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Rodney D. Davies, Sir Francis Graham-Smith and Andrew G. Lyne

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Elected FRS 1955

BY RODNEY D. DAVIES† FRS, SIR FRANCIS GRAHAM-SMITH FRS AND ANDREW G. LYNE* FRS

Jodrell Bank Centre for Astrophysics, Jodrell Bank Observatory, University of Manchester, Macclesfield, Cheshire SK11 9DL

Bernard Lovell is remembered for the iconic radio telescope at Jodrell Bank that bears his name, and for the research group at the University of Manchester that has become the Jodrell Bank Centre for Astrophysics. His enthusiasm and warm personality inspired several generations of radio astronomers, many of whom now lead their own research groups. Lovell also played a key role in the development of airborne radar during World War II.

EARLY YEARS

Alfred Charles Bernard Lovell was born on 31 August 1913 to parents Gilbert and Laura (née Adams), who lived in the village of Oldland Common near Kingswood on the outskirts of Bristol, Gloucestershire. At this time of settled communities, Oldland Common had been home to many generations of Lovells and Adamses. Although an only child, the young Lovell grew up surrounded by numerous cousins, uncles and aunts who engaged in the communal activities of sport, music and the Methodist chapel. The Adams family dominated musical, practical and material aspects of village life. They formed one of the earliest cricket teams; W. G. Grace was well remembered locally. Laura was captain of the Oldland Common Women’s Cricket team. The chapel was the nucleus of the community with its social and musical activities. Gilbert, a tradesman, was a lay preacher with a keen knowledge of the Bible, English literature and grammar, which he instilled in his son. From the age of 10 years Bernard would play the organ for chapel services and play cricket as a substitute in the Adams cricket team. As we shall see, these influences from the two families were to play a significant part in his later life.

* andrew.g.lyne@manchester.ac.uk
† Deceased 8 November 2015, after this manuscript was completed.
Biographical Memoirs

Schooling

Bernard attended the local Oldland primary school and at the age of 11 years transferred to Kingswood Secondary School, which was refounded as the Kingswood Grammar School in 1921 (it was subsequently renamed the Kingsfield School and is now the King’s Oak Academy). At this time he began a passion for radio, building receivers at a stage when radio was moving from crystal set to valves. Little was he conscious of where this skill would lead in his subsequent life. His father renamed his business ‘The Oldland Cycle and Radio Company’ in the expectation that his son would join him when leaving school after the fifth form. By the end of the fifth form he had shown such significant progress that his headmaster successfully pleaded with his father to continue his education in the sixth form. Here his interest in science blossomed.

A pivotal event was the class visit in 1928 to the Physics Department, Bristol University, to hear Professor A. M. Tyndall (FRS 1933) give a precursor of his 1930 Royal Institution Children’s Christmas Lectures on ‘The electric spark’. This made a deep impression on Bernard and convinced him to continue in science. He was encouraged in this ambition by his left-wing mathematics teacher, E. R. Brown. His interest in the relation between science and religion was stimulated by discussions at home with Brown and his father and by reading the Gifford Lectures, published as Scientific theory and religion, by E. W. Barnes, Bishop of Birmingham. In this period Bernard became distracted from his schoolwork by cricket, in which he became the captain of the school cricket team. Nevertheless he won a Major Scholarship in the Faculty of Science in the University of Bristol to undertake a three-year honours physics course.

University of Bristol

Bernard Lovell entered the University of Bristol in the autumn of 1931. The H. H. Wills Physics Laboratory had been opened in 1927. Under the guidance of A. M. Tyndall it attracted an outstanding team of academics and research staff. These included the Nobel laureates C. F. Powell (FRS 1949; discoverer of the pi meson), W. Heitler (FRS 1948; quantum theory of the chemical bond) and subsequently N. F. (later Sir Nevill) Mott (FRS 1936; solid state physics). Bernard found the physics course to be so stimulating that he asked to come back in the vacations to work with the research staff on projects in crystallography and geophysics. He found the coursework so absorbing that, despite the pleas of the university cricket captain, he gave up his immediate cricket ambitions. These would find a place in his later life. In June 1934 he was awarded first-class honours in science.

During his undergraduate days Lovell enlarged his interests in music, not finding it a distraction from his science. A friendship between Bernard and a fellow physics student, Deryck Chesterman, was to develop in two significant ways. First, they were both interested in organ music, which led to his developing his skills at the organ by receiving lessons and ultimately playing on the finest organs in Bristol and Bath. The second was his meeting with Joyce, Deryck’s sister, whom he was subsequently to marry.

On the basis of his first-class degree, Bernard was awarded a grant from the Department of Scientific and Industrial Research (DSIR) to undertake research for a PhD degree under the supervision of Professor Tyndall for the two-year period from September 1934 to September
Alfred Charles Bernard Lovell

1936. His research project was directed towards understanding the electrical resistance of thin films of alkali metals deposited on glass surfaces. At the time there was no consistency in the results of similar experiments conducted in leading laboratories. His immediate supervisor was E. T. S. Appleyard, who wished to investigate why the resistivity of potassium, rubidium and caesium in invisible thin surface layers was much greater than that of the bulk metal. It soon became clear that the problem was due to the cleanliness of the surface. With the assistance of the department’s skilled glassblower, J. H. Burrow, an apparatus made from ultra-clean Pyrex and using ultrahigh vacua brought the values for thin layers and bulk material into agreement (1, 2). Further developments showed that the addition of even small amounts of contaminants to the surface layer greatly increased the resistivity, as found in earlier work. Lovell developed his critical and experimental skills in this project. For this work he was awarded the PhD degree in October 1936 along with a Colston Research Fellowship.

UNIVERSITY OF MANCHESTER

Professor Tyndall strongly advised Lovell to approach larger university departments, to broaden his research experience. The Physics Department of Birkbeck College, London, headed by Professor P. M. S. (later Lord) Blackett FRS (PRS 1965–70), and the Manchester Physics Department, headed by Sir Lawrence Bragg FRS, both had openings. Although Lovell preferred the cosmic ray research at Birkbeck to the X-ray work at Manchester, an Assistant Lecturer post was immediately available in Manchester. He was appointed to the three-year position on 29 September 1936. As it turned out, Lovell’s wish was fulfilled a year later when Blackett succeeded Bragg, who was appointed Director of the National Physical Laboratory.

During the first year of his appointment, Lovell was able to bring his researches on the resistivity of thin metallic films to a satisfactory conclusion. This involved continuing some experiments with the Bristol group, analysing the results and publishing them (3–5). Lovell was delighted that he had been invited to work with Blackett, a world authority on cosmic ray physics. His principal task was to take charge of the automatic counter-controlled cloud chamber required for the detection of cosmic ray showers. He made observations with the improved cloud chamber that clearly demonstrated that a more extensive programme of cosmic ray research was feasible (6). In the same period, his paper comparing his cloud chamber observations with current theoretical models of cosmic ray shower production was published (7).

RADAR

In August 1939 Lovell was preparing an expedition to the Pic du Midi Observatory, intending to observe cosmic ray showers by using a cloud chamber at high altitude. He was instead ordered by Blackett to abandon research and join the team of academic scientists rapidly assembled by J. A. Ratcliffe (FRS 1951) for the development of radar. At the declaration of war on 3 September he was at Staxton Wold, near Scarborough, observing echoes on the screen of a Chain Home (CH) radar. Among the echoes from aircraft there were transient echoes, dismissed as irrelevant by the operators, that excited his attention. Could they be echoes from ionization left by cosmic ray showers? The possibility became a driving force after the war, but it had to remain at the back of his mind through years of intense concentration on radar.
In the UK, radar had developed rapidly since the first demonstration of reflection of radio waves from aircraft in 1935. Airborne radar was already also becoming a reality, using Yagi antennas at a wavelength of 1.5 m. Lovell was soon at the embryonic Telecommunications Research Establishment (TRE), based originally in Perth, Scotland, but moved in November 1939 to an uncomfortable existence at St Athan airfield in South Wales. Here E. G. Bowen (FRS 1975), the originator of airborne radar, involved Lovell and his colleagues in the installation of AL (Airborne Interception) radar in Blenheim and Beaufighter aircraft and ASV (air to surface vessel) radar in Hudson aircraft. The group included J. W. S. Pringle (FRS 1954) and A. L. (later Sir Alan) Hodgkin (FRS 1948), who were also working on equipment using the shorter wavelength of 50 cm, with the advantages of narrower beamwidths.

In May 1940 TRE moved to Worth Matravers, near Swanage, in Dorset. Before packing for the move Lovell returned briefly (and unofficially) to cosmic ray showers by setting up one of the ASV radars on the ground, using a simple Sterba array looking upwards. No echoes were to be seen. It would be another five years before a more serious attempt could be made, but Lovell and Blackett nevertheless wrote a paper on the theoretical possibilities of echoes from cosmic ray showers, published in 1941 (9).

The successful use of the short wavelength of 10 cm depended on the resonant cavity magnetron valve developed by J. T. Boot and H. A. H. Randall in Birmingham in 1940. Valve development and production for all armed services was coordinated by the Committee for Valve Development (CVD), and contracts were placed by the Admiralty Signals Establishment (ASE). Naval radar was based at the Signal School at Eastney (Portsmouth); after a slower start than the Air Ministry, the Navy had a successful shipborne radar at 7.5 m wavelength (Type 79), and was developing 3.5 m and 1.5 m versions (see Howse 1993). The possible use of 10 cm for naval radar led to an important liaison with TRE soon after the move to Swanage.

In May 1940, P. I. Dee (FRS 1941), who had been working at the Air Defence Department of the Royal Aircraft Establishment, moved to TRE with W. E. Burcham (FRS 1957) and J. G. Wilson. Dee was then in charge of a formidable group of future FFRS who were beginning to realize the potential of 10 cm radar using the new magnetron as a transmitter. Lovell’s part was the design of antenna systems. Horns were used in the initial tests, but after persuasion from H. W. B. Skinner (FRS 1942) and advice from N. F. Mott, parabolic cylinders and eventually paraboloids were adopted. Lovell explored a new technique of swinging the beam by a transverse movement of the feed dipole; this was applied at Jodrell Bank Observatory many years later.

A 10 cm radar was demonstrated to Navy visitors in October and November 1940. They were so impressed with seeing echoes from small vessels including a surfaced submarine that they immediately arranged for a copy to be built for development at the Signal School. The main problem in adapting to a shipborne installation was the narrow vertical beamwidth, which was incompatible with large angles of roll. Lovell suggested the solution: use truncated paraboloids, the now familiar ‘cheese’ antenna, to give a vertical fan beam. The rapid adoption by the Signal School of the TRE design led to the widely used and very successful Type 271 naval radar. This radar, which was the world’s first operational 10 cm radar, went into service in April 1941.

Radar for AI developed rapidly from the 1.5 m versions through a series of 10 cm versions, first using klystrons and then adopting the magnetron. Lovell’s group concentrated on the idea of lock-follow, in which a scanned radar beam could locate and lock onto an aircraft echo. Hodgkin proposed using a spiral scan, which involved rapid rotation combined with varying
beam offset; in May 1941 the group successfully demonstrated automatic following on an
echo from a Blenheim aircraft. Installing this in an aircraft was a formidable engineering task,
which occupied the autumn of 1941. Contracts were placed in December with Metropolitan–
Vickers and Ferranti for a lock-follow installation in Beaufighters. Lovell was an enthusiast
for this system, but in January 1942 he was taken off the project and given charge of a new
and very urgent programme for Bomber Command. This built on his hard-won experience of
antenna design and aircraft installation, but it also required leadership and determination of a
very high order.

In 1941 the Royal Air Force (RAF) emphasis on defence changed to attack, building up
a bomber force that could strike at German towns and industry. It was, however, obvious
that navigation at night or over cloud was so uncertain that many aircraft failed to find their
targets. Two ground-based navigation devices GEE and OBOE, which were brought into
use in February and December 1942 respectively, transformed the situation, allowing the
first 1000-bomber raids on Cologne and Essen. The range of these devices was limited by
the curvature of the Earth, so that the more distant targets in East Germany, and particularly
Berlin, could not be reached. An autonomous onboard navigation system was urgently needed.

Dee and his group had noticed that the ground return from their 1.5 m AI radar gave a rough
map of the terrain, which might be much improved by the use of a shorter wavelength such as
10 cm. There was a similar requirement for 10 cm radar from Coastal Command, in which the
detection of surfaced submarines by 1.5 m airborne radar had been very successful for a few
months but had been defeated by the German Metox detection system. It was possible that a
centimetric radar might escape detection by submarines. The new magnetron was already in
use for shipborne radar. Pressure to use the magnetron for airborne radar built up rapidly. The
navigation system for the RAF became a top priority, urged on by Churchill on advice from
his Scientific Advisor, Lord Cherwell FRS. It was called H2S.

The pressure to equip Bomber Command with a long-range navigation system, and the
high-level decisions taken to give priority to H2S, have been set out in the biography of
‘Bomber Harris’ by Dudley Saward (Saward 1984a), who was appointed Chief Radar Officer
in December 1941. Perhaps the most influential appointment was Sir Robert Renwick to the
Ministry of Aircraft Production in October 1941; Lovell was to rely on his help on several
important occasions when resources were particularly scarce. From this background Lovell
was given extraordinary responsibility and the authority to bring H2S to operational use,
preferably within a few months.* The alternative was the well-known but less powerful
klystron. Lovell was pitched into the urgent requirement for a working 10 cm system, but was
restricted to using the klystron. Comparative tests convinced Lovell that the higher power of
the magnetron was essential, but he was officially only allowed to develop the klystron system.
At this point he displayed the resourcefulness and determination that characterized the whole
of his subsequent career: he led a parallel development of complete radars using both systems,
installed in two different Halifax aircraft. He achieved this through a remarkable partnership

* There was, however, a barrier to the use of the magnetron for airborne radar. It was thought, wrongly as it turned
out, that German radar engineers did not have the technique to make a magnetron, so that an aircraft crashing
on enemy territory might reveal the secret of the high-powered 10 cm transmitter. As had been anticipated, a
magnetron was found by German radar engineers in a crashed bomber near Rotterdam in February 1943. It was
examined by a Telefunken engineer, Otto Hachenberg, who, like Lovell, after the war built a large steerable radio
telescope. This coincidence, and the comparative state of centimetric radar on the two sides, was described by
Lovell in 2004 (34).
with Dudley Saward, the newly appointed Chief Radar Officer of Bomber Command, and close liaisons with EMI, which developed the radar set, and with Nash & Thompson, which built the scanning antenna.

Lovell and his group were under intense pressure to produce a working H2S. Swanage, which had been a pleasant place for living and working, was increasingly under attack by air, and in May 1942 TRE moved en masse to Malvern; Lovell likened the subsequent chaos to the Marx Brothers film *Hellzapoppin*’. Much worse was the total loss on 8 June of the Halifax aircraft equipped with the only working magnetron system, with the death of key members of the EMI team including the chief EMI designer, A. D. Blumlein. The pressure only increased, culminating in a meeting with Churchill on 10 July at which he demanded 200 sets by mid October. At this stage there was no satisfactory H2S using either system; much effort had been wasted on the klystron until in July 1942 the Secretary of State ruled that the klystron work should cease. Adding to a very heavy load, Lovell was also given responsibility for providing H2S equipment for Coastal Command ASV, for which the use of the magnetron was allowed.

The dreadful shipping losses by U-boat attack in the Atlantic, which had been cut dramatically by the introduction of 1.5 m radar, rose again in January 1943 when the detection system Metox was installed on German submarines, enabling them to dive before they were detected on the surface. A new 10 cm radar was being developed for Coastal Command Wellington aircraft independently of Bomber Command, and Lovell found himself embroiled in an unpleasant controversy between competing development groups and manufacturers, which could only be resolved at the highest level. The rational solution prevailed, and Lovell’s group equipped a small number of Wellingtons with modified H2S radar. The result was dramatic, and was a major factor in the Battle of the Atlantic. From March 1943 onwards the U-boats suffered losses that proved unsustainable. Later in the year American Liberator aircraft equipped with 10 cm radar took over the Atlantic patrols. Surprisingly, no 10 cm detection system was installed on the U-boats for many months; it emerged after the war that there was very little research into centimetric techniques in Germany, on the assumption that they would have no effective use during the course of the war. Another vital factor was the lack of close liaison between radar engineers and the military services, which in the UK was successfully provided by TRE.

Bomber Command first used H2S with the 10 cm magnetron in January 1943. The heavy attack on Hamburg that followed in August was guided by a Pathfinder force using H2S. It was a complete success. Reliable navigation now allowed bombers to reach Berlin, but the H2S radar map only showed the big city as a large undifferentiated mass. Effective bombing of such an extensive target required a more precise selection of targets within a detailed map, which could only be provided by the narrower beamwidth given by using a shorter wavelength.

A 3 cm version of H2S was already under development both in America and in TRE. There followed another argument about the suitability of the American equipment, and production delays in the UK. Lovell and Saward, with minimal higher authority, cut across the muddle by using local resources at TRE to produce six Pathfinder Lancasters by November equipped with 3 cm H2S. There followed raids on Berlin and Leipzig that were completely successful. Success brought a further burden: the US Bomber Command now wanted to use H2S, and TRE effort had to be diverted through the summer and autumn of 1943 to equipping Fortresses and Liberators. However, the American efforts soon took over, particularly using a 3 cm radar which they named H2X. Development of new radars, including the even shorter K-band wavelength of 1¼ cm, had become rapid and extensive. Throughout 1944 there was a
confusing and stressful proliferation of proposals, including improving 3 cm H2S by using a larger (6 ft) antenna, and developing K band using American magnetron production. The early days at Swanage, when H2S was a simple aspiration, had been overwhelmed.

The story of H2S radar was told in fascinating detail by Lovell in his book *Echoes of war* (33), which was based on his personal wartime diary (now in the Royal Society archives) as well as TRE papers and material deposited in the Imperial War Museum. The close partnership between the scientists of TRE and the RAF, which was vital to the success of H2S, is best illustrated by Dudley Saward’s biography of Lovell (Saward 1984b).

Lovell retired ill in February 1945, exhausted by superhuman effort. He seldom spoke about the vital part he had played in the devastating bombing campaign, even within his own family. He was clearly affected by the moral issues of involvement in mass bombing, but found some consolation in the vital contribution made by his anti-submarine radars in the Battle of the Atlantic.

**RETURN TO MANCHESTER**

In April 1945 Lovell accepted the position of Lecturer in the Physics Department of the University of Manchester. Blackett encouraged Lovell in his plan to search for radio echoes from the ionization produced by cosmic ray showers and also to follow up the sporadic echoes seen in radar systems during the war. In the autumn of 1945 Lovell brought two trailers of ex-army radar equipment back to Manchester and attempted to set up receivers in the Physics Department quadrangle. It was immediately obvious that radio interference generated by electric trams in the city centre made observations impossible. As a consequence he moved the two trailers to Jodrell Bank 20 miles south of Manchester, where the University Botany Department had a research station (figure 1).
On 14 December the first observations were made. Strong echoes were seen on the cathode ray tube. Were these the cosmic ray echoes or perhaps meteor echoes? It was soon recognized that the strongest echoes were from the ionization trail of meteors passing through the atmosphere. Lovell was seeing the Geminid meteor shower of 9–15 December. By early 1946, echoes were clearly from individual ionized meteor trails. No echoes from cosmic rays were found, as predicted by Blackett & Lovell in 1941 (9). It was subsequently found that full account had not been taken of the damping factor, which substantially reduced the strength of the echo signal. Meteor radio astronomy became the main programme at this time.

**Meteor astronomy at Jodrell Bank**

The Jodrell Bank site proved to be ideal for meteor studies, with little or no radio interference and dark skies away from city lights. The first decisive radio detection of a meteor shower was of the Giacobinids of 9–10 October 1946 (12). There was a marked correlation between the naked-eye meteor rate and the radio echo rate. These echoes were seen by specular reflection from the ionized trail left by the meteor, when the direction of observation was perpendicular to the trail (12). The coincidence with optical sighting was clearly established. More quantitative data were provided by the inclusion in the team of Manning Prentice, an amateur meteor expert. He was able to provide estimates of a meteor’s trajectory as well as its optical brightness (11). The electron density in the trails was deduced from the intensity of the echoes (16).

A major effort was directed towards identifying the daytime meteor streams incident on the sunlit side of the Earth. Some 13 day-time meteor streams were found during the 1947 and 1948 seasons, with well-defined radiants and with maximum rates between 10 and 60 per hour (13, 18). The streams were a recurrent phenomenon from year to year. The activity of the most intense streams was comparable with that of the well-known night-time streams such as the Geminids and the Perseids. Their radiant points are in a narrow strip of the celestial sphere following the ecliptic, as expected for objects in the Solar System.

A long-standing question in meteor astronomy had been whether or not the sporadic meteors were of interstellar origin. A critical factor in resolving this problem was a measurement of the orbital velocity of each meteor. By recording the Fresnel diffraction pattern of the echo as the meteor passed through the telescope beam, the speed could be determined with considerable accuracy. Any object moving in a closed orbit around the Sun would have a velocity relative to the Earth of between 12 and 72 km s\(^{-1}\). Detection of velocities greater than 72 km s\(^{-1}\) would be evidence for an interstellar origin in a hyperbolic orbit. An extensive series of observations between 1948 and 1951 (19–22, 24) found no evidence for a significant hyperbolic velocity component. Some 90% of the sporadic meteors are moving in elliptical orbits with periods of about two years. Less than 1% had velocities significantly greater than 72 km s\(^{-1}\). This result settled the debate in favour of a Solar System origin.

Bernard Lovell’s book *Meteor astronomy* (23) was a masterly summary of the situation in the subject at that time.

**Other astronomy at Jodrell Bank before the Mk I telescope**

Solar activity was detected from time to time in the meteor systems operating at 46 and 72 MHz. In the 25 July and 2 August 1946 events the radio emission was \(10^4–10^5\) times the
normal blackbody emission of the Sun (10). This indicated that the emission was coming from coronal regions. In the period July to December 1950 a geomagnetic storm sequence resulting from a coronal M region persisted for at least seven solar rotations. There was associated metre-wavelength emission and strong auroral echoes during this period, again showing the 27-day solar rotation period.

Substantial effort by Lovell and his team was directed towards understanding the structure of the ionosphere by using the radio-echo techniques developed at Jodrell Bank (15, 17). Meteor trails were used to study the properties of the E region at heights of 60–100 km. The amplitude fluctuations of the reflected signal were caused by distortions in the ionized column left by the meteor. Fresnel diffraction theory applied to the time sequence of the echo gave the scale of the structure. Turbulent winds of the order of 20 km s$^{-1}$ were inferred.

Radio echoes were found from a spectacular auroral activity on the night of 15–16 August 1947 (14). The most intense activity was in a faint blue cloud in the zenith, with lesser echoes from striation structures extending over distances of 400–700 km. Subsequent studies at frequencies of 46 and 72 MHz found that the true heights were 100–300 km, placing them in the E and F2 ionospheric layers. Electron densities were about $10^6$ cm$^{-3}$, values typical of the night-time ionosphere.

Following research in World War II, J. S. Hey (FRS 1978) found radio emissions from the constellation Cygnus. Rapid fluctuations in radio brightness were interpreted as indicating the presence of a compact object, possibly Galactic. Simultaneous follow-up observations at Cambridge and Jodrell Bank at a separation of 210 km confirmed that the fluctuations were not intrinsic to the source but were most probably of local origin in the F2 layer of the ionosphere. A continuing study at Jodrell Bank showed that the fluctuations could be understood in terms of Fresnel diffraction in the ionosphere, as in the case of meteor trail echoes (Little 1951). Continuous tracking was made of the two brightest radio sources, Cygnus and Cassiopeia, which are both circumpolar at Jodrell Bank. At high elevations the fluctuations were well correlated with the ionospheric spread-F diffuse echoes at a height of about 400 km and a scale size of about 5 km on timescales of 10–40 min. At low elevations in the north, fluctuations were always present as a result of the passage of the radio waves through the continuously disturbed ionospheric and auroral regions at high magnetic latitudes.

Echoes were obtained from the Moon in 1953 (25). An array of 160 half-wave elements operating at 120 MHz was built to receive echoes from the Moon over a range of elevations at the time of meridian transit. Lunar echo signal strengths of up to 100 times the receiver noise level were recorded. A long-period (1-hour) deep fading was prominent after sunrise, which was interpreted, correctly, as being due to the Faraday rotation in the ionosphere. The experiment provided a direct measure of the electron content of the ionosphere (Murray & Hargreaves 1954).

**THE 218 FT TELESCOPE**

Although there were fascinating discoveries in meteor astronomy with small-area arrays in 1946 and 1947, Lovell still harboured an ambition to search for radio echoes from cosmic ray air showers. His calculations showed that a telescope with a large collecting area was required. A giant reflector paraboloid would be ideal. It would have much better angular resolution and moreover it would enable many frequencies to be used. New areas of radio astronomy including Galactic and extragalactic studies were opening up that would hugely benefit from such a
telescope. This concept evolved into the fixed vertically directed 218 ft diameter paraboloid, built very simply from scaffold poles and wire, with a 126 ft mast to support radio receivers at the focus. The first observations were made in the spring of 1948. In 1949 Robert Hanbury Brown (FRS 1960), who was involved in the early development of airborne radar during World War II, joined Lovell at Jodrell Bank. He, along with research students, led a vigorous programme of observations that clearly demonstrated the potential of large-area telescopes. By tilting the mast by 15° from the zenith, Hanbury Brown showed that the Andromeda Nebula M31 and other nearby galaxies were radio sources similar to the Milky Way (Hanbury Brown & Hazard 1951). Lovell became convinced that a fully steerable radio telescope of at least the size of the fixed 218 ft paraboloid was essential for observational radio astronomy.

THE 250 FT TELESCOPE

From the start, Lovell specified the diameter as 250 ft (76.2 m), and he maintained this specification through thick and thin, overcoming difficulties and disasters of design, finance and construction. Substantial progress was made when Charles Husband was appointed as Consulting Engineer in 1949, and in 1950 a Royal Society committee gave its support to the proposed telescope, which was expected to cost between £50000 and £100000. The university applied to the DSIR for the costs of a preliminary study, and a formal proposal was written in 1951. The cost was estimated at £250000. In 1952 the estimate was revised to £333000, too much for the DSIR; fortunately the Nuffield Foundation offered to share the cost, and the project was approved in April. The 250 ft Mk I radio telescope was completed more than five years later, at more than double the cost (figure 2).

Apart from some underestimates and a serious increase in the cost of steel, there was one major design change that accounts for a large part of the increased costs. The original
design was for a wire mesh reflecting surface, suitable for operation at wavelengths of 1 m and longer, but the discovery in 1951 of the hydrogen line at a wavelength of 21 cm demanded an upgrade to a solid surface. This in turn increased vulnerability to wind pressure, requiring the addition of a stabilizing wheel. This was added in 1955, and the cost reached £550,000. The DSIR held a public inquiry in January 1956, by which time the project was practically unstoppable. Responsibility for the project and its cost was shared between the university, the DSIR and Husband, but in practice it was focused on Lovell himself, whose only aim was to have a completed and working telescope. Lovell was always grateful for the support of the university. A fuller story emerged when the files were opened more than 40 years later (see, for example, the discussion on legal matters in Bromley-Davenport (2013)).

Happily the great problems with the increasing cost of the telescope were soon overtaken by immediate operational success.

On 4 October 1957 Sputnik I was launched by the USSR. The Mk I radio telescope was nearly enough complete for Lovell to install a simple radar, which by 12 October was able to track the launch vehicle. No other radar existed that could do so. Lovell’s telescope suddenly made him an international hero. The cost overrun, which had reached £260,000, was met by the DSIR and the Nuffield Foundation, with the final contribution of £50,000 paid by Lord Nuffield in May 1960. The telescope could now settle down to its planned programme of research.

**Astronomy with the 250 ft telescope**

As soon as the 250 ft telescope came into operation, Bernard Lovell, with collaborators, began two observing programmes in which its large collecting area could make a significant contribution. One was the search for radio emission from stars that were known to flare optically. Was there an equivalent of the giant radio bursts from the Sun and could they be a significant contributor to the radio emission from the Galaxy? The second contribution was a measurement of the low-frequency spectrum of the strongest radio sources.

In 1950 the International Astronomical Union recognized flare stars as a new type of variable star. UV Ceti, a binary star, is the prototype. To obtain a convincing detection of radio flares, it was necessary to have an optical detection at the same time, as was the case for solar bursts. A campaign including three northern optical telescopes was run during the period September 1958 to April 1960. Fifteen significant events were detected in five flare stars at both optical and radio (100, 158 and 240 MHz) frequencies (28, 29). The radio spectrum was similar to that of solar bursts and was presumed to be via the synchrotron mechanism from relativistic electrons spiralling in enhanced magnetic fields in the stellar envelope (30). Modern interest in flare stars continues (32) and centres on high-angular-resolution radio studies in conjunction with optical spectroscopy.

The challenge to Lovell of understanding the low-frequency spectrum of the two brightest radio sources was first undertaken with the 218 ft transit telescope operating at 16.5, 19.0, 22.6 and 30 MHz (26). Observations could only be made in the summer, when Cassiopeia and Cygnus transit in darkness; at this time of day ionospheric scintillations are a minimum, as are interfering long-distance scatter signals. Both sources, which lie close to the Galactic plane, showed an abrupt fall in intensity at frequencies below 22 MHz. This was attributed...
to absorption in ionized hydrogen in the Galactic plane. Confirmation of these results was achieved when the steerable 250 ft telescope became operational (27). A 305 m baseline interferometer was constructed between the 218 ft and 250 ft telescopes working in the range 16.0–26.0 MHz. With lobe separations of 2–4°, the sources could be readily identified and their spectra determined. These results showed that their spectra were very similar, indicating that the synchrotron mechanism was at work for two quite different objects—one a Galactic supernova remnant and the other a distant extragalactic object.

The record of astronomical research up to 1970 with the Mk I telescope was well documented by Lovell (31). Since then the telescope, now affectionately known as the Lovell Telescope (figure 3), has been in almost continuous use, both as a single large aperture and as an element in interferometers such as eMERLIN and international networks.

**SPACE TRACKING ACTIVITIES**

The launch of Sputnik I in October 1957 was the start of the race between USSR and USA, in which Lovell and the new telescope were involved for more than a decade. Realizing that there were no operational radars capable of tracking space vehicles, he equipped the telescope with a radar that was already being developed for measuring the electron content of the ionosphere, including using echoes from future Earth orbiters such as the USA’s Vanguard. This was the first radar to obtain an echo from the carrier rockets of Sputniks I and II (figure 4). This demonstrated the capability of the telescope for both tracking and communicating with spacecraft, and for detecting intercontinental ballistic missiles (ICBMs). Jodrell Bank became both a reserve radar for detecting ICBM launches while the Fylingdales radars were
under construction, and at the same time a tracking station for the USA’s Pioneer and Ranger series of spacecraft and the USSR’s Luna and Venera series. The most notable result was the confirmation that Luna 2 had indeed hit the Moon, followed by the reception and publication of photographs of the Moon’s surface by Luna 9. Throughout these activities Lovell was in the delicate position of liaison with both sides of the space race, obviously being provided by both with sensitive information on launch dates and radio frequencies and dealing with recorded data that was in demand from both sides. He maintained throughout that Jodrell Bank was dedicated to scientific research, and that all results of his observations were freely available. A detailed account of Jodrell Bank’s involvement with the many space vehicle launches during this period is in the Jodrell Bank Archive (Sven Grahn, ‘Jodrell’s role in early space tracking activities’, http://www.svengrahn.pp.se/trackind/jodrell/jodrole1.htm).

These activities took place during the height of the cold war. Lovell was invited to visit the USSR in 1958, 1963, 1975 and 1976. To his surprise, in 1963 he was invited by his hosts to visit the tracking station at Eupatoria and was shown antennas whose existence was previously unknown in the West. On his return to the UK he naturally reported these to the defence authorities with whom he was in contact, whereupon his report was classified as secret and was not made available until after his death (Bromley-Davenport 2013). His diaries from that period are held by the Royal Society.

**Science and space policy**

Lovell’s wartime experience, and his plans for the Mk I telescope, inevitably drew him into consultations with government ministries. From 1953 to 1958 he served on the Air
Navigation Committee of the Aeronautical Research Council, and as a council member from 1955. In 1957, the year in which the telescope was completed, he joined the Scientific Advisory Council on Defence, and in 1962 the Strategic Scientific Policy Committee of the Air Ministry. Although these appointments ended with the creation of the Ministry of Defence in 1964, there were momentous consequences for Jodrell Bank. The unique capability of the telescope in tracking space vehicles by radar led to the provision by the Ministry of Supply of a powerful radar that would allow the telescope to track an ICBM launch from the USSR. This function was eventually taken over in 1963 by the BMEWS radar at Fylingdales, but from 1960 to 1963 Jodrell Bank acted as a front-line standby. The radar was, of course, available for scientific research on the Moon and the planets.

With more direct relevance to science, Lovell served on an Astronomy Committee at the formation of the DSIR in 1958, and as an original member of the Science Research Council in 1965, chairing the Astronomy and Space Research Board in 1970.

Lovell was an early advocate for developing a comprehensive UK space programme. By 1970 he was lamenting the demise of the Blue Streak launcher and the slow development of spacecraft instrumentation in the UK, and he became very critical of the expense of supporting the European Space Research Organisation. He was acutely aware of the difficult funding situation in the 1960s, especially as he was developing new plans for radio astronomy at Jodrell Bank.

BIGGER AND BETTER RADIO TELESCOPES

By 1960 Lovell was already looking at the possibilities for larger steerable radio telescopes. The worst problem seemed to be the windage when looking towards the horizon; with Husband again as consultant, Lovell proposed to expand horizontally rather than vertically, making an elliptical reflector surface. A comparatively small version, the 38 m × 25 m Mk II, was built in 1964 both for observational needs and as a prototype for a much larger version (figure 5). In 1966 another of the same size was built as a much lighter structure, for use with the Mk I as an interferometer. This, the Mk III telescope, was sited at Wardle, 24 km from Jodrell Bank, and was intended to be demountable for erection at a more distant site. By this time the condition of the Mk I was causing some anxiety, and in 1970 an extensive reconstruction was undertaken. The performance was greatly improved, with a more accurate reflecting surface, and gravitational deflections were reduced by the addition of a large new load-bearing wheel. This conversion gave the telescope its present appearance; it was renamed the Mk IA. On its 40th birthday in 1997 it was given its present name, the Lovell Telescope. Most recently, in 2003 the surface was replaced yet again to improve its performance even further.

The aspiration of building a bigger telescope had given way to the necessity of reconstructing the Mk I, and to the almost simultaneous demands on the Science Research Council by Martin (later Sir Martin) Ryle FRS to fund his One Mile Synthesis Telescope at Lords Bridge, near Cambridge. The project did, however, continue and reached the stage of a design for a 120 m diameter telescope, known as Mk V. When it appeared that the costs of this would be insupportable, the emphasis switched to long-baseline interferometry, using an array of radio telescopes distributed at distances up to 240 km. This became the Multi-Element Radio Linked Interferometer Network, or MERLIN; after improvements in 2009 it became the synthesis telescope eMERLIN, which is run by the Research Council as a national facility.
Lovell was much in demand for public lectures on astronomy, cosmology, philosophy of science, and science policy. Most notably he gave the BBC Reith Lectures, published as ‘The individual and the universe’ (1958; http://www.bbc.co.uk/programmes/p00h9ld8/episodes/guide). Among many other named lectures, he gave the Gregynog Lectures (1962), the Halley Lecture (1964) and the Royal Institution Christmas Lecture on Exploration of the Universe (1965). In 1975 he gave the Presidential Address (‘In the centre of immensities’) to the British Association meeting in Guildford.

The Visitor Centre and the Jodrell Arboretum

Public interest in Jodrell Bank was encouraged by Lovell, but he was astonished by the huge crowds that came when the Mk I telescope first moved and obtained the radar echo from the carrier rocket of Sputnik I. Lectures were hastily arranged in a marquee, and soon a Visitor Centre was constructed, complete with a planetarium, which became a major educational resource for schools over a large catchment area. A rebuilt centre, known as the Discovery Centre, opened in 2011. Since its inception in 1966, the centre has welcomed an average of 100000 visitors a year. As a uniquely accessible operational scientific instrument, the Lovell Telescope has inspired generations of schoolchildren with an interest in astronomical research and science in general.

In 1971 Lovell obtained a grant from the Granada Foundation to establish the Granada Arboretum on 35 acres adjacent to the Visitor Centre at Jodrell Bank. Some 2000 species of Northern Hemisphere trees and shrubs were planted over the next decade. These included the National Collections of Sorbus and Malus (crab apple) with a large selection of Crataegus
(hawthorn). The planning gave interesting views of the Jodrell Bank telescopes and panoramas of the Pennines. The Heather Society’s *Calluna* collection was a feature of the display at various times during the year. Lovell was pleased to see the upgrade of the Arboretum and the Discovery Centre in the new millennium. This included a redesign of the arboretum to incorporate a ‘Galaxy garden’ as well as seven smaller gardens by the well-known garden designer Chris Beardshaw.

**THE QUINTA ARBORETUM**

The Edwardian house known as The Quinta, in the Cheshire village of Swettenham, was the Lovell home from 1948. With its several acres of surrounding land, Bernard used the opportunity to establish a significant garden around a small lake. By the 1960s this had become a serious project with a wide range of trees and shrubs from around the world. The arboretum now covers 28 acres and includes more than 2000 species, some very rare. The National Collections of *Pinus* and *Fraxinus* (ash) are of particular interest, along with an extensive collection of oaks. Autumn brings a colourful display of flowering shrubs (see Lees-Milne & Verey 1982). The Quinta Arboretum is now open to the public; it is managed by the Tatton Garden Society.

**CRICKET**

Apart from his love of the game, Bernard Lovell used cricket as a distraction from tensions of telescope acquisition and construction. As soon as the family was settled in Swettenham he joined the local Chelford Cricket Club and was soon made captain. He was mainly a bowler but was also a stylish batsman. The drying pitch on the slope of the small Chelford stream was an asset to his bowling. In the summer, Saturday afternoons were sacrosanct to the game of cricket.

A great advantage of being near Manchester was the easy access to Old Trafford, the home of Lancashire Cricket Club. His strong allegiance to Gloucestershire county (in the person of Walter Hammond) was soon switched to Lancashire (Cyril Washbrook). As Vice-president (from 1982), and subsequently President, he made his contribution to the club by proposing aids to umpires for when difficult decisions were required, particularly in areas around the stumps (for example lbw, caught-behind or run-outs). His ideas about measuring light levels under cloudy conditions were accepted by the club; light meters were installed showing both the umpires and the public the light conditions. He was an adviser to the Test and County Cricket Board in deciding the further aids to umpires that are familiar today.

**MUSIC**

Throughout his life Lovell was a keen musician, playing the piano and organ and supporting local music societies. In particular, he was organist at St Peter’s Church, Swettenham. He served as President of the Chopin Society and of the Guild of Church Musicians, and as Master of the Worshipful Company of Musicians.
Bernard Lovell had a very happy family life (figure 6). His wife, Joyce, who died on 8 December 1993, was reputed to be in firm control of the enthusiastic texts of his public lectures; she was the greatest possible support for him during the many stressful periods of his career. Through their five children, the family had extended to no fewer than 14 grandchildren and 14 great-grandchildren at the time of his death.

A WIDER PERSPECTIVE

Bernard Lovell’s family background and his early enthusiasm for science led him to a lifelong concern with deep questions of science and religion. This is reflected in his early essay *Science and civilization* (8), and particularly in his BBC Reith Lectures. In the last of his Reith Lectures he said:

On the question of the validity of combining a metaphysical and physical process as a description of creation, this, as I said earlier, is the individual’s problem. In my own case, I have lived my days as a scientist, but science has never claimed the whole of my existence. Some, at least, of the influence of my upbringing and environment has survived the conflict, so that I find no difficulty in accepting this conclusion. I am certainly not competent to discuss this problem of knowledge
outside that acquired by my scientific tools, and my outlook is essentially a simple one. Simple in the sense that I am no more surprised or distressed at the limitation of science when faced with this great problem of creation than I am at the limitation of the spectroscope in describing the radiance of a sunset or at the theory of counterpoint in describing the beauty of a fugue.

He is remembered with great affection by his family and by his many friends and colleagues.

ACKNOWLEDGEMENT

The frontispiece photograph is reproduced by courtesy of Jodrell Bank, University of Manchester.

AWARDS AND HONOURS

The following are a few of the numerous awards won by Lovell.

1946 Officer of the Order of the British Empire
1955 Fellow of the Royal Society
1960 Royal Medal of the Royal Society
1961 Knight Bachelor
1964 Honorary Fellow of the Society of Engineers
1967 Honorary Degree (Doctor of Science), University of Bath
1969–71 President, Royal Astronomical Society
1970 Vice-president, International Astronomical Union
1974 Member, American Philosophical Society
1975–76 President, British Association
1980 Benjamin Franklin Medal
1981 Gold Medal of the Royal Astronomical Society

REFERENCES TO OTHER AUTHORS

Alfred Charles Bernard Lovell

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2004 The cavity magnetron in World War II: was the secrecy justified? *Notes Rec. R. Soc.* 58, 283–294.