50 years of the Lovell telescope Transcript

Date: Wednesday, 5 December 2007 - 12:00AM
50 YEARS OF THE LOVELL TELESCOPE

Professor Ian Morison

The Early days at Jodrell Bank

In late 1945 Dr Bernard Lovell (as he then was) returned to Manchester University after working on the development of radar during the war years. His aim was to continue his researches into cosmic rays - highly energetic particles that enter the Earth's atmosphere from outer space. He had the idea that sporadic echoes sometimes received by military radars might be the result of cosmic rays entering the atmosphere and thus radar observations might provide a new way to continue his researches. Radar observations were not practical in the centre of Manchester so he took his ex-army radar system out to the University's Botanical Grounds at Jodrell Bank, some 20 miles to the south. By the middle of December 1945, the system was operating and his team was soon able to prove that the echoes were coming not from cosmic rays but from ionized meteor trails left behind when small particles, released from comets, are burnt up in the upper atmosphere of the Earth.

Radar Antenna in the Botany Grounds.

The Jodrell Bank Experimental Station.

The observations continued and, to house the expanding staff and equipment, the Jodrell Bank Experimental Station was built in the field next to the Botanic Grounds. Lovell realised that a much more sensitive radio telescope would be required to detect cosmic rays and so, in 1947, the researchers built a large parabolic reflector, 66-m across, pointing upwards to observe the sky passing overhead. Called the Transit Telescope, it was then the largest radio telescope in the world. By angling the mast that carried the receiving aerials 126ft above the wire mesh surface it was possible to swing the beam. Thus, over a period of time, a broad strip of sky, carried overhead by the rotation of the Earth, could be observed. Echoes from cosmic ray showers were never detected, but instead they began to use the giant telescope to search for astronomical objects that emit radio waves. The telescope detected the remnant of "Tycho Brahe's" 1572 supernova in the constellation of Cassiopeia, invisible at optical wavelengths, and made the first detection of radio waves from the Andromeda galaxy - the first proven extragalactic radio source.

The Jodrell Bank Experimental Station with 66m transit telescope at upper right.

Building the MkI Telescope

The 66.4-m transit telescope had proved a great success, but its barely steerable beam limited the observations that could be made with it. Lovell thus laid plans for an even larger telescope that would be "fully steerable" and so capable of observing the whole sky visible at Jodrell's latitude. Charles Husband, a consulting engineer from Sheffield with expertise in bridge building, joined Lovell to design a 76-m telescope which, like the transit telescope, would use a wire mesh bowl capable of making observations down to a wavelength of 1 metre.
The original "wire mesh" design of the Mk1 Telescope

However, in 1951, the design was changed. The 21 cm wavelength emission from the hydrogen atom had been detected, holding out the prospect of studying the spiral structure of the Milky Way and carrying out other fundamental research. This, together with a request from the Ministry of Defence for the telescope to be made capable of operation at the even shorter wavelength of 10 cm, resulted in the mesh design being abandoned for one with a smoother, solid steel, surface. This naturally increased the cost which was then compounded with a further modification to the design. Late during its construction, Lovell had given a talk about the telescope at the National Physical Laboratory. It was suggested to him that it would be sensible to test a model of the telescope in a wind tunnel as there was a chance that the bowl of the telescope might start to oscillate and break up in a similar manner to the Tacoma Narrows suspension bridge which had collapsed due to wind-induced vibrations in 1940. Tests proved that this would have been the case so a "wind stabilisation girder" had to be added below the bowl.

As a result, the final cost of the telescope greatly exceeded the funding that had been provided for the telescope's construction. This was to cause major problems for the University of Manchester, eventually solved when Lord Nuffield (William Morris of Morris Cars) paid off the final debts. The upgraded design was, however, to prove invaluable in later years. In recognition of his gift, the Jodrell Bank Experimental Station became known as the Nuffield Radio Astronomy Laboratories and remained so until the year 2000 when the observatory became known as the Jodrell Bank Observatory.

The MkI Radio telescope was nearing completion at the moment that the Russians launched the first Earth satellite, Sputnik 1, into space. A crash programme was instituted to complete the final commissioning along with the installation of low loss cables to the focus to allow the telescope to be used as a radar transmitter. On the 12th October 1957, the third stage of the rocket that had put Sputnik into orbit (and which was also orbiting the Earth) was conclusively detected as it passed over the Lake District. It was the only telescope in the western world capable of such a feat and instantly came to the attention of the world.

The Mk 1 Telescope as built with its metal surface.

It was some years before comparable radio telescopes were built in either Russia or the USA and so the telescope played a role helping both countries in their early forays into space. The telescope tracked the Lunar 2 spacecraft on its route to the Moon and proved that it had impacted on the surface - something the Americans had doubted. It was used by the Americans to receive telemetry from their first spacecraft to head towards the Moon. This project was supposed to be secret until the rockets were launched. However, large trailers bringing the equipment to Jodrell Bank from the USAF base at Burtonwood were spotted emblazoned on the side with "Jodrell Bank, U.S. Air Force, Project Able" and the secret was out! The first launch failed just after takeoff, but the second launch, on October 11th 1958, was successful and telemetry from the space probe, which came to be called the Pioneer 1, was received by the MkI telescope ten minutes after launch. Pioneer 1 did not reach the Moon as intended, but provided valuable data on the Earth's radiation belts. Collaboration with the Americans lasted until 1960 when a signal from the MkI telescope fused the bolts to release the Pioneer V spacecraft from its rocket, sent command signals to the probe and collected the scientific data transmitted from it whilst it travelled 35.4 million km into space.

In early 1966, the Russians made the first soft landing on the Moon with their spacecraft Lunar 9. The form of the telemetry was recognised by the Jodrell Bank scientists and it was realised that, if we had access to a Mufax machine of the type used by newspapers to send monochrome images around the world, we might be able to receive pictures of the lunar surface. The Daily Express offices in Manchester sent one out to Jodrell Bank and an image was received from Lunar 9. This image was published across the whole of the Daily Express front page the next day - perhaps the first extraterrestrial scoop. The Russians were not well pleased, and thereafter encrypted their spacecraft transmissions!

The role of the MkI in the defence of the United Kingdom
During the years 1960 to 1963 the telescope was given the unexpected and, until recently, secret role to act as the United Kingdom's early warning radar. During this critical time in the cold war - which included the Cuban Missile Crisis - the Mk1 telescope was equipped with a very powerful radar system giving a 100 kW of peak power at frequencies of 300 MHz or 500 MHz. Using this radar a 10 cm² target at a range of 500 km could have been easily detected! Should a time of national emergency have occurred with the possibility of nuclear war, the telescope would have been used to detect the echoes from missiles, targeted on the UK, launched from the Baltic States. This would have given us a warning of about 7 minutes allowing our Bomber Force to be scrambled and enable the population to move to positions of relative safety. It was thought that this could have saved several million lives.

The discovery of Quasars

Space tracking was, however, always a minor part of the work of the Mk1 Telescope. Its most valuable scientific contribution in the early years was, perhaps, its role in the discovery of quasars. In a series of experiments led by Dr Henry Palmer in the early 1960's the signals received with the Mark I were combined with those from smaller telescopes located at increasingly greater distances from Jodrell Bank. It was discovered that a number of the most powerful radio sources then known had extremely small angular sizes - so small, in fact, that they would appear as "stars" on a photographic plate. This meant that they were very hard to identify until their precise positions were found. The precise position was found when, fortuitously, it was occulted by the Moon in August 1962. Its position was found by noting the times when the quasar signal was, first, lost and then reappeared. From the positions of the Moon's leading and trailing limb at these two times the position was found to an accuracy of ~ 2 arc seconds. It was then possible for the 200" Hale Telescope on Mt Palomar to photograph it showing that a "jet" was seen to extend from the otherwise starlike object. From lunar occultation observations it was shown that the object had a very bright core at the heart of the object along with a jet as seen in the optical photograph.

Maartin Schmidt was able to take a spectrum of the quasar and discovered that the Hydrogen Balmer lines (as discussed in the lecture "Colour in the Cosmos") were highly "redshifted". The unprecedented redshift indicated that it lies at a distance of ~ 2.4 billion light years!

Some thoughts about redshifts

In the lecture "Watchers's of the Skies", the blueshifts and redshifts measured by Slipher were regarded as being due to the Doppler effect. This would be perfectly correct when considering the blue shifts shown by the galaxies in the local group. However in the cases of galaxies beyond our local group there is a far better way of thinking about the cause of the redshifts that we see. As Hubble showed, the universe is expanding so that it would have been smaller in the past. In addition it is not right to think of the galaxies (beyond the movements of those in our local group) moving through space but, rather, that they are being carried apart by the expansion of space. A nice analogy is that of baking a current bun. The dough is packed with currents and then baked. When taken out of the oven the bin will (hopefully) be bigger and thus the currents will be further apart. They will not have moved through the dough, but will have been carried apart by the expansion of the dough.

When a photon was emitted in a distant galaxy corresponding to a specific spectral line, the Universe would have been smaller. In the time it has taken that photon to reach us and the photon has travelled through space, the universe has expanded and this expansion has stretched, by exactly the same ratio, the wavelength of the photon. This increases the wavelength so giving rise to a redshift that we call the "Cosmological Redshift". A simple analogy is that of drawing a sine wave (representing the wavelength of a photon) onto a slightly blown up balloon. If the balloon is then blown up further, the length between the peaks of the sine wave (its wavelength) will increase.

Quasars

These objects were found to be the most distant and most luminous objects in the Universe. They were called Quasi-Stellar-Objects (as they looked like stars) and are now known as Quasars. The study of these enigmatic objects has formed a major
part of our research at Jodrell Bank ever since. The source of energy is located at the heart of a giant galaxy and, because these give out far more energy that normal galaxies like our own Milky Way galaxy we call them **active galaxies**.

**Active Galaxies**

These are galaxies where some processes going on within them make them stand out from the normal run of galaxies particularly in the amount of radio emission that they produce. At the heart of our galaxy, lies a radio source called Sgr A*, one of the strongest radio sources in our galaxy. However this would be too weak to be seen at if our Milky Way galaxy was at a great distance and our galaxy would therefore be termed a "normal" galaxy. However there are some galaxies that emit vastly more radio emission and shine like beacons across the universe. Because most of the excess emission lies in the radio part of the spectrum, these are called radio galaxies. Other galaxies produce an excess of X-ray emission and, collectively, all are called active galaxies. Though relatively rare, there are obviously energetic processes going on within them that make them interesting objects for astronomers to study.

We believe that the cause of their bright emissions lies right at their heart in what is called an active galactic nucleus - or AGN. We now believe that black holes, containing up to several billion solar masses, exist at the centre of all large elliptical and spiral galaxies. In the great majority of galaxies these are quiescent but in some, matter is currently falling into the black hole fuelling the processes that give rise to the X-ray and radio emission.

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

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

These highly luminous objects were first discovered by radio astronomers in a in a series of experiments to measure the angular sizes of radio sources. In the early 1960's, the signals received with the 75-m Mark I radio telescope at Jodrell Bank were combined with those from smaller telescopes located at increasingly greater distances across the north of England. It was discovered that a number of the most powerful radio sources had angular sizes of less than one arc second. So small, in fact, that they would appear as "stars" on a photographic plate. They were thus given the name "Quasi-Stellar-Object" (looking like a star) or "Quasar" for short. This meant that they were very hard to identify until their precise positions were known. The first
quasar to be identified was the 273rd object in the third Cambridge catalogue of radio sources so it had the name 3C273.

Though its image, taken by the 5-m Hale telescope, looked very like a star, a jet was seen extending ~ 6 arc seconds to one side. It was discovered that its distance was about 611 Mpc or 2,000 million light years - then the most distant object known on the Universe. But 3C273 is one of the closer quasars to us and the most distant currently known lies at a distance of ~4000 Mpc, or 13 billion light years! So quasars are some of the most distant and most luminous objects that can be observed in the Universe.

An interesting exercise is to calculate how much mass a quasar must "consume" in order to give their observed brightness. If we assume that 10% of the mass is converted into energy, then \( E = \frac{1}{10} mc^2 \) giving \( m = \frac{10 E}{c^2} \). The brightest quasars have luminosities of order \( 10^{41} \) watts. (That is, \( 10^{41} \) joules/sec, so that we must use \( 3 \times 10^8 \) m/sec for our value of c.) This equation will then give the mass required per second.

\[
m_{\text{sec}} = 10 \times 10^{41} / (3 \times 10^8)^2 \quad \text{kg} = 1.1 \times 10^{25} \text{kg}
\]

So the mass per year \( m_{\text{year}} = 86400 \times 365 \times 1.1 \times 10^{25} \text{kg} = 3.5 \times 10^{32} \text{kg/year} \)

As usual, this can be converted into solar masses:

\[
M_{\text{Sun/year}} = 3.5 \times 10^{32} / 2 \times 10^{30} = \sim 175 \text{ solar masses}
\]

The Sloan Digital Sky Survey (SDSS) has observed more than 120,000 galaxies. Of these, 20,000 contain massive black holes in their centres that are currently active and growing in mass - showing that many galaxies have super-massive black holes at their centre. Whether nuclei of galaxies are "active" is thus a question of whether mass is being fed into these black holes.

Observations of Pulsars

Pulsars are rapidly-rotating neutron stars; the collapsed cores of super-giant stars that have exploded as supernovae. They are exceedingly dense, weighing more than our Sun, but the size of a city, and are highly magnetised. As the star spins, radio waves emerge as a beam above the magnetic poles. Sometimes these beams will sweep across the Earth's position in space and we see regular pulses of energy, much like the flashes from a lighthouse.

The first pulsar was discovered by Jocelyn Bell in 1967. She was then a research student at the Mullard Radio Observatory at Cambridge and noticed a "little bit of scruff" on a chart that seemed out of place. She, with her supervisor Tony Hewish, followed this up and discovered a radio source that was giving out a very regular train of pulses. They did not know at that time of the existence of pulsars and first wondered if this might be a message from an extraterrestrial civilisation and Jocelyn called it "LGM1" - the "LGM" for Little Green Men! The real nature of the objects giving rise to these periodic signals was soon realised.
Following the discovery paper in the journal "Nature" the MkI telescope immediately dropped its planned observations in order to observe the pulsar. As the observatory was equipped with a very high precision atomic clock, it was possible to learn further details about the pulsar's properties. A paper - the second ever about pulsars - was published by the Jodrell group in "Nature" just three weeks later. As will be discussed later, the discovery and observation of pulsars has been a major part of the Telescope's work since that time.

The MkIA upgrade

After 12 years of continuous use, the telescope was showing signs of wear and tear. In particular cracks, caused by metal fatigue, were found in the two cones that transfer the weight of the bowl to the elevation bearings. To rectify this, two circular "wheel girders" were constructed beneath the bowl to transfer 1/3 of its weight to a new central railway track. This would have unbalanced the bowl structure and so a new reflecting surface was built above the old reflector. The new surface had a shallower parabolic profile and was smoother than the old one. This improved its sensitivity and allowed it to be used at shorter wavelengths. By the end of 1971, Jodrell Bank had essentially acquired a new telescope and it was thus given a new name, the MkIA. Following a narrow brush with disaster during a storm in January 1976, when the telescope barely survived a wind gust of 94 mph, diagonal bracing girders were added to give the telescope structure that remains in place today. In 1987, on its 30th birthday, the MkIA radio telescope was renamed the Lovell Telescope.

The discovery of Gravitational Lenses

Following the telescope upgrade to become the MkIA, Professor Lovell asked his staff for projects that could make use of the enhanced performance of the rebuilt telescope. Dr. Dennis Walsh proposed that the telescope be used to make a survey of part of the sky in the constellation Ursa Major to first discover, and then identify, new radio sources. In January 1972 a radio source was found that initially appeared to be associated with a galaxy, but more precise positional measurements gave a position mid-way between the galaxy and a close pair of blue stellar objects. When the pair of stellar objects was investigated further it was found that they were quasars which had virtually identical spectra - essentially identical twins! Further observations showed that the image of one of them was very close to a foreground galaxy.

It was soon realised that we were observing two images of the same distant quasar. The mass of the galaxy was distorting the space-time around it and acting as a "gravitational lens" just as predicted by Einstein's theory of Gravity (his General Theory of Relativity). One image was seen directly, but the second was an image that was formed from waves whose path had been curved as they passed close by the galaxy. These waves had had to travel further though space so took longer to reach us; by 417 days in fact, so we see the quasar at two times during its existence! Since then large numbers of gravitational lenses have been discovered, many by Jodrell Bank astronomers, and it appears that approximately one in 500 distant radio sources is split into multiple images due to lensing by a foreground galaxy. Observations of these multiply images quasars have enabled us to make an accurate measurement of what is called "Hubble's Constant" - related to the scale size of the Universe. This has helped astronomers to understand how our Universe has evolved over the past fourteen thousand million years.

The Telescope's role in the MERLIN array.

The array of telescopes now known as MERLIN, the Multi-Element Radio-Linked Interferometer Network, first came into operation in 1980. The signals from five remote 25-m telescopes, having a maximum separation of 134 km, were brought back over microwave radio links to Jodrell Bank. Here they were combined with signals from the Mk II or MkIA telescopes (or both) in a "correlator" which provided the raw data from which detailed images of radio sources could be produced in a computer. In a
major upgrade to MERLIN, completed in 1991, a new 32-m telescope was built at Cambridge to increase the maximum telescope separation to 217 km. This now gives MERLIN a typical resolution of 1/20 of a second of arc, equivalent to resolving a one-pound coin from a distance of 100 km and giving it an imaging capability comparable to that of the Hubble Space Telescope. As the surface area of the Lovell Telescope is equal to the total area of all the other telescopes in the array, it doubles the sensitivity of the MERLIN when incorporated into the array - a highly significant increase in performance.

MERLIN is the only radio instrument that routinely matches the angular resolution of the Hubble Space Telescope allowing much collaborative research to be carried out. A key use of the Lovell Telescope as part of the MERLIN array was when it was used to image the area of sky known as the Hubble Deep Field (HDF). In late 1995, the Hubble Space Telescope (HST) was trained upon a speck-sized spot in the constellation Ursa Major for a total of 10 days. The observations produced the most detailed optical view of the distant Universe ever produced. The image showed a bewildering assortment of at least 1500 galaxies at various stages of their evolution. In one sense the image was like a time machine looking back into the past to witness the early formation of galaxies, perhaps less than one billion years after the birth of the Universe in the Big Bang some fourteen billion years ago.

Observations made by MERLIN, including the Lovell telescope, were made over a total period of 18 days and detected 92 radio sources in the region of the Hubble Deep Field and its surroundings. A very valuable contribution to the HST was provided by MERLIN's ability to measure positions to very high accuracy - far better than can be done optically. This work has enabled observations of the HDF taken at different wavelengths to be accurately aligned. The MERLIN observations showed that the radio sources observed were dominated by "Starburst" galaxies where the galaxy is undergoing a massive burst of star formation. The observations imply that their star formation rates were significantly higher than that observed in nearby galaxies. The Universe was then undergoing the most dynamic period in the whole of its existence!

**The Lovell Telescope's role in the European VLBI network**

Even higher resolution than that achievable with MERLIN can be obtained by combining the signals from widely spaced telescopes in what are termed "VLBI" arrays. "VLBI" stands for Very Long Baseline Array, indicating that the telescopes are located far apart. Jodrell Bank Observatory is a founder member of the European VLBI Network (EVN) whose telescopes span Europe from Spain to Finland and from the United Kingdom to Poland. The EVN now has a dedicated facility, JIVE (the Joint Institute for VLBI in Europe), at Dwingeloo in the Netherlands, where the wideband correlator to combine the data is located. Data are now normally transferred from the telescopes to JIVE on hard disks, but are increasingly being sent in real-time over the internet - in what is known as e-VLBI. As the array covers the whole of Europe, and now can incorporate two telescopes in China, the EVN allows radio source images to be made with angular resolutions as small as 100 micro-arcseconds - the highest resolution images obtainable by any astronomical instrument. Due to the number of large telescopes participating in the array, including the Westerbork array in Holland and the 100-m Effelsberg Telescope in Germany, the EVN is the highest sensitivity VLBI array in the world. With its westerly location and large collecting area, the Lovell telescope plays a key role in the EVN.

**The National Facility**

The MERLIN and VLBI systems at the Jodrell Bank Observatory are now operated as a National Facility by the University of Manchester on behalf of the Science and Technology Facilities Council (STFC). Its remit is to operate MERLIN for the benefit of the whole astronomical community and to provide the support necessary to participate in VLBI operations.
The Lovell Telescope takes part in the Project Phoenix SETI search.

SETI stands for the Search for Extra Terrestrial Intelligence. From 1998 to 2003, the Lovell Telescope joined with the 305-metre Arecibo Telescope in Puerto Rico to take part in what was the most sensitive and comprehensive search ever undertaken for possible radio signals from extraterrestrial civilisations beyond our Solar System. The 5 year research programme, Project Phoenix, was led by the privately-funded SETI Institute who had continued the NASA SETI observations when the US Congress cut the SETI funding from the NASA budget. During the 5 year period, with 40 days of observations per year, over 850 of the nearest Sun-like star systems were targeted in the hope that an advanced civilisation might exist on a planet within one of these systems. The Arecibo Telescope used a 56-million channel receiver to make initial detections of signals that could perhaps be of extraterrestrial origin. Information about those signals which were not in the data bank of known terrestrial signals, were passed on to two further sets of identical receivers at Arecibo and Jodrell Bank. Due to the rotation of the Earth, and the great distance separating Jodrell Bank and Arecibo, a signal from outside the Solar System will have precisely calculable differences when observed at the two observatories. This enabled any signals originating the Earth or from satellites orbiting the Earth or the Sun to be eliminated. Sadly, ET did not phone home.

The Lovell Upgrade.

By the late 1990’s the “new” 1971 surface was beginning to corrode quite badly. Rust was spreading out from the spot welds that secured the steel plates to the backing structures of the 336 panels that make up the surface. If nothing had been done the telescope would soon have come to the end of its operational life. Salvation came from a fund set up by the Government and the Wellcome Foundation and to provide for the support of British Science. Called the Joint Infrastructure Fund (JIF), it made a £2.33M grant, administered by the Particle Physics and Astronomy Research Council (PPARC), to upgrade the telescope.

During the summer of 2000, before major work was carried out on the surface, the outer railway track on which the telescope rotates in azimuth was re-laid and some remedial work to its foundations carried out. In April 2001, the telescope was taken out of action for the first summer of resurfacing work. SHAL Engineering began to replace the rusting plates with new ones made from galvanized steel. The spot welds that secured the plates had to be ground away and the backing structure cleaned and covered with mastic before each new plate was laid and screwed into position. To enable the work to be carried out on the higher, and thus steeper tiers, three “Bowl Excursion Vehicles” or BEVs were built in our telescope workshop. Winched up the telescope surface they provided a flat working surface from which to remove and replace the panels. By October of that year, a full sector - one third of the surface - and each alternate segment round the remainder of the bowl had been completed. With the mix of old and new surfaces the telescope had a rather dramatic appearance during the winter months that followed!

Engineers replacing a segment of the surface

Following the completion of the first year’s resurfacing, work on the third part of the upgrade swung into action. The University commissioned VertexRSI, a world leader in telescope control, to design and implement a new drive and control system for the telescope. Each of the 10 drive motors, 4 in azimuth and 6 in elevation, were replaced. In contrast to the old system where the motors were driven in groups, each motor now has its own controller and thus can be driven independently to optimise the overall drive characteristics of the telescope. The individual motor controllers are under the overall control of a very sophisticated computer system. The results have been excellent; the telescope now accelerates more quickly and drives faster from source to source (thus improving its observing efficiency) and can follow a radio source with a precision many times better than before.
The resurfacing was completed during the spring and early summer of 2002 and then, in late August, the mammoth task was begun to clean and prepare the surface prior to painting. Pumps had to be brought in to lift water 150ft up into the bowl to enable the surface to be scrubbed down - by hand as a machine cleaner may have harmed it! When completed, the surface was painted with a matt-white two-part epoxy paint. This is an extremely robust surface and it should be many years before it has to be painted again. Finally, at the end of September, the surface was cleared of all the contractor's equipment and the pristine bowl was tipped from the zenith for the first time to allow us to view it from the ground. It looked beautiful.

One final task remained; that of setting the surface to the precise parabolic shape. The old surface had typical errors of 5 - 10 mm from the ideal shape limiting the shortest radio waves that could be observed to approximately 18 cm wavelength. The positions of the panels were measured with a laser theodolite and radio holography. The resulting measurements enabled them to be precisely adjusted into the desired profile. This has increased substantially the frequency range over which the telescope can operate, so greatly enhancing its capabilities.

The Lovell Telescope as it is today

**Popular Culture**

Over the years, the Lovell Telescope has played a small part in popular culture; the pop bands D:REAM and Placebo have been seen performing in its bowl, the fourth - and many think the best - Dr Who, Tom Baker, met his “death” after falling from the telescope and Jodrell Bank Scientists also failed to spot the arrival of the Vogons in Douglas Adams' Hitch-Hikers Guide to the Galaxy as they were too busy making a cup of tea!

**Searching for missing spacecraft**

Though we now rarely take part in space tracking activities, we have been asked by NASA to search for the two missing Mars space probes, Mars Observer and Mars Polar Lander and, on Christmas Day 2003, hoped to receive the first signals from the Beagle II spacecraft that should have soft landed on Mars early that morning. Sadly, despite having put together the most sensitive receivers in the world to undertake these tasks, we were unsuccessful. It appears that the Mars Observer exploded when NASA attempted to fire its retrorockets to enter Martian orbit and that both Mars Polar Lander and Beagle II crash landed.

**A surprisingly useful survey**

It seems surprising that observations made many years ago by the telescope at the long wavelength of 73.5 cm could have a bearing on present day observations of the Cosmic Microwave Background (CMB) which can only be observed at very short radio wavelengths. Observations, initiated by Dr Glyn Haslam using the Mk1 telescope, with further data from the 100-m Effelsberg and 64-m Parkes Telescopes, produced the 408 MHz all-sky survey that was published in 1982. This has proved to be an invaluable source of information about the galactic foreground radiation that has to be subtracted from all-sky maps of the CMB - such as that produced from data observed by the WMAP satellite. The 1982 paper has had over 200 citations since the year 2000!
Further Pulsar discoveries

One of the more surprising discoveries made by the Lovell Telescope was the finding of a very rapidly rotating pulsar in the globular cluster M28. As pulsars age they slow down and finally cease to radiate. Globular clusters are very old, and thus it was not expected that any would be found there. However, it seems that a close encounter between a neutron star and one of the cluster stars had "spun-up" and re-activated this pulsar whose period (3.054 milliseconds) is measured in milliseconds - hence the name. Many other globular clusters are now known to harbour millisecond pulsars. Such pulsars, spinning up to 712 times a second, are exceedingly good timekeepers and may even be more stable than the best atomic clocks.

With simultaneous observations by the Lovell Telescope and MERLIN, pulsar positions can be measured very precisely. Observations have shown that some are moving through space at speeds greater than the galaxy's escape velocity. It thus appears that many new born pulsars will be travelling so fast that they will escape the gravitational pull of our Galaxy and be lost into the depths of space.

Over three quarters of the more than 1700 pulsars now known have been discovered by Jodrell Bank astronomers, often in collaboration with astronomers at the 64-metre Parkes Telescope in Australia. The Parkes Telescope has been equipped with a 13-beam receiver system whose very low-noise amplifiers and much of the data acquisition hardware were built by Jodrell Bank engineers. The pulsar surveys made with this telescope in recent years have discovered more pulsars that had been found in the previous 30 years. Many of the more than 900 new pulsars discovered with this fast, highly sensitive, system are now being studied with the Lovell Telescope.

The Future

During the last 50 years, the Lovell Telescope has become an icon of British science and technology but, as I hope the latter part of this article has shown, the Lovell Telescope is still carrying out front rank astronomical research, both as an individual instrument and as part of MERLIN and the EVN. With its recent major upgrade it is now performing better than at any time in its history and there is no fundamental reason why that should not continue to do so well into the future. It is still the third largest fully-steerable radio telescope in the world, and a perfect instrument for use in Pulsar observations. In addition, MERLIN is currently undergoing a major development which will see 30 GBits per second of data brought back over dedicated optical fibre links from our outstation telescopes to Jodrell Bank. This will give us the ability to observe over vastly greater bandwidths and so, when combined with the signals from the Lovell Telescope, will make MERLIN easily the most sensitive radio instrument in the world. With the Lovell Telescope's enhanced frequency coverage as a result of its recent upgrade its role in the EVN is more important than ever.

The telescope that now bears his name was the creation of one man, Bernard Lovell. It is wonderful that, at the age of 93, he has been able to see its successes over the past 50 years and is sharing in our 50th anniversary celebrations.

We cannot foresee the future - many of the phenomena that the Lovell Telescope has observed were unknown when it was first conceived - but we can only hope that its future will be as exciting as its past!

Sir Bernard Lovell in his 95th year.