proposed as a large telescope on a railway track that would move up to three-quarters of a mile from the Mk I, this proposal soon changed to be a 400ft diameter telescope on a site within 100 miles of Jodrell. It was suggested that it would cost between four and five million pounds.

That left the problem of a site for it. Lovell happened to know the owners of Chick Castle near Wrexham and meeting them on 17th August 1967 they suggested a valley west of the road from Oswestrey to Welshpool. In the valley a mile west of the village of Meifod he found a suitable site and the university bought a farm of 86 acres plus 13 acres of woodland to house the telescope.

However, a change in Government in 1970 caused the budget of the SRC to be reduced and that combined with an escalation of steel costs lead to the demise of the telescope.

Not willing to see the project completely die he reduced its size to 375ft and proposed a concrete structure along the lines of the Mk II to reduce costs. However, by 1974 the costs had escalated once more to £16 - 17 million which in a press statement on 28th June 1974 the SRC said that they were not going to fund. That was the end of Lovell's dreams of any further large single-dish telescopes.

Eventually, there was one good outcome of the saga for the university. They sold the farm at Meifod on 8th February 1978 for £92,500 which had been bought in May 1968 for £16,000.

Interferometers

As well as tracking space probes the Mk I was also being used as the home station of an interferometer, replacing the 218ft transit instrument meant that it had access to many of the 2,000 radio sources known at the time. Between 1960 and 1962 Robert Hanbury Brown, Henry Palmer and LR Allen measured the angular size of 324 of these sources at a frequency of 158.6MHz.

Unlike the intensity interferometer this used a much more sensitive phase stable technique involving equipment developed by O. Elgaroy, D. Morris and B. Rowson using radio links between Jodrell and a portable 30 ft by 25 ft cylindrical parabaloid aerial. One link sent a 175MHz signal from Jodrell to synchronise the remote station's local oscillator, the other used a microwave transmitter at the remote station to send the radio noise back to Jodrell for correlation with that coming from the Mk I.

Using this technique they managed to get to a baseline of 61,100 wavelengths (115km), which required the use of a repeater at the BBC station on Holme Moss. At this distance seven sources were still unresolved implying that their diameters were less than 3 seconds of arc. It was the optical identification of one of these, 3C48, that lead to the discovery of quasars.

As the cylindrical aerial was limited to observing sources as they crossed the meridian this was replaced by a steerable 25ft diameter dish in 1964 and positioned 180,000 wavelengths (at 408MHz) away at Pocklington in the Yorkshire Wolds with a repeater on Windy Hill in the

The 25ft steerable dish with the microwave transmitter

Pennines. After these experiments were completed in September 1964 the dish was dismantled with still five sources unresolved.

The pursuit of even more resolving power lead to the establishment of a radio link between Jodrell and Royal Radar Establishment Malvern at Defford, where one of the two 25m telescopes there (built by Hey on the pretext that they would be used for detecting missiles, but actually used for radio astronomy!) was used as the remote station of an interferometer.

To return the signals back to Jodrell a three-hop radio link was established using a 120ft tower at Defford, then an 80ft tower on Clee Hill in Shropshire and finally another 80ft mast on Camp Hill near Stafford. Both repeater sites being owned by the Civil Aviation Authority.

Although at a similar distance (127km) the telescope could be used at the far higher frequency of 1422MHz giving a baseline of over 600,000 wavelengths. By May 1965 the new interferometer was working, but the five sources were still unresolved and found to be less than 0.1 arc seconds in extent.

As they had reached the limit with this technique in England they turned to another one that had been proposed during Lovell's visit to Russia in 1963. That was to use the Mk I in combination with a large telescope on the coast of the Black Sea. To do this via radio links would have required fifty links and so was not really practical. Instead the proposal was to make tape recordings of the radio noise at each telescope along with a precise time stamp and subsequently bring the tapes together to correlate the signals.

Eventually, in March 1969 they had a working system, but it was two years after the Americans and Canadians had developed their systems to do the same (there was a rumour that they had got the idea from the Russians). So in November 1969 Jodrell established a transatlantic baseline of 6,400km to Arecibo, a baseline of 13 million wavelengths at 610MHz giving a resolving power of 15 milliarcseconds. Even this was not able to resolve some of the many quasars and radio galaxies known at the time, whose angular size to distance relationship was crucial in distinguishing between the Steady State and Big Bang theories of the day.

It was the relentless pursuit of the nature of the quasars that led Dennis Walsh, Ian Browne, Ted Daintree and two research students to use the Mk I between 1972 and 1973 to undertake a survey, down to its sensitivity limit, of a limited area of sky. They would then search the Palomar Sky Survey plates for an optical identification of any sources found.

Some could not be found on the plates and it was while trying to identify these sources at the Kitt Peak National Observatory that on the night of 29th March 1979 Walsh discovered that one of the quasars was apparently double with the components having identical spectra and redshifts. This turned out to be the first gravitational lens discovered.

Cosmic Rays

The original reason for Jodrell's existence, the detection of cosmic rays, was revisited by Rob Porter, a graduate student, in the summer of 1964. Although the original technique had been to try to detect cosmic ray showers with radar it was realised that the tracks of ionised particles only lasted for less than 100ns and would make such detections extremely difficult. However, John Jelly in his 1958 book on Cherenkov radiation suggested that the electrons in the shower themselves would emit radio waves.

To try to detect these, Porter constructed a 6 x 6 array of full-wave dipoles running on a frequency of 44MHz next to Blackett's hut at Jodrell. As this was in the band used by BBC TV, observations could only take place at night as in those days the transmitter was turned off overnight. The particle detector, built by Trevor Weekes, a graduate student from University College, Dublin, consisted of three trays of Geiger counters spaced 50m apart next to the aerial.

With this setup he saw a coincident event on the first night of observing on 20th August 1964. Observations continued until March 1965 producing 4500 triggered events and 11 coincidences. The results being published in Nature.

After hearing Jelly speak to physics under-graduates at the University of Birmingham late in 1965, Ralph Spencer joined Jodrell in October 1966 and chose to work on cosmic rays. He first used a frequency of 105MHz, just above the broadcast band at the time, again on the assumption that it

The 25 m telescope at Defford

The Festival of Britain dish

would be quiet at night. Later experiments used 240 and 408MHz with the Festival of Britain 9m diameter dish.

He did not see any strong radio pulses from the 4000 photographs taken. So to observe with a wide bandwidth at low frequencies they moved to a quiet location in Hafern Forest in mid Wales. Operating between 30 and 60MHz and using four conical aerials they detected more pulses than expected, but all except one (31st August 1969) were put down to various sources of interference.

After returning to Jodrell with the aerial array and battling with many sources of local interference they eventually abandoned any further work on cosmic rays.

Pulsars

Radio astronomy in those days was mainly a male pursuit, with one or two notable exceptions. One was Mary Almond, who was one of the earliest PhD students at Jodrell and between 1949 and 1952 worked on measuring the velocity of sporadic meteors using radar. Another wrote to Lovell in 1949 as a young girl, asking what subjects she should study to be a radio astronomer. He recommended that she should study physics.

This she duly did, at Glasgow University and in her final year she attended the first summer school to be held at Jodrell in 1964. As there was no accommodation for women on site, she and the only other woman, Julie Turner (a physics student from Birmingham University), stayed at Henry Palmer's house (as he was running the course).

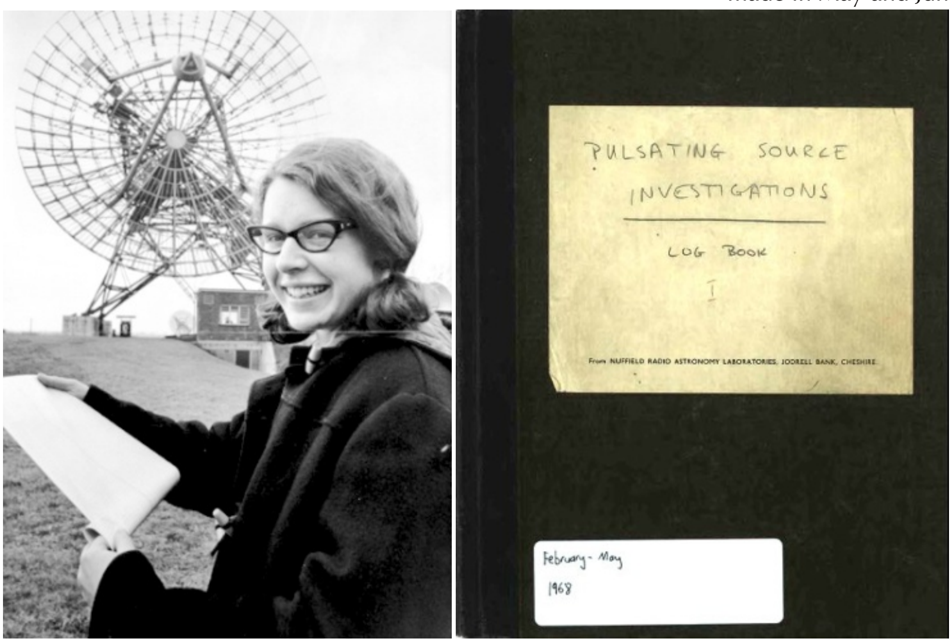
By the end of the summer she was even more convinced that she wanted to follow a carrier in radio astronomy, but when she applied for a post graduate course at Jodrell she heard nothing back. There was a feeling that this was due to an incident that happened a few years before in the dormitory and from that point on Lovell had decreed that he would have no more women on site.

Nothing more was heard of her until on the afternoon of 21st February 1968 Lovell was at a meeting of the Science Research Council in London. Fred Hoyle was at the meeting and came over to sit next to him. What followed next was to change the line of research undertaken at Jodrell for years to come as Hoyle told him that at a colloquium in Cambridge the night before, Tony Hewish had announced that he had discovered some radio sources which emitted in pulses with intervals of about a second.

The truth was that it was not Tony Hewish who had discovered these pulsars, but his student Jocelyn Bell had, in August 1967. Bell was none other than the woman who had applied to Jodrell four years before. She had gone on to work at the Mullard Radio Astronomy Observatory in Cambridge and ironically Henry Palmer became her external examiner when she submitted her PhD thesis in January 1969. Although the thesis was on "The measurement of Radio Source Diameters using a Diffraction Method" it contained in appendix 1 a description of her discovery of "Pulsed Radio Sources".

Lovell realised that the Mk I telescope was ideally suited to observe these pulsars as it could follow them continuously when they were above the horizon, rather than the four minutes a day that Cambridge could achieve with their transit telescope. So on 24th February Andrew Lyne started a new log book entitled "Pulsating Source Investigations" and with it opened a new chapter in Jodrell's history. After only two weeks' work observing on 151, 240 and 408MHz they had enough data to publish a paper in Nature on the new phenomenon.

In 1968 he made a survey of low galactic latitudes and in 1972 Andrew Lyne, John Davies and John Seiradakis made surveys with the Mk I to find new pulsars, discovering 11 new ones between 26th July and 21st August. Further surveys were made in May and June 1973.

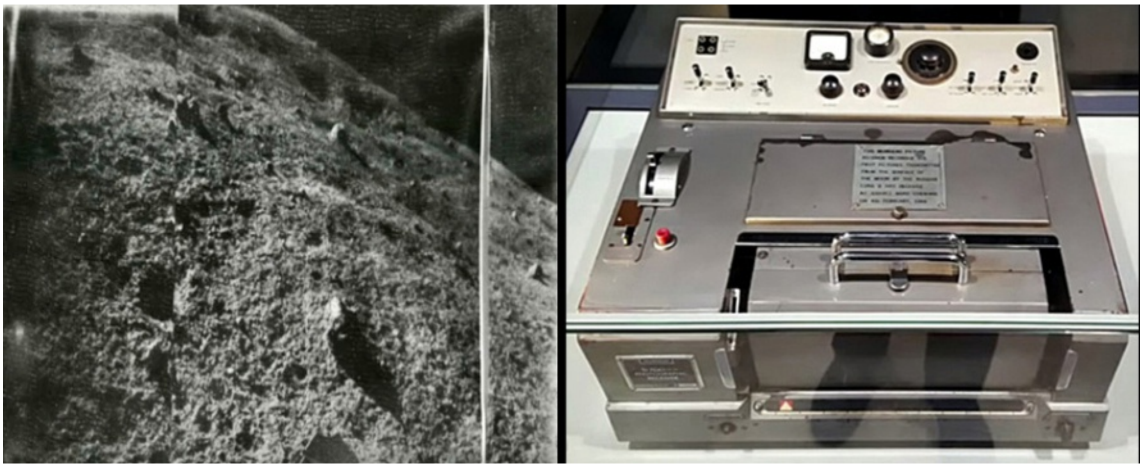


Left, Jocelyn Bell and right Andrew Lyne's first pulsar log book

Moon landings

Throughout the 60s the Russians continued to send probes towards the Moon and on 3rd February 1966 Lovell and J.G. Davies were tracking Luna 9 towards the Moon when the signal suddenly stopped. They thought that it had crashed, but the signal just as quickly reappeared in a different form. Davies recognised it as the signal from a photograph sending machine as used by newspapers. They got in touch with the Daily Express who the next day let them borrow one of their receiving machines (now in the Science Museum in London), which when connected to the telescope out popped a picture of the surface of the Moon.

At this point the control room was full of the press, so immediately



Luna 9's picture of the Moon produced by the Muirhead Picture Receiver

the picture was sent around the world scooping the Russians who had strangely remained silent. The Daily Express were not slow in announcing their role in the picture as their headline for Saturday 6th February read "From Luna 9 to Manchester - The Express Catches the Moon".

When Lovell later met the general in charge of the Luna missions the only complaint he had about the scoop was that the aspect ratio of the picture was wrong (as their machine fed the paper at a different rate) so the rocks looked to have sharp peaks whereas they were in fact rounded.

Russia's Zond 6 was another interesting Moon probe tracked at Jodrell as it flew around the Moon on 14th November 1968, just one month before Apollo 8. It carried biological specimens and was supposed to land back on Earth, however it crashed on re-entry. The surprising thing was they heard Russian voices coming from it, not from people actually on the probe but from repeated transmissions from Earth to test the communications channel with strings of technical numbers and codes.

When Apollo 11 was launched on 16th July 1969 Jodrell was not officially involved, however they used the 50ft telescope on top of the control building to monitor its landing on the Moon. They measured the Doppler shift of the carrier signal from the Eagle lander and noticed the time when Neil Armstrong took over manual control, by wiggles in the chart.

The Mk I telescope was however used at the same time to track the Russian's robotic Luna 15 sample return mission which made an attempt to land on the Moon on 21st July just after Buzz Aldrin and Neil Armstrong had completed their moon walk. However, as they listened to its signal they noticed from the Doppler shift that it was attempting to land, but the signal stopped suddenly as it crash landed.

Public outreach

With all the publicity surrounding the tracking of the American and Russian space probes there was a constant stream of requests from individuals and groups to visit Jodrell. Although being a department of Manchester University meant that they had a duty to educate as well as to carry out fundamental research they found it impossible to receive even the most deserving groups of visitors.

When Lovell suggested to the vice-chancellor that they provide some visitor facilities, the vice-chancellor doubted that the demand would justify the expense. So to test the demand they erected a marquee in the summer of 1964, the idea being that for two weeks they would have open days and Lovell would give explanatory lectures to the public.

They charged an entrance fee of half a crown (12.5p) to cover the cost of the marquee and on the first Sunday afternoon the queue of cars trying to gain entry stretched for two miles. Eventually, after two weeks 35,000 people had visited the site, but the University were still not convinced. They repeated the experiment the following year, with the same result.

This time the University were convinced, so a building (called the Concourse Building) was erected and opened on 3rd May 1966. In 1971 this was extended to include a planetarium and in 1972, more than 30 acres of adjoining land were planted as an arboretum. Lovell, being a keen gardener had all ready created an extensive one at his house in Swettenham.

All was going well, then in October 1973 a certain student called Mark Edwards turned up!

Bob Pritchard, John Davies and Bernard Lovell in the Space Tracking Lab (Lab 5), 1967

I originally wrote this article several years ago, but for some reason I never submitted it to Mira. The 50th anniversary of Apollo 14 led me to revisit it.

A Black Hole in One – Golf in Space

By Mike Frost

The original edition of Trivial Pursuit contained at least one question with a wrong answer. Namely:

"How many golf balls are there on the Moon?"

The answer given was "three" and this is incorrect. Not because all the lunar golf balls were faked in a movie lot in southern California. Rather, there was a misunderstanding over the shots in the only round of golf ever played on the Moon.

Let me explain. Apollo astronauts were allowed to take a few personal items with them. Buzz Aldrin selected containers of bread and wine and quietly took communion before stepping onto the lunar surface from Apollo 11. David Scott, commander of Apollo 15, took 398 first-day covers to the Moon, and sold many of them when he returned to Earth.

Alan Shepard, on Apollo 14, had other ideas. He took two golf balls and the head of a Wilson 6-iron club. Shortly before the mission finished, after all the scheduled work had been finished, Shepard attached the 6-iron head to one of the lunar sample scoops, to fashion a rudimentary golf club.

Shepard put down one of the golf balls and began taking swings. His first swing missed the ball completely. The second swing made brief contact with the ball and pushed it a few inches. The third sent the ball off around twenty-four yards. Shepard then put down the second ball; addressed it with his rudimentary golf club, and with the final shot of the round, dispatched the ball forty yards into the distance. We now know these distances because of recent careful analysis of lunar photographs by Alan Saunders; see for example `https://www.bbc.co.uk/sport/golf/55927727`

"That went for miles and miles", said Shepard, somewhat tongue-in-cheek.

So, there are only two golf balls on the Moon. The misunderstanding probably arose over the second and third swings, which at first sight appear to feature different balls.

The number of golf balls on the Moon is not the only bone of contention. Shepard's *"miles and miles"* remark seems to have founded the myth that his final shot was the longest in golfing history. There is a good reason why people might believe this. In many respects the Moon is an ideal place to play golf. Gravity is only a sixth the value at the surface of the Earth, so that the energy expended in a normal golf swing ought to send the ball a lot further on the Moon. Furthermore, there is no atmosphere on the Moon, and so no air resistance to slow the ball down.

There are disadvantages, of course. The Moon features more sand traps than your average golf course, so when a golf ball finally touches ground it won't roll on very far. Additionally, Alan Shepard forgot to pack a golf tee. More prosaically, the spacesuits worn by the Apollo astronauts were not designed with golf in mind. They did not allow fast or flexible movement; they did not give Shepard a good view of the ball; he didn't have chance to practice his swing in reduced gravity. And he had to swing single-handed.

So, although the potential existed for Shepard to produce the longest golf drive in history, circumstances conspired against him. The longest golf shot ever played remained one of a mile-and-a-half, driven across the Antarctic ice near Mawson Base by Nils Lied, an Australian meteorologist, in 1962.

That is, until Nov 23rd 2006. On that day, a Russian Soyuz spacecraft was making a delivery mission to the International Space Station. One of the cosmonauts, Mikhail Tyurin had taken a golf club, ball and tee with him to the space station. This time, the reason was nakedly commercial. Element 21, a Canadian manufacturer of golf clubs, had paid an unspecified amount to the Russian space agency for Tyurin to hit a golf ball into orbit with one of their clubs. (Element 21 in the periodic table is Scandium, a silvery-white metal which the Canadian company manufactures into various products including golf clubs)

Some thought had gone into the publicity stunt. The golf ball was not legitimate for normal play – it weighed only three grams, to ensure that it would burn up more quickly when it re-entered the Earth's atmosphere. The golf club was gold-plated. A special spring tee ensured that the ball could be addressed accessibly.

Tyurin was scheduled to make a space walk for maintenance of the Space Station. Initially he had difficulty putting on his spacesuit and so almost lost his tee-time. But he sorted out his problems, and before proceeding with the scheduled work plan (to fix an antenna), produced ball and club.

Ball, club and golfer all hung completely weightless in Earth orbit. For this reason a conventional golf swing was almost impossible. Somehow Tyurin managed to twist his body so that the club connected with the ball. It wasn't a clean swing – the ball sliced badly. Nonetheless, Element 21 had their publicity shot.

So, what happened to the golf ball? It went into low-Earth orbit, of course, going round the Earth once every ninety minutes; the change of velocity imparted by the golf club being small in comparison with the space station's orbital velocity of sixteen thousand miles an hour. And like the space station, the orbit was not stable, because of the vestiges of Earth's atmosphere, which, even 140 miles up, still slow down the space station and cause its orbit to decay slowly. The space station needs to be boosted in its orbit, each time a spacecraft visits.

How long the ball remained in orbit is a matter of some dispute. According to Nataliya Hearn, Element 21's president, the golf ball was predicted to stay in space for three years, traveling *"a billion miles"* – an exaggeration to match Shepard's *"miles and miles"*. Holly Ridings, NASA's spacewalk flight director, was more sanguine, stating that the golf ball would only stay in orbit for two or three days.

That sounds rather pessimistic to me, but let's assume she was right, and two to three days later, the golf ball re-entered the upper atmosphere and burned up as a fireball. You might even have seen it! Sixteen orbits in each day, each of twenty-four thousand miles.

Which beats the previous record by around half a million miles.