Jodrell Bank Observatory

Nomination for Inclusion in the World Heritage List

Nomination Document

Cover image: Anthony Holloway

Image: Tim O'Brien

World Heritage List

Nomination Form

Convention Concerning the Protection of the World Cultural and Natural Heritage

Under the terms of the Convention concerning the Protection of the World Cultural and Natural Heritage, adopted by the General Conference of UNESCO in 1972, the Intergovernmental Committee for the Protection of the World Cultural and Natural Heritage, called 'the World Heritage Committee' shall establish, under the title of 'World Heritage List', a list of properties forming part of the cultural and natural heritage which is considers as having Outstanding Universal Value in terms of such criteria as it shall have established.

The purpose of this form is to enable States Parties to submit to the World Heritage Committee nominations of properties situated in their territory and suitable for inclusion in the World Heritage List.

This Nomination Document has been prepared in accordance with the 'Format for the nomination of cultural and natural properties for inscription in the World Heritage list' issued by UNESCO.

This form has been completed in English and is sent in two copies to:

The Secretariat
World Heritage Centre
UNESCO
7 Place de Fontenoy
75352 Paris 07 SP
France

Jodrell Bank Observatory

Nomination for Inclusion in
the World Heritage List

Foreword

On behalf of the United Kingdom Government, as State Party to the World Heritage Convention, I am pleased to submit the Jodrell Bank Observatory for inclusion on the World Heritage List.

Since the United Kingdom ratified the World Heritage Convention in 1984, we have been delighted to welcome the inscription of 31 sites in the UK and its Overseas Territories. We remain committed to identifying and protecting places that have outstanding universal value, including The University of Manchester's Jodrell Bank Observatory.

Jodrell Bank Observatory is the earliest radio astronomy observatory in the world that is still in existence and is a key representative site for astronomical heritage. It is the one remaining site, worldwide, that includes evidence of every stage of the post-1945 emergence of radio astronomy, and, as such, played a pivotal role in expanding our understanding of the universe.

In 1945, scientists from the University of Manchester began work at the site, chosen because it was free from radio interference. In order to facilitate their work, they created new equipment which aimed to push the boundaries of knowledge, including the iconic Lovell Telescope. This development imprinted science onto the landscape of the site. The creation of the Observatory is well-documented and it has been maintained to such a high standard that it still carries out world-leading research today. It currently hosts the UK's national array of seven radio telescopes, and collaborates with many other institutions worldwide. It is an iconic landmark in the UK and an educational destination, teaching future generations of astronomers about the universe.

I present this nomination dossier detailing the case for this extraordinary site to take its rightful place on the World Heritage list. I wish to thank the Jodrell Bank team, the University of Manchester, Historic England and the UK National Commission to UNESCO for contributing to the development of this nomination.

John P. Glen

John Glen MP,
Minister for Arts,
Heritage & Tourism, DCMS

Image: The University of Manchester

Image: Anthony Holloway

Preface

The University of Manchester is one of the UK's leading universities, with a worldwide reputation for the strength of its scientific research, built upon a long history of discovery and innovation.

There is no better symbol of this than Jodrell Bank Observatory, which emerged from the post WWII blossoming of research and technology to become the symbol of science and engineering that it is today.

As well as its commitment to world-leading research and outstanding teaching, the University prioritises social responsibility, and is delighted to welcome visitors, schools and community groups to Jodrell Bank to engage with the heritage, cultural activity, education and research of the site.

While the University owns and operates the site, it is aware that it holds it "in trust" for future generations. There is a great pride in the 'sense of place' that the Observatory, and especially the iconic Lovell Telescope, creates for communities both near and far.

It is therefore a great honour for the University to support the nomination of Jodrell Bank Observatory for inclusion on the World Heritage List. We look forward to our teams continuing to work with the many local, national and international people and communities who will be able to enjoy and celebrate this unique site, its stories, and its work, for years to come.

Professor Dame Nancy Rothwell FRS
President and Vice-Chancellor of
The University of Manchester

Image: NASA/CXC/SAO/STScI/NSF/NRAO/AUI:VLA

Executive Summary

State Party

United Kingdom

State, Province or Region

England (Cheshire East administrative authority)

Name of Property

Jodrell Bank Observatory

Geographical Coordinates to the nearest second

N 53° 14' 05"   W 2° 18' 18"

Textual description of the boundary of the nominated property

The boundary of the nominated property has been drawn so that it encompasses all of the areas and attributes that are a direct and tangible expression of its Outstanding Universal Value.

The property is 17.38 hectares in size and encompasses the site of the Jodrell Bank Observatory, which is wholly owned by the University of Manchester. The University owns further land around the boundary of the nominated property, which allows it control of its immediate surroundings. The Buffer Zone has been established using the pre-existing radio silence zone (similar to a 'dark night sky' zone around an optical observatory), which is an area of 18569.22 hectares around the property.

A4 or A3 size map(s) of the nominated property, showing boundaries and buffer zone (if present)

See maps enclosed in dossier.

Criteria under which property is nominated (itemize criteria)

(i), (ii), (iv), (vi)

Draft Statement of Outstanding Universal Value

a. Brief Synthesis

Jodrell Bank Observatory is the earliest radio astronomy observatory in the world that is still in existence.

It is the one remaining site, worldwide, that includes evidence of every stage of the post-1945 emergence of radio astronomy, and, as such, played a pioneering role in a revolution in our understanding of the Universe.

Radio astronomy showed that there is far more to the Universe than meets the human eye, and that entirely new information can be obtained by using radio waves – a revolution exemplified by a range of features across the site.

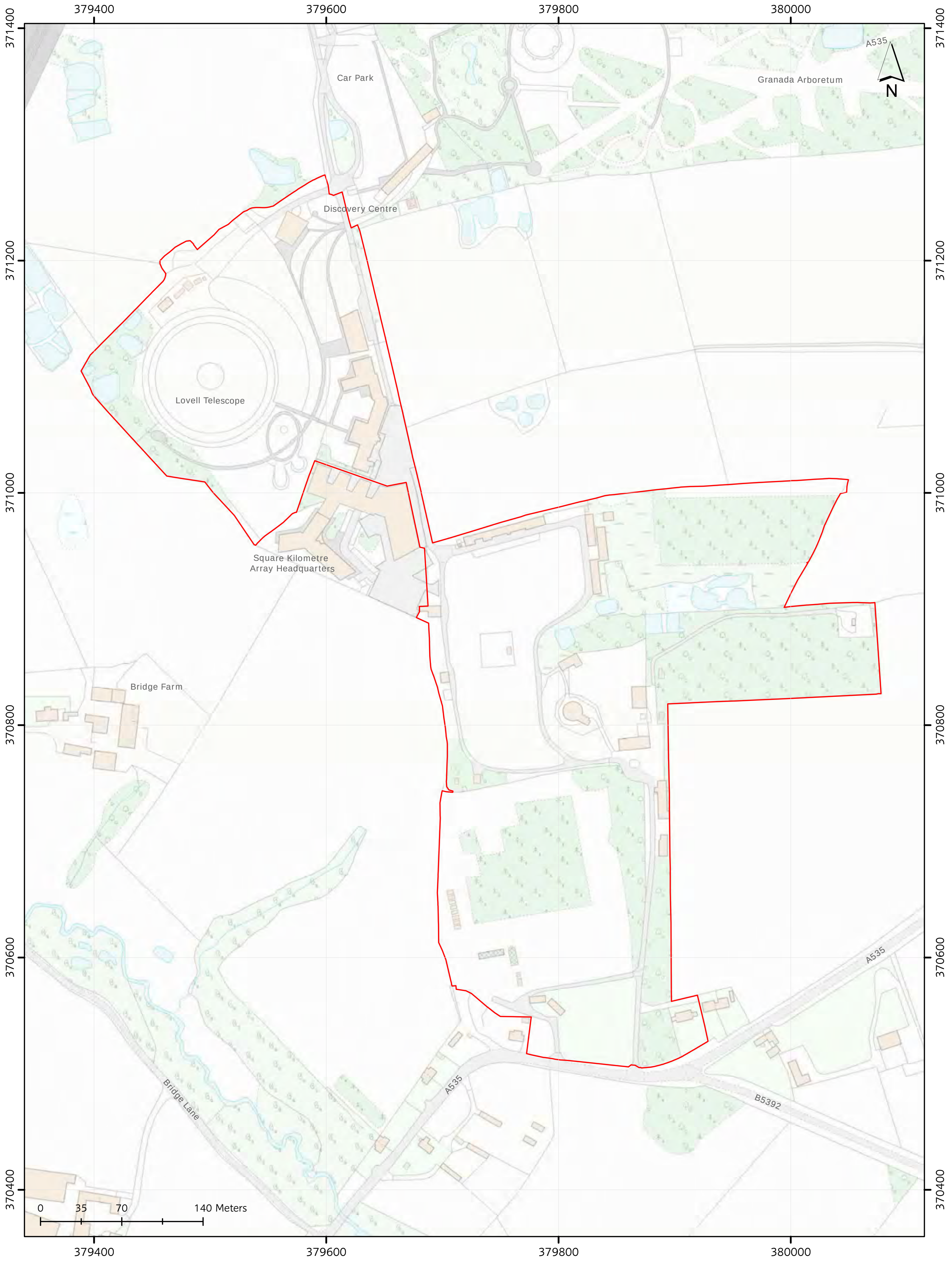
Located in rural Cheshire in northwest England, the Observatory, which is part of the University of Manchester, is dominated by the iconic Lovell Telescope, the first very large fully-steerable radio telescope in the world. Constructed between 1952 and 1957, its first act was to track the carrier rocket for Sputnik 1, the first satellite ever launched into orbit and humanity's first step into space. The Telescope was the largest of its kind in the world for 15 years and inspired the construction of many other instruments worldwide.

The property encompasses a number of other radio telescopes, including the Mark II Telescope, and functional buildings on a 17.38-hectare site. Many of these are original structures and instruments, while remnants of earlier structures also persist, some of them below ground.

The character of the Observatory has been determined by the evolution of radio astronomy. Scientists first arrived at the southern boundary of the site in 1945, and then moved northwards as they made new discoveries, creating new equipment and experiments, thereby imprinting the development of the science on the landscape of the site.

The Observatory is not solely a scientific monument as it still carries out world-leading research. It currently hosts the UK's national array of 7 radio telescopes, and collaborates with many other radio telescopes worldwide.

The scientific importance of the property is demonstrated by the influence of its work, evidenced by the data and scientific publications in its archive, and its continuing research.



Coordinate System: British National Grid
Projection: Transverse Mercator
Datum: OSGB 1936
Scale: 1:3,000 at A3

KEY:

Nominated Property Boundary

Map of the Nominated Property

b. Justification for Criteria

Criterion (i) represents a masterpiece of human creative genius
Jodrell Bank Observatory is an outstanding example of supreme scientific and technical achievement, which revolutionised our understanding of the Universe. The post-1945 emergence of the science of radio astronomy was a turning point in the progress of 20th century astronomy. At Jodrell Bank, evidence of every stage of this is present in the property. This includes: the early use of recycled radar equipment; the construction in 1947 of the Transit Telescope (then the world's largest telescope); and the creation of the iconic Lovell Telescope in 1957 (superseding the Transit Telescope as the world's largest). The development of the Observatory, as a whole, was driven by the vision, determination and creative scientific genius of Sir Bernard Lovell and the team that gathered around him.

Criterion (ii) exhibits an important interchange of human values
The Jodrell Bank Observatory contains numerous examples of physical evidence of the international interchange of ideas at a significant time in history, as the new science of radio astronomy and the space age developed during the 1940s-60s. This is epitomised by the structures of the iconic Lovell Telescope and the Mark II Telescope, which dominate the site and effectively 'bracket' the property. It is also embodied in the character of the landscape itself and the structures that housed and exemplify the work that was at the heart of this unique flowering of international cooperation and exchange of values and ideas. These included developments in astronomy, but also extended more widely to include, for example, quantum optics; interferometry; spacecraft tracking and satellite communications.

Criterion (iv): an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history
Jodrell Bank Observatory is the unique technological and landscape ensemble, globally, that exemplifies, through its surviving physical evidence, the transition from traditional optical astronomy to modern multi-wavelength astrophysics that took place during the 1940s and the years that followed. Developments at all stages of this history took place within its boundaries, with many of the earliest features, or their locations, extant and recognisable. This was a significant stage in the history of understanding our place in the Universe.

It was also a significant stage in the peacetime development of 'Big Science', which followed the Second World War, and was characterised by a leap in the scale of projects, paralleled by a leap in scale of funding and in numbers of collaborating scientists and engineers. While the size of the Lovell Telescope means that it is the most obvious feature of the site, it is, in fact, the Observatory as an ensemble that is at the heart of the property. The character of the landscape and the interrelation between buildings and structures speaks of the revolutionary developments that took place there, and represent this significant stage in human history.

Criterion (vi) directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance
Jodrell Bank Observatory is inextricably linked to the fundamental concept underpinning modern astronomy: that we live on a planet orbiting a star, one in a galaxy of several hundred billion stars, itself only one of a hundred billion galaxies in the observable universe.

When radio telescopes were first pointed at the sky, it became apparent that there were whole aspects of the Universe, including exotic objects previously unimagined, which ordinary (optical) telescopes cannot see.

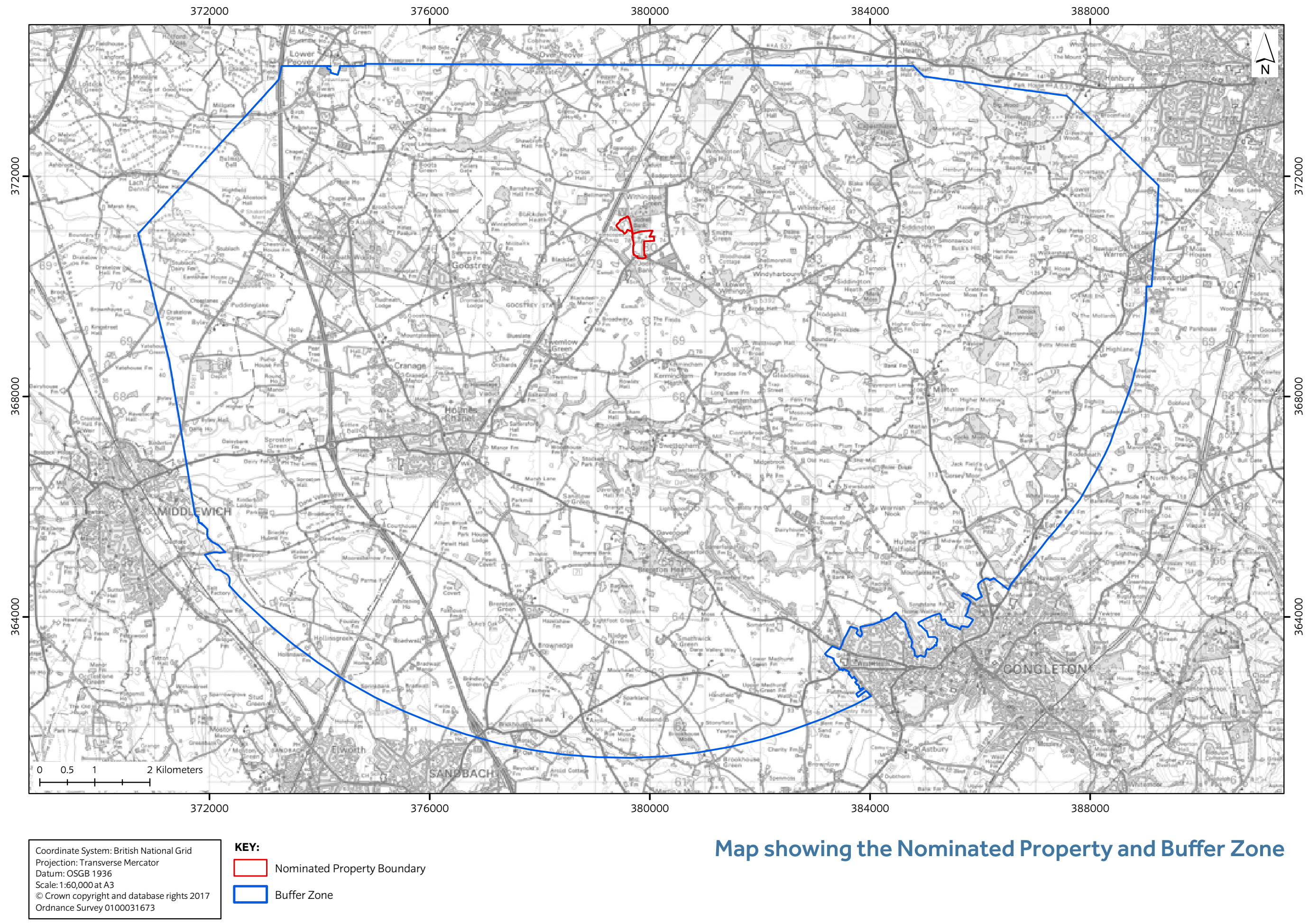
Jodrell Bank Observatory is intrinsically linked to this discovery – that there is far more to the Universe than meets the human eye, and that entirely new information can be obtained by using 'invisible' light, beyond the usual 'rainbow' of visible colours. Modern astrophysics now uses this 'invisible light' as a matter of course, to examine the Universe, but the first major step towards this was taken by radio astronomy.

c. Statement of Integrity

All the tangible attributes of the property sit within the site boundaries. The nominated property is solely owned by the University of Manchester, and the boundaries of the site are clearly identifiable in the Deeds of Ownership of the land. The property is generally in a good state of conservation. The integrity of some elements of the property is compromised (for example, only 5-10% of some of the original scientific instruments remain, as traces below ground). However, most of the buildings in the property are in good condition and the Grade 1 listing and continued research use of the Lovell Telescope and the Mark II Telescope has ensured that the integrity and function of the most iconic elements of the property have been retained.

d. Statement of Authenticity

Despite the rapid and continuing developments at Jodrell Bank, the site preserves good evidence for the emergence of the science of Radio Astronomy and retains a high level of authenticity due to its function as an observatory. The character of the Observatory landscape persists, major structures are preserved in working order and sites of all the major phases of development survive, even if in some cases only as archaeological evidence. The authenticity of this is supported by a very strong body of associated documentation, including many thousands of international research papers, a variety of archives and a huge number of archived media reports. The contributions of the property to the science of astronomy are documented extensively in scientific literature from its emergence to the present day.



Map showing the Nominated Property and Buffer Zone

e. Requirements for Protection and Management

The Lovell Telescope was awarded Grade 1 Listed status in 1988 and therefore enjoys full statutory protection under this and other planning regulations. In 2017, the Mark II Telescope was also Grade I listed and five other historical structures at the site were also listed at Grade II.

The Buffer Zone for the property (which is 18569.28 hectares in area) has been set up using the radio telescope protection zone around the Observatory , which was established by the Jodrell Bank Radio Telescope Direction (1973). (This is similar to an area protecting a 'dark night sky' around an optical observatory, and has acted as a de facto buffer zone since 1973).

The Jodrell Bank property is relatively small (17.38 hectares), has clear boundaries and a single owner. All elements expressing the OUV of the site sits within the boundaries of the property.

The property benefits from being solely owned by The University of Manchester, which has a robust and successful management system in place, including a site Governance Group, that takes oversight of all activities.

A Steering Group including all stakeholders will oversee the management of the World Heritage Site. It is also planned to establish a deemed strategy of consent with all relevant stakeholders in 2018/19.

The University of Manchester, owner of the property, is investing £15million in conservation of the property, in order to provide a good basis for future management.

The property also benefits from a very successful visitor facility, the Jodrell Bank Discovery Centre, which already attracts 185,000 visitors each year, including 26,000 school pupils on educational visits. The visitor facility has plans in place for the sustainable management of future visitation levels and recently secured funding of £20.5million (from various sources) for a new visitor gallery that will be constructed in the buffer zone.

Name and Contact Information of official local institution/agency

Organisation:
The University of Manchester

Address:
Professor Teresa Anderson MBE
Director
Jodrell Bank Discovery Centre
The University of Manchester
Macclesfield
Cheshire
SK11 9DL
UK

Tel:
+44 (0)161 306 9586

E-mail:
teresa.anderson@manchester.ac.uk

Web Address:
www.jodrellbank.manchester.ac.uk
and
www.jodrellbank.net

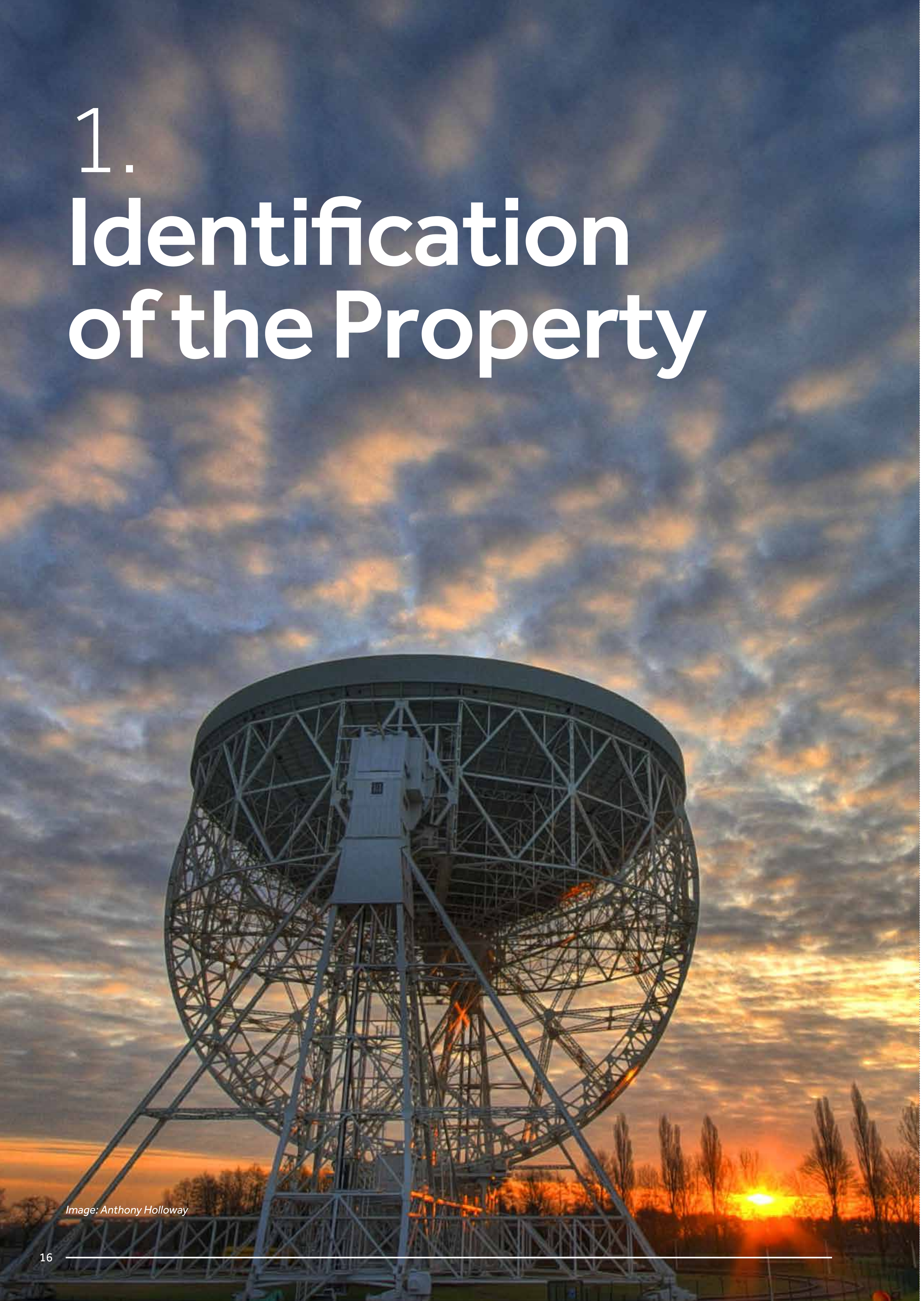


Image: Anthony Holloway

1. Identification of the Property

1.a Country (and State Party if different)

United Kingdom

1.b State, Province or Region

England (Cheshire East administrative authority)

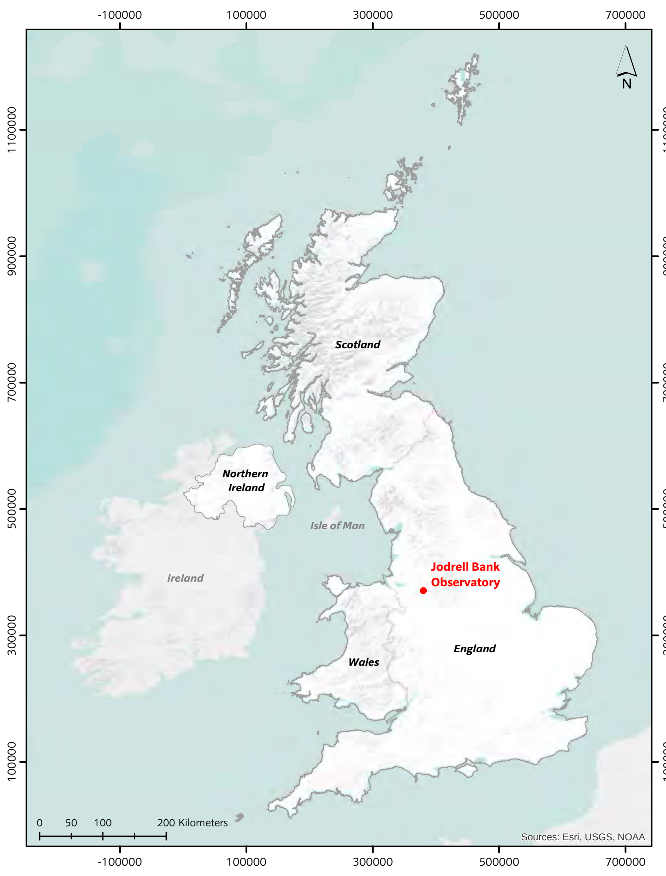
1.c Name of Property

Jodrell Bank Observatory

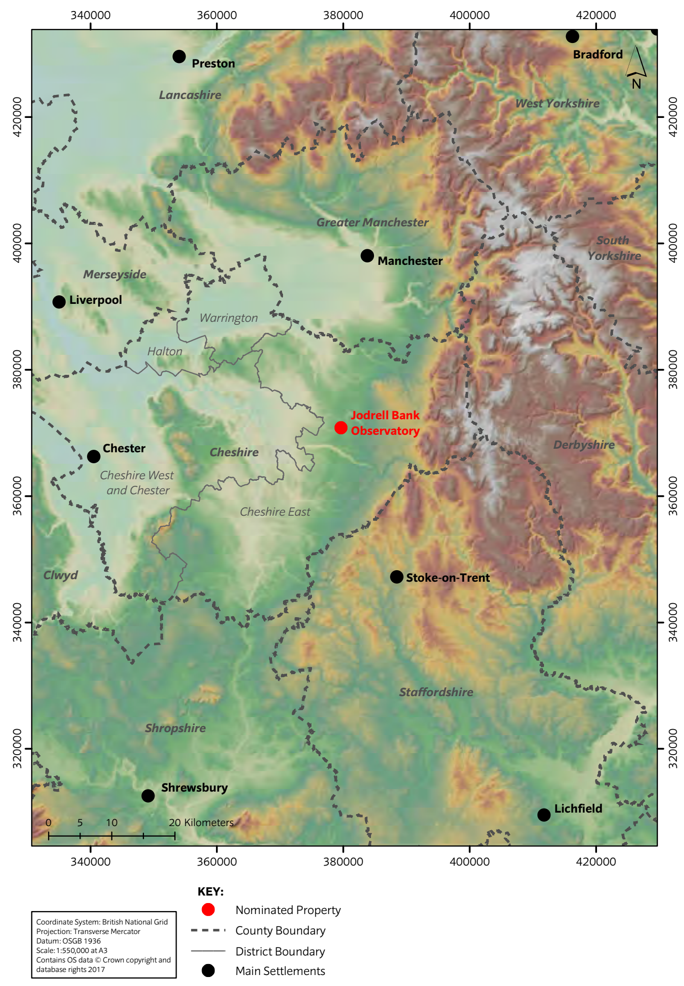
1.d Geographical Coordinates to the Nearest Second

N 53° 14′ 05″ W 2° 18′ 18″

[Note: This is a position on the Green just north of the tarmac square]



Map showing location of Jodrell Bank Observatory in the context of the United Kingdom



Map showing the location of Jodrell Bank Observatory, the Nominated Property

1.e
Maps and Plans Showing Boundaries of the Property

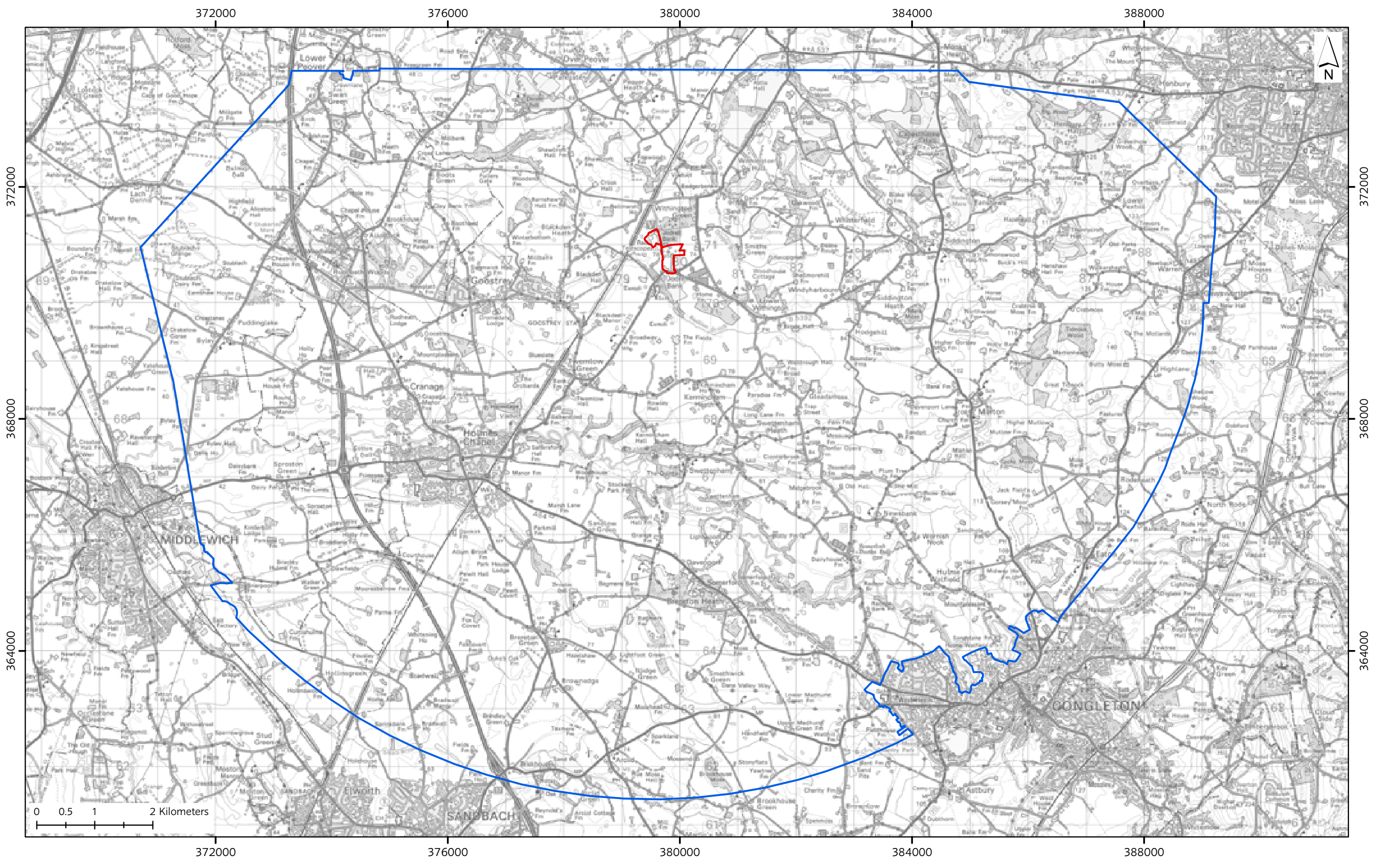
- Map showing the Nominated Property and Buffer Zone (this section)
- Map of the Nominated Property (this section)
- Map of property and surrounding area (Section 2.a.2)
- Map of Property and Buffer Zone, showing boundaries of local authorities 'Cheshire East' and 'Cheshire West and Chester' (Section 5.d)

1.f
Area of the Property

Area of nominated property:
17.38hectares

Area of Buffer Zone:
18569.22 hectares

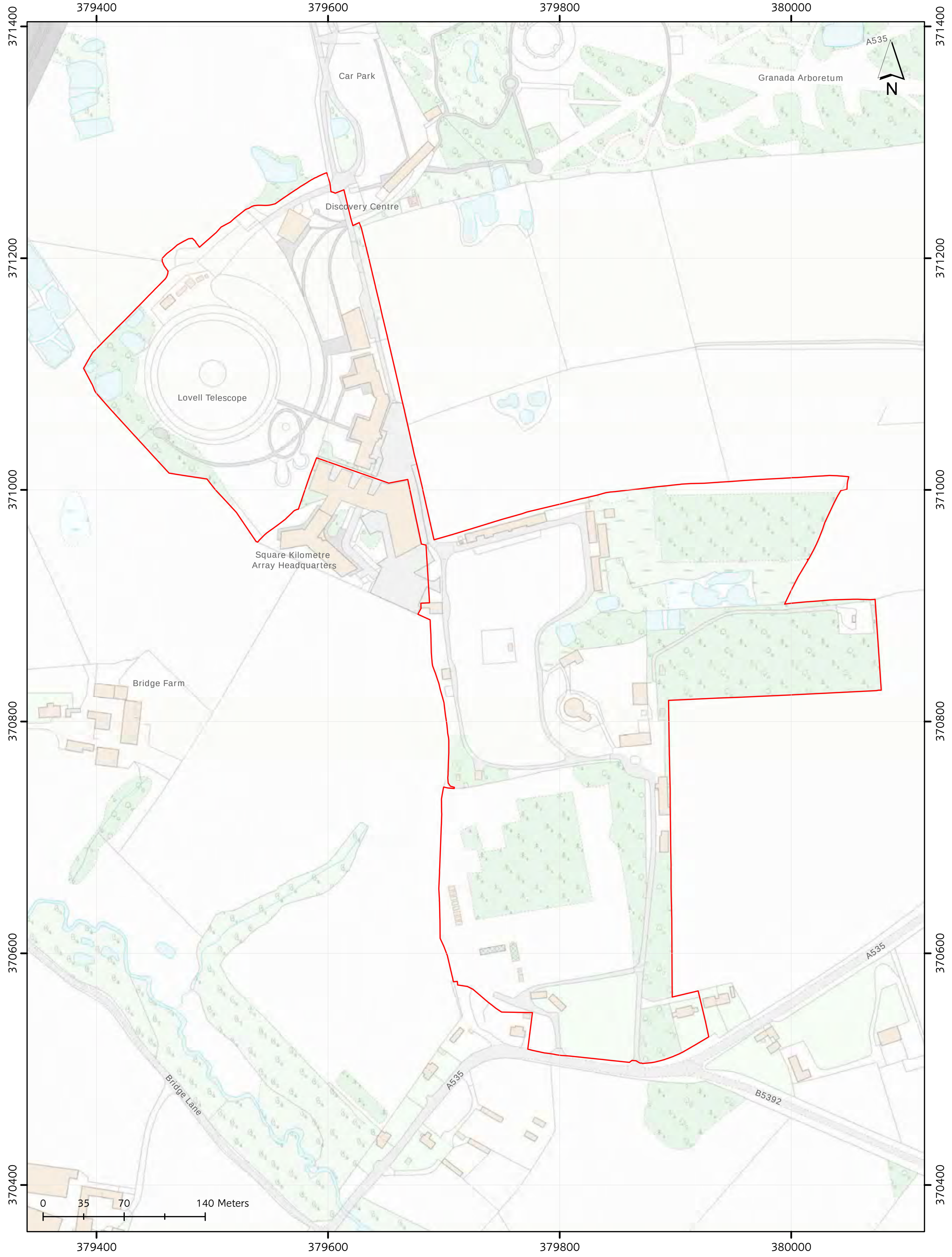
Total Area:
18586.6 hectares



Coordinate System: British National Grid
Projection: Transverse Mercator
Datum: OSGB 1936
Scale: 1:60,000 at A3
© Crown copyright and database rights 2017
Ordnance Survey 0100031673

KEY:
Nominated Property Boundary
Buffer Zone

Map showing the Nominated Property and Buffer Zone



Coordinate System: British National Grid
Projection: Transverse Mercator
Datum: OSGB 1936
Scale: 1:3,000 at A3
© Crown copyright and database rights 2017
Ordnance Survey 0100031673

KEY:
Nominated Property Boundary

Map of the Nominated Property

2. Description

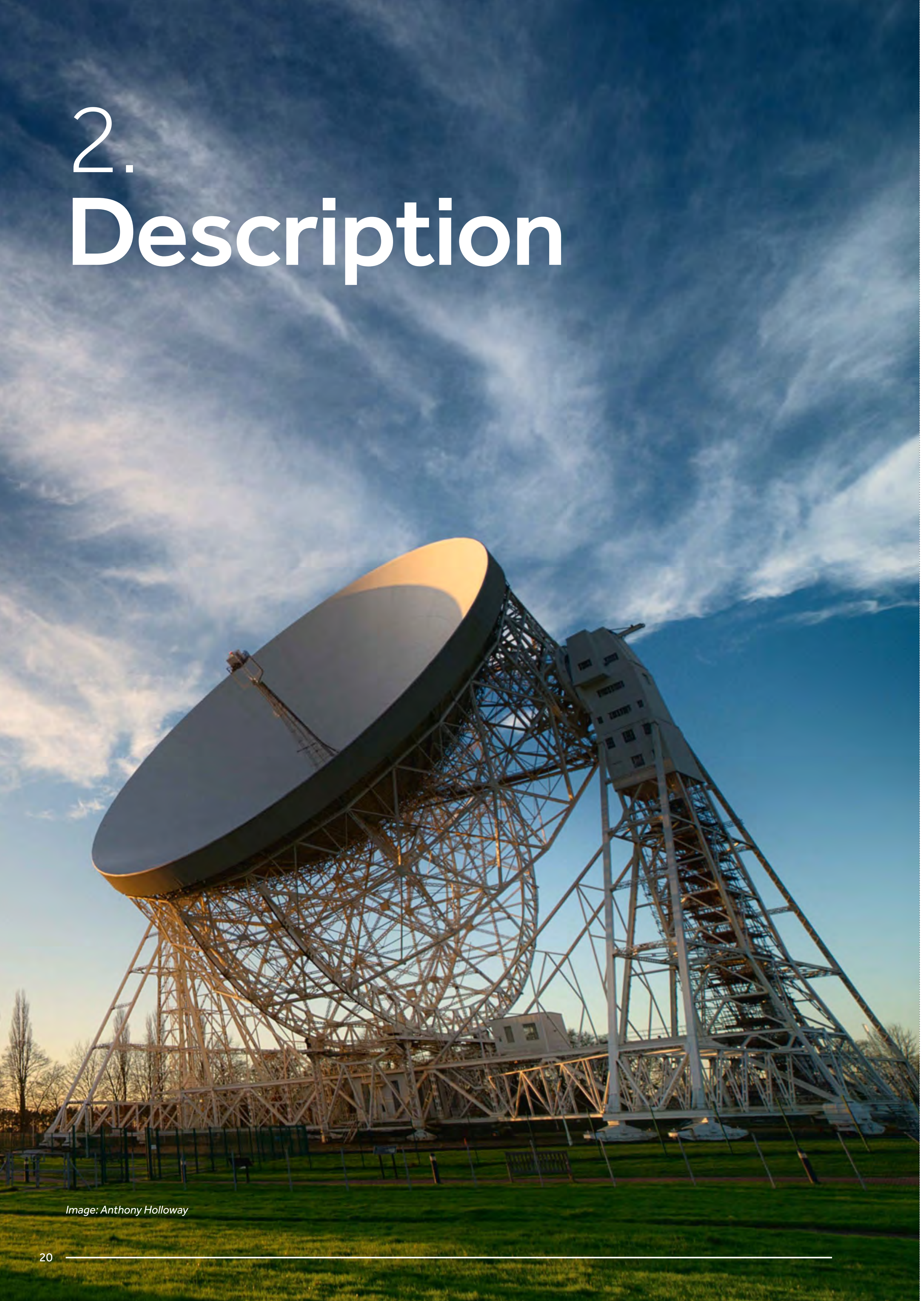


Image: Anthony Holloway

2.a Description of Property

2.a.1 Overview of the property

Jodrell Bank Observatory is the one remaining site, worldwide, that includes every stage of the post-1945 emergence of the new science of Radio Astronomy - which was humanity's first step into modern Astrophysics.

The property, which is part of The University of Manchester, is located in a rural area of Cheshire East in northwest England. The site is in open countryside and surrounded by agricultural land. There are a small number of residences bordering the site and a number of small settlements or villages within a 5 mile radius. The nearest large settlement is Macclesfield, at a distance of around 8 miles.

At the south end of the site is land formerly used as University Botany research grounds, including wooden gardeners' huts and the remains of glasshouses. A tarmac road through this area provides an entrance route for staff and leads to the Green. This area, which is at the heart of the site, is the location of the Grade I listed Mark II Telescope and is bounded by the ensemble of modest research buildings (some of which are now Grade II listed) in which much of the early work of the Observatory took place. This area also contains remnants and traces of early scientific instruments.

To the north of the Green, the site is dominated by the Grade I listed Lovell Telescope, which sits in a working compound containing a number of engineering sheds, and by its Control Building. This area also includes some of the modern buildings of the Discovery Centre used to welcome visitors and schools groups.

The first use of the property for radio astronomy occurred in December 1945, when Bernard Lovell arrived at the most southerly point of the site to begin observations of meteors using ex-army radar equipment. The site was selected because it was in the ownership of the University of Manchester (as it is now) and because it was free from the radio interference caused by trams passing the University campus within Manchester itself.

From that time onwards, scientific activity moved from south to north across the site with many new instruments developed, and then abandoned, as the field of radio astronomy was created.

While much of the early scientific equipment was demolished, or re-used in subsequent instruments, some of the remnants still survive either above or below ground.

Jodrell Bank Observatory is now the hub of the UK's national 217-km-wide array of up to seven radio telescopes ('e-MERLIN'). The signals from all seven telescopes are combined at Jodrell Bank so that the array operates as if it is a single Telescope, which has a similar resolving power to the Hubble Space Telescope. The Lovell and Mark II Telescopes are used as part of this array.

Along part of the western border of, and just outside, the property sits the International Headquarters for the Square Kilometre Array Organisation (SKAO), the international project planning the next generation large telescope for the world's radio astronomy community. This land is also in the ownership of the University of Manchester, but is not part of the nominated property, as it carries no attributes of the OUV. The SKA Organisation is due to become an International Treaty Organisation in the near future, demonstrating the interchange of ideas that underpins modern astrophysics.

To the north-west of the property, set around the Lovell Telescope, there are spaces open to the general public (part of the 'Discovery Centre') which include visitor facilities. The rest of the visitor facilities (and gardens that include an Arboretum) sit just outside the property to its north-east. These areas exemplify the tradition of public engagement at Jodrell Bank and are also essential to the management of visitors. All these facilities are on University-owned land.

The site now comprises a unique combination of attributes, which convey the Outstanding Universal Value of Jodrell Bank Observatory. Taken together, they represent the past, present and future of radio astronomy at Jodrell Bank, effectively laying down the progress of every stage of the history of radio astronomy on the landscape, from its emergence as a new science to the present day.

2.a.2
The Landscape and Layout of the Site

In this section we describe the features as follows:

- The Landscape and Layout of the Site
- The Lovell Telescope and the Mark II Telescope
- The Control Building
- The Green and associated Observatory Buildings
- The site of the Transit Telescope
- Sites and remnants of other early scientific instruments
- The Botany Huts

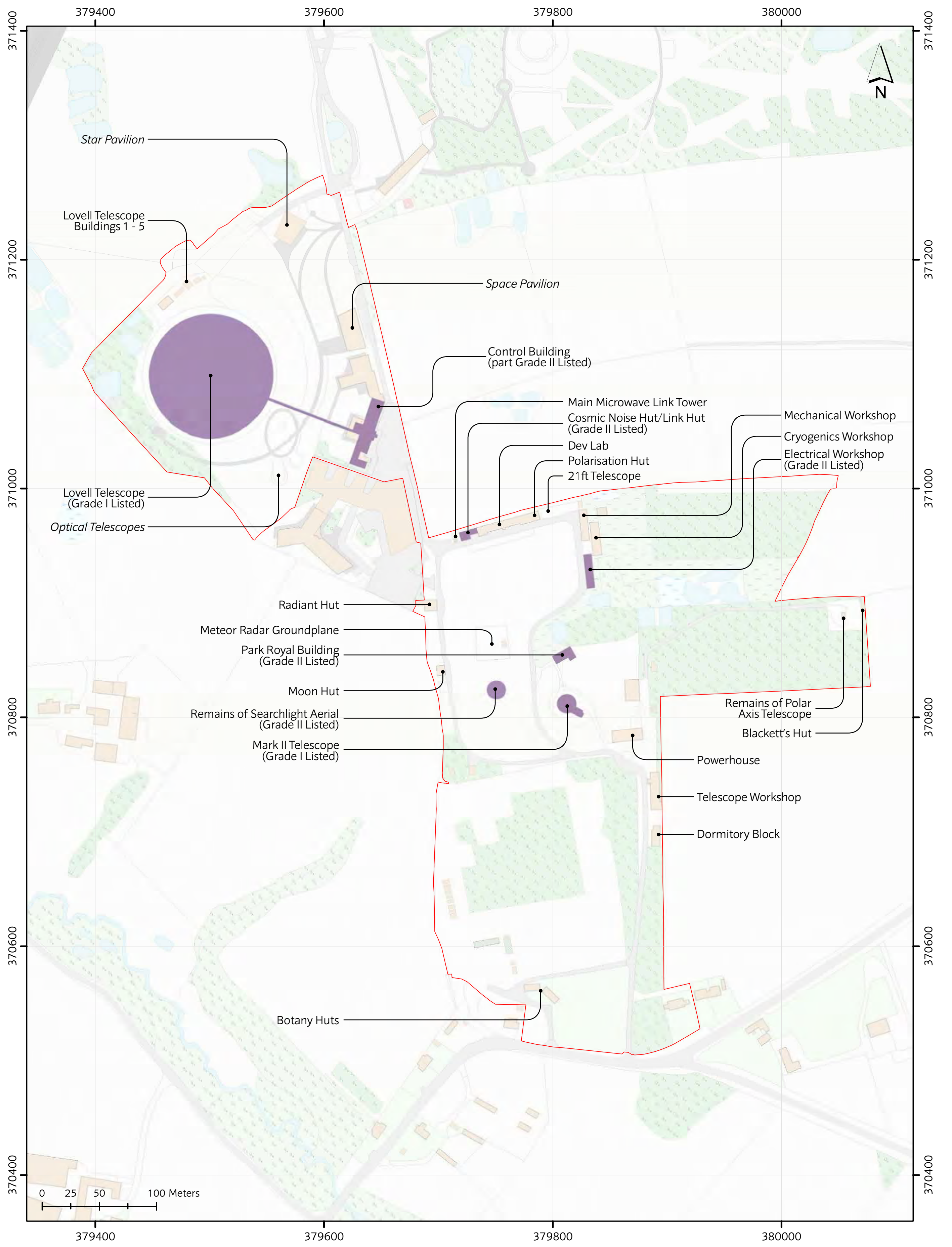
The configuration of the site (Figure 2.1) is a key element of its sense of place as a working Observatory. Largely determined by the evolution of the Observatory in the early days of the emergence of radio astronomy, the landscape is much the same today as it was then. In this section, we describe the current state of the landscape zones, moving through the property from the area now most in use (the north) to the area that is now less used (the south). The landscape zones in the nominated property are described in detail in the Conservation Management Plan Gazetteer (Included in dossier). The Gazetteer code numbers for each landscape area are given at the start of each paragraph below.

a. L03 – The field which once surrounded the Lovell Telescope has now been landscaped and provides public access via a circular tarmac path. Interpretation panels, interactive exhibitions and picnic tables are located across the area. The Control Building and its access path to the Lovell Telescope as well as the area immediately surrounding the base of the Lovell Telescope are fenced off and public access prohibited. Besides hard landscaping, the area comprises grassland with scattered specimen trees.

b. L05 – The Green: The Green is an open area of grassland around which circles a tarmac access road, alongside which stand the Observatory buildings created in the late 1940s, when the permanence of the Observatory was first established. It is the location of many of the attributes of the OUV of the site (e.g. the Mark II Telescope, the site of the Transit Telescope and other instrument sites and remnants, see below) and carries significant OUV in itself.

c. L06 – Blackett's Wood: Originally known as Blackett's Field (named after Professor Patrick Blackett, the charismatic Chair of Manchester University's Physics Department who carried out experiments on magnetic fields there), this area of the site is now heavily overgrown and wooded. It is included here not because of Blackett's work (which was unrelated to the emergence of radio astronomy) but because it is the site of many experiments in the 1950s and 1960s and requires investigation and evaluation.

d. L07 – Former Botany Grounds: This area is the location of the Botany Huts, which are a key attribute of the OUV of the property, as the initial arrival point of Bernard Lovell at the site. Apart from these buildings, the landscape itself does not carry OUV, as work on the emergence of radio astronomy transferred to the Green area quite soon after Lovell's arrival and there are no archaeological remains of astronomical activities. The majority of this area comprises rough grassland; a recently constructed car park and staff community allotment; and plantations of even-aged stands of poplar, ash, and alder with no real shrub layer. The southern access road to the property crosses this area south to north, and the open grassland area is crossed by a track joining the main driveway to the botany department structures in the west.



Coordinate System: British National Grid
Projection: Transverse Mercator
Datum: OSGB 1936
Scale: 1:3,000 at A3
© Crown copyright and database rights 2017 Ordnance Survey 0100031673

KEY:
Nominated Property Boundary
Listed Buildings

Figure 2.1: Map of property and surrounding area

2.a.3

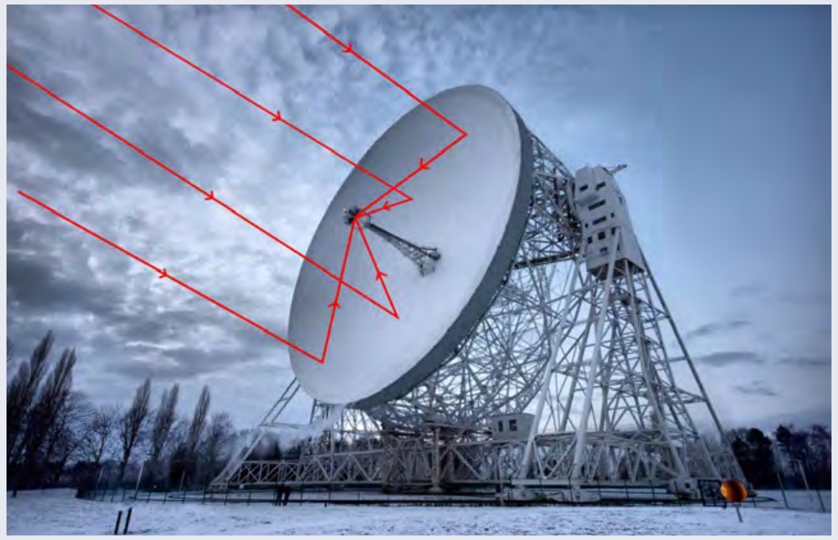
The Lovell Telescope and Mark II Telescope

The Lovell Telescope

The most prominent feature of the Observatory is the Lovell Telescope (Figure 2.2), the largest fully steerable radio telescope in the world on completion in 1957, and which still operates as the third largest on Earth. The Telescope, which is a Grade I listed structure, stands 89m high (around the same height as the Big Ben clock tower in Westminster), dominating the Cheshire plains.

Active in both the Space Race and the Cold War, the Lovell Telescope now constitutes a huge, internationally-recognised, public landmark within an area that stretches west from the Pennines out to the Welsh border and is visible for many miles.

However, despite the fact that it is the most publicly recognisable part of the Jodrell Bank site, it effectively represents the culmination of the work that went before it and there are many other elements of the site that are highly important in terms of its heritage.



Radio Telescopes

A radio telescope collects radio waves coming from space in a similar way to an optical telescope, which collects visible light. In general, the radio waves are collected by a dish, which reflects the radio waves to a receiver at the focus. This is similar to the way that an optical telescope lens or mirror reflects light towards a focus at which there is a camera or eyepiece.

In a radio telescope, the receiver is an antenna, which transforms the radio waves into electrical signals, which pass through amplifiers and signal processing electronics and are analysed by astronomers using computers. The analysis yields information about a wide range of astronomical objects, such as super-massive black holes at the heart of distant galaxies, pulsars (the spinning, collapsed cores of exploded stars) and the origin of the Universe in the Big Bang.

Parallels can be drawn between Jodrell Bank and Stonehenge in this – both have iconic structures that are generally held to signify the complex as a whole, but both also have a wealth of other attributes that are part of the OUV of the property.

The Telescope was conceived by Sir Bernard Lovell, founder of the Jodrell Bank Observatory, and designed by engineer Charles Husband. It is made of steel and is largely painted white, with some sections painted grey. The main reflector dish is a colossal 76 metres in diameter and is paraboloid in shape. It sits nested within the dish that was installed at the time of construction. This original bowl of welded sheet steel is still extant in form, although in the process of being replaced, with the guidance of Historic England. The support structure for the later bowl is carried through the earlier bowl to link with the original steel frame.

The dish arrangement is mounted on bearings that were recycled from the gun turrets of two battleships, HMS Royal Sovereign and HMS Revenge. The bearings sit at the top of two triangular steel lattice towers (known as Red and Green Towers) that rest on wheel bogeys running on two concentric tracks of double rails. The head of each tower is enclosed to form a multi-level equipment space containing bearings, racks and drive motors. These are accessed by lifts within each tower.

The outer diameter of the rail track is 107m. The track allows the Telescope to rotate in azimuth (horizontally) so that it can point in any direction. The horizontal (azimuth) drive is powered by 50 horse power electric motors at the foot of each tower. The bearings allow the Telescope to move in elevation (vertically) so that it can be tilted to point at any particular height,

Image: Anthony Holloway

Figure 2.2: The Lovell Telescope.

driven by electric motors at the top of the towers. These two movements allow it to observe any point in the sky above it.

The dish surface is accessed via lifts in the towers that support the bearings and walkways that run between the towers at high level. At the centre of the dish a lattice tower supports the radio receiver, which is housed in a cryogenic cabinet and reached via a cage lift.

One of the walkways also accesses the original 'swinging lab' that hangs beneath the centre of the dish and was originally used (before the advent of computers) by scientists taking readings from the telescope signal.

The lifts of the towers have been replaced, but retain their original control buttons. The equipment room at the base of the Telescope retains much original 'Brush' electrical power equipment, and analogue control and monitoring equipment, as well as modern replacements for many of these items. A substantial amount of modern data cabling is also present. The emergency generator house contains a modern diesel generator.

Below the centre of the Telescope is the cable turning chamber. This in turn is connected to the tunnel that links the Telescope and Control Building. The annular chamber has smooth concrete walls and contains modern data and control cabling. Central in the room is the tall metal drum containing the cable-turner, which allows the cables entering the telescope to rotate with it through 420 degrees.

At the southeast, it gives access to the tunnel to the Control Building, along which the cabling runs in wall trays. The tunnel has plain shuttered concrete walls. It is included (up to the point where it joins the Control Building) in the Grade I listing of the Telescope. The curtilage of the Telescope is generally interpreted to encompass its compound and up to the line of the Control Building west wall (to the Telescope's east).

Figure 2.3: The Mark II Telescope (foreground) and the Lovell Telescope (background).

Image: Anthony Holloway

The Mark II Telescope

The Green area at the heart of the property is dominated by the Mark II Telescope (Figure 2.3), which is located to the southeast corner of the area. It is the third largest radio telescope in the UK and is characterised by the distinctive concrete mount for the telescope dish, which itself has an elegant elliptical shape. It was Grade I listed in 2017.

The telescope was designed by Husband and Co (the designers of the Lovell Telescope), in 1960 and construction, by Arrol Engineering, took place between 1962 and 1964.

A variant of the Mark II design was used for the Goonhilly 1 telescope built to receive the first TV signals relayed by the Telstar satellite across the Atlantic.

The parabolic reflecting surface of the Mark II Telescope had an elliptical outline to increase the collecting area over a circular aperture (it was a pilot for a much larger telescope which was never constructed). It was the first telescope of any type in the world to be controlled by a digital computer, the Ferranti Argus 100. This was one of the very first computers designed for real time control and built using germanium transistor logic and a ferrite core store.

The Telescope has a building at its base that houses the mount and engine room, a first-floor central room and bracket. All of these are made of pre-stressed concrete.

The reflector bowl has a lattice-work steel frame, supported on the concrete bracket with concrete counter-weights to the rear. The elliptical, paraboloidal bowl is constructed of welded steel sheet with a major axis of 125ft (38.1m) and minor axis of 83ft 4in (25.4m). Overlaying this is a later, more accurate, circular surface of aluminium panels (installed in 1987). With a focal length of 40ft (12m), the focus box is supported by four lattice-work legs standing out from the edge of the bowl structure; the lower, right leg incorporates a narrow flight of steps to access the focal point with a hanging flight of steps to allow access from the roof of the engine house.

The ground-floor engine room contains the original gearbox, with an updated drive system, on a deep concrete engine bed. This powers a vertical driveshaft, gear chain and cogs, which move rollers to control the horizontal position of the alt-azimuth mount in the circular base building. On the east side of the gearbox are the two original motors of the control system for the telescope, now replaced by control cabinets along the south west side of the room. The circular base building contains the alt-azimuth mount, which sits on 54 steel rollers in a 12.8m (42ft) diameter on a concrete foundation block.

There is a narrow walkway around the outside. The first-floor central room contains a central, full-height, circular cabinet of riveted steel panels known as a 'twister' through which the telescope cables are threaded to prevent their tangling. The room also has a small 500kg travelling crane above a trap door in the floor through which the alt-azimuth mount can be reached. The small engine room on the northeast side contains a motor and gearbox, which drives a vertical driveshaft which controls the vertical position of the telescope.

2.a.4
The Control Building

The original Control Building was completed in 1955. It was subsequently extended in 1961, and again in the 1970s.

It is constructed primarily of brown brick in Flemish Bond, window surrounds of concrete and metal casement windows. In plan, it has a linear rectangular shape, roughly aligned north-south. There is a central two-storey block with single-storey wings and some rooftop extensions to the south wing, and ground-floor extensions to the north. The Building stands south east of the Lovell Telescope, to which it is linked, at basement level, by a tunnel (which itself forms part of the Grade I listed Lovell Telescope structure). The Control Building was Grade II listed in 2017.

On approach, its central external feature is the main entrance (which is in the east wall at the centre of the two-storey block), reached by two steps and a modern access ramp with handrails (Figure 2.4).

The two full-glazed timber entrance doors are set in a glass-block surround and over-sailed by a concrete canopy, all highly characteristic of the period.

The entrance doors lead to the lobby, which is designed as an approach to the most important space in the building, the Control Room. Steps lead to this along the rear wall from left and right to a small central landing, with recessed doorways leading to the left and right, hidden by wing walls. The rear wall of the landing is glazed, with windows leaning away at the top, which afford a view into the control room. This wall, which was the original control room doorway, is removable, so that the original entrance route can be used either for reception of important visitors, or for practical reasons (e.g. during events including television broadcasts).

Image: Howard Barlow

Figure 2.4: The Control Building also showing the 42-foot (12.8m) Telescope and Lovell Telescope

Image: The University of Manchester

Figure 2.5: Aerial photograph of the Green in 2015, looking east and showing the encircling road, original research buildings and the Mark II Telescope.

The steps' inner face is gently concave, and against this, between the columns, is a bespoke curved oak bench whose back follows the profile of the steps with their outward-leaning risers. The metal balustrade with oak handrail carries a plaque recording the construction of the Lovell telescope, and listing the contractors.

From the lobby, stairs also lead to the first floor. The first-floor gallery retains original windows overlooking the control room, although now boarded over.

To the right is a single-storey block with a continuous glazed strip of ten windows. This area houses a mix of offices and laboratory space. To the left of the entrance the ground floor is similar but with only a five-window strip. Both wings were extended towards the front soon after construction to provide additional office space.

Further left, a short section of the original eastern wall is largely obscured by the concrete podium building of the 42-Foot telescope, and above the original brick wall is a single-storey glazed timber rooftop extension. Again, this area of the building houses a mix of laboratory space and offices, including the Director's office created for Sir Bernard Lovell, which retains its door, parquet flooring and waffle-iron radiators.

The west elevation of the building is dominated by a glazed wall of four vertical lights, which are the windows in the Control Room facing the Lovell Telescope. These provide the Telescope Controller with a full view of the Lovell telescope. The Control Room is dominated by the central U-shaped Control Desk, the structure of which is largely original, with updated internal equipment and control panels.

Below the western wall of Control Room there is a semi-basement extension that surrounds it, in red engineering brick in stretcher bond. A doorway with open concrete porch is offset slightly to the right, aligned over the tunnel from the telescope and with the south side of the control room.

To the left of this extension is a small timber entrance extension, which is used by Jodrell Bank engineers to move between the Telescope and the Control Room.

The north wall of the original Control Building is obscured by the extension built in the late 1960s, which houses a mix of offices, a library, a lecture room and some general meeting spaces. This structure was excluded from the Grade II listing of the Control Building in 2017.

To the west of that extension is the concrete mounting pad for the helical antenna (see Section 2.a.7). This is a concrete bed 4m square, with mounting bolts in each corner, set within the grassed lawn.

Generally, in the control building alterations to the original rooms have largely been to the function and contents rather than to their essential character and finishes, although some room entrances have been adjusted, and the installation of the processing computer (the e-MERLIN correlator) and its cooling did require some physical works.

2.a.5 The Green and associated Observatory buildings

The Green is the area at the heart of the property that forms its historic core.

This is the area (shown in Figure 2.5) in which Sir Bernard and his team built up and expanded the Jodrell Bank Experimental Station (today known as the Jodrell Bank Observatory). It continues to perform its intended function, which is to provide an open space upon which to set and carry out scientific experiments. A wide range of experiments were set up there which are vital in the history of Jodrell Bank and its role in the development of radio astronomy.

It comprises mainly a square area of grassland. In the southern part of this there is a small area of developing trees and scrub, including birch, willow and ash. The amenity grassland is separated by a tarmac road to the west of the Mark II Telescope and east of the Moon and Radiant Huts. This road provides access all around the Green. There are mixed native hedges along the western and northern boundaries with mature pedunculate oaks. Buildings in the northeast of the Zone are adjoined by amenity grassland, scrub and trees.

Between the outer edge of the road and the boundary of the property are spaced a group of research and engineering buildings, which largely date back to the early days of the Observatory.

The centre area and the land between buildings is still used, as it has been since the inception of the site, for temporary scientific experiments. The open arrangement of this area is a key attribute of the property.

The important buildings in this area are described below.

The Park Royal Building

Park Royal is a single-storey hut that has been used variously as a control room, to house scientific apparatus, laboratories and research offices. It is currently used as a general store, with some unused areas.

It was built in 1949 of pre-cast concrete system with concrete portal frames and walls of large, concrete blocks. The doors and vertical, rectangular windows have pre-cast concrete frames and the majority of windows are multi-paned with galvanised metal frames. A small extension was added in 1963-64. The building was re-roofed in 2016.

The building's name derives from a military trailer which Bernard Lovell acquired in 1946, described as a large cabin packed with electronic equipment built onto a prime mover which was commonly known in the service as a 'Park Royal'. The name originated from Park Royal Vehicles Ltd who were the London coach-builders who built the vehicles.

When moving the Park Royal trailer from the original Botany Grounds to the north end of the site (then bounded by the north side of the 'Green' area), it became stuck in the mud. It then remained there, determining the siting of several aerials and then the first purpose-built, permanent buildings. The Park Royal building was constructed specifically to house the apparatus from the trailer and the name transferred to the building along with the equipment.

Originally it was used as the control room for the Transit Telescope (see Section 2.b.1 and 2.a.6) which was used to detect radio waves from the Andromeda Galaxy, the first known extragalactic radio source, and the remnant of Tycho's supernova. When the Mark II telescope was built in 1962-64 the Park Royal Building was extended with a small, projecting control room added on the south-east side looking towards the telescope, built in 1963-64. The Mark II was the first telescope in the world to be controlled by a computer and it is believed that this computer was housed in the Park Royal Building.

In 2017, it was awarded Grade II listed status for the following reasons:

- *Historic interest:* as one of the earliest, purpose-built auxiliary buildings at the Observatory built as the control building for the 218ft Transit Telescope, then adapted for use as the control building for its replacement, the Mark II Telescope, the first telescope in the world to be controlled by computer;
- *Development of the site:* the control building replaced a temporary military vehicle housing equipment and as such demonstrates the more permanent establishment of the Observatory with financial investment in the site infrastructure;
- *Group value:* the Park Royal Building has a strong functional link with the Mark II Telescope for which it was the control building, and visually with similar huts around 'The Green' built to support the scientific research Lovell and his team were undertaking into the new discipline of radio astronomy. (see The National Heritage List for England, List Entry Number: 1443093)

Cosmic Noise Hut (Link Hut)

The Cosmic Noise Hut stands at the north-west corner of the Green and is attached by the Development Lab to the 21-Foot telescope control room in the Polarisation Hut to its east. The hut was originally built in 1949, using a standard construction system, as a control and receiving room for the adjacent 30-Foot telescope (a paraboloid mesh radio-telescope that was sited to the west of the hut). This telescope was designed to investigate 'cosmic noise', i.e. the background extra-terrestrial radio signals that had been first discovered by Karl Jansky in 1932 and was the first paraboloid telescope at Jodrell Bank purpose-built for radio astronomy (and for a few years, the largest fully-steerable telescope in the world). Only its mounting bed now remains.

The hut was extended in 1953 with a darkroom to house a spectrohelioscope.

In common with many of the other original buildings at the property, it is constructed of a pre-cast concrete frame, with concrete block walls, metal-framed windows, felt roof, and concrete telescope bed.

It was used in the 1950s by Robert Hanbury Brown for the experiments that led to the discovery of the Hanbury Brown and Twiss effect in quantum optics.

In plan, it is a single-storey, L-plan building with the front facing south, and with the concrete pad for the 30ft telescope to the west. The extension is set back at the right, with a large central window and a lower flat roof. The timber Development Lab projects forwards at the right. The eastern wall of the extension is obscured by the attached Development Lab.

Inside the building, the floor is of herringbone parquet throughout, with linear edgings indicating the original location of partitions. Within the extension, two concrete pads within the parquet floor relate to the optics experiments, including the first experiments in optical intensity interferometry, which took place here.

In 2017, this building was awarded Grade II listing status, because of the following reasons:

- *Scientific importance:* for its role in important developments in astronomy, and in particular as the site of the first experiments in optical intensity interferometry, which led to the discovery of the Hanbury Brown and Twiss effect and the creation of the field of quantum optics;
- *Degree of survival:* being relatively little-altered and having been enhanced with features specifically relating to the major optical intensity interferometry experiments, notably the concrete floor pads for equipment, which are retained;
- *Group value:* as a representative example of the first phase of permanent building early in the history of the site, together with the Park Royal Building and the Electrical Workshop (see The National Heritage List for England, List Entry Number: 1443486).

Quantum Optics

Robert Hanbury Brown (1916-2002; at left with Cyril Hazard on right) was one of the original 'boffins', working from 1936 to 1942 under Sir Robert Watson-Watt on the development of radar. Arriving at Jodrell Bank in 1949, in 1950 he was one of the astronomers responsible for confirming sources of radio emissions beyond our own galaxy. In 1955, together with Richard Q Twiss, he conducted in the Noise Hut the first experiments in optical intensity interferometry. This relies on the effect of interference between simultaneous signals from the same source, on simultaneous measurements of the intensity of that source. When applied to the interaction of sub-atomic particles the Hanbury Brown and Twiss effect also explains observed results and has been important in advancing our understanding of quantum physics.

Electrical Workshop

The Electrical Workshop, was built circa 1949, along with the other buildings around the Green. It stands along the east edge of the Green and is connected to the Mechanical Workshop (see below) by the Cryogenics Workshop.

The building is single storey and made predominantly of concrete, with a pre-cast concrete frame and concrete block walls, in the same vein as the other buildings that stand around the Green. Like them, it has metal window frames set in concrete surrounds.

The Electrical Workshop was originally used as the Main Office for the observatory, and housed the Library, Lecture Room and Sir Bernard Lovell's office (until the Control Building was completed in 1955). It was from this office that Lovell planned and directed the construction of the Lovell Telescope. The building also housed a number of examples of the interchange of ideas – for example, in 1953, over 40 radio astronomers from around the world gathered in the Lecture Room for one of the earliest meetings to discuss the emergence of this new science.

Once the hub of the Observatory transferred to the Control Building, the building was re-purposed as a workshop and in the 1970s the northeast corner was modified by the addition of the Cryogenics workshop, which now links the Electrical Workshop to the Mechanical Workshop.

In 2017, the building was awarded Grade II listed status because of the following reasons:

- *Historic associations:* for its role as the first permanent administrative and teaching hub of the first planned radio astronomy observatory in the world, and notably as the centre of planning and co-ordination of the extraordinary achievement of the construction of the Lovell Telescope;
- *Degree of survival:* retaining much of its historic character, principally through the survival of many internal features;
- *Group value:* with other buildings from the first permanent phase of the observatory, in particular the Park Royal Building (List entry 1443093) and the Link Hut (List entry 1443486). (See The National Heritage List for England, List Entry Number: 1444238).

Building 'ensemble' around the Green

The Cosmic Noise Hut and Electrical Workshop are part of an ensemble of buildings around the Green, the construction of which marked the establishment of permanent radio astronomy research at the property.

Other buildings of the same type in this area include:

- *The Mechanical Workshop:* Stands at the northern end of the east side of the Green and is connected to the Electrical Workshop by the more recent extension known as the Cryogenics Workshop. It has retained its original use since it was built, in 1949. It has been extended to the east.
- *Polarisation Hut:* Located at the eastern end of the north side of the Green, this building is now connected to the Cosmic Noise Hut by the Development Lab. It housed various research offices including those of Roger Jennison and Mrinal Dasgupta who pioneered early experiments in long-baseline interferometry. It is now the control room for the 21-foot telescope (sometimes called the 7m telescope) used in undergraduate experiments.
- *Radiant Hut:* This building is located at the northern end of the west side of the Green. It is of the same construction as the other buildings and has a long-standing timber extension at its rear. It originally housed instruments that measured the outputs from arrays of Yagi aerials situated either side of the building used in radar studies of meteors (hence the name Radiant, after the point on the sky from which a meteor shower appears to radiate). It is currently used as an archive store.

- *Moon Hut:* Standing at the southern end of the west side of the Green, this building, which is of the same type as the others around the Green, was also constructed in 1949. It originally housed researchers working on radar examinations of the lunar surface.

The Powerhouse

The Powerhouse is just east of the southeast corner of the Green, immediately SE of the Mark II Telescope. Originally built in 1948 to house two 105kW generators, it was the first permanent building of the Observatory. It was extended in 1953 to house an additional 240kW generator. This generator is still in situ.

It is constructed of cream brick, with concrete window and door-sills and lintels. It has metal window frames and a flat roof.

The building still operates as the Powerhouse for the Observatory. Internally, it consists of a main central space that houses the generators and switchgear. It has two full-width mezzanine floors at either end (East and West). Below the East mezzanine there is a workshop.

To the east there is an extension that is used for vehicle maintenance.

Telescope Workshop and Dormitory Block

These buildings are located along the southern access road, just south of the Powerhouse.

They were constructed at the same time in the early to mid 1950s, using a concrete portal framework with walls of pre-cast concrete blocks. They have metal window frames, set in concrete window surrounds. Both buildings had new entrance foyers and the Telescope Workshop has a canopy, which were all added in the late 1950s.

The Telescope Workshop, which is the northernmost of the two buildings, includes a large abstract mural in its entrance foyer, which is believed to date from 1966. The building was originally constructed in the early to mid 1950s as a staff canteen for the whole site community. The Lounge area at the southern end of the building was the social hub of the site where people would play cards, or hold parties. It was re-purposed as a workshop in around 1970 following construction of a café in the recently constructed visitors centre to the north of the site (now replaced by the Jodrell Bank Discovery Centre).

Just to the south of the Telescope Workshop lies the Dormitory Block. It was originally designed as an accommodation block (in keeping with many Observatories worldwide) for scientists who were working overnight on site. It retained this use until the early-mid 2000s and is now used for storage.

The two buildings were sited on what was, for many years, the main entrance road to the site, and is now used as the main staff entrance.

2.a.6 The site of the Transit Telescope

In the southeast corner of the Green lies the area that was once the site of the Transit Telescope, completed in 1947 and used until the 1960s.

This is now no longer present above ground, and the site itself has been built over, in part, in subsequent years. The Mark II Telescope stands at one corner of its former location, but the landscape still indicates clearly where the Transit Telescope once stood (see Figs 2.5, 2.6 and 2.13).

Geophysical scanning of the area has indicated that archaeological traces of the Telescope and its supporting structures remain underground.

Some elements of the Transit Telescope (including steel support poles and concrete anchor blocks) are also retained here and elsewhere on site.

A full archaeological examination of the area is planned in the near future. See also Section 2.b.1.

Figure 2.6: The mesh bowl of the Transit Telescope and its central focus tower circa 1959, with the Park Royal building at left and the Powerhouse beyond

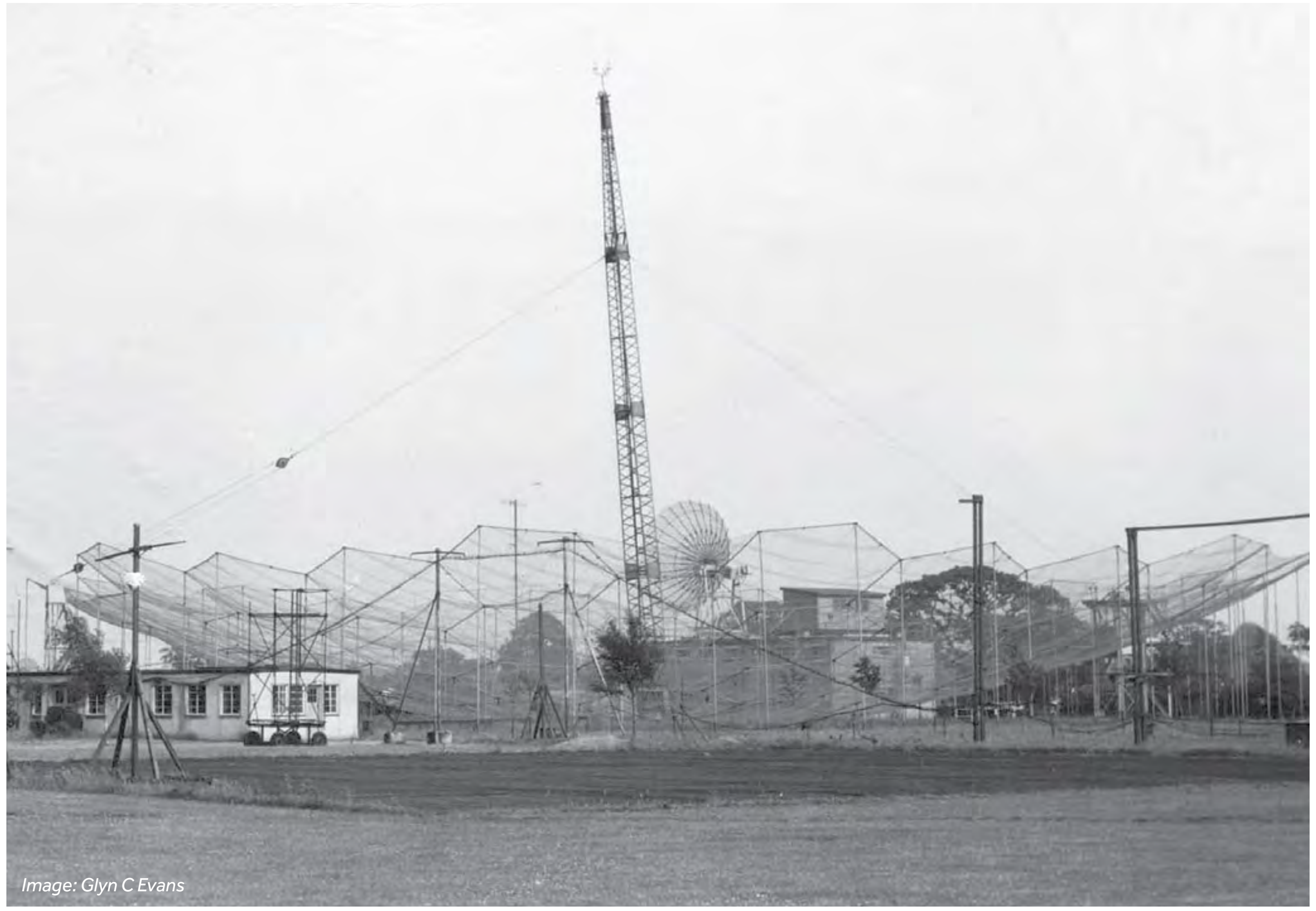


Image: Glyn C Evans

2.a.7

Sites and remnants of other early scientific instruments

In addition to the Telescopes that are currently in use at the Property, which is a working Observatory, there are traces and remnants of a number of early scientific instruments.

The Searchlight Telescope

Standing in the Green, just south of its centre, are the remains of the Searchlight Telescope, an aerial created from the base of a Second World War trailer-mounted searchlight in 1946. These are the earliest remnants of a scientific instrument on the property.

The searchlight base wheels have been removed and the chassis immobilised by a framework of scaffolding poles set into a concrete pad. The mount is now rusted and unlikely to revolve at present (although conservation work may free this up in future). The aerial structures are no longer present.

Two large girders and associated bolted L-shaped girders resting on timbers across the top of the mount do not form part of the original structure.

Around the pad there is an area of partly-obscured hard standing that corresponds to the area used as the turning circle of the Telescope when it was in operation

To either side of this area (east and west) run concrete channels that originally housed cabling. These run towards Park Royal and Moon Hut respectively.

The Searchlight Aerial was originally created by John Clegg, who was an expert on radar aerials, in order to observe meteors with more accuracy. The searchlight mount was originally a loan from the army and was placed at its current position near to the (then) location of the Park Royal trailer (see section above). It was subsequently used for several other pieces of research and was used as the backdrop for group photos, including the formal photograph that celebrated the appointment of Bernard Lovell as the world's first Professor of Radio Astronomy in 1951 (Fig 2.11).

In 2017, the structure was Grade II listed, and archaeological and conservation work are planned in the near future.

Helical Antenna Base

This concrete footing lies outside the Control Building. It is approximately 4m x 4m in size and stands in the lawn in that area. It was originally constructed as the base of a distinctive helical antenna deployed at Jodrell Bank by the United States' Space Technology Laboratories team in circa 1959 for their spacecraft tracking programme.

30ft Telescope Base

Standing to the west of the Cosmic Noise Hut, this concrete pad is around 4m x 4m in size and is flush with the tarmac that now surrounds it. Originally constructed in circa 1949, it was the footing of the steerable 30ft Telescope that was one of the inspirations for the Lovell Telescope. It contains a circle of mounting bolts (just over 1m in diameter), slightly west of its centre, that indicates the location of the original telescope fixings.

Meteor Radar Ground Plane

In approximately the centre of the Green, this consists primarily of a tarmacadam surface 27m x 27m in size. Its southern edge is delineated by a concrete cable duct, sitting flush with the ground, that runs along the line of a former field boundary (this can be identified clearly by a change in ground level). This was used in tandem with a radar transmitter working at 60 MHz and two receiving aerials at its south edge, in experiments to measure the heights of meteors. When in use this reflecting plane was covered in wire mesh. The surface is still used as an area for experimental apparatus.

Total Rates Antenna Base

This concrete plinth stands approximately 30m south of the remains of the Searchlight Telescope, is around 2m x 2m in cross section and stands around quarter of a metre above ground level. It has 4 mounting bolts at each corner. This was originally the base block for the 'Total Rates' antenna.

2.a.8

The Botany Huts

The Botany Huts stand close to the very south perimeter of the Property. They were built for University of Manchester Botanists who used the site as a testing ground.

Figure 2.7: One of the two Botany Huts.

Image: The University of Manchester

The two buildings are built of timber and are both single-storey (see Figure 2.7). They are unremarkable in themselves, but significant in that they were the first structures used by the scientists who were instrumental in creating the field of radio astronomy.

Both structures, which are set at a slight angle to each other, have one large room plus some smaller rooms. There is some overgrowth by vegetation.

Following the arrival of Lovell at Jodrell Bank in 1945, the two huts became exclusively used by Lovell's team as their base; Lovell says that originally one of the huts had a coke stove where the team thawed out, brewed tea and ate their packed lunches.

The botany huts continued to be used for around ten years with former staff recalling that one hut was used for research and storage with a canteen and the other was used as a dormitory. Eventually they were replaced by a purpose-built canteen building (now the telescope workshop) and companion dormitory building constructed in the mid-1950s. Their ownership then returned to the Botany Department, which used them until, it is believed, the early 1990s. Both huts are presently disused.

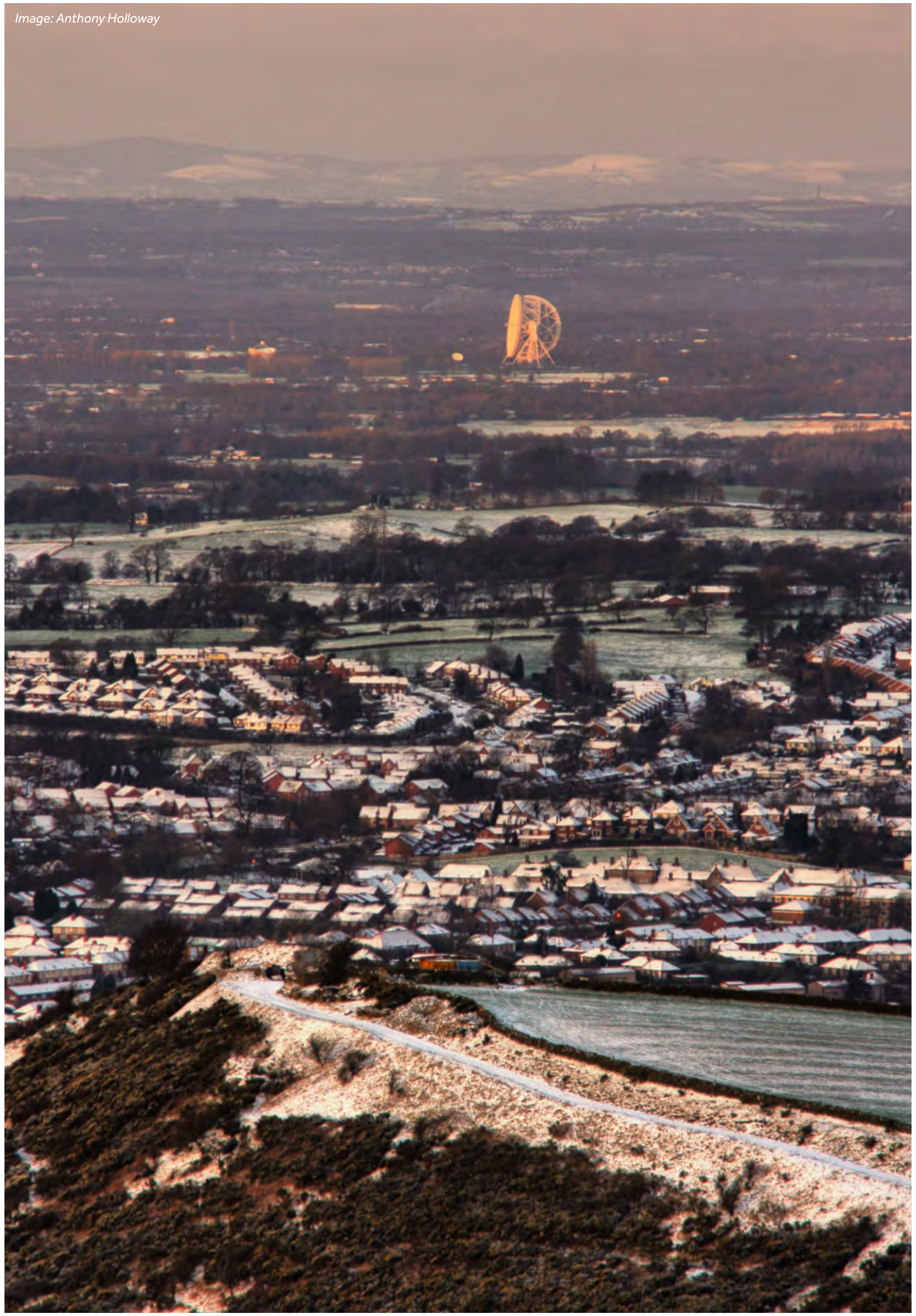
2.a.9
Gazetteer of Elements of the property

The Conservation Management Plan for the property contains a complete gazetteer of all its elements. Table 2.1 lists key elements of the property that contribute to the attributes as described above, together with their Gazetteer codes. Their locations are shown in the map in Figure 2.2, Section 2.a.2.

Table 2.1: Key elements of the property

Brief description	CMP Code	Type	Condition	Protection	Note
The Lovell Telescope: Radio telescope, standing 89m high, with dish of diameter 76m. First very large radio telescope in the world.	B07	Structure	Good	Grade I listed	Still in use as a radio telescope
The Control Building: Principal building in the property, completed in 1955 and housing the Control Room for the Lovell Telescope.	B05	Building	Good	Grade II listed	Later (unlisted) extensions in poorer condition
Helical Antenna base: Concrete pad, approx. 4m x 4m, which was originally the base of the Helical Antenna installed by the US Space Technology Laboratories team in around 1959.	A01	Archaeology	Good		
The Green: Landscape at the heart of the property	L05	Landscape	Good-moderate		
30ft Telescope base: Concrete pad, approx. 4m x 4m, originally the footing of the steerable 30ft Telescope that was part of the inspiration for the Lovell Telescope.	A02	Archaeology	Good		
Cosmic Noise Hut: Concrete building now known as the Link Hut, originally the control room for the 30ft Telescope, later altered to accommodate solar and optics experiments.	B11	Building	Mixed	Grade II listed	
Polarisation Hut: Another typical hut in the style of the ensemble around the Green. Originally used as the base for early experiments in long-baseline interferometry.	B13	Building	Mixed		
Mechanical Workshop	B17	Building	Moderate		
Electrical Workshop: Original site of the Main Office for the Observatory, including Lovell's office, lecture room and library.	B19	Building	Good	Grade II listed	
Radiant Hut: originally home to the meteor research group	B26	Building	Moderate		
Moon Hut: original home to the lunar and planetary radar group	B25	Building	Moderate		
Park Royal: Original control building for the Transit Telescope, subsequently used as the control room for the Mark II Telescope	B20	Building	Good	Grade II listed	
Powerhouse: location for electrical generators	B23	Building	Moderate		Still in use for original purpose
Mark II Telescope: Completed 1964, it was the first large telescope in the world to be controlled by digital computer.	B21	Structure	Good	Grade I listed	Still in use as a radio telescope
Remains of searchlight aerial: only the base remains	A05	Archaeology	Good	Grade II listed	
Remains of 218ft Transit Telescope: first very large paraboloidal telescope at the site, inspiration for Lovell Telescope	A13	Archaeology	Good		

Figure 2.8: A view of Jodrell Bank from Teggs Nose in Macclesfield, 15 km away.



2.b

History and Development

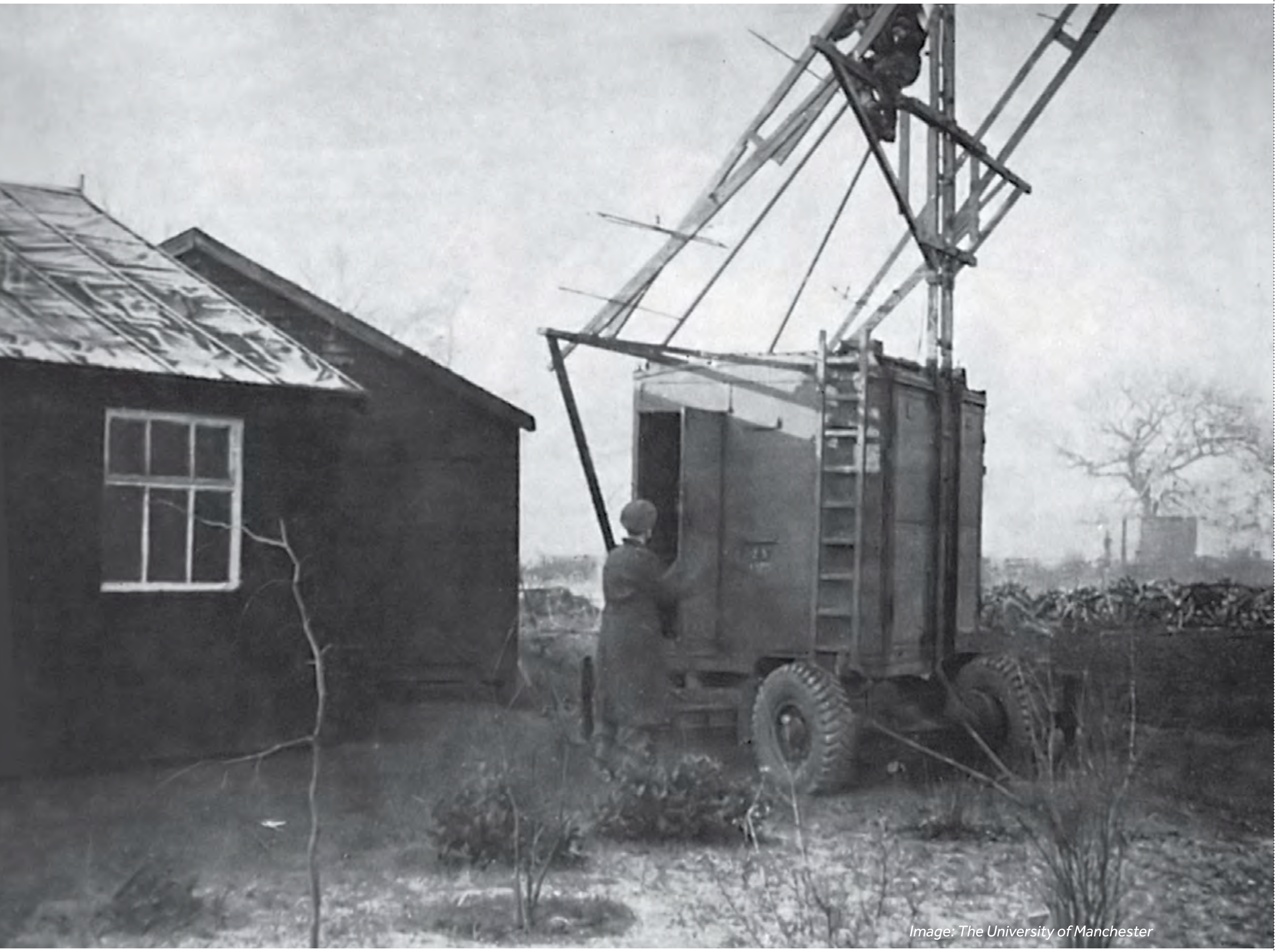


Figure 2.9: The first day at Jodrell Bank showing the Botany Huts and radar equipment

2.b1

The origins of Jodrell Bank as a site for radio astronomy

The Observatory at Jodrell Bank is one of the earliest planned sites for radio astronomy in the world. It had a pivotal role in the development of this new science, the first major step towards modern multi-wavelength astrophysics, revolutionising our understanding of the Universe.

The first use of the site for radio astronomy was in December 1945 when Bernard Lovell moved there from the Physics Department of the University of Manchester to escape the impact of city-centre radio interference on his experiments in radar.

Bernard Lovell and wartime radar

The outbreak of World War II led to the employment of many research physicists in development of essential wartime technology such as radar. In 1939 Bernard Lovell (who was at the University of Manchester carrying out research into cosmic rays) joined the Telecommunications Research Establishment (TRE) – the British organisation leading the development of radar technology as part of the war effort. During the war, he led the work on H2S radar, used for night-time bombing guidance, detection of submarines and on landing craft; work for which he was awarded the OBE in 1946.

After the war, scientists like Lovell who had worked on radar returned to universities to continue their research careers.

Peacetime research

On his return to Manchester in the summer of 1945, Lovell initially planned to pick up his research on cosmic rays (highly charged particles from outer space that pass through the Earth's atmosphere) using a cloud chamber, which had been standing, unused for 6 years, in the Department of Physics. However, he was reminded by Patrick Blackett, then Head of Department, of their wartime discussions concerning the possibility of detecting radar echoes from cosmic rays. Lovell arranged for the loan of a high-power radar system from James Stanley Hey of the Army Operational Research Group. This was delivered, on three trailers (one containing the transmitter, another the receiver and a third the diesel generator), to the University's Department of Physics in Manchester. Lovell found, however, that radio interference, particularly that caused by the electric trams on nearby Oxford Road, obliterated any signals he might have detected.

Figure 2.10: Moving army surplus equipment into place at Jodrell Bank in 1945.

The move to Jodrell Bank

After discussion with colleagues, it was eventually suggested that a University site south of the city in rural Cheshire might be free of interference. The Jodrell Bank Experimental Grounds, purchased by the University in 1939, comprised 11 acres of land used by the botany department for crop trials. Lovell was given permission to set up his three trailers there for two weeks. Again, he called on J.S. Hey, who provided an army team of technicians and trucks to help him make the move. The receiver was sited alongside the only two buildings then at the site, the Botany Huts (which are still present), and the transmitter and generator a hundred metres or so away (Figure 2.9). After some help from the two gardeners and a local farmer, the frozen diesel generator was started and the first radar pulses were transmitted into space. This was the 14th December 1945, the first day of radio astronomy at Jodrell Bank.

Lovell was soon joined by other scientists from TRE, notably John A. Clegg (a radar aerial specialist) and C. John Banwell (an electronics expert from New Zealand). Early in 1946, they enlisted the help of a local farmer and his tractor to tow their radar equipment north from its original position to the third and most distant of the three fields owned by the University. This part of the site is today referred to as 'The Green'. A rough track (now a tarmac road) was laid out, providing access between the southern entrance of the Site and this field. It was along this track that Clegg drove a Park Royal truck packed with sophisticated radar equipment onto the Green up to the point at which it became stuck in the mud. It was never restarted. Its accidental positioning influenced the layout of the site and when a permanent building replaced it in 1949, it was named Park Royal after the truck.

Meteors and the Searchlight Aerial

The first radar experiments at Jodrell Bank produced several echoes per hour, far more than they expected from cosmic rays. Lovell learnt from Hey that at least some of these must be from the trails left by meteors as they streaked through the atmosphere (a discovery Hey had made whilst engaged in radar detections of V2 rockets). At this stage Lovell knew very little about meteors and contacted J.P. Manning Prentice, a solicitor and Director of the Meteor Section of the British Astronomical Association, for his advice. Prentice observed alongside Lovell at Jodrell Bank in August of 1946, during the Perseid meteor shower. Side by side in deckchairs, Lovell learnt his astronomy from Prentice, as they watched for the streaks of meteors coinciding with their radar echoes visible on the cathode ray tube in the cabin of the Park Royal truck.

The Jodrell Bank team collected large amounts of army surplus apparatus, which were invaluable in enabling their research over the coming months and years. A significant item was a searchlight, loaned from the army and used as the steerable mount for an array of Yagi aerials designed specifically to investigate meteors (Figure 2.11). Prentice suggested observations on the night of the 9/10 October 1946 when he predicted there might be a shower from the passage of the comet Giacobini-Zinner. As luck would have it, they were to witness one of the great meteor storms of the twentieth century. Lovell later recalled, "…the sky seemed to be ablaze with streaks of light…by 3am we were in a frantic daze, unable to count either the meteors in the sky or the echoes on the tube."

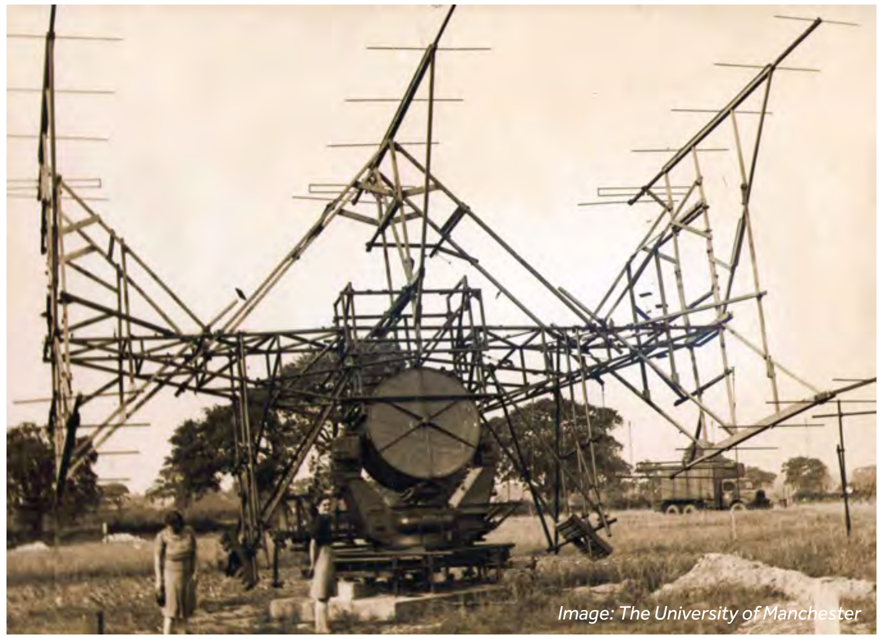


Figure 2.11: Searchlight Aerial circa 1946.

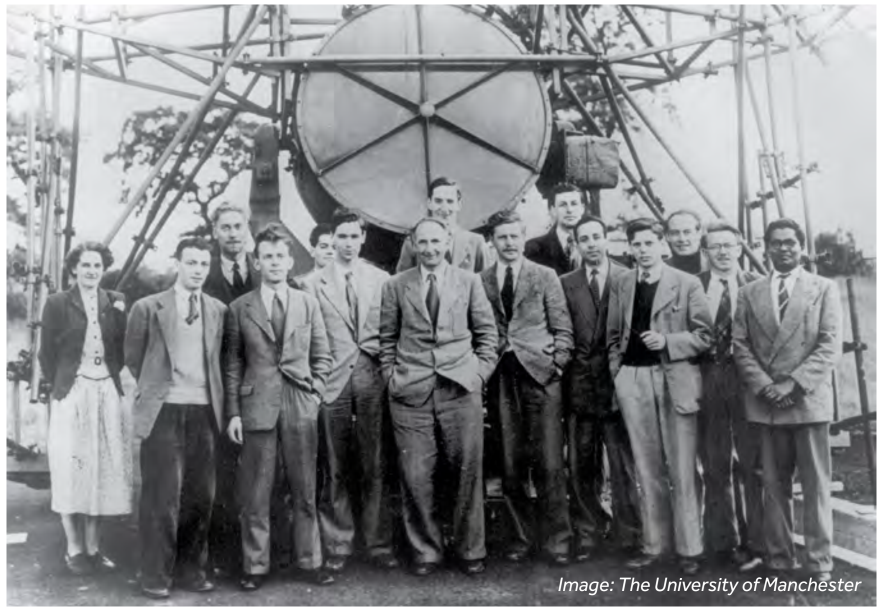


Figure 2.12: The Jodrell Bank research team and the Searchlight Aerial in 1951.

The Searchlight Aerial was the first purpose-built scientific instrument at Jodrell Bank and was a popular backdrop to group photographs, including one of Lovell and his research team taken on the occasion of his appointment as the world's first professor of Radio Astronomy in 1951 (Figure 2.12).

Despite frequent requests from the army for the return of the mount, the remnants of it are still at the property over 70 years later, and in 2017 were Grade II listed by the Government Department for Digital, Culture, Media and Sport on the advice of Historic England.

It was the Giacobinid meteor storm observations with the Searchlight Aerial which, when presented by Lovell at the 13 December 1946 meeting of the Royal Astronomical Society alongside Prentice and Hey, led the President of the Society to announce the arrival of "an entirely new field of astronomical research". Radio astronomy was starting to becoming mainstream, almost a year to the day after Lovell's first observations at Jodrell Bank.

The Transit Telescope

In January 1946, Lovell realised that a mistake he had made in a wartime calculation significantly overestimated the strength of radar echoes from cosmic rays and a much larger aerial would be needed to detect them. He and Clegg began work on a very large broadside array – a framework of scaffolding tubes with a height of around a hundred feet (30m) and a similar width. By the summer of 1946 they had built part of the intended framework, but it was never completed and the idea abandoned. They thought of a much better use for the tubes – as the framework for a fixed giant dish-type reflector in the shape of a paraboloid - the Transit Telescope (see Figs 2.6 and 2.13). This giant wire paraboloid would be easier (and safer) to construct and be far more flexible in changing operating wavelengths, something that would have required disconnecting and rebuilding dipole connections in a broadside array whose structure itself determines the operating wavelength.

When completed in 1947, the 218-foot (66 metre) diameter Transit Telescope was the world's largest. Rather pragmatically, this diameter was fixed by the space available between the Park Royal truck and the hedge at the edge of the field, whilst its curvature was fixed by the height of the ladders that could reach its outer edge. This also meant that the central pole supporting the receiver/transmitter needed to be 126 feet (38m) high. Purchase and installation of this pole was funded by the UK Government's Department of Scientific and Industrial Research (DSIR) – the first research grant obtained by Lovell for Jodrell Bank and another step on the path towards its establishment as a professional astronomical observatory.

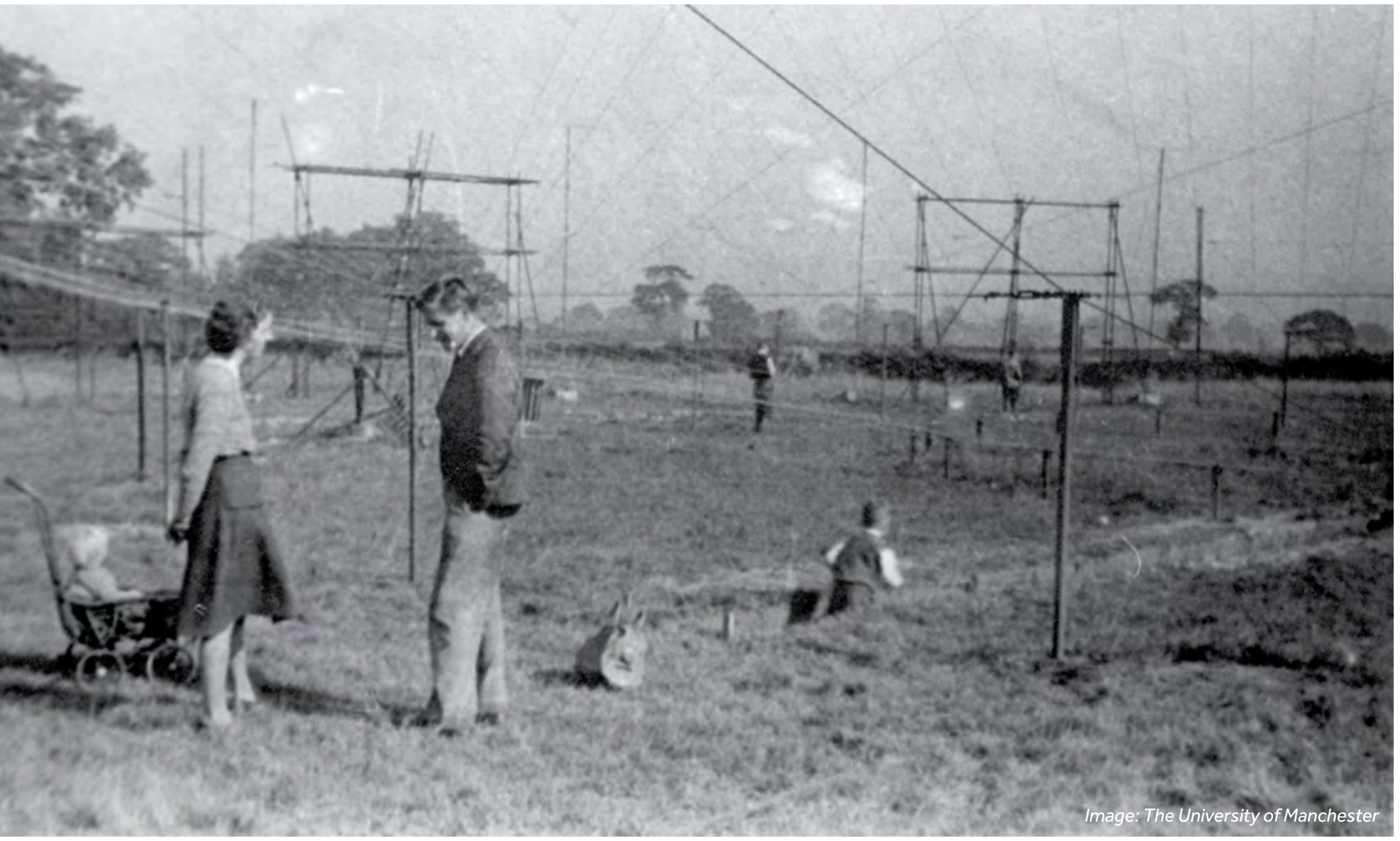


Figure 2.13: Bernard Lovell's wife Joyce speaking to John Clegg whilst the Lovell children play under the wire mesh of the Transit Telescope circa 1946/7. Lovell recalled that families were drafted in at weekends to help attach the wires.

Lovell and his research student Victor Hughes began radar observations with the Transit Telescope in November 1947 – but there was no evidence of echoes from cosmic rays, just those from meteors with which they were already familiar. However, as the Earth turned and the plane of our Milky Way galaxy moved through the narrow pencil beam of their great paraboloid, the received signal increased dramatically. Although the original function of the Transit Telescope was never fulfilled, it turned out to be crucial in a much wider field of research – the study of these extra-terrestrial radio waves, or as it soon became known, radio astronomy.

> *"…we soon recognized that we had a built a major instrument for the study of radio waves from the universe. Indeed this, the first of the large radio telescopes, was to shape our future destiny. It was a beautiful and elegant instrument, the slim mast emerging from the Cheshire countryside as though it were a great finger directing our thoughts and efforts to the remote regions of time and space."*
>
> **– Bernard Lovell**

The discovery of extra-terrestrial radio waves

Karl Jansky provided the first evidence for radio waves arriving from space. His serendipitous discovery, whilst working as an engineer for Bell Telephone Laboratories at Holmdel, New Jersey, USA, was published in Nature and the Proceedings of the Institute of Radio Engineers in 1933. Jansky showed that these extra-terrestrial radio waves originated in the Milky Way galaxy, but from 1934 did little more in this area.

Grote Reber, a radio amateur also working in the USA, was inspired by reading about Jansky's discoveries. In 1937, he built a 31.4-foot (9.6m) diameter parabolic dish in his backyard in Wheaton, Illinois. With this he continued and extended Jansky's work, mapping the radio sky and publishing his results in Proc. IRE and the Astrophysical Journal. Reber, who died in 2002, is sometimes cited as the first radio astronomer. A small casket containing some of his ashes is housed in the foyer of the Control Building at Jodrell Bank, and similar ones were placed in other observatories around the world.

However, the early work of Jansky and Reber was not immediately taken up elsewhere. As Reber himself said, "The astronomers were afraid of it because they didn't know anything about radio." The technology of radio engineering was, it seems, too far removed from traditional optical telescopes employing lenses and mirrors, for astronomers to instantly take it to heart.

Instead, the efforts directed towards the development of radar technology during the Second World War provided a second genesis for the subject. In the opinion of the pre-eminent historian of radio astronomy, Woodruff T. Sullivan III,

'..the independent wartime discoveries in England of extraterrestrial radio waves meant that the post-war course of radio astronomy around the world would undoubtedly have proceeded much as it did even if Jansky and Reber had never made their discoveries."

This wartime work on radar led directly to the development of the four world-leading radio astronomy groups in the decade after 1945: Jodrell Bank (led by Bernard Lovell); Cambridge (Martin Ryle); Sydney (Edward Bowen); and the British Army Operational Research Group (James Stanley Hey).

During 1948, Hughes measured the beam of the telescope (its sensitivity to radio waves arriving from different angles) by flying an aircraft fitted with a transmitter across it at a height of 3000 feet and in various directions. He then carried out a study of the radio emission from the narrow strip of sky that passed overhead and compared this with the work of Jansky and Reber. But it was not until Robert Hanbury Brown arrived at Jodrell Bank that the full potential of the Transit Telescope was realised.

Lovell had heard that Hanbury Brown (a wartime radar pioneer who had worked in TRE and at the American Naval Research Laboratory) was interested in researching at Jodrell Bank and wrote to him in June 1949, saying, "...we must discuss what sort of work you might like to do... for example, there is a great harvest to be reaped in the cosmic noise field when we can bring some intelligence to bear on it".

Lovell himself had been unaware of the existence of these extra-terrestrial radio waves – or cosmic noise – until in 1946 Banwell brought to his attention the pre-war work of Jansky and Reber. However, Hanbury Brown had read during the war about Reber's pioneering work in the USA, and inspired by the potential of the transit telescope, responded positively: "With Reber's paper on 'Cosmic Static' in mind I accepted his offer with enthusiasm and went to work at Jodrell Bank in September 1949."

With a research student, Cyril Hazard, he embarked on a study of the radio sky: "Our programme, therefore, was simple and exciting: it was to look at everything in our field of view". Together, they went on to use the telescope to detect radio waves from the Andromeda Galaxy, the first known extragalactic radio source, and the radio remnant of Tycho's supernova, not seen since the 1570s.

The publication, in November 1950, of their observations of the Andromeda Galaxy, established beyond doubt that this spiral galaxy also emitted radio waves of much the same intensity as our own Milky Way galaxy. Lovell describes how "in astronomical importance and in significance for our developing plans, this publication exceeded by far anything that had previously emerged from the equipment in the Cheshire fields. By the standards of the day this was a tour de force. Radio waves had been detected from a galaxy two million light years distant, and it was no longer possible to regard the local galaxy as in any way unique as a radio emitter".

The Transit Telescope also played an important role in the development of long baseline interferometry, discussed below – an essential part of modern day astronomy. It remained the largest telescope of any kind in the world for a decade until, in 1957, it was surpassed by the 250-foot (76m) Lovell Telescope, also at Jodrell Bank, for which it was a scientific precursor.

The Transit Telescope had a number of upgrades, including a replacement focus tower enabling easier pointing of the telescope, and a more sophisticated mesh and hexagonal grid surface. It was dismantled to make way for the Mark II Telescope, completed in 1964. However, traces of the Transit Telescope remain on the site, including the Park Royal building in which its receivers were located, archaeological evidence below ground, concrete blocks used in its foundations, and some of the scaffolding poles which supported the surface repurposed in various ways across site.

2.b.2
Establishment of the property as a permanent observatory

Figure 2.14: Aerial photograph of the site circa 1950 showing the Green with its associated buildings viewed looking east and the Transit Telescope at centre right. Compare with the modern view in Figure 2.5.

Figure 2.15: View of a section of the Transit Telescope in the late 1950s showing its replacement hexagonal mesh surface and tilting central tower.

When the Searchlight Aerial was built in 1946, the Jodrell Bank group comprised only a few people working out of ex-army trailers in a Cheshire field.

As more discoveries were made using the Searchlight Aerial, the Transit Telescope and other instruments at Jodrell Bank and elsewhere, the group grew and it became clear that permanent buildings were required.

In 1948, the Powerhouse was built to house the diesel generators and in 1949, the sheds and former army trucks were replaced by a set of modest concrete-framed buildings. Unremarkable in themselves, the construction of these in fact represents a turning point for the property, which at that point became established as a permanent research station in its own right.

The buildings were sited around a central space, appropriately called the Green – although as it filled with all manner of unusual aerials and antennas, locals came up with another name for it, the Fairground. This layout, with the Green, an encircling road and surrounding research buildings, lends the Property a unique character that has persisted to the present day (Figure 2.14). Maintaining this central open space was, from the very early days of the site, vital to enabling on-going scientific experimentation and research. Aside from its scientific use, the Green was also used for recreational purposes, staff often playing football or cricket there. A few visitors, such as Nelson Rockefeller, are even known to have used The Green as a helipad.

The buildings, some evocatively named after the research carried out by the occupants – Moon Hut, Radiant Hut, Cosmic Noise Hut – still remain, and several have now been Grade II listed. Surrounding the buildings was a range of instruments, some of which were there for a few weeks or months and some of which remained for years. Only remnants of some of these are now extant.

The main building, which is now known as the Electrical Workshop, was placed on the eastern side of the Green. It included a Library, Lecture Room and Bernard Lovell's office. Some of the earliest international discussions on the new science of radio astronomy were held in the Lecture Room (for example a symposium in July 1953 attended by more than 40 radio astronomers from around the world), and this was the key administrative and teaching building in the early years of the observatory. It was also from his office in this building that Lovell planned and co-ordinated the extraordinary achievement of the construction of the radio telescope that now bears his name.

Alongside the main office building was placed a Mechanical Workshop, essential to an observatory constructing its own telescopes and instruments. On the opposite side of the Green stood (and still stand) Radiant Hut and Moon Hut.

Figure 2.16: Radiant Hut with associated array of meteor radar aerials (late 1950s).

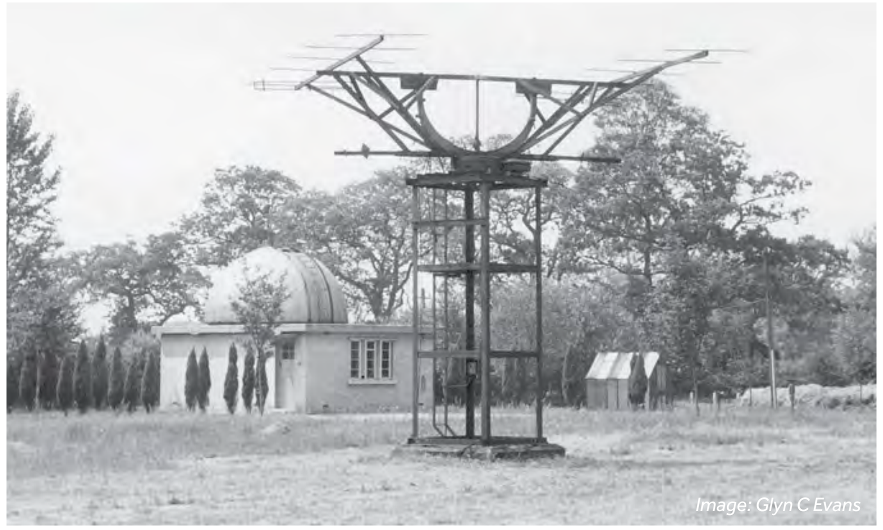


Figure 2.17: The Total Rates antenna with optical telescope dome in background (late 1950s).

Radiant Hut, which housed the meteor radar group (the point on the sky from which meteors appear to radiate is known as the radiant), was originally flanked by an array of aerials (Figure 2.16). It was also the control room for the Total Rates Antenna (designed to measure the total number of meteors, Figure 2.17), the concrete base of which is still on site. Moon Hut housed the lunar radar group, from where they operated a aerials directly outside the hut on the Green. Alongside Moon Hut, there was once a wooden Venus Hut housing equipment for radar measurements of the distance to Venus using the Lovell Telescope.

On the north side of the Green were placed Cosmic Noise Hut (now known as Link Hut) and Polarisation Hut. Noise Hut (Figure 2.18) was used as a control room for a 30-foot (9.1m) Telescope acquired by Bernard Lovell from the RAF radar station on Beachy Head where it was used for radar defence. At Jodrell Bank, this fully-steerable paraboloidal telescope was repurposed for 'cosmic noise surveys' and observations of interstellar hydrogen. Although now removed, elements of its power supply still remain within the hut and the concrete base for the telescope still stands alongside.

In 1955, Noise Hut also played host to a famous experiment. Robert Hanbury Brown and Richard Twiss used its dark room extension to develop optical intensity interferometry. The so-called Hanbury Brown and Twiss Effect led to the development of modern quantum optics and to Hanbury's measurements of the optical diameter of Sirius at Jodrell Bank and of other stars in the rather clearer skies of Narrabri, Australia. The original hut remains little altered, and the extension retains concrete footings in the parquet flooring thought to have supported the optical bench in these pioneering experiments.

Figure 2.18: The 30-foot (9.1m) Telescope and Cosmic Noise Hut.

Interferometry

The sharpness of view (angular resolution) of any optical instrument is determined by the number of wavelengths of light which span the aperture over which it collects the light (its mirror, lens or dish). The wavelength of radio waves is around 100,000 times that of visible light, and so a radio telescope needs to be 100,000 times larger than an optical telescope to obtain the same sharpness of view. For example, a radio telescope would need to be 5 kilometres across in order to match the sharpness of a small optical telescope with a very modest lens 5 cm in diameter. Hence, a single radio telescope, even one as large as the 76-metre Lovell Telescope, has a rather blurred view of the sky.

The solution is interferometry – the technique by which the signals from several telescopes at various distances apart, are combined so that they behave together as if they are a single, much larger instrument. Such an instrument is known as an interferometer.

The larger the spacing between the telescopes, the sharper the view – the more the interferometer is able to 'zoom in' to very distant objects across the Universe. The larger the 'collecting area' of the combined telescopes, the more radio waves it collects, which allows it to detect fainter sources of radio emission and image them with more fidelity.

e-MERLIN is an interferometric array of seven radio telescopes connected by optical fibres so that they have the sharpness of view of a telescope 217 kilometres across.

2.b.3

Long-baseline interferometry

Surveys in the late 1940s and early 1950s with the Transit Telescope and by the other main radio astronomy groups, in Cambridge and Sydney, showed that the radio sky contained discrete sources of radio emission, the so-called 'radio stars'.

Interferometers at both Cambridge and Sydney began to obtain more accurate information, and a few identifications with previously known objects such as the Crab Nebula, but the nature of the majority of radio stars was still totally unknown – were they stars like the Sun, but for some reason very bright at radio wavelengths, or something else entirely? As well as position, the astronomers needed to determine their size. Hanbury Brown embarked on two separate programs of long-baseline interferometry at Jodrell Bank intended to achieve the highest possible angular resolutions using very widely-spaced antennas. He hoped to determine their angular sizes, even if they appeared extremely small on the sky as expected for distant Sun-like stars.

From 1950, he worked with Richard Twiss, Roger Jennison and Mrinal Dasgupta on building an intensity interferometer, a completely novel approach distinct from the phase-linked interferometers which were being used in Cambridge and Sydney. It was intended to enable the interferometer elements to be very widely separated, connected by radio links and, for separations of thousands of kilometres, to use tape recording of the signals. The home element of this interferometer was sited between Cosmic Noise Hut and Polarisation Hut on the north side of the Green, with its receivers and correlator housed in the latter (Figure 2.19). During 1952/53, the remote element was transported on a lorry to a range of locations across Cheshire and its signals sent back to Jodrell Bank (up to a longest baseline of 12 km) via a radio link where they were combined with those from the home element. They made a key astronomical discovery with this instrument (the double nature of the radio galaxy Cygnus A – with radio emission either side of the central faint optical galaxy). However, it had very quickly turned out that, in Hanbury's words, they had "built a steam-roller to crack a nut" and a more traditional, at that time shorter-scale, interferometer would have been capable of determining the angular sizes of their targets Cassiopeia A and Cygnus A.

In a second interferometer programme, from 1953, Hanbury Brown began work with Henry Palmer, Richard Thompson and others using the Transit Telescope together with a mobile antenna. This phase-linked interferometer developed through various techniques as they increased the baseline (the separation of the mobile antenna from the Transit Telescope), including radio links and, when it became available after 1957, use of the 250-foot (76m) Lovell Telescope as the home station. It was this programme that, as American astronomer Allen Sandage explained in a 1999 review, made an invaluable contribution to the identification and study of quasars: "The heroes of the quasar discoveries were clearly Palmer for his brilliant measurements with his Jodrell Bank colleagues of the radio angular diameters, Matthews for all aspects of the identification work [at Owens Valley, USA] and for the organization of the joint Owens Valley–Palomar collaboration, Hazard for the position of 3C 273 [at Parkes, Australia], and Oke (1963) and Schmidt (1963) [at Mount Wilson and Mount Palomar, USA, respectively] for their joint discovery of the redshift of 3C 273."

This pioneering work on long-baseline interferometry continued through the 1960s and 70s, leading to the present-day e-MERLIN network of seven radio telescopes in the UK, including the Lovell Telescope and Mark II Telescope at Jodrell Bank. The scaffolding towers holding the original dishes for the radio links in this array are still present at the Property whilst the current optical fibre links exist underground. The Jodrell Bank array has baselines of around 200km, intermediate in length between arrays built in the USA, Australia, the Netherlands and India, and the trans-continental Very Long Baseline Interferometer (VLBI) arrays including the European VLBI Network (of which Jodrell Bank is a founder member). The future Square Kilometre Array (whose global headquarters is at Jodrell Bank and which involves many nations) will use similar technology to the e-MERLIN system to link antennas over initially a hundred or so km, and eventually much longer distances.

Figure 2.19: A view south across the Green in the late 1950s. The 'Home Element' for Jennison and Dasgupta's intensity interferometer can be seen between Polarisation Hut and Noise Hut on the near edge of the Green, whilst the Transit Telescope can be seen on the far side. The Botany Huts are visible in the distance. All the major buildings visible are still present today.

Quantum optics and optical interferometry

An important separate program of work grew out of the development of the intensity interferometer. In 1955, inspired by their work at radio wavelengths, Hanbury Brown and Richard Twiss carried out an experiment in optical interferometry in the dark room extension of the Cosmic Noise Hut. This demonstrated the so-called Hanbury Brown and Twiss (HBT) Effect, widely cited as leading to the important field of quantum optics and with current applications in high-energy nuclear physics, condensed matter and atomic physics. The concrete footings for their optical bench still exist in the Cosmic Noise Hut.

Following the success of this experiment, later in 1955 they built an optical interferometer using two Army searchlight mirrors, with its control equipment sited in what would become the 250-ft Lovell Telescope's (at that time, still empty) Control Room in the Control Building. They used this to measure the angular diameter of the star Sirius (the first time the size of a main-sequence star, rather than a giant, had ever been measured). Unlike the radio astronomy experiments at Jodrell Bank, this optical experiment was badly affected by the cloudy weather and so Hanbury Brown determined to build his next instrument under the clearer skies of Australia. This large optical stellar intensity interferometer was constructed at Narrabri Observatory, Australia. Hanbury Brown moved to Australia to oversee its construction and became a member of staff at the University of Sydney. It operated from 1963 to 1972 and inspired a number of follow-on instruments.

2.b.4
The Lovell Telescope

By 1948, Jodrell Bank was already known to the research community for its pioneering work in the new field of radio astronomy, but the development that established it firmly in the eyes of both scientists and the wider public as a world-leading site was the creation of the Lovell Telescope.

The Telescope stands, to this day, as both an international icon of science and engineering, and as a working research instrument that inspired the construction of others around the world.

Concept

The Lovell telescope was first conceived by Bernard Lovell in 1948, as a means of building on the success which had by then been achieved at Jodrell Bank with the fixed-dish Transit Telescope, which could only survey the section of sky passing above it at any time. He wanted a huge dish, which could be tipped and turned in order to study extra-terrestrial radio waves coming from any direction. Such was the engineering challenge presented by the idea that the first firms approached expressed incredulity, but in September 1949 the engineer H. Charles Husband agreed that its construction was possible.

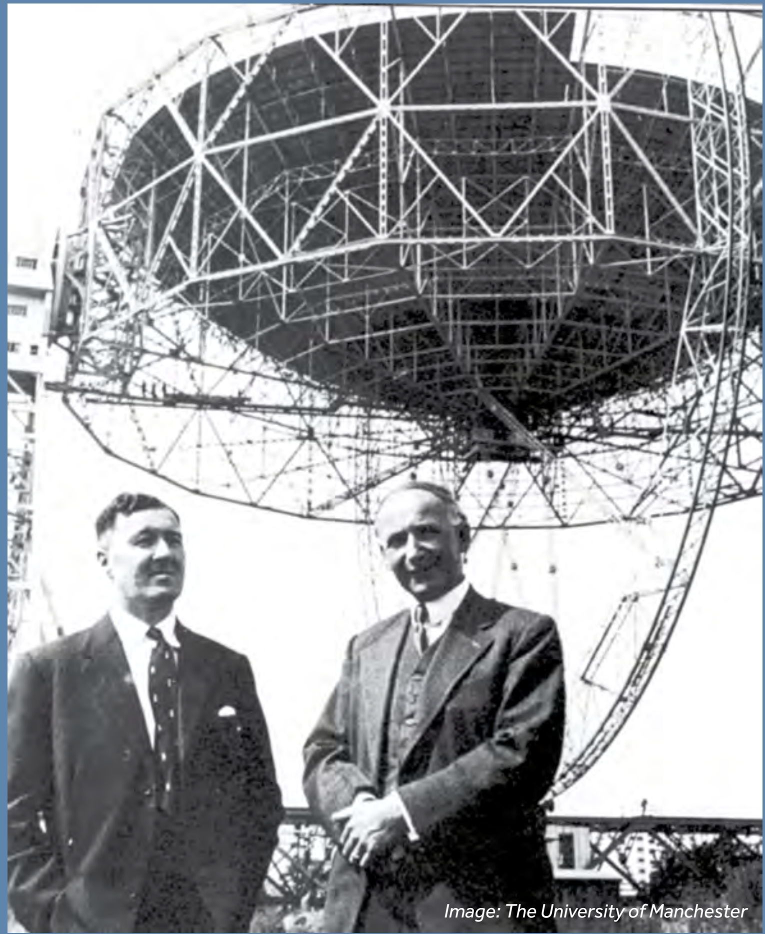


Image: The University of Manchester

Figure 2.20: Charles Husband (L) and Bernard Lovell (R) in front of the near-complete Lovell Telescope in 1957.

Bernard Lovell and Charles Husband

The structural support system of the 30ft Telescope, alongside the Cosmic Noise Hut, closely resembled that of the Lovell Telescope and, as Lovell himself recalled, both the 30-foot Telescope and the Transit Telescope inspired the construction of the new 250-foot Telescope:

So it was that on 8 September 1949 I met H.C. Husband on the perimeter of the transit telescope at Jodrell Bank.

'What's your problem?'

'I want a telescope of at least this size mounted like that small 30-ft. paraboloid over there so we can steer it to any part of the sky. I've now been trying for over a year to persuade someone to do it but I'm told it's impossible.'

Husband looked at the device for a few moments, gazed up at the focal point 126 ft. above ground, and then said calmly:

'Oh, I don't know. It should be easy – about the same problem as throwing a swing bridge over the Thames at Westminster.'

I had emerged from the wilderness!

Engineering

In the summer of 1950 the Department of Scientific and Industrial Research provided £3,300 to pay for a detailed design study by Husband based on an estimate that the telescope would cost in total around £120,000, including the Control Building and ancillary items. The so-called 'Blue Book' was produced, laying out both the technical design of the telescope and its proposed scientific programme. It specified that the diameter of the antenna should be 250ft (76m), with a deep bowl for easier access to the focus and for protection from interference. The antenna was to operate at wavelengths as short as one metre with a reflecting mesh of 5cm spacing. It was to be mounted in azimuth-elevation fashion, with tracking of radio sources controlled through a novel analogue computer system. In elevation, the bowl would be driven on gear racks from 15-inch gun-turrets (obtained as surplus from battleships HMS Royal Sovereign and HMS Revenge, decommissioned at the end of the Second World War, Figure 2.21) mounted on trunnion bearings supported by two 190-foot (58m) high steel towers. In azimuth the dish would turn on a circular double railway track.

Construction began in September 1952, with foundation piling down to over 30 metres in places.

The original design presented many unsolved engineering problems. Redesigns were required due to advances in the field of radio astronomy (notably with the discovery of the hydrogen line at 21cm wavelength requiring a move away from a mesh surface).

In an age before digital computing, the calculations alone for the drum-shaped frame supporting the bowl (instead of the originally-envisaged large rear girder) took a year.

Other substantial problems included how to move 2,000 tonnes with accuracy at a quarter of an inch per minute (with variable wind loading), how to avoid resonance frequency vibrations of the kind that destroyed the Tacoma Narrows suspension bridge in 1940, and how to compensate for the changing weight distribution as the dish was tilted and it turned.

When completed, the telescope comprised a bowl of over 7,000 steel plates, true to within 1 inch and of 250ft diameter and 62ft 6in depth, with a mast-mounted receiver at the focus.


Image: The University of Manchester

Figure 2.21: The Lovell Telescope under construction showing one of the battleship gear racks being lifted into position at the top of a tower.


Image: The University of Manchester

Figure 2.22: The Lovell Telescope under construction, showing the support structure for the dish surface.

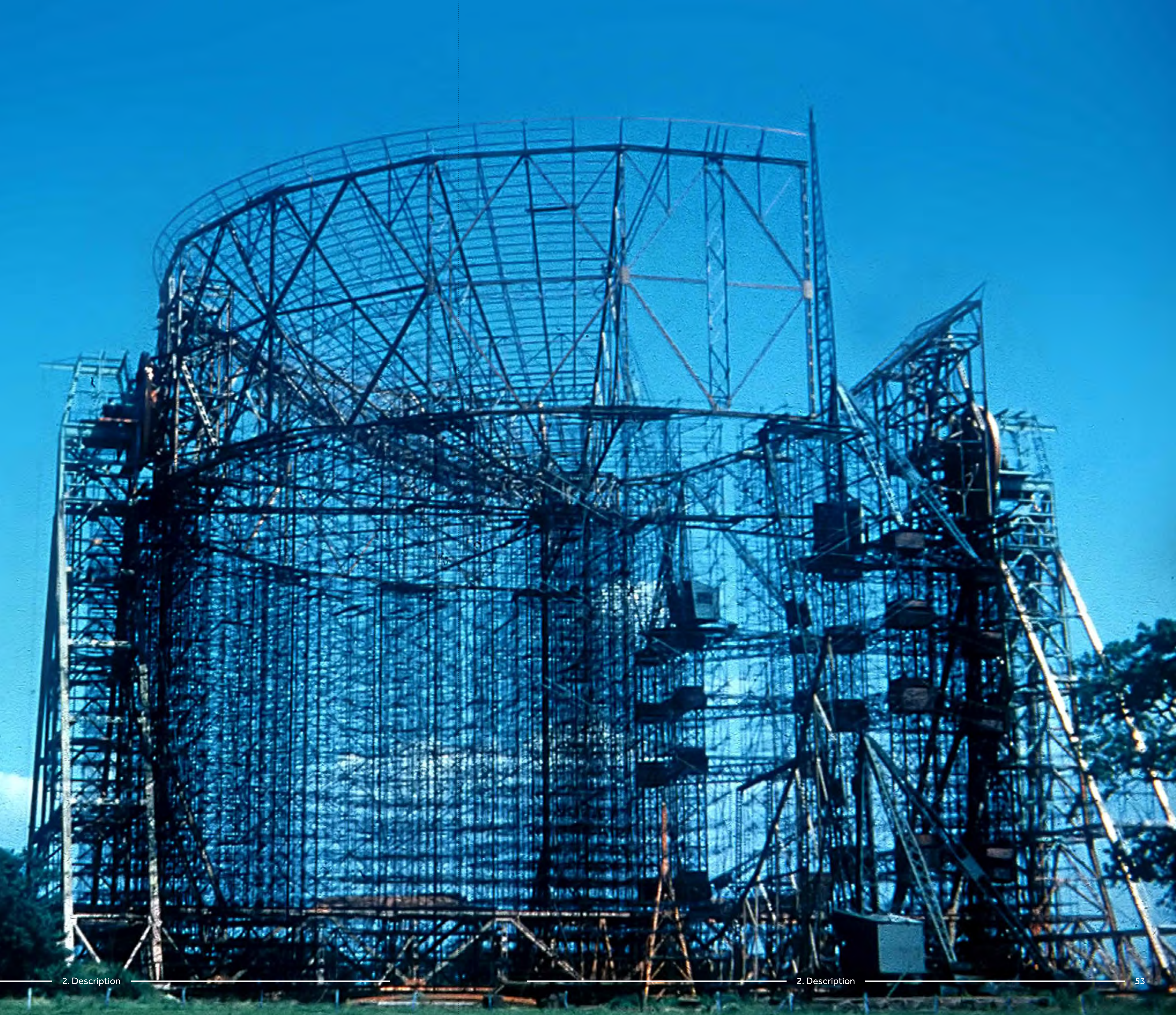


Figure 2.23: Construction of the Lovell Telescope required around 90 miles of scaffolding tubes.

Image: Wayne Young

Figure 2.24: The Lovell Telescope inverted.

The telescope was also designed so that the bowl could be completely inverted – the original intention having been to use a moveable tower at the base of the telescope to change the receivers at the focus. A detailed description of the engineering design and construction of the Mark I Telescope is provided by Husband in the Proceedings of the Institution of Civil Engineers.

Image: The University of Manchester

Figure 2.25: Bernard Lovell showing the Sputnik echo to the press .

Funding Challenges

As construction progressed, costs quickly soared far beyond the first estimates as the engineering problems of building such a unique instrument started to emerge.

The formal application to DSIR for £259,000 was submitted in March 1951 and a year later the project was approved, at an increased estimate of £335,000, once the private Nuffield Foundation agreed to split the cost. Construction began in 1952, but not until five years later and a final expenditure of around £750,000 would the dish first operate.

The dish was moved in azimuth under power for the first time on 12 June 1957, and on 20 June it was tilted for the first time. 'First Light' – when the telescope was first used to collect radio waves from space – took place on 2 August.

However, by the end of summer 1957, the project was unfinished, and progress slowing almost to a standstill because of lack of funding and wrangles between the various engineering teams.

Lovell himself said 'We need a miracle to save us' – that miracle was the launch of Sputnik 1.

Sputnik 1 and the dawn of the space age

On 4 October 1957, the USSR launched Sputnik 1, the world's first artificial satellite.

The satellite itself was easily tracked, as it carried a transmitter that sent out a regular 'ping'. The carrier rocket itself, however, was a different matter. The only place in the world that would be capable of tracking it with radar was the near-complete Lovell Telescope at Jodrell Bank.

Lovell was persuaded by a phone call 'from London' that this was important as the rocket was an intercontinental ballistic missile and so there were defence implications. At the same time there was growing and unrelenting pressure from the media expecting Jodrell Bank to do something, although they did not know what. Husband summoned all the parties required and work previously expected to take months was completed in 48 hours driven by the stimulus of the excitement of Sputnik. On 9 October, the telescope was controlled remotely from the Control Room for the first time and on 11 October the Sputnik carrier rocket was tracked for the first time with a radar set attached to the telescope. This was confirmed the next night as it passed over the Lake District and Lovell presented the results to the press and the world (Figure 2.25).

Space Tracking

The success of Sputnik led Jodrell Bank and the Lovell Telescope to be drawn into the tracking of spacecraft, working with both American and Soviet missions, a field of endeavour not imagined when the science programme was drafted for the Blue Book.

After the early Russian success, the Americans did not want to fall too far behind and decided that they would launch a rocket to the Moon. In July 1958, the US Air Force flew a trailer of equipment to the UK and installed it next to the Control Building, so that they could use the Lovell Telescope to track their own space rockets (which the Manchester Guardian newspaper of 25 July called "a telling tribute to the versatility and power of the great telescope"). The USAF contractor Space Technology Laboratories also erected an antenna array with several helical aerials on it (Figure 2.26), fixed to a concrete pad alongside the control building, for additional telemetry. This concrete pad is still extant.

This initial US Moon programme, dubbed Project Able, was largely unsuccessful. The only real success coming with the interplanetary probe Pioneer V in 1960. The Lovell Telescope was used to send the signal that separated the spacecraft from its launch rocket and later communicated with it at a then record distance of 36 million kilometres. Lovell received a congratulatory telephone call from William Morris, Lord Nuffield, Chair of the Nuffield Foundation, who had been part of the funding scheme for the Mark I Telescope from the outset. He offered to pay off the Telescope's final outstanding debt of £50,000 in May 1960 (£25,000 from the Foundation and £25,000 as a personal gift). In light of this the Jodrell Bank Experimental Station was renamed the Nuffield Radio Astronomy Laboratories. It became the Jodrell Bank Observatory in 2000 when the optical astronomy group from the city-centre campus moved to the site, although some senior staff still refer to the site as 'The Station'.

After three Sputniks were launched into orbit, the Russians had also turned their attention to the Moon. Their great success was the Luna 2 rocket, which, on 12 September 1959, became the first to reach the surface of another celestial body. At the request of the Russian team, who had telexed all the required information on times and transmitter frequencies, the Lovell Telescope was used to track the rocket onto the Moon. In the Control Building, John G. Davies measured the Doppler shift caused by the Moon's gravity, a technique used in all subsequent moon approaches, and proving, despite some doubting voices, that the mission had indeed been a success.

Out of many space missions tracked with the Lovell Telescope, another great success was Luna 9 in 1966. The spacecraft was the first to soft-land on the Moon, from where it transmitted the first close-up photographs of the lunar surface back to Earth. The Jodrell Bank team tracked the spacecraft onto the Moon and intercepted the return signals, whose form was recognized by J.G. Davies. An early type of facsimile machine, a picture receiver, was borrowed from the Daily Express newspaper and placed in the basement of the Control Room where it was used to print the photographs being received by the telescope. They made it onto the front pages of newspapers across the world (Figure 2.27).

Figure 2.26: The Helical Antenna after it had been moved to the roof of the Control Building.


DAILY EXPRESS

From Luna 9 to Manchester

THE EXPRESS CATCHES THE MOON

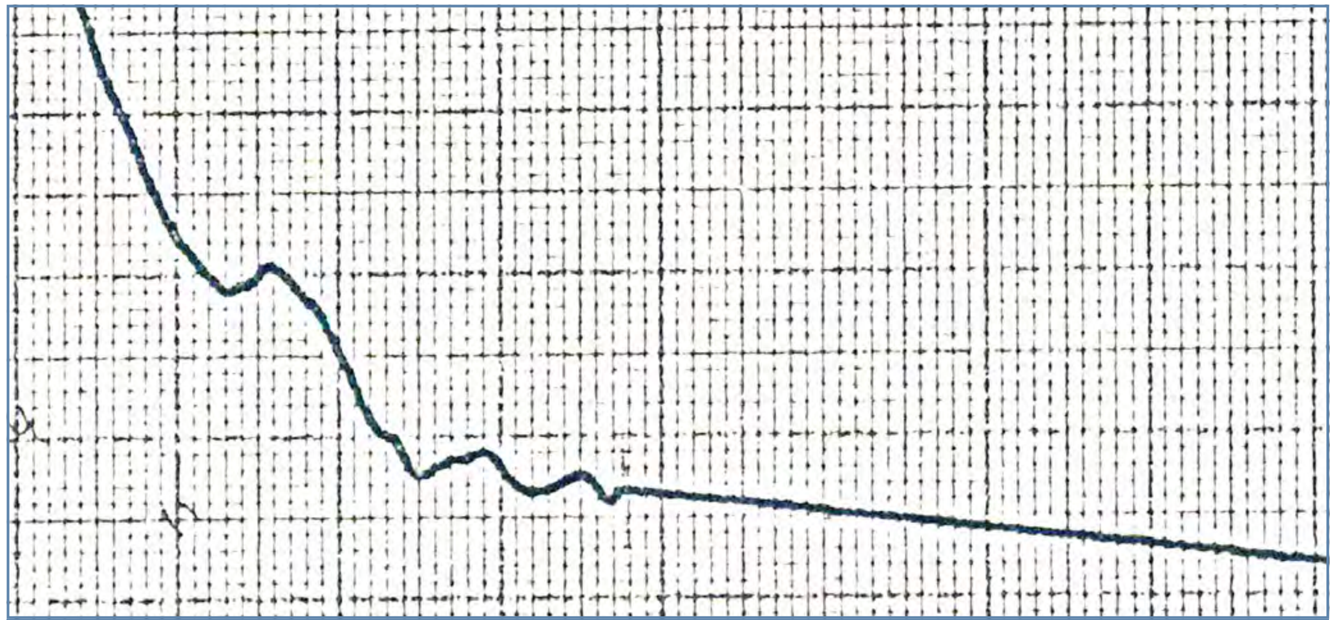
How we did it...

Figure 2.27: The Luna 9 image of the Moon's surface.

Other space missions tracked by the Lovell Telescope during the 1960s include:

Pioneer V (March 1960) – interplanetary probe
Mars 1 (November 1962) – attempt to fly by Mars
Luna 4 (April 1963) – flew past the Moon
Zond 1 (April 1964) – attempt to fly by Venus
Zond 2 (November 1964) – attempt to fly by Mars
Luna 5 (May 1965) – flew past the Moon
Luna 6 (June 1965) – flew past the Moon
Luna 7 (October 1965) – crashed into the Moon
Luna 8 (December 1965) – crashed into the Moon
Luna 9 (Feb 1966) – first spacecraft to soft land on Moon; intercepted photographs
Luna 10 (March 1966) – entered lunar orbit
Luna 11 (August 1966) – lunar probe, facsimile signals received
Luna 12 (October 1966) – lunar orbiter, Russians used frequency switching to prevent Jodrell interception of pictures
Luna 13 (December 1966) – lunar lander, Jodrell received pictures
Venera 4 (June 1967) – first spacecraft to enter atmosphere of Venus
Luna 14 (April 1968) – lunar orbiter
Zond 5 (September 1968) – circumlunar & re-entry, voice signals relayed from Yevpatoria
Zond 6 (November 1968) – circumlunar & re-entry
Luna 15 (July 1969) – failed attempt to soft land on Moon and return samples (at same time as 50-ft telescope was used to track Eagle Lander onto surface)
Zond 7 (August 1969) – circumlunar & re-entry, received voice signals

The USA and Soviet Union constructed their own tracking facilities so the need for Jodrell Bank's help gradually reduced during the 1960s.



Luna 15 and Apollo 11

In July 1969, the world watched as the USA's Apollo 11 mission approached the Moon. Astronauts Neil Armstrong and Buzz Aldrin began their descent towards the surface of the Moon in the Eagle Lander. Tracked by the scientists at Jodrell Bank using the 50ft Telescope, the plot above shows their journey downwards traced by the Doppler shift of their signal, the jolts and judders as Neil Armstrong took manual control in order to find a good landing site and then the even trace as the lander touched down and became stationary.

As the astronauts walked on the surface of the Moon, the USSR's Luna 15 module was tracked down towards the surface of the Moon using the Lovell Telescope. Intended as a 'sample return' mission, it would, had it succeeded have represented a momentous challenge to the primacy of the USA in the superpower Space Race. The module, however, crash-landed and did not return.

The Cuban Missile Crisis

Following its use to track the launch rocket of Sputnik I at the request of Robert Cockburn, the Controller of Guided Weapons and Electronics at the UK Government's Ministry of Supply, the Lovell Telescope's ability to help in defence matters had been clear. For example, the Air Ministry asked whether the telescope could be used to detect high-flying aircraft and a successful experiment was carried out in spring 1959, detecting and tracking a Canberra aircraft flying at over 40,000ft. In 1960, the Government entered into discussions with Lovell (and in general terms with the University of Manchester) concerning the use of the Mark I Telescope to detect the launch of Soviet ballistic missiles. Training of RAF personnel in the use of the Telescope began in January 1962. In early autumn 1962, as the Cuban crisis was developing, Lovell was asked to remain behind following one of his regular meetings with the Chief of Air Staff (CAS):

His message was alarming. The Soviets had mounted ICBMs targeted on London. BMEWS [Ballistic Missile Early Warning System], then under construction at Fylingdales, was seriously delayed by a series of strikes. He wanted to be assured that the arrangements were in place for using the Jodrell Bank telescope to give early warning should the ICBMs be launched. Lovell replied that it would be possible to give notice of lift-off of the ICBMs but nothing further could be done. CAS's response was, 'On the contrary, we estimate that an interval of about 7 minutes would elapse between the launching and the descent of the ICBMs on London, during which time at least a million people in London could be saved and the Bomber Force would be scrambled."

These arrangements for the use of the telescope in the event of a declaration of a military emergency commenced in January 1962 and continued through the Cuban crisis of October 1962 until the autumn of 1963 when Fylingdales became operational.

Figure 2.28: Halfway through the installation of the third reflecting surface on the Lovell Telescope in 2001. The old surface segments appear red and the new galvanised steel panels are silver before being painted white.

Modifications

By the mid 1960s, the condition of the Mark I Telescope (as the Lovell Telescope was then known) was becoming a serious concern. As Husband pointed out in a letter to Lovell of June 1966, 'By next year the telescope will have been running for ten years, which is a very long time for what was virtually a prototype'. Deterioration in the concrete footings and cracks in the steel cones that transfer the load from the bowl to the trunnion bearings at the tops of the towers had been noticed. Two upgrades had also been identified: modification of the drive system to digital computer control and improvement of the smoothness of the surface to enable work at shorter wavelengths.

Consequently, in 1970/71, a new reflecting surface with a shallower curve was added above the original, together with a large new wheel girder system, designed to share the load on the trunnion bearings, and supported by a second inner circular railway track. The shallower bowl was more efficient, enabling the focus to 'see' more of the surface, effectively increasing the collecting area. The new bowl was also a more accurate paraboloid, enabling observations at shorter wavelengths and further increasing the scope of its observations. The conversion to what then became known as the Mark IA Telescope cost £665,000, a similar amount to that spent to build the telescope in the first place. Husband said it was the most difficult engineering job he had ever tackled.

By the late 1990s, the surface added to the Telescope in the Mark IA upgrade was corroding and was in urgent need of replacement. This was made possible through a grant of over 2 million pounds, funded jointly by the UK Government and the Wellcome Foundation (the Joint Infrastructure Fund), which was awarded in 1999. A new galvanised steel surface was installed between 2000 and 2002 (Figure 2.28), along with a new highly sophisticated drive system to improve the telescope pointing accuracy. The surface was bolted into place and could be adjusted after installation to fine-tune its shape, achieving an average accuracy of just a few mm across its surface. The Telescope's outer railway track was also replaced and the focal tower strengthened to support heavier receivers. The telescope was thus more capable than ever before. It was formally re-opened by HRH The Prince of Wales in April 2003.

In order to remain in good operational order, the Telescope must be continuously maintained and faults rectified. For example, in 2007, the first of the Telescope's original wheels, which run on the railway tracks, had to be replaced after it cracked. Several more have since been replaced on a like-for-like basis. Sections of the original elevation gear racks have been replaced (with spares from the same battleships). The cracked (original) racks have been retained on site for use in an exhibition currently under design. Work is underway to restore, on a like for like basis, the original, but now increasingly corroded, 1957 surface. Although it is not possible to retain all of the original fabric of the surface on site, sections of this will be carefully kept for use in a new indoor exhibition about the heritage of the property. This will ensure that these elements of the original fabric are protected from further deterioration and preserved.

2.b.5
The Mark II Telescope

The Mark II telescope was instigated in 1960 by discussions between Bernard Lovell and Charles Husband. When approaching the design of this second large telescope at Jodrell Bank various issues were addressed.

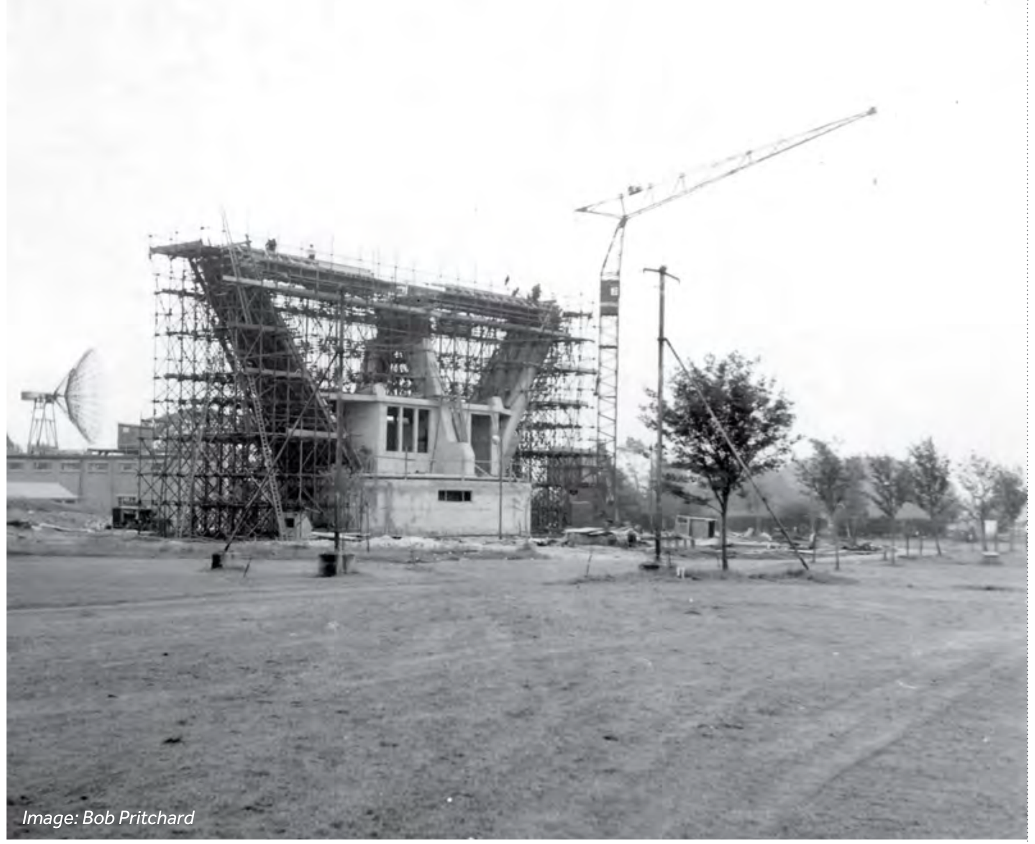


Image: Bob Pritchard

Figure 2.29: The Mark II Telescope under construction.

The idea of an oval (elliptical) reflector arose as a response to the design problems of constructing a very large reflector (the Mark II was originally intended as the prototype of a far larger telescope, later referred to as the Mark IV, which for funding reasons was never constructed); whilst maximizing the horizontal size, Husband wanted to keep down the vertical size to avoid constructional and aerodynamic problems. He also preferred to construct the whole turntable of pre-stressed concrete rather than structural steel for reasons of rigidity and economy. Funding for the construction of the Mark II telescope was requested on 19 December 1960, but the Research Council of the Department of Scientific and Industrial Research did not pass this until December 1961.

The telescope was built on the site of the Transit Telescope and was operational by summer 1964 (Figures 2.29 and 2.3). It had a steel sheet paraboloidal reflecting bowl with an elliptical aperture of major axis 125ft (38.1m) and minor axis of 83ft 4in (25.4m). The focal length was 40ft (12.2m), the mounting was alt-azimuth with 420 degrees of travel in azimuth and 0 to 90 degrees in elevation. The drive was a Ward-Leonard system with digital computer control giving great accuracy of positioning. The Mark II was the first telescope in the world to be steered by digital computer, a Ferranti Argus 100, which was one of the very first computers designed for real time control, with a storage capacity of 12 Kbytes.

A combination of greater surface accuracy of the bowl and the design of more precise control devices meant that the Mark II was able to observe at shorter wavelengths than the Lovell Telescope and thus complement it. As well as operating as a solo instrument the telescope was intended to work as an interferometer with the Lovell Telescope and others. It still operates in this way today.

In 1971 the Mark II's computer was upgraded to an Argus 400 computer, also capable of carrying out data acquisition for the telescope's observing programs, with the original transferred to the upgraded Mark I. During the 1970s the telescope worked in conjunction with the Mark III telescope (built to the same dimensions in 1966 at Wardle, Nantwich, Cheshire and intended to be portable but never moved). This work led to the development of the Multi Telescope Radio Linked Interferometer (MTRLI) and then Multi-Element Radio Linked Interferometer Network (MERLIN) arrays of which it is an integral part.

As with the Lovell Telescope, the Mark II has been upgraded. In 1987 the bowl was upgraded with a circular surface of new aluminium panels mounted on top of the original steel surface. The new surface had an accuracy of 1/3mm and was set using a holographic technique, enabling it to work at frequencies of up to 22 GHz. In the late 1990s a new, more compact carousel for the receivers was installed in the aerial focus.

The Mark II Telescope continues in daily use with the majority of current observational time spent either as part of e-MERLIN or in Very Long Baseline Interferometry (VLBI), joining radio telescopes around the world.

2.b.6
Evolution of the Observatory after the mid 1960s

The basic form and layout of the Observatory has not changed since the mid 1960s (by which point all the attributes expressing the OUV of the Property had been established). A southern entrance road leads to the Green with research buildings arrayed around an encircling road; the Mark II Telescope is at one side of the Green and, to the north, there is the Lovell Telescope and its associated Control Building.

However, consistent with its role as a working scientific research facility rather than a historical monument, there has been continuous adaptation and improvement since that point, in both instrumentation and use of buildings, as well as in scientific developments and discoveries.

Since the mid-1960s, many of the significant telescope developments (beyond the upgrades and modifications to the Lovell and Mark II Telescopes described earlier) have taken place outside the Property, with the construction of the remote telescopes used in MERLIN being the most significant. Within the Property, in 1964 a 50-foot (15.2m) telescope was placed adjacent to the Control Building and used primarily for space tracking (including the tracking of Apollo 11's Eagle Lander on to the lunar surface). This was replaced in 1982 with a 42-foot (12.8m) Telescope primarily used for pulsar timing, most notably of the Crab Pulsar. At around the same time, a 21-foot (6.4m) telescope was placed on the side of the Green adjacent to Polarisation Hut (both telescopes had been transferred from the missile-testing range in Woomera, Australia). A 50-foot (15.2m) equatorially-mounted telescope, used for lunar radar and known as the Polar Axis, was constructed to the east of the Green near to Blackett's Hut in 1962. The dish was removed circa 1972 but its concrete mount remains. Many of the aerials around and on the Green were removed, leaving some remains, as attention became focused on use of the large Mark II and Lovell Telescopes and the national array.

The original permanent buildings all remain. A timber framed building, now known as the Development Lab, connecting Cosmic Noise Hut and Polarisation Hut was constructed in the 1960s. A similar building, known as the Cryogenics Workshop and connecting the Mechanical Workshop and the Electrical Workshop, was constructed around the early 1970s. A small building, originally housing an 18-inch (46cm) optical telescope, was constructed at the southwest corner of the Green early in the 1950s. The rooftop dome and telescope were removed in 1971 and the latter donated to Salford Astronomical Society where it still remains. The Lovell Telescope Control Building has been extended a number of times since it was first completed in 1955 (see the Gazetteer) but still retains its original central Control Room and two wings.

The construction of the iconic Lovell Telescope generated huge public interest in the work of Jodrell Bank. This led to a visitor centre building being constructed to the north of the Control Building. Opened in 1966, this was extended a number of times over the next few decades until it was finally demolished in 2003. It was replaced with a new public facility, the Discovery Centre, which now has three buildings: the Planet Pavilion (2011; outside the Property), the Space Pavilion (2011; inside the Property) and the Star Pavilion (2015; inside the Property). The Discovery Centre also incorporates the arboretum and gardens, first planted by Lovell in the early 1970's and lying adjacent to but outside the Property to the north, and a pathway with interpretation around the Lovell Telescope inside the Property.

2.b.7
MERLIN/VLBI: The national facility for radio astronomy

The work on long-baseline interferometry started by Hanbury Brown in the early 1950s became an increasingly important focus for research at Jodrell Bank. In the early 1960's, the group led by Henry Palmer were the only ones in the world pursuing increasingly higher resolution studies of radio sources such as quasars. This was fundamental to understanding the nature of these enigmatic objects, in particular answering the question of how so much energy could be generated in what turned out to be a very small volume of space.

Figure 2.30: The mobile antenna mounted on a truck and taken to Pocklington in the early 1960s.

The key parameter for determining the sharpness, or resolution, of an observation is the number of wavelengths across the baseline (the separation of the antennas in an interferometer). This resolution can be increased by either increasing the length of the baseline, or by changing the receiver to reduce the wavelength of the radio waves being collected.

Palmer's group took a mobile antenna (a 25-foot, 7.6m, paraboloidal dish, Figure 2.30) as far as Pocklington in Yorkshire, 131 km away, and linked it back to the Lovell Telescope, achieving a baseline of 180,000 wavelengths in 1964.

The following year, the baseline was increased to 600,000 wavelengths by linking the Lovell Telescope and an 82-foot (25m) telescope at the Royal Radar Establishment in Defford, Worcestershire (in collaboration with British Army radio astronomy pioneer J.S. Hey who was working there), and using a wavelength of 21-cm. Eventually during 1966, they achieved a 2 million wavelength baseline by using the Mark II Telescope (whose more accurate surface enabled shorter wavelength observations than were possible with the Lovell Telescope at that time) and the Defford telescope at a wavelength of 6cm. A further baseline was established with the completion of the Mark III telescope at Wardle, Cheshire, in 1966, enabling studies to be made with various combinations of the three telescopes.

By 1973, it had become apparent that Lovell's plans to build an even larger single-dish telescope (the Mark IV, V and VA proposals) were unlikely to be achieved because of cost, Palmer proposed adding more telescopes to the existing long baselines. The aim was to develop a network combining signals from all the telescopes, enabling the production of radio images using the technique of aperture synthesis. This technique had been developed in the 1960s at Cambridge, but Palmer's proposed array would enable higher angular resolution at a given wavelength because of its far longer baselines, up to 127km to Defford, compared to the 5-km Telescope in Cambridge (later the Ryle Telescope) and the, at that time 1.6km, Westerbork Synthesis Radio Telescope in the Netherlands.

In 1975, work began on the addition of three new 25-m telescopes to the existing Lovell, Mark II and Mark III Telescopes. The new system was operational in 1980 and soon became known as MERLIN – the Multi-Element Radio-Linked Interferometer Network. The new telescopes were designed by E-Systems in the USA who had been engaged to produce 27 telescopes for the Very Large Array, an interferometer sited in New Mexico with baselines up to 36km and which was completed in 1980. The new telescopes were sited at Knockin (Shropshire), Darnhall (Cheshire) and Tabley (now known as Pickmere, Cheshire), with radio link towers at Clee Hill, Camp Hill and Sellatyn. A seventh telescope, the 32m Cambridge Telescope (located on the site of the Mullard Radio Astronomy Observatory in Cambridge), was added in 1990, increasing the longest baseline (and hence resolution) from 134km to 217km, providing the only interferometric array in the world operating at these baselines. MERLIN was significantly upgraded in the 2000s when the radio links were replaced by underground optical fibres allowing for much higher bandwidths to be transferred back from the remote telescopes to Jodrell Bank. The first image from this new facility, renamed e-MERLIN, was produced in 2010.

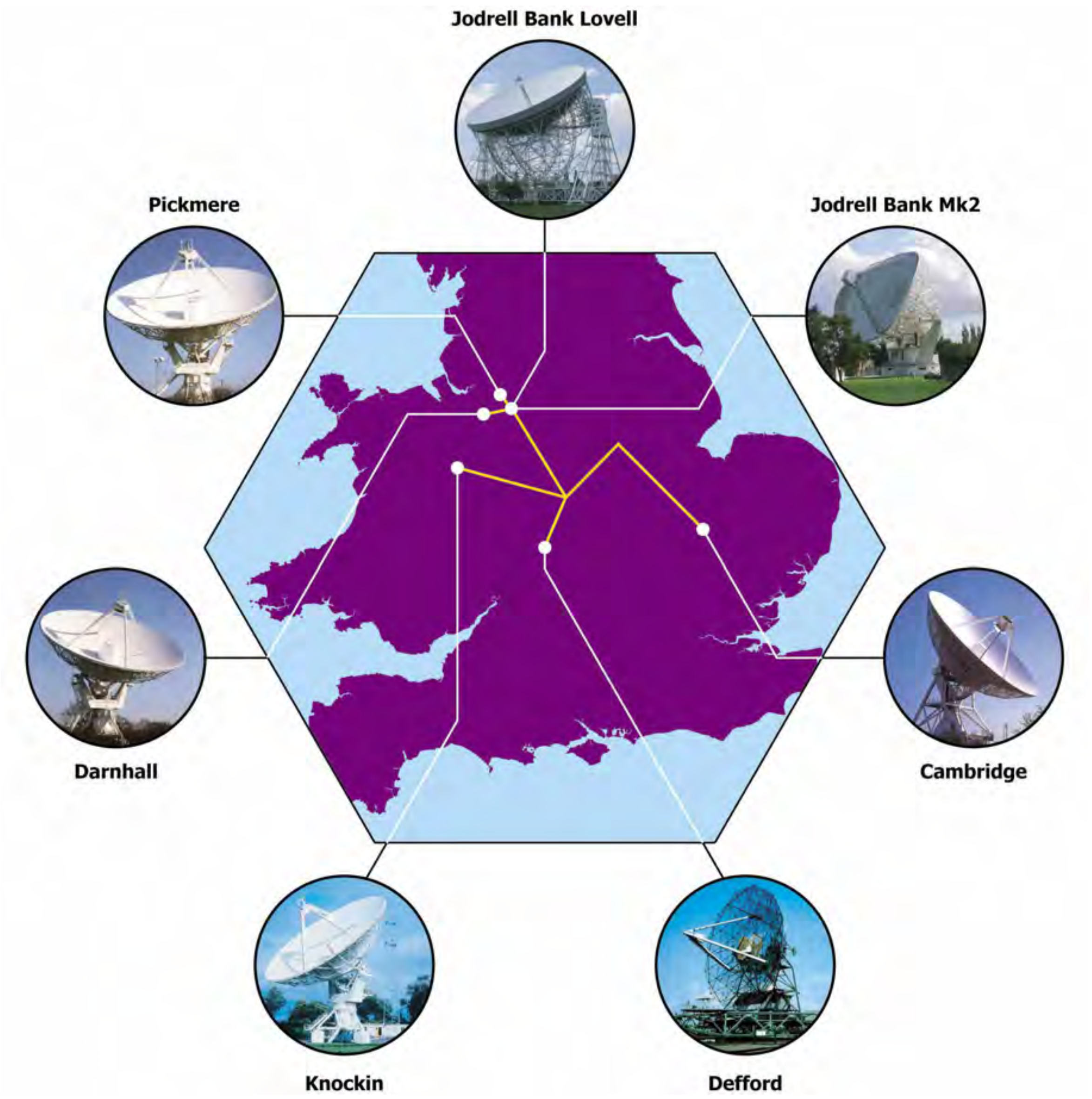


Figure 2.31: e-MERLIN is the UK's National Radio Astronomy Facility based at Jodrell Bank. Seven telescopes are included in the array extending for over 200km across England.

During a visit by Lovell to the Soviet Union in 1963, he discussed the possibility of achieving multi-million wavelength baselines on continental scales using tape recording of the signals at each site and combining them later. The desire to connect telescopes across such large distances was driven by the work of Palmer's group at Jodrell Bank. The technical details were explored over the coming years but in the end, at least partly for reasons of limited resource, this was first achieved not by Jodrell and the Russians but by a Canadian group in 1967, closely followed by an American group. This technique became known as VLBI (Very Long Baseline Interferometry). Jodrell's first involvement was in 1968 in an experiment connecting the Lovell Telescope to Canadian telescopes in Algonquin (at a distance of 5127 km) and Penticton (6833 km). In 1980, Jodrell Bank was one of the five founding members of the European VLBI Network (EVN, Figure 2.32) alongside the Max Planck Institute for Radioastronomy (Bonn, Germany), the Institute of Radio Astronomy (Bologna, Italy), ASTRON (Dwingeloo, The Netherlands), and the Onsala Space Observatory (Onsala, Sweden). Jodrell Bank telescopes, including the e-MERLIN array, now regularly observe as part of EVN and global VLBI.

The move from mobile remote antennas to the fixed telescopes of MERLIN is equally as significant a step in the evolution of the Observatory as the shift from the ex-army trailers to the first permanent buildings in 1949. A further revolutionary step was taken in 1992 with the establishment of MERLIN/VLBI as the UK's National Facility for Radio Astronomy, developing a private instrument operated for the local research group into something used widely by other UK and international astronomers. This network of telescopes, including the Grade I listed Lovell and Mark II Telescopes at Jodrell Bank, is therefore an example of "a 'collective instrument', shared by a professional group of astronomers", as described by the Thematic Study of 2010. The unique capabilities and scientific achievements of these telescopes can be said to have made "a decisive improvement in observational techniques and/or theoretical progress at the level of universal exceptional value."

The latest step in this evolution is the location at Jodrell Bank of the international headquarters of the Square Kilometre Array (SKA), a huge array of radio telescopes to be sited in South Africa and Australia. The first office building for the SKA Organisation was opened in 2012 just south of the Control Building and to the west of the Green, just outside the nominated Property. This has been extended in 2016. The decision taken by the 10 member countries of SKA to site their headquarters at Jodrell Bank reflects the Observatory's global importance in both the heritage and current practice of radio astronomy.

The move that occurred during and following the Second World War towards science being done in large-scale projects funded by national governments, or several governments, has come to be known as 'Big Science'. The work at Jodrell Bank Observatory in the twenty years after the end of the Second World War is an outstanding example globally of the move from the lone scientist to the 'Big Science' that now characterises much modern scientific research, and is further evidenced today by the Observatory's role in e-MERLIN, VLBI and SKA.

Figure 2.32: The European VLBI Network (EVN) is an interferometric array of radio telescopes spread throughout Europe (and beyond). It is the most sensitive VLBI array in the world, thanks to the collection of extremely large telescopes that contribute to the network. This map shows the current EVN telescopes following the most recent addition of the Irbene Telescope in Latvia in October 2016.

Image: EVN

2.b.8

Impact on science

The Thematic Study on Astronomy and World Heritage from 2010 emphasises the importance of demonstrating that the Property has 'authenticity in its scientific context and use'. This section therefore summarises some of the major scientific and technical achievements of the Jodrell Bank scientists and their instruments. These are supported by many publications in the astronomical literature.

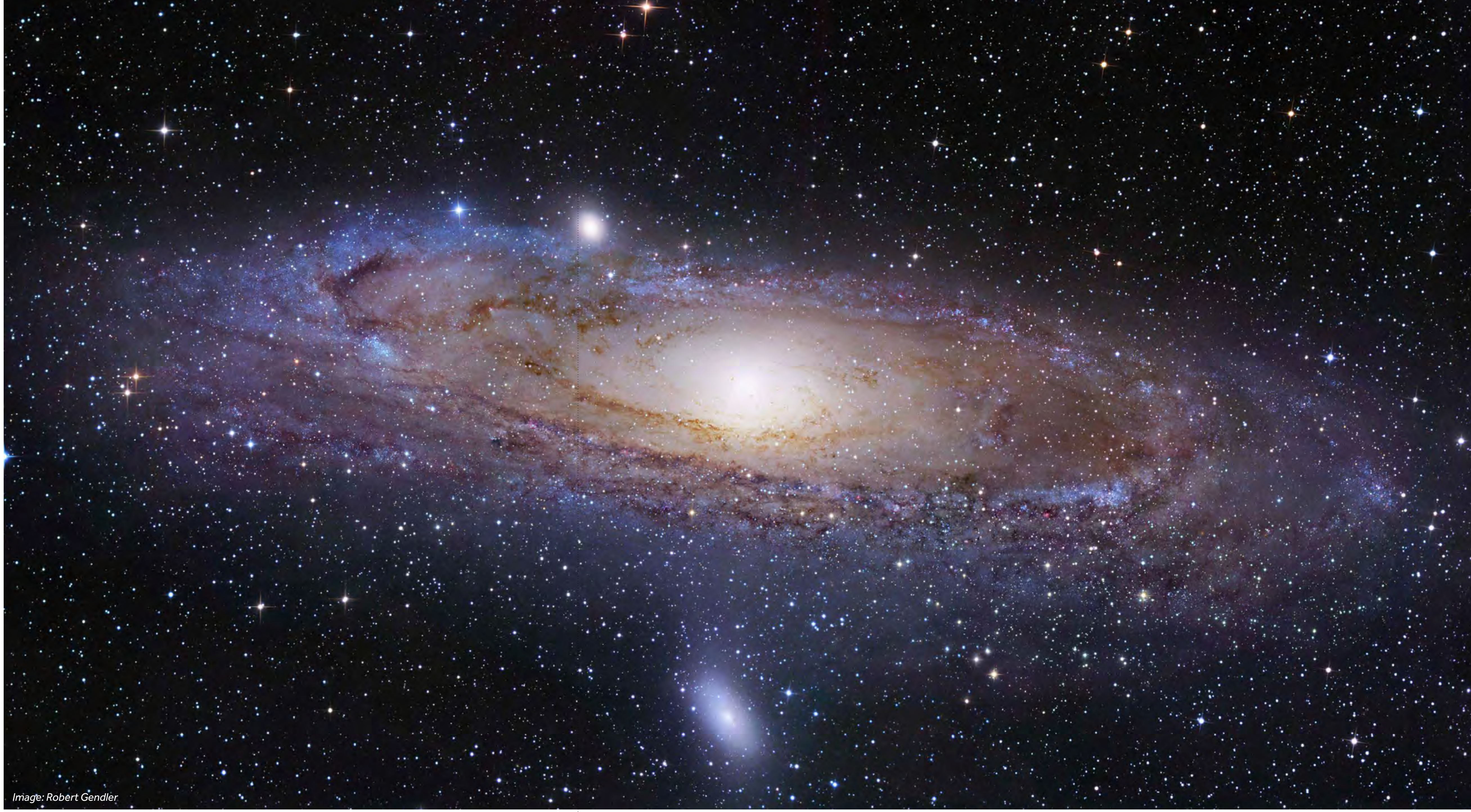


Figure 2.33: The Andromeda Galaxy

Emergence of Radio Astronomy

As described in the previous sections, Jodrell Bank was a pioneer in the emergence of the new science of radio astronomy in the first few decades after the end of the Second World War. Uniquely, the Observatory still operates at the same site where observations began in December 1945 and so a continuous record of this emergence is present at the Property. The founder of the Observatory, Bernard Lovell, became the world's first Professor of Radio Astronomy in 1951 and was knighted for his contributions to radio astronomy in 1961.

Meteors

The early radar observations of meteors in the late 1940s and early 50s resulted in a number of important discoveries including: several previously unknown daytime meteor showers such as the Arietids and the Zeta Perseids; the measurement of the velocity of meteors demonstrating that sporadic meteors were not of interstellar origin; the study of ionospheric winds.

The Moon

Radar studies of the Moon in the 1950s included a demonstration that only the central part of the Moon's visible disk was efficient at reflecting radar pulses and that the fading of reflected pulses was caused by a phenomenon known as Faraday rotation in the ionosphere.

Very Large Paraboloidal Telescopes

Jodrell Bank constructed the largest telescope in the world in 1947, the 66m Transit Telescope. This fixed dish was surpassed by the fully-steerable 76m Lovell Telescope in 1957. It inspired the construction of other very large telescopes elsewhere, but remained the world's largest fully-steerable telescope until the 100m Effelsberg Telescope was completed in Germany in 1972.

Detection of Andromeda Galaxy

Radio waves from the Andromeda galaxy were detected using the Transit Telescope in 1950. This was the first clear identification of an extragalactic radio source and showed that, like the Milky Way, other normal galaxies are radio sources. The Transit Telescope was also used to detect the remnant of Tycho Brahe's supernova in the constellation of Cassiopeia, not seen since the 1570s, and to survey the sky for other radio sources.

The 21cm Hydrogen line

Early work on the hydrogen line was done using the 30-ft Telescope, particularly under the leadership of Rod D. Davies who went on to use the Lovell Telescope to study the distribution of hydrogen in the Milky Way and other galaxies. A survey of atomic hydrogen using the Lovell Telescope (known as HIJASS) in the 2000s discovered a dark galaxy, VIRGO HI21.

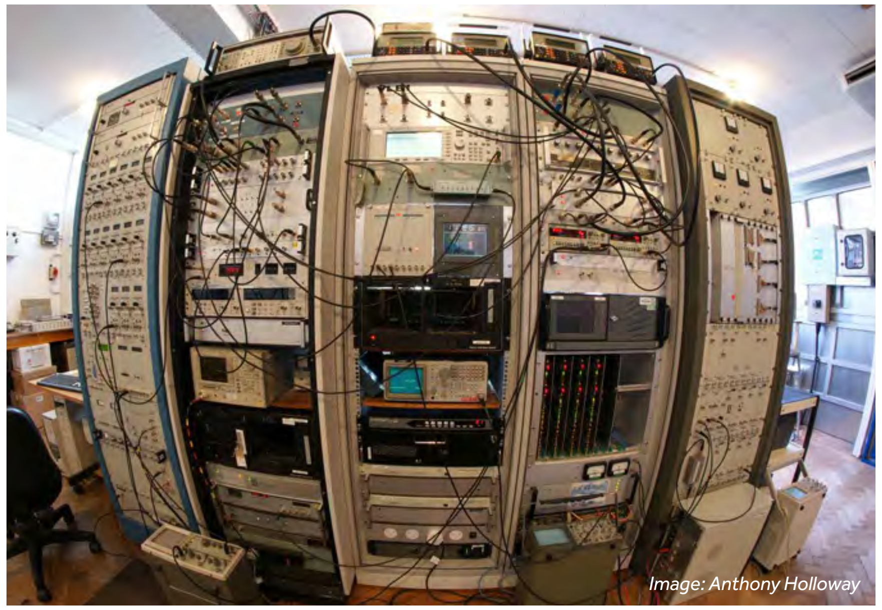


Figure 2.34: The receiver racks in the e-MERLIN/VLBI room in the Control Building at Jodrell Bank.

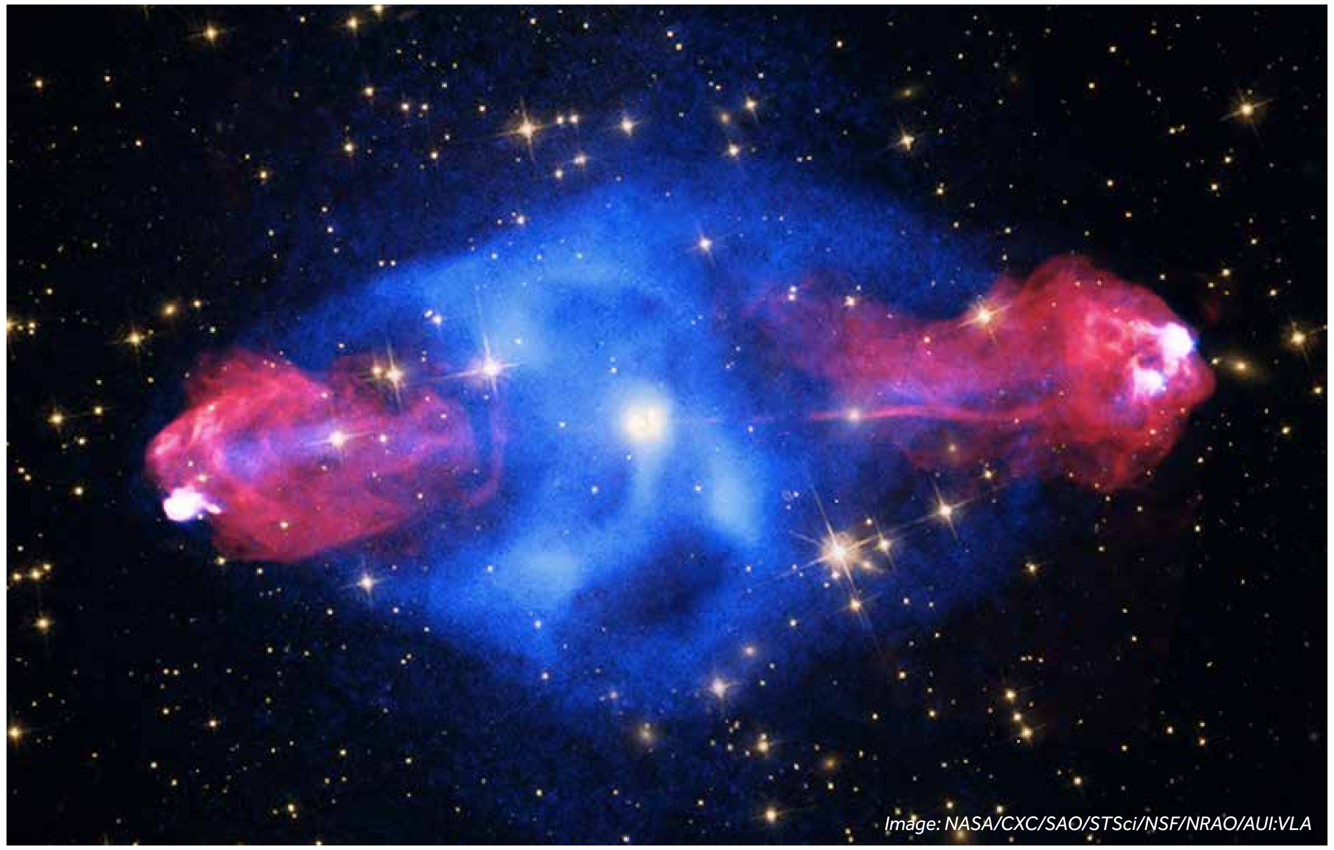
Long-baseline interferometry

From the early 1950's onwards, a key focus of Jodrell Bank work was the development of interferometry focusing on long baselines using radio-linked antennas. This extends to the present day with the e-MERLIN and VLBI networks and the future SKA telescope.

The double nature of Cygnus A

Using the novel intensity interferometer, the bright radio source Cygnus A (Figure 2.35) was shown to be a double source, with radio components at either side of the faint visible galaxy. This was the first known radio galaxy, many of which are doubles, now understood to be two radio lobes produced by oppositely directed jets from a central supermassive black hole.

Figure 2.35: The double lobes of the radio galaxy Cygnus A, seen here in red in a radio image from the Very Large Array, were first revealed by the intensity interferometer. This composite image also includes X-ray emission shown in blue and optical emission in yellow.



Closure Phase

During the 1950s, Roger Jennison, developed a fundamental technique in interferometry called 'closure phase' which is now used in adaptive optics and to calibrate all large-scale radio interferometers, including e-MERLIN, the European VLBI Network and the Event Horizon Telescope designed to take the first images of supermassive black holes.

Discovery of Quasars

The long-baseline interferometers developed during the 1950s and 60s provided the highest-resolution observations of distant radio sources and thereby played a key role in identifying the quasars – distant galaxies powered by supermassive black holes – and inspiring the development of Very Long Baseline Interferometry (VLBI).

Quantum Optics

The experiments of Hanbury Brown and Twiss in the mid 1950s led to the discovery of the Hanbury Brown and Twiss Effect and the development of the modern field of quantum optics.

Optical interferometry

These same experiments led Hanbury Brown to construct an optical interferometer at Jodrell Bank and make the first direct measurement of the diameter of a main-sequence star, Sirius.

Space tracking

The Lovell Telescope in particular played a key role in the space race, tracking a series of space probes launched by both the Soviet Union and the USA. This included tracking the launch rocket of Sputnik 1, the first spacecraft to reach the Moon and the first to send back photographs form its surface.

Pulsars

Following the discovery of pulsars by Jocelyn Bell and Antony Hewish at Cambridge in 1967, the Lovell Telescope proved to be an ideal instrument for studying these enigmatic objects. Since then, Jodrell Bank astronomers have gone on to become one of the world's leading research teams on pulsars. They have been involved in the discovery of around 70% of all known radio pulsars and play a leading role in pulsar surveys with for example the Parkes Telescope in Australia, with the Lovell Telescope being used for long-term timing. They also used the Lovell Telescope to discover the first pulsar in a globular cluster in 1986 and were a key part of the team who discovered the first double pulsar in 2004, an important laboratory for testing Einstein's General Theory of Relativity.

Gravitational Lensing

Observations with the Lovell and Mark II Telescopes beginning in 1972 led to the identification of an unusual object now known as the Double Quasar. When followed up optically by a team led by Jodrell Bank's Dennis Walsh in 1979, it proved to be the first example of a Gravitational Lens, caused by the warping of space-time as predicted by Einstein. Many more gravitational lenses were subsequently found in surveys using MERLIN, VLA and VLBI.

Observations of gravitational lenses are now a key part of modern astrophysics.

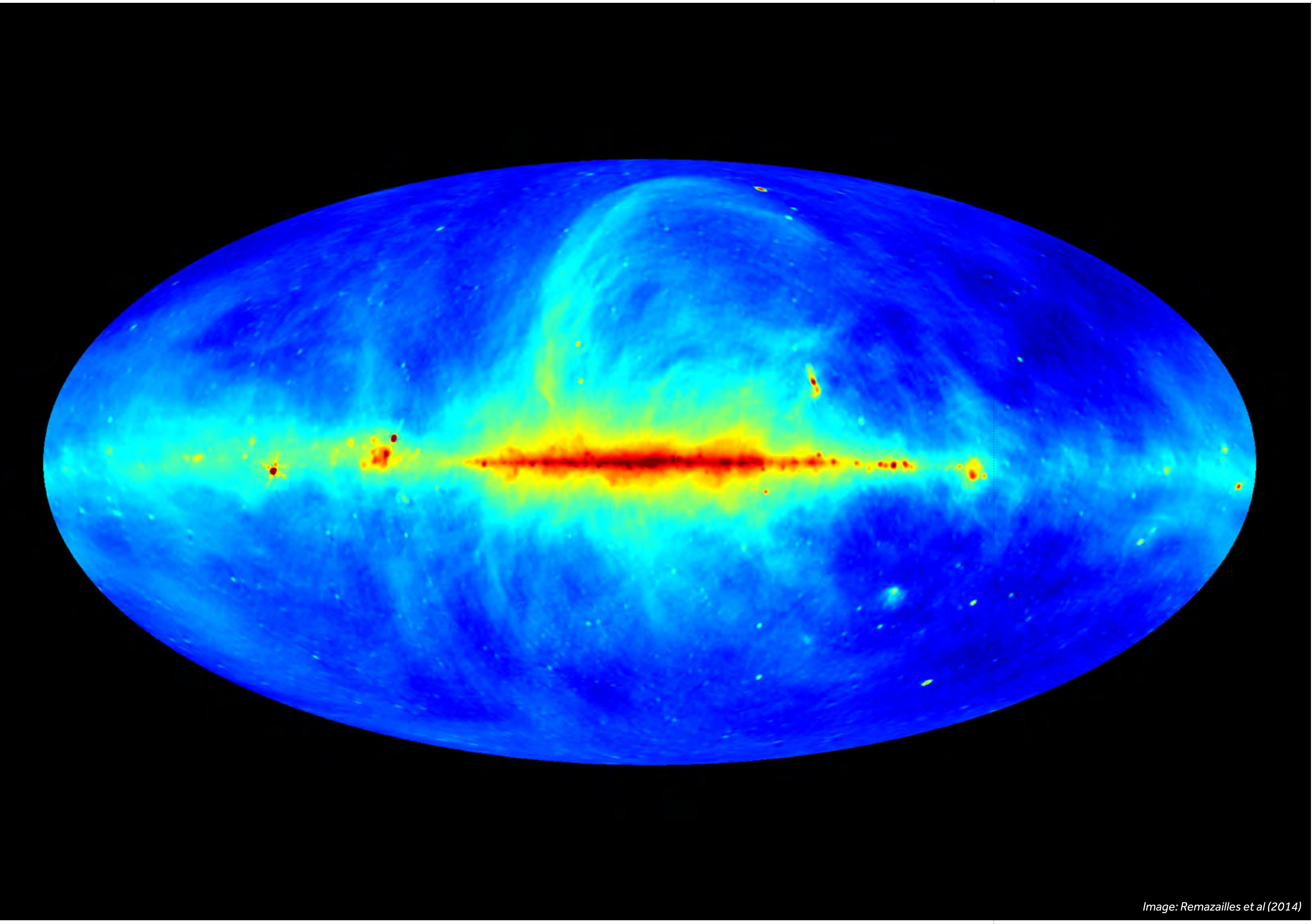


Figure 2.36: The 408MHz radio map of the whole sky was made using the Lovell Telescope at Jodrell Bank Observatory, working with the Effelsberg Telescope in Germany and the Parkes Telescope in Australia.

Surveying the radio sky

Building on the first surveys made with the Transit Telescope, the fully-steerable Lovell Telescope, together with the Effelsberg Telescope in Germany and the Parkes Telescope in Australia, was used to produce a complete map of the radio sky at a frequency of 408 MHz. This map, published in 1981, remains a fundamental tool for astronomers to the present day (Figure 2.36).

Galaxies at high redshift

MERLIN was used to determine the population distribution of star-forming galaxies and active galaxies at high redshifts from radio imaging of the Hubble Deep Field and flanking fields.

Radio galaxies and quasars

Building on the pioneering work of the 1950s and 60s, MERLIN proved fundamental to a number of discoveries in the area of radio galaxies and quasars, including: development of the Unified Scheme of quasars and galaxies; determining the density and magnetic field distributions in the ambient medium surrounding radio galaxies and quasars; and determining the structure of relativistic jets.

Starburst galaxies

The point sources in the starburst galaxy M82 were identified as the remnants of supernova remnants and their detailed evolution was followed as they expanded.

Astrometry

The high resolution of MERLIN was essential to linking the positional reference frames of the Hipparcos satellite and the radio reference frames (the International Celestial Reference Frame) including the astrometric alignment of the Hubble Deep Field.

Circumstellar shells

MERLIN was used to discover circumstellar OH maser shells; to make the first detection of angular expansion in such maser shells; and to determine the structure of magnetic fields in circumstellar envelopes and star-forming regions.

Explosive outbursts

MERLIN was used to make the first direct observation of the expansion and evolution of classical novae. It also tracked the detailed expansion and apparent superluminal motion of material ejected from micro-quasars (stellar black holes) and measured the mean space velocities of pulsars at their birth in supernova explosions.

The Cosmic Microwave Background

Jodrell Bank has a long history of involvement in experiments to map anisotropies in the cosmic microwave background providing a picture of the Universe as it was around 380,000 years after the Big Bang. This began with experiments at Jodrell Bank in the 1990s, which then moved to a dryer site on Tenerife, and eventually into space using the Planck spacecraft launched in 2009, some of whose extremely low noise amplifiers were built at Jodrell Bank. Planck has produced the best-yet maps of the Cosmic Microwave Background.

2.b.9
Impact on education and inspiration

Jodrell Bank Observatory has a long history of public engagement with science. Scientific discoveries about our place in the Universe made possible by modern astrophysics capture the public imagination and innovative public engagement has been a key feature of the site's activities since the Lovell Telescope first began working in 1957. It is rare that a 'scientific' location other than the NASA launch sites has captured public imagination to such an extent.

At Jodrell Bank, the public fascination for sky watching and optical astronomy has been translated into a vibrant engagement with modern astrophysics. This began in the very early stages of its work and has been carried on and built upon by subsequent generations of scientists and communicators.

In the early days, public engagement was generally informal but in 1966, permanent visitor facilities were constructed close to the Lovell Telescope. This was followed by the construction of a distinctive planetarium and restaurant. Eventually, these facilities were in need of significant repair and were replaced with new facilities in the Discovery Centre, which continue to underpin the site's important public engagement mission. The Observatory, and particularly the Lovell Telescope, continues to inspire those who see it, from astronomers and engineers who work there to the many thousands who come to visit it.

The breadth and depth of Jodrell Bank's research programme, coupled with the long-term appeal of the large telescopes at the site enables it to play a leading role in public engagement with astrophysics research. Three public pavilions provide spaces in which to welcome visitors and engage them directly with the actual research happening at the site. Current exhibits highlight this research, for example the work of the Lovell Telescope, e-MERLIN, interferometry, the evolution of stars and the technology behind Big Telescopes. The world's largest orrery is located in the Planet Pavilion and provides one of many interactive exhibits at the Site.

The current Discovery Centre prides itself on having hands-on knowledgeable staff with a background in physics/astrophysics and on working closely with the researchers from the Observatory e.g. in 'Meet the Expert' talks during school holidays and in public events such as the Lovell lectures. This engagement with live science and active researchers at a working observatory is crucial to the site's programme of public engagement. Visitor numbers have grown year on year since the Discovery Centre opened in 2011, recently reaching 185,000 annual visits, of which 26,000 are school pupils on organised educational visits. On-site year-round out-of- classroom education sessions for ages 4 to 18 as well as outreach sessions in a wide range of schools are on offer. This provides children with a unique learning experience and the opportunity to experiment with live science.

Over the last seven decades many hundreds of scientists and engineers have worked and trained at Jodrell Bank, often going on to work at other observatories across the world. Past postgraduate students from Jodrell Bank have become the Director of ASTRON (the Netherlands Institute for Radio Astronomy) and the Square Kilometre Array Organisation. The Observatory is part of the School of Physics & Astronomy at The University of Manchester. This is a leading physics department, rated as the best in Europe in the 2017 Shanghai Jiao Tong Academic Ranking of World Universities. The School now attracts around 320 physics undergraduates each year, the largest undergraduate physics school in the UK – the research facilities at Jodrell Bank and its high public profile are a key attractor.

Teacher-training and short courses for adults are also on offer at the Discovery Centre, as well as arboricultural training in the Arboretum. The latter provides further opportunities for public engagement with both science and nature; for example through activity based trails and interpretation boards. A formal volunteering programme is now in place.


Image: The University of Manchester

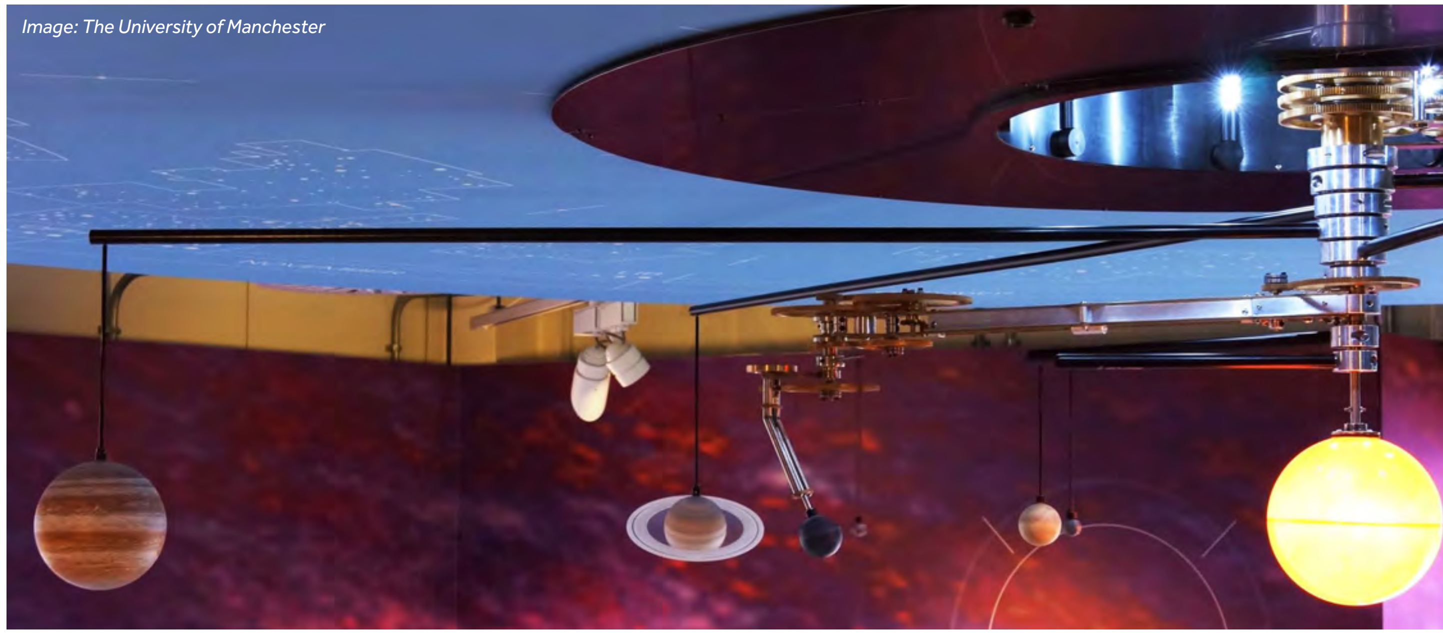


Image: The University of Manchester

Figure 2.37: The world's largest orrery, a scaled mechanical model of the solar system, can be found in the visitor facilities for the property.

The site's philosophy on public engagement is further extended via its extensive and popular events programme. This includes, for example, a programme of themed science demonstrations run during the school holidays, evening events (e.g. Stargazing Nights and regular 'Girl's Night Out' sessions) and the hugely successful bluedot science-music-art festival, which has attracted around 15,000 people in both 2016 and 2017. Taking place over a whole weekend, the festival features live music on multiple stages, science exhibitions and science talks and workshops, as wells as art installations. These events also include archive image and film relating to the creation of both the Observatory and the Lovell Telescope, which have been projected onto the Telescope itself. These cultural events reach a completely different audience from those who might usually visit Jodrell Bank and extend the reach of engagement with both the science and heritage of the Property.

Jodrell Bank has become a beacon and centre of excellence for science engagement, with many other scientific organisations taking inspiration from its work and philosophy. The Discovery Centre was awarded Tourism Attraction of the Year by Marketing Cheshire in 2012 and includes an award- winning café. The Director of the Discovery Centre and Associate Director of the Observatory, Professors Teresa Anderson and Tim O'Brien were awarded the Kelvin Medal of the UK Institute for Physics for their innovative work in public engagement with physics via the Jodrell Bank Discovery Centre. Evidence of impact of the Centre's activities can be found in a consistent appetite for its events and exhibitions, audience growth at the new Discovery Centre (from 94,000 visitors in the first full year 2011/12 to 180,000 in 2016/17), positive feedback and repeat visits from schools and the general public. A national online survey carried out by Harris International in 2008 showed that 54% of the UK population recognise Jodrell Bank as a UK science facility – a 'brand' recognition unparalleled amongst active UK science centres and indicative of the impact of our public engagement. Another Harris survey in 2012 found 76% of our visitors are very likely or absolutely certain to recommend a visit to friends.

A visit to Jodrell Bank has been a fixture in the life of school pupils in the region for decades, drawn in particular by the monumental Lovell Telescope and the wonder of the site's mission to understand our place in the Universe. Many of these visitors have also been inspired to take up a career in science and technology. When Sir Bernard Lovell died in 2012, a book of condolence was opened and the entries provide perhaps the best summary of the impact across the world.

Figure 2.38: During the bluedot festival in 2016, the musician and artist Brian Eno worked to create an installation that projected images onto the Lovell Telescope

Image: Howard Barlow

Quotes from Book of Condolence for Sir Bernard Lovell FRS in 2012

'Sir Bernard [was] a great man and scientist. His pioneering work in radio astronomy and his achievements have allowed exciting development and discoveries in this new discipline. He will always be remembered and will remain an example all over the world.'

Luigina Feretti,
Director of INAF Istituto di Radioastronomia, Rome, Italy

'Sir Bernard Lovell... made a towering contribution to science and this country. It is a legacy that has inspired several generations and we must ensure it continues to do so in the decades ahead.'

David Rutley,
Member of Parliament for Macclesfield

'Sir Bernard achieved many great things, but his lasting legacy is the generations of students Jodrell produced and the impact they have had around the world in astronomy and many other fields.'

Professor Mike Garrett,
Director, ASTRON (the Netherlands Institute for Radio Astronomy), Dwingeloo, The Netherlands

'Sir Bernard was a man of exceptional talent, courage, passion and compassion, and with the vision and determination that enabled him to create the world-renowned centre of excellence that is Jodrell Bank.'

Professor Mike Bode,
Astrophysics Research Institute, Liverpool John Moores University

'... the Lovell Telescope, as it rightly called these days, and Jodrell Bank Observatory [are] shining examples of how things could and should be done.'

Professor Michael Kramer,
Director, Max-Planck-Institut fuer Radioastronomie, Bonn, Germany

'The Universe is a larger place thanks to his work.'

NASA Goddard Space Flight Center

'...Amongst many achievements, Sir Bernard was a great pioneer of radioastronomy and his legacy lives on at Jodrell Bank. Inspirational projects like the Square Kilometre Array have their foundations in Sir Bernard's work.'

Patricia Kelly,
Chair, Australia/New Zealand SKA Coordination Committee

'It is with great sadness that we learn of the death of one of the pioneers of radio astronomy and patriarchs of the space era, Professor Sir Bernard Lovell. Throughout his career he has been, and will remain forever, an example of scientific vision and the embodiment of the spirit of exploration.'

Joint Institute for VLBI in Europe, Dwingeloo, The Netherlands

'Many generations of Jodrell Bank students owe him their thanks. The world radio astronomy community always regarded him with awe. He will be missed.'

Professor Philip Diamond,
Chief of Astronomy and Space Science, CSIRO, Australia

'Sir Bernard was one of the heroes of 20th Century astronomy and his legacy will endure.'

Professor Patricia Whitelock,
Director, South African Astronomical Observatory

Image: The University of Manchester

2.b.10
Impact on culture

Jodrell Bank, and the Lovell Telescope in particular, has captured public imagination and made its way into a wide range of popular culture, inspiring writers, artists, musicians and filmmakers.

The site's function as a space observatory has clearly led to a strong association with science fiction. The telescope was the source of inspiration for cosmologist and writer Fred Hoyle's story for A for Andromeda, a BBC TV serial from 1961, remade for Italian television in 1972 and by the BBC in 2006. It features a giant radio telescope, which picks up signals from the Andromeda Galaxy. In 1966, the film director Stanley Kubrick was working to ensure that his film, 2001: A Space Odyssey would have the credibility that science fiction often lacked in popular culture. He assembled a list of renowned thinkers of the time and filmed interviews with them in which they spoke about the possibility of alien cultures, intelligent computers and the origins of life. One of these was Sir Bernard Lovell, founder of Jodrell Bank. Kubrick's original plan was that the interviews would be shown as a prologue to his 1968 sci-fi masterpiece. In the end, time pressure meant the prologue was never shown and the short film is now lost, but the transcript still exists in the Kubrick archive showing how Lovell and Jodrell Bank occupied a key role in popular conceptions of the space race and the exploration of the universe.

The work of Jodrell Bank has also featured strongly in the classic BBC TV series Dr Who. It has been mentioned at least seven times over the years and was represented in Logopolis as the place in 1981 where the Fourth Doctor, played by Tom Baker, regenerated into Peter Davison. Bernard Lovell was also represented in the movies Meteor (1979) and the Lovell Telescope in Hitchhikers Guide to the Galaxy (2005) after Douglas Adams had written Jodrell Bank into his original radio series (1978) and books. Author Jeanette Winterson has featured Jodrell Bank in her novels Tanglewreck (2006) and The Stone Gods (2007); it played a central role in Alan Garner's Boneland (2012); and Nigel Kneale explained that the lead character, the head of the British Experimental Rocket Group in his classic British science-fiction series Quatermass (1953-2005) was named Bernard Quatermass after Bernard Lovell.

The Lovell Telescope appears in music videos by Electric Light Orchestra (Secret Messages, 1983), D:Ream (Party up the World, 1995), Placebo (The Bitter End, 2003) and Public Service Broadcasting (Sputnik, 2015) and in 1992 on the cover of Space Face, a single by Sub Sub (later Doves). In 1979, the band Joy Division, who famously featured a pulsar trace on their Unknown Pleasures album cover, used a picture of the Orion Nebula obtained from a postcard bought from Jodrell Bank on the cover of their debut single Transmission. Since 2011, the bluedot and Live from Jodrell Bank music and science festivals have hosted many bands and artists including the Flaming Lips, Sigur Ros, New Order and Jean-Michel Jarre. The 2012 performance by Elbow was released as a live CD and DVD.

The Observatory has played host to many TV programmes over the decades, from the live coverage of the space race and Moon rockets, to more recent popular science programmes such as the BBC Stargazing Live series (2011-16), which attracted several million viewers for each episode. Notable science and media figures have visited Jodrell Bank for these programmes including astronaut Buzz Aldrin, astronomer Sir Patrick Moore, physicist Jocelyn Bell, physicist and broadcaster Brian Cox, comedian and broadcaster Dara O'Briain, and many more. The site has also played host to many visits from dignitaries including HRH The Prince of Wales, HRH Princess Margaret and HRH The Duke of Edinburgh. The Olympic torch was taken to the top of the Lovell Telescope's focus tower by comedian John Bishop in 2012 ahead of the London Olympics.

The Lovell Telescope is an iconic cultural symbol, recognised worldwide as representing astronomy, technology and the exploration of space. In 2011, the Royal Mail chose to depict the Lovell Telescope as 'J' for Jodrell Bank in their alphabetical landmarks stamp series. It has also previously featured on many stamps worldwide, including from Haiti, Hungary, Ascension Island, Barbuda, Liechtenstein and Tanzania. A series of images of these postage stamps featuring the Lovell Telescope compiled by astronomer and author Ian Ridpath (credit **www.ianridpath.com**) and reproduced below demonstrates how this impact has extended far beyond the UK.

Haiti, 1958
Part of an International Geophysical Year commemorative set and is the earliest representation of the telescope on stamps.
Stanley Gibbons nos. 581, 585

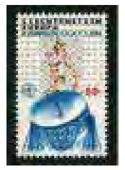
Hungary, 1965
A set issued to mark the International Year of the Quiet Sun. Above the telescope is a chart of the northern polar sky.
Stanley Gibbons no. 2059

Sharjah, 1965
Jodrell Bank featured on an unusual triangular stamp from Sharjah in the United Arab Emirates, part of a set on the theme of science, transport and telecommunications.
Stanley Gibbons no. 118

United Kingdom, 1966
Britain's first astronomy-related stamp, part of a set saluting British technology.
Stanley Gibbons no. 701

Ascension Island, 1971
Ascension, an island in the South Atlantic, included the Lovell Telescope in a set depicting the evolution of space travel.
Stanley Gibbons no. 143

Barbuda, 1986
The Lovell Telescope on one of Barbuda's Halley's Comet stamps contrasted with a traditional optical refracting telescope.
Stanley Gibbons no. 866



Liechtenstein, 1988
One of a pair of stamps on that year's Europa theme of Transport and Communications. The Telescope is shown receiving or emitting a stream of data.
Stanley Gibbons no. 931

United Kingdom, 1990
The Lovell Telescope is featured on one of a set of four astronomy stamps commemorating the 200th anniversary of Armagh Observatory in Northern Ireland and the centenary of the British Astronomical Association.
Stanley Gibbons no. 1522

Tanzania, 1993
Part of a commemorative set for the 450th anniversary of the death of Nicolaus Copernicus.
Scott catalogue (US) 1034.

Montserrat, 1996
This souvenir sheet accompanied a set of four stamps commemorating the centenary of Guglielmo Marconi's first radio transmissions. It depicts the Lovell Telescope's role in the Pioneer V space mission of 1960.
Stanley Gibbons no. MS944

United Kingdom, 2011
Part of an alphabetical series issued by Royal Mail in which the letter J is represented by Jodrell Bank, showing the Lovell Telescope in the local landscape.

3. Justification for Inscription

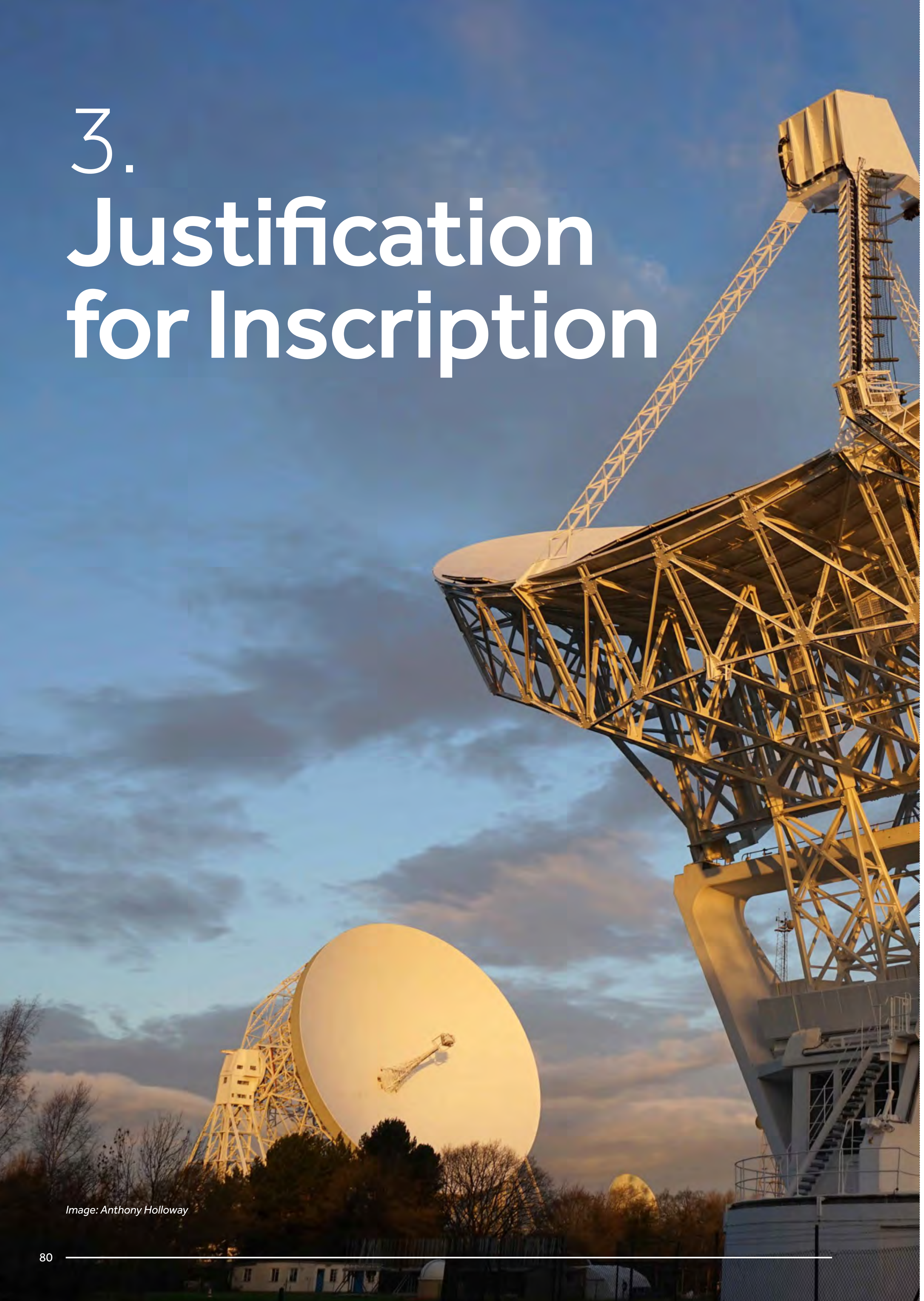


Image: Anthony Holloway

The Jodrell Bank Observatory is proposed for inscription on the World Heritage list in order to recognise and celebrate its achievements in science, and to safeguard the property for future generations worldwide.

Recognizing that there was a gap in the World Heritage List for properties related to science, and that the scientific value of cultural properties related to astronomy was not always recognized, UNESCO created a thematic initiative on Astronomy and World Heritage in 2003. In 2008, UNESCO and the International Astronomical Union began working together on this initiative, setting up a Working Group on Astronomy and World Heritage. ICOMOS, working with this group, has produced a Thematic Study on astronomical heritage (volume 1 was published in 2010[1], volume 2 in 2017[2]). In 2015, the IAU also approved the creation of a new Commission on World Heritage and Astronomy, thereby significantly raising the profile of world heritage among professional astronomers. The initiative stimulated the development of this nomination, with Jodrell Bank Observatory being added to the UK Tentative List in 2011.

The Thematic Study identified the main characteristics and astronomical values of the generic type of heritage site from a World Heritage perspective, discussed the various categories of heritage and their relevance to astronomy, types of astronomical heritage (including artefacts, observatories, instruments and archives), and listed a number of Astronomical Heritage themes worthy of further development. These latter included 'The development of radio astronomy' which is clearly relevant to this nomination. The chapter on this[3] in the Thematic Study has been very helpful in preparing the dossier, as has the illustrative case study of a particular instrument (the Stockert Telescope).

Since that chapter was published, there have been a number of further publications prepared by experts elsewhere (e.g. 'Cosmic Noise: A History of Early Radio Astronomy' by Woodruff T Sullivan III). These have been invaluable in the preparation of this dossier.

Preparing this Nomination Dossier has taken almost 10 years, during which time the process itself (and particularly the research required for the development of the site Conservation Management Plan) has been one of discovery, inventory and identification.

Tangible evidence of every stage of the emergence of radio astronomy has been found at the property during this time, together with evidence of its authenticity and advice on its management and conservation.

It has also become apparent that the Jodrell Bank radio telescope consultation zone[4], which is equivalent to 'dark night sky' protection for an observatory that uses optical telescopes, has been a de facto Buffer Zone for the Observatory since 1973.

In summary, the process of preparing for nomination has been a turning point in safeguarding the heritage of this property for future generations.

[1] ICOMOS-IAU: 'Heritage Sites of Astronomy and Archaeoastronomy in the context of the UNESCO World Heritage Convention: A Thematic Study' (June 2010) Edited by *Clive Ruggles and Michel Cotte*

[2] ICOMOS-IAU: 'Astronomy and Archaeoastronomy in the context of the UNESCO World Heritage Convention - Thematic Study 2' (June 2017) Edited by *Clive Ruggles*

[3] Chapter 13: The Development of Radio Astronomy, *Richard Wielebinski and Tom Wilson*

[4] Reference : Jodrell Bank Direction 1973

3.1.a

Brief synthesis

Jodrell Bank Observatory is the earliest radio astronomy observatory in the world that is still in existence. It is the one remaining site, worldwide, that includes evidence of every stage of the post-1945 emergence of radio astronomy, and, as such, played a pioneering role in a revolution in our understanding of the Universe.

Radio astronomy showed that there is far more to the Universe than meets the human eye, and that entirely new information can be obtained by using radio waves – a revolution exemplified by a range of features across the site.

Located in rural Cheshire in northwest England, the Observatory, which is part of the University of Manchester, is dominated by the iconic Lovell Telescope, the first very large fully-steerable radio telescope in the world. Constructed between 1952 and 1957, its first act was to track the carrier rocket for Sputnik 1, the first satellite ever launched into orbit and humanity's first step into space. The Telescope was the largest of its kind in the world for 15 years and inspired the construction of many other instruments worldwide.

The property encompasses a number of other radio telescopes, including the Mark II Telescope, and functional buildings on a 17.38-hectare site. Many of these are original structures and instruments, while remnants of earlier structures also persist, some of them below ground.

The character of the Observatory has been determined by the evolution of radio astronomy. Scientists first arrived at the southern boundary of the site in 1945, and then moved northwards as they made new discoveries, creating new equipment and experiments, thereby imprinting the development of the science on the landscape of the site.

The Observatory is not solely a scientific monument as it still carries out world-leading research. It currently hosts the UK's national array of 7 radio telescopes, and collaborates with many other radio telescopes worldwide.

The scientific importance of the property is demonstrated by the influence of its work, evidenced by the data and scientific publications in its archive, and its continuing research.

The Outstanding Universal Value of Jodrell Bank Observatory is conveyed by the following attributes:

The Landscape and Layout of the Site

Of all the early radio astronomy sites to develop worldwide, Jodrell Bank Observatory alone retains its original landscape, layout and function.

The Observatory was founded in 1945 when Bernard Lovell, a physicist at the University of Manchester, arrived with army radar equipment on trailers, with the intention of studying cosmic rays.

The Observatory grew from that point, as Lovell gathered a team of scientists around him. Over the two decades following this, they pioneered the new science of radio astronomy, humanity's first step beyond traditional optical astronomy, moving from south to north across the site, laying down all traces of its emergence on the landscape.

Having been used continuously since it was founded in 1945, it is now a technological and scientific ensemble that gives a clear illustration of the evolution of radio astronomy, and is a testament to the collective vision, determination and creative scientific genius of the people who founded it.

The landscape and layout tells the story of the emergence of this new science. Early work with innovative instruments gave way to permanent buildings, built in arrangements to serve the science, culminating in the spectacular telescopes that are the emblems of the Observatory today

The Lovell Telescope and Mark II Telescope

The nominated property is dominated by two very large radio telescopes: the Lovell Telescope and the Mark II Telescope, which are both Grade I listed structures.

The largest, and most iconic, of these is the Lovell Telescope. The world's biggest telescope when it was completed in 1957, its collecting area was almost 10 times more than any similar instrument. It inspired the construction of many other very large paraboloidal telescopes across the world, and six decades on, it remains the third largest fully-steerable telescope in the world.

The Mark II Telescope is the site's second large-scale fully steerable radio telescope and the first in the world to be controlled by a digital computer. Completed in 1964, its design was used as the basis for the world's first paraboloidal satellite communications antenna, Goonhilly No 1 in Cornwall.

Standing 89 metres above the Cheshire plain, the Lovell Telescope is both an international icon of science and engineering and a popular landmark that dominates the surrounding area, looming above the trees and hedgerows of its largely agricultural surroundings and visible for many miles. Its unique design stands today as a symbol of the emergence of the new science of radio astronomy and the peak of a post-1945 movement in science which will never be repeated or surpassed.

The Control Building

The Control Building was completed in 1955, a decade after the inception of the site. It houses the control room, purpose-built for the Lovell Telescope, and is still the hub of Observatory operations. The first use of the building was for a Symposium of the International Astronomical Union in August 1955, attracting astronomers from around the world to discuss the latest developments in radio astronomy.

It was the site of several landmark achievements in the space race, including the point from which the Lovell Telescope was driven to track the carrier rocket for the soviet Sputnik 1 satellite (the world's first extra-terrestrial vehicle) on 11 October 1957, and where signals were received from the Luna 2 rocket on 13 September 1959 (the first spacecraft to reach the surface of another celestial body).

These early instances of the international interchange of human values exemplify the way in which this permeates the whole site, including not only developments in astronomy but also quantum optics; interferometry; spacecraft tracking & communications; and wider culture. Many of the structures on the site housed, and embody, the work that was at the heart of this flowering of international co-operation and exchange of values and ideas.

The Green and associated Observatory buildings

This series of modest concrete-framed huts, arranged around an open central space (appropriately called 'The Green'), was built in 1949. Its creation marked the transition of the Observatory from a place that was simply the location of experimental equipment, mostly housed in ex-army trailers, to a permanent research station.

The buildings, some evocatively named after the research carried out by the occupants – Moon Hut, Radiant Hut, Cosmic Noise Hut – still remain. Several have now been Grade II listed: the Park Royal building (the control room for the Transit Telescope and later the Mark II Telescope); the Electrical Workshop (before the Control Building, this was the 'Main Office' housing the site's library, lecture room and Bernard Lovell's office); and the Link Hut, originally Cosmic Noise Hut (the control room for a 9.1m telescope used to investigate 'cosmic noise' and interstellar hydrogen).

Arranged so that they were interspersed with space for a range of experimental aerials and telescopes, the ensemble gives the site a very particular character, which exists to the present day.

The site of the Transit Telescope

In 1947 the Jodrell Bank team built what was then the world's largest radio telescope – the 218-foot (66.4m) diameter Transit Telescope, a mesh bowl fixed to point directly upwards at the sky passing overhead as the Earth turns. Its size was, rather practically, determined by the space between hedgerows and on-site roads that are still in existence. Although it was dismantled in the early 1960's, some remnants of the telescope still exist in concrete footings, below ground archaeology and steel poles recycled for use elsewhere on site. The Mark II Telescope now stands on one edge of its location.

It was the largest telescope in the world from 1947 to 1957 (when it was superseded by the Lovell Telescope) and, in 1950, was used to make the revolutionary first identification of radio waves originating from an object outside our own galaxy, the Andromeda Galaxy.

Sites and remnants of other early scientific instruments

As scientific questions changed and technology developed, instruments were built for specific uses and then set aside, modified or dismantled to be recycled into something new. This characteristic evolution in practice has left a trail, across the Observatory, of locations of early instruments and some physical remains.

These include the remnants of the earliest example of a permanent radio-astronomical instrument at Jodrell Bank, the Searchlight Aerial, built in 1946. When observations of the Giacobinid meteor storm made with this were presented at the December 1946 meeting of the Royal Astronomical Society, the President of the Society announced it as the birth of "an entirely new field of astronomical research". Radio Astronomy had arrived.

The Botany Huts

Bernard Lovell arrived at the University of Manchester's Botany Grounds at Jodrell Bank in December 1945, with two trailers of army radar equipment, with which he proposed to study cosmic ray trails in the atmosphere. The iconic first photograph of that day shows him, with the trailers, standing outside the two wooden Botany Huts, which were then used by the gardeners.

The Botany Huts remain, now unoccupied, in the abandoned botany grounds, as a tangible reminder of those first days at Jodrell Bank, the first days of the Observatory itself. It was from these modest beginnings that a completely new way of understanding the Universe developed.

Figure 3.1: View of the Green from the Powerhouse showing the mesh surface of the Transit Telescope in the foreground and the Lovell Telescope in the background, circa 1959.

Conclusion

Jodrell Bank Observatory is the earliest radio astronomy observatory in the world that is still in existence.

It is the one remaining site, worldwide, that includes evidence of every stage of the post-1945 emergence of radio astronomy, and, as such, played a pioneering role in a revolution in our understanding of the Universe.

Radio astronomy showed that there is far more to the Universe than meets the human eye, and that entirely new information can be obtained by using radio waves – a revolution exemplified by a range of features across the site.

Located in rural Cheshire in northwest England, the Observatory, which is part of the University of Manchester, is dominated by the iconic Lovell Telescope, the first very large fully-steerable radio telescope in the world. Constructed between 1952 and 1957, its first act was to track the carrier rocket for Sputnik 1, the first satellite ever launched into orbit and humanity's first step into space. The Telescope was the largest of its kind in the world for 15 years and inspired the construction of many other instruments worldwide.

The property encompasses a number of other radio telescopes, including the Mark II Telescope, and functional buildings on a 17.38-hectare site. Many of these are original structures and instruments, while remnants of earlier structures also persist, some of them below ground.

The character of the Observatory has been determined by the evolution of radio astronomy. Scientists first arrived at the southern boundary of the site in 1945, and then moved northwards as they made new discoveries, creating new equipment and experiments, thereby imprinting the development of the science on the landscape of the site.

The Observatory is not solely a scientific monument as it still carries out world-leading research. It currently hosts the UK's national array of 7 radio telescopes, and collaborates with many other radio telescopes worldwide.

The scientific importance of the property is demonstrated by the influence of its work, evidenced by the data and scientific publications in its archive, and its continuing research.

3.1.b

3.1.b Criteria under which inscription is proposed (and justification for inscription under these criteria)

It is proposed that Jodrell Bank Observatory be inscribed under criteria (i), (ii), (iv) and (vi).

(i) represents a masterpiece of human creative genius

Jodrell Bank Observatory is an outstanding example of supreme scientific and technical achievement, which revolutionised our understanding of the Universe. The post-1945 emergence of the science of radio astronomy was a turning point in the progress of 20th century astronomy. At Jodrell Bank, evidence of every stage of this is present in the property. This includes: the early use of recycled radar equipment; the construction in 1947 of the Transit Telescope (then the world's largest telescope); and the creation of the iconic Lovell Telescope in 1957 (superseding the Transit Telescope as the world's largest). The development of the Observatory, as a whole, was driven by the vision, determination and creative scientific genius of Sir Bernard Lovell and the team that gathered around him.

Jodrell Bank Observatory is only site in the world that has an unbroken thread from its pioneering work in the development of radio astronomy in the 1940s to the present day. The Observatory as a 'collective instrument' represents a masterpiece of human creative genius, exhibiting revolutionary achievements in both science and engineering. When the founder of the property, Sir Bernard Lovell, passed away in August 2012 at the age of 98, Lord Martin Rees, the United Kingdom's Astronomer Royal commented on Lovell, Jodrell Bank and its revolutionary role, citing Bernard Lovell as 'one of the great visionary leaders of science'.

Of course, it was not just Lovell who was responsible for what is seen today at the Jodrell Bank Observatory. This remarkable achievement, still evident in the attributes of the property, relied upon the visionary work and creative genius of a number of astronomers and engineers, whose names occur repeatedly in the histories of the time (see Section 2.b for a summary of this). The Observatory is, of course, recognised worldwide for the iconic 76m Lovell Telescope, the world's first and lasting icon of radio astronomy.

As Section 2 explains, in 1949, Lovell persuaded engineer Charles Husband to work with him on creating this new type of instrument at Jodrell Bank Observatory: a large fully-steerable paraboloidal radio telescope. This combined the power of the large Transit Telescope with the steerable design of the smaller 30ft Telescope at Jodrell Bank. Husband brought engineering skills and experience of building road and rail bridges to the construction of the Lovell Telescope, when other engineers were not prepared to take on the challenge.

When they began work, the largest other steerable telescopes were only about 15m in diameter (the US Naval Research Laboratory, USA). By the time the 76m diameter Lovell Telescope was completed in 1957, the largest others worldwide were only 25m in diameter (Dwingeloo, Netherlands; Stockert, Germany).

The construction problems of creating the Lovell Telescope were therefore unique. As Bryan Lovell, eldest son of Sir Bernard Lovell has said:

'There were no prototypes. There was just the first large fully steerable telescope in the world.'

It was a huge leap in capability as the previous radio telescopes (mentioned above) had only around 10% its collecting area. It remains the third largest steerable telescope in the world with a unique design whose construction was at the limit of engineering capabilities then and now.

Although the Lovell Telescope is the most recognisable symbol of the site, the whole story of the radically new development of radio astronomy underpins its importance and is apparent at the property.

The Lovell Telescope is the direct result of work on the 218-ft (66.4m) Transit Telescope (of which traces now remain on the site) and the 30-ft (9m) Telescope (of which the concrete base remains). Documentation and images of both these show their authenticity as precursor steps towards the Lovell Telescope.

Without them, and the remnants of other instruments and structures on the site, the Form and Design; Materials and Substance; and Use and Function of the Lovell Telescope and the Mark II Telescope are inexplicable. These elements, together with their associated research and control buildings laid out across the Property, tell the story of this highly significant step forward in human knowledge, which revolutionised our understanding of the Universe.

"Bernard Lovell ranks as one of the great visionary leaders of science.

"Along with others of his generation, World War II gave him responsibility and opportunity at an early age. He was thereby encouraged to 'think big' when he returned to academic science. He had the boldness and self-confidence to conceive a giant radio telescope, and the persistence to see it through to completion, despite the risk of bankruptcy. It was a huge project by the standards of the 1950s. What is even more remarkable is that, more than 50 years later, this instrument (after several upgrades) is still doing 'frontier' science: for instance, it is helping to test Einstein's theory to a precision 10,000 times better than was possible when it was built, by observing objects called 'binary pulsars' that weren't known to exist until much more recently.

"Jodrell Bank is one of the world's leading observatories. As its centrepiece, the 'Lovell Telescope', as it is now rightly called, continues to probe the cosmic frontiers, though it has also now become as iconic and familiar a part of our heritage as Stonehenge.

"I recall the celebrations of the telescope's 50th anniversary in 2007. Lovell, though nearly blind, played a full part in the festivities and made a superb speech. He rightly took great pride in this lasting monument. Over his long career he contributed hugely to UK and international science, both at the organizational level, and as an inspiring and eloquent speaker on science and its place in society."

Lord Martin Rees, Baron Rees of Ludlow,
Astronomer Royal, past President of the Royal Society
(sciencemediacentre.org)

(ii) exhibits an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design

The Jodrell Bank Observatory contains numerous examples of the physical evidence of the international interchange of ideas at a significant time in history, as the new science of radio astronomy and the space age developed during the 1940s-60s. This is epitomised by the structure of the iconic Lovell Telescope and Mark II Telescope, which dominate the site and effectively 'bracket' the property. It is also embodied in the character of the landscape itself and the structures that housed and exemplify the work that was at the heart of this unique flowering of international cooperation and exchange of values and ideas. These included developments in astronomy, but also extended more widely to include, for example, quantum optics; interferometry; spacecraft tracking and satellite communications.

In their conclusion to the first volume of the ICOMOS/IAU Thematic Study on Astronomy and World Heritage, Cotte and Ruggles point out that, in astronomical heritage, "it is important to recognise the continual interchange between the 'tangible' and 'intangible' categories, which is part of the fundamental paradigm that constitutes the scientific process in general."

This interchange exists both within a site and, more importantly, between sites, increasingly internationally as communication develops with time. This continuous interchange and influence extending both in and out is very apparent at the nominated property. Several key examples of interchange of human values at the property are therefore described below.

Very large paraboloidal dish telescopes

A key attribute of the property is the presence of two very large radio telescopes, the Lovell Telescope and the Mark II Telescope. Both rely on a basic technological concept, the paraboloidal reflecting dish.

This concept also determined the shape of their precursor, the fixed Transit Telescope, the first large reflecting dish used at Jodrell Bank Observatory (remains of which still exist at the property).

In itself, the use of a reflecting dish was not new. Small reflecting dishes had been used in optical instruments for millennia and radio communications had been made across the English Channel in the 1930s using dishes that reflected radio waves.

Grote Reber had been the first to use one in radio astronomy in 1937. Lovell himself had used them in airborne radar systems in 1940, and the German Würzburg radar dishes became an invaluable tool for various nascent radio astronomy groups after the war.

In consequence, it was not the use of a paraboloidal dish (as a concept) in Jodrell Bank's Transit Telescope that was innovative. What was new, and significant, was its phenomenal size – far larger than any other in the world – and hence its power to collect faint signals from great distances out in space.

This use of the Transit Telescope as a tool for radio astronomy did not go unnoticed. For example, it inspired John Bolton, of the Radiophysics Laboratory in Sydney to build a similar, albeit much smaller, instrument at Dover Heights, which itself made significant discoveries.

Further transit telescopes followed, some of which are still in use today, e.g. the Arecibo Telescope in Puerto Rico (1963), which, as Francis Graham-Smith in his book on telescope technology, Eyes on the Sky, comments, also followed *"the early example of the 218-foot fixed reflector dish at Jodrell Bank"*. The largest yet, the FAST transit telescope was inaugurated in 2016 in China.

The next new type of instrument – the Lovell Telescope – created at Jodrell Bank Observatory (a large *fully steerable* paraboloidal radio telescope) was without precedent.

Figure 3.2: View of the Transit Telescope looking west and showing the Searchlight Aerial, Moon Hut and Park Royal, circa 1949.

However, while there may not have been prototypes, there were design influences, which shaped the creation of the Lovell Telescope and can still be seen in its structure today. For example:

- the aerodynamic stability of suspension bridges;
- mechanical control of Navy battleship gun turrets;
- experience from railways in the azimuth railtrack;
- the detection of the hydrogen line leading to a solid dish.

There were learning points too, which have had impacts elsewhere. For example:

- there are significant cost savings in an alt-azimuth mount over an equatorial mount which had been traditional in optical astronomy – this carried across into later large radio telescopes; and
- wind loading at height is a key consideration (even in the 2000s, the European Southern Observatory installed monitors on the Lovell Telescope to investigate wind loading for their optical Extremely Large Telescope in Chile due for completion in the 2020s).

But the most influence occurred because of the inspirational scale of the structure itself. By building the world's first very large, fully-steerable, paraboloidal telescope, Jodrell Bank had demonstrated that it was possible in engineering terms and could also attract significant external funding. This motivated other groups around the world to embark on their own projects.

As early as 1952, before it was completed, the Lovell Telescope was cited as inspiring plans for the next very large telescope, the 64m Parkes Telescope (Australia) that was eventually constructed between 1959 and 1961. Edward Bowen, the driving force behind the telescope, later commented, *"to some extent it was indigenous – we thought this is the way to go but it was stimulated by the fact Lovell's beating this bandwagon in England. And it certainly looked a very good idea to me."*

In his book that reviews international radio astronomy, A Single Sky, Munns also commented, *"The reality of Jodrell Bank gave Bowen a figure to aim for, a size to propose, and, perhaps most important, a reality that he could point to."*

The USA did not want to lag behind. Citing the construction of the giant radio telescopes at Jodrell Bank and in Australia, a consortium of American universities proposed the creation of a National Radio Astronomy Observatory with a series of radio telescopes at Green Bank, West Virginia.

The experience gained from the design, construction and operation of the Lovell Telescope also informed the design of the second large telescope at Jodrell Bank, the Mark II Telescope. The Mark II was designed by Husband and Co and constructed by Sir William Arrol and Co who, 80 years earlier, had constructed the Forth Rail Bridge (which is on the World Heritage List).

The Mark II was the first telescope in the world to be controlled by a digital computer (the Ferranti Argus 100). The innovative design using a pre-stressed concrete mount was also used by Husband for Goonhilly 1, the large communications dish in Cornwall, UK, which was used to receive the first transatlantic TV transmissions via the Telstar satellite. This was the first paraboloidal satellite communications dish and as such formed the prototype for all those that followed.

In 1967, Husband and Co listed the various telescopes or communications dishes they had designed or had been consulted on up to that date, following their work on the Lovell and Mark II Telescopes. These included:

- two alternative 140-ft (43m) telescope designs for Green Bank in the USA;
- work on the proposed, but never completed, U.S. Navy 600-ft (183m) alt-azimuth telescope at Sugar Grove;
- the 90-foot (27m) Goonhilly 2 satellite communications dish;
- technical comparisons of various designs for other satellite communications systems for Cable & Wireless Limited;
- and other work for Telespazio and Boeing Airplane Company.

Since the pioneering work at Jodrell Bank introduced and demonstrated the use of very large paraboloidal dishes, many large dishes have been built around the world performing a vital function in the fields of telecommunications and defence, as well as radio astronomy. (Many of these are described in Section 3.2).

Scientific Achievements of Jodrell Bank Observatory

Jodrell Bank has a significant legacy in its scientific and technical achievements.

This includes:

- **construction of the world's largest telescopes;**
- **world-leading studies of pulsars, the remnants of exploded stars;**
- **production of one of the first maps of the invisible radio sky;**
- **the identification of quasars – distant galaxies powered by supermassive black holes; and**
- **the discovery of gravitational lenses – the warping of space-time by mass predicted by Einstein.**

As well as its pioneering work in creating 'big dish' radio telescopes, its technical innovations include development of early computers (e.g. the Mark II Telescope was the first in the world to be controlled by digital computer) and advances in 'interferometry'.

Long-baseline interferometry

Techniques for long-baseline interferometry were developed at Jodrell Bank Observatory at around the same time as teams at Cambridge and Sydney pioneered work in phase-linked interferometers. The Jodrell Bank team wanted the interferometer elements (i.e. the radio telescopes) to be very widely separated, either connected by radio links or, (for separations of thousands of kilometres) by the use of tape recording of the signals. This work included the novel approach known as 'intensity interferometry' (Figure 3.3; see Section 2.b for the detail on this). A variety of interferometers were constructed making use of the Transit Telescope, the Lovell Telescope and the Mark II Telescope.

During this same period astronomers, working in the Polarisation Hut, also developed a fundamental technique in interferometry called 'closure phase' which is used in adaptive optics and to calibrate all large-scale radio interferometers, including e-MERLIN and the European VLBI Network. It is also used in current efforts to use a global array, the Event Horizon Telescope (which includes antennas in Chile, Mexico, Spain, France and the USA), to take the first picture of a Black Hole.

These long-baseline techniques have evolved, and continue to the present day with the UK's e-MERLIN array of telescopes operated from Jodrell Bank, other arrays in the USA, Australia, the Netherlands and India as well as trans-continental arrays including the European VLBI Network (of which Jodrell Bank is a founder member) and the future Square Kilometre Array (whose global headquarters is on the wider Jodrell Bank site, and which involves many nations).

This interchange of ideas and techniques has pushed back the frontiers of human knowledge and understanding of our place in the Universe.

Image: The University of Manchester

Figure 3.3: Mrinal Dasgupta and Roger Jennison working in Polarisation Hut on their Intensity Interferometer, circa early 1950s.

Quantum optics & optical interferometry

The first experiments in optical interferometry, carried out by Hanbury Brown and Twiss in the dark room extension of the Cosmic Noise Hut, demonstrated the effect that now bears their name (the 'Hanbury Brown and Twiss Effect' – HBT). The concrete footings for their optical bench still exist in the Cosmic Noise Hut.

Their experiments lead to the important field of quantum optics, which has current applications, worldwide, in high-energy nuclear physics, condensed matter and atomic physics.

International scientific dialogue and influence

It was observations with the Searchlight Aerial which, when presented at the 1946 December meeting of the Royal Astronomical Society, led the President of the Society to announce the arrival of Jodrell Bank and radar astronomy as *"an entirely new field of astronomical research"*.

This pioneering role of Jodrell Bank in the new science of radio astronomy and its development through dialogue between scientists across the world is exemplified by a series of international meetings at Jodrell Bank in those early days.

These included a meeting on meteor astronomy in 1948, another in 1953 on radio astronomy including a "considerable number of astronomers who had come from abroad", and a 1955 symposium of the International Astronomical Union held in the Lecture Room of the Control Building (the very first use of this building).

Over the years since there have continued to be many similar meetings (including, at the time of writing, an international conference to celebrate the 50th Anniversary of the discovery of Pulsars).

Influence was mediated not just by the international discussions and sharing of information, but also by the exchange of people, who transferred in and out of the Observatory team. For example:

- John Galt, the first employee of Canada's new Dominion Radio Astrophysical Observatory (DRAO), was posted to Jodrell Bank in 1957, and worked in the Cosmic Noise Hut, before returning to play a leading role in establishing Canadian Radio Astronomy as Director of DRAO from 1963-1980;
- Another early staff member was Mrinal Dasgupta, Figure 3.3, who came from India on a research fellowship to undertake a PhD under Hanbury Brown from 1950-54 and returned to a distinguished career in Indian radio astronomy;
- John V. Evans who worked on radar studies in the Moon Hut at Jodrell Bank, including in tracking of the Sputniks, moved to the USA where he became Director of the Lincoln Laboratory at the Massachusetts Institute of Technology and had a distinguished career in satellite communications, including as President and Director of COMSAT Laboratories.

There are many other similar examples.

Figure3.4: The Mark II Telescope (foreground) and the Lovell Telescope (background).

Image: Anthony Holloway

(iv) an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history

Jodrell Bank Observatory is the unique technological and landscape ensemble, globally, that exemplifies, through its surviving physical evidence, the transition from traditional optical astronomy to modern multi-wavelength astrophysics that took place during the 1940s and the years that followed. Developments at all stages of this history took place within its boundaries, with many of the earliest features, or their locations, extant and recognisable. This was a significant stage in the history of understanding our place in the Universe.

It was also a significant stage in the peacetime development of 'Big Science', which followed the Second World War, and was characterised by a leap in the scale of projects, paralleled by a leap in scale of funding and in numbers of collaborating scientists and engineers. While the size of the Lovell Telescope means that it is the most obvious feature of the site, it is, in fact, the Observatory as an ensemble that is at the heart of the property. The character of the landscape and the interrelation between buildings and structures speaks of the revolutionary developments that took place there, and represent this significant stage in human history.

The Jodrell Bank Observatory is an outstanding technological ensemble illustrating the emergence and subsequent development of radio astronomy in the twenty years after the end of the Second World War. This was a significant stage in both the history of understanding our place in the Universe and of the peacetime development of 'Big Science' following the application of science to warfare, in this case radar. The property is unique in the combination of its pioneering role and its unbroken record in scientific research from 1945 to the present day, with physical evidence of all these stages still remaining.

The significant stage in human history can be defined in terms of two important developments:

1. the emergence of radio astronomy and
2. the transition from world war to peacetime research – the emergence of 'Big Science'.

The emergence of radio astronomy

Structures at the property include a range of radio telescopes still in use, and other equipment, buildings and archaeological traces. Other sites worldwide at which pioneering work took place either no longer exist or their work has moved to other locations so that evidence of their early history, or their character as an observatory no longer survives.

The Lovell Telescope (1957) in particular stands out as the first very large steerable radio telescope which inspired others around the world and which contributed not only to the science of radio astronomy but also to the exploration and exploitation of space. The second large telescope still in use at the site is the Mark II Telescope (1964). It worked in tandem with the Lovell Telescope (previously known as the Mark I) and was the prototype for the first large paraboloidal satellite communications dish.

Alongside these two large telescopes are control buildings, huts and the remnants of other earlier astronomical instruments dating back to the founding of the Observatory as a permanent scientific institution in the 1940s. It was in these simple functional buildings that the scientists worked to develop new instruments and techniques to explore the Universe using radio waves. The buildings include workshops, a canteen and a dormitory that supported (and in some cases continue to support) these activities. The buildings and telescopes are set in a landscape around a Green still recognisable from those pioneering years.

The work at Jodrell Bank resulted in breakthroughs in science documented in learned journals and in the personal writings of, and interviews (transcribed, and in film and audio) with, the participants themselves and others worldwide published in books and held in archives.

Swords into ploughshares: the emergence of 'Big Science' and the post-war revolution in scientific research

The foundation of Jodrell Bank Observatory directly benefited from wartime work in ways that are still apparent at the site today. Skills in radar engineering were clearly essential to the rapid development of radio astronomy but in those first years after the end of the Second World War, all the equipment was ex-military, collected and brought to the site.

The first purpose-built permanent scientific instrument at Jodrell Bank was a meteor radar, constructed on an Army searchlight mount in 1946, parts of which remain today.

Even now the Lovell Telescope is tipped using huge gear racks originally part of the 15-inch guns of two World War One battleships which were scrapped at the end of the Second World War. Jodrell Bank Observatory exemplifies the development of radio astronomy as the transformation of 'swords into ploughshares'.

The Second World War marked a turning point in the way in which science was organised and conducted. Scientific research during the war had been directed towards major projects including nuclear physics, rocketry, code breaking and radar. By the end of the war there was recognition of the key role played by the 'boffins' and a determination to make the most of these skills in peacetime. In the UK, for example, government expenditure on civil and defence research increased hugely from £10 million in 1939 to £220 million in 1955-56 (similarly in the USA it increased from $74 million in 1940 to $1,600 million in 1952). A post-1945 expansion in secondary and tertiary education led to significant growth in university science and there was development of major new facilities, including Jodrell Bank. The importance of science in the eyes of government and public in the immediate post-war years was realised in the UK by the 1951 Festival of Britain (in which Jodrell Bank played a role), which 'promoted a spectacular pageant of science, discovery and exploration as elements of a national rebirth'. This was a significant stage in history when government began to provide significant funding for scientific facilities and anything seemed possible if only enough effort were directed towards it.

This move that occurred during and following the war towards science being done in large-scale projects funded by national governments, or several governments, has come to be known as 'Big Science', for example the Manhattan Project, CERN and the Apollo space programme. At Jodrell Bank, this move is embodied in the structure of the Lovell Telescope, a massive instrument that dominates the landscape was funded, at least in part, at a national level and is operated as a collective instrument, now used by groups of astronomers across the world, who book 'observing time' in its schedule. It is less visible, but equally present, in the work of the Observatory today, which involves large networks of radio telescopes that span countries and continents.

As Agar, in his book, Science and Spectacle, explains, the concept of 'Big Science' has also been characterised as the influx of 'money, manpower, machines, media and military'. The scientists at Jodrell Bank certainly sought and received the money, they built a huge machine, their work was the focus of worldwide media attention and there was military involvement. This work at Jodrell Bank Observatory in the twenty years after the end of the Second World War is therefore an outstanding example globally of the move from the lone scientist to the 'Big Science' that now characterises much modern scientific research.

(vi) directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance

Jodrell Bank Observatory is inextricably linked to the fundamental concept underpinning modern astronomy: that we live on a planet orbiting a star, one in a galaxy of several hundred billion stars, itself only one of a hundred billion galaxies in the observable universe.

When radio telescopes were first pointed at the sky, it became apparent that there were whole aspects of the Universe, including exotic objects previously unimagined, which ordinary (optical) telescopes cannot see.

Jodrell Bank Observatory is intrinsically linked to this discovery – that there is far more to the Universe than meets the human eye, and that entirely new information can be obtained by using 'invisible' light, beyond the usual 'rainbow' of visible colours. Modern Astrophysics now uses this 'invisible light' as a matter of course, to examine the Universe, but the first major step towards this was taken by radio astronomy.

For thousands of years, humans had looked up to the skies using just their eyes. Four hundred years ago, Galileo's use of the telescope enhanced that view, but still relied on visible light.

The emergence of radio astronomy marked a revolution in which the range of human perception was extended beyond visible light to other areas of the electromagnetic spectrum. This radically changed the view of the universe, allowing a new understanding of what was already known, but also revealing an invisible universe, previously unknown.

The sky seen by radio telescopes turned out to be filled not with stars, but 'the stuff between the stars', electrons spiralling around the magnetic field of the Milky Way; clouds of interstellar hydrogen; the remnants of exploded stars; distant galaxies powered by matter falling into supermassive black holes; even the fading glow of the Big Bang itself.

Modern Astrophysics now uses the entire 'invisible rainbow' of the electromagnetic spectrum to investigate our place in the Universe.

Pivotal developments in the field of radio astronomy occurred at several specific locations in the property. For example, the Transit Telescope that operated at the Observatory from 1947 was then the largest in the world and identified the first radio signal known to originate outside our own Milky Way galaxy (from the Andromeda Galaxy).

The Lovell Telescope, the site's most prominent landmark, has carried out crucial work on important astronomical phenomena in the invisible radio sky (including quasars, pulsars and gravitational lenses).

The work of Jodrell Bank captured the imagination of a generation when the Lovell Telescope began operating in order to track the carrier rocket of Sputnik 1 as it orbited the Earth – the first artificial satellite and the dawn of the Space Age. It is linked to many other world events from the space race, including receiving the first photograph ever sent from the surface of the Moon.

The Telescope is held in high public regard nationally and internationally as an icon of science and engineering, embodying the fascination that humanity has always held for the exploration of space and the understanding of our place in the Universe.

Image: Anthony Holloway

Figure 3.5: The Lovell Telescope with stars revolving around the North Celestial Pole as the Earth turns.

3.1.c

Statement of Integrity

All the tangible attributes of the property sit within the site boundaries. The nominated property is solely owned by the University of Manchester, and the boundaries of the site are clearly identifiable in the Deeds of Ownership of the land. The property is generally in a good state of conservation. The integrity of some elements of the property is compromised (for example, only 5-10% of some of the original scientific instruments remain, as traces below ground). However, most of the buildings in the property are in good condition and the Grade I listing and continued research use of the Lovell and the Mark II Telescopes has ensured that the integrity and function of the most iconic elements of the property have been retained.

Possible adverse impacts are, on the whole, addressed very well, as the property has strong protection due to ownership, as well as the 'de facto' Buffer Zone that has been provided by the Jodrell Bank Direction (which is enshrined in local authority plans) since 1973.

Does the property include all elements necessary to express its Outstanding Universal Value?

All the tangible elements and attributes required to express the Outstanding Universal Value of the candidate for nomination sit within its boundaries. The property is owned solely by The University of Manchester. The University's ownership is clearly identifiable in the Deeds of Ownership of the land.

The local Planning Authority is Cheshire East Council. The potential World Heritage Site inscription has been written into the Council's Strategic Plan. The site is within the North West of England and national level heritage protection is provided by the north-west division of Historic England.

The Buffer Zone of the Property is defined by the boundaries of the long-standing statutory consultation zone for development set out in the UK Government's Town and Country Planning (Jodrell Bank Radio Telescope) Direction 1973. This zone is identified in the adopted Local Plan for Cheshire East Council and by the neighbouring Cheshire West And Chester Council, into which the zone extends.

Intangible elements of the attributes (scientific records, images, oral histories etc) are accessible, regardless of the site boundaries, as described in the section on Authenticity. They provide independent international verification of the attributes expressing the OUV.

The area dedicated to the International Headquarters of the SKA Organisation (adjacent to the property and within the Buffer Zone) will become an Inter-Governmental Organisation by International Treaty in 2017/18. This, again, reflects the international recognition of the importance of the site for Radio Astronomy. The land on which the SKAO Headquarters sits is leased from The University of Manchester, which has control over this area.

The public visitor facility, the Jodrell Bank Discovery Centre, sits partly within the boundary of the property, in the area around the Lovell Telescope, and partly just outside it. The part outside the property is on land wholly owned by the University of Manchester, which has control over this area. This is entirely appropriate, as the Centre exists to engage the wider public with the scientific work and heritage of the site.

Image: Anthony Holloway

Is the property of adequate size to ensure the complete representation of the features and processes which convey the property's significance?

At Jodrell Bank Observatory, the boundaries of the property encompass the complete set of features and processes, which convey the property's significance.

The location of the first experiments at the site (the 'Botany Huts' and the 'Searchlight Aerial'), the position of the Transit Telescope (now the site of the Mark II telescope), and the original Control Building coexist within the landscape with the Lovell Telescope, the Mark II telescope, Observatory buildings and the remnants of early experiments around the Green.

The property also demonstrates the transition, largely determined by scale, from tangible, moveable astronomical heritage (e.g. early radar equipment, mounted on trailers, used to track meteors) to tangible immoveable heritage, where immense radio telescopes were created in fixed positions and the trucks that housed equipment were replaced by permanent buildings with instruments in control rooms.

Tangible traces of early equipment remain both above and below ground, and the early buildings, that were used to operate and analyse the data from early instruments, are all still in existence and in use.

The property has benefited from continued use from its founding more than 70 years ago. Although this has led to some modification and repurposing – itself a characteristic of a scientific research site – it has ensured that buildings and telescopes are kept in good condition. The Lovell Telescope was Grade I listed in 1988 and the Mark II Telescope was Grade I listed in 2017. This means that they are afforded the greatest protection under planning regulations. In 2017, five other structures at the property were Grade II listed, which also ensures that any conservation and necessary modifications are carried out under the guidance of Historic England.

Some 'like-for-like' replacement of parts is necessary, e.g. the replacement of corroded metal elements of instruments. This has parallels with, for example, the replacement of eroded sandstone elements in the fabric of a church such as Durham Cathedral. In such cases, the form and function of the structure is prioritised over the retention of original fabric, which has a fixed natural lifetime when exposed to the weather.

As the Thematic Study of 2010 mentions:

"Integrity analysis must take into account the logic of maintenance and innovative evolution of instruments, in the context of the duration of their uses for continuing and successive astronomical objectives...

For example, fragile or dynamic elements must be carefully checked, and in some cases regularly adjusted or replaced with new spare parts. If not, the use and consequently the 'living state' of the instrument could be compromised. Furthermore, the use of astronomical instruments with a high level of scientific efficiency must follow the innovations and improvements regularly offered through the availability of new technical components that are stronger, more precise, etc., and sometimes through radically new individual or collective technical solutions to existing astronomical problems. The renewal of material and instruments...is a living aspect of science/technology in general, and of instrumental astronomy in particular[5].

[5] Thematic Study 2010: Introduction P10

Image: Anthony Holloway

Figure 3.6: The Control Desk of the Lovell Telescope.

Some details of the level of completeness of the tangible heritage present are set out below:

Landscape of the property

The landscape of the property has been modified as the Observatory developed, which is, in part, the reason why the development of radio astronomy is laid down upon the site itself. This is now preserved as an attribute of the property and is under the control of the University of Manchester.

The Lovell Telescope

This instrument stands outside in the landscape, and at a height of 89metres, is the most dominant example of tangible immovable heritage within the Observatory. It is also a working astronomical instrument, retaining its original function and level of scientific accuracy. It contains a high percentage of its original material, both in the telescope bowl and in its supporting and moving structures. As the original material of much of the Telescope is mild steel, corrosion requires planned 'like for like' replacement of elements of the structure as needed, and with the guidance of Historic England.

There have been several additions or alterations to the structure (recorded in the Jodrell Bank Engineering Archive) over the years since its construction, while retaining original fabric and form where possible. (See Section 2.b for description of these).

The Mark II Telescope

Although this is also a major structure and stands outdoors in the landscape, this radio telescope has undergone very little modification since its construction (other than the addition of a higher-quality surface fixed onto the original surface which is still present) and is wholly intact.

Control Building

This original building (including a very early extension) still remains. In the Control Room, original instrument panels and dials have been replaced with computers and display screens over the years since installation. (Examples of the original panels and dials have been retained for use in public engagement). The original telescope control desk remains, however, and is still in daily use (Figure 3.6). This building has now been listed at Grade II. There is a proposal, subject to funding, that later, poor quality, additions will be removed whilst restoring the original structure in line with the listing protection.

The Green and associated Observatory buildings

The Green area and the associated Observatory buildings around it are generally in very good condition. Continued use as a research station, maintained by the University's Division of Estates has ensured that they have received necessary repairs and upkeep.

Sites and remnants of the Transit Telescope and other early scientific instruments

- **Transit Telescope:** The site of the Transit Telescope remains and is delineated by the location of hedgerows and structures around it, including its original control building, Park Royal. Geophysical surveys indicate that there are still traces of the Telescope anchor blocks and trenches underground, but it is estimated that less than 5% of the original structure remains. Scaffolding poles that once formed part of its structure are re-used in various locations and some will be incorporated into a new exhibition to present and promote the property. The authenticity of this telescope is high, however, and images and documents of the Telescope and the work that was carried out with it offer a strong opportunity for public engagement with the location.
- **Searchlight Aerial:** Remnants of this persist both above and below ground, with the base of the original mount still present. Around 15-20% of the mount remains, and is soon to be subject to a process of archaeological excavation and preservation. The remains were listed at Grade II in 2017, affording them special protection as the earliest example of a radio astronomy instrument at the property.

- **Telescope baseplates:** Several radio telescopes are now not present on site, but their bases (square concrete pads at various locations) remain (See Sections 2.a and 2.b for descriptions of these). These provide an opportunity for public engagement with the heritage, in a way that clearly sets out the evolution of the science of Radio Astronomy in relation to the site itself. The authenticity of this is underpinned by documents, images etc.

The Botany Huts

The Botany Huts remain remarkably well-preserved (almost intact), considering their age. They are now overgrown by trees and shrubs. Work is planned to address this sympathetically in the next 1-2 years, although it is unlikely that it will be possible to render them suitable for visitors, due to Health and Safety and Accessibility requirements. A badger sett has also been established under one of them, which brings its own legal restrictions.

Intangible Heritage

Alongside the preservation of the fabric of the Observatory, its history is safeguarded in a number of archives, including the Jodrell Bank National Archive at the University of Manchester's John Rylands Library and archives of Sir Bernard's personal papers held by the Imperial War Museum and the Royal Society. These intangible elements combine with the physical elements of the site to express its OUV.

Addressing Possible Adverse Impacts

Resourcing

The maintenance of the Jodrell Bank site and its telescopes (particularly the Grade I listed Lovell and Mark II Telescopes) has, to date, been an outcome of research activities and support from the University of Manchester. The needs of the research have therefore resulted in conservation of both the telescopes and the buildings on the site, as they have been essential to the ongoing performance of the Observatory at the leading edge of radio astronomy.

In recent years (and especially prior to the last Technical Evaluation) there was significant pressure on funding and tension therefore existed between prioritising repair work that would maintain scientific operations and conservation work that would maintain the original fabric of the site and the structures upon it.

However, this has now been addressed by a capital allocation (in 2014) of £15million by the University of Manchester, which is being used to carry out major restoration and conservation works on the Lovell Telescope, ensuring that its condition is improved and stabilised for the next 30 years, creating a firm foundation for conservation for the future. Historic England is, of course, involved in this process.

In addition, in May 2015, the Heritage Lottery Fund awarded Jodrell Bank just over £12million for a major project (of total value £20.5million) both to conserve the site and provide appropriate space to accommodate increased numbers of visitors. This project is now fully funded by additional contributions of £4 million pounds from the UK Government and donations totalling £2.5 million pounds from Trusts and Foundations. This is underpinned by a business plan that includes additional staff, who will be directly responsible for managing aspects of the site's heritage, delivering a dedicated education programme and facilitating visitor engagement. This project is expected to be delivered between 2018 and 2021.

A separate project of £1.8million, which is already fully funded, is currently underway to improve car parking and arrival facilities in 2018/19.

New developments on site

The University has control over all new developments both within the nominated property and within its own landholdings immediately bordering the property.

Within the areas immediately bordering the property, new buildings have been created in recent years (e.g. the International HQ for the Square Kilometre Array Organisation) and are due to be created in future (e.g. new visitor facilities and car park).

The location of the buildings, their architecture and construction is managed so that they maintain and enhance the OUV and do not damage existing heritage attributes or the setting of the property.

New developments outside the site

As has been described in detail in Section 5, the property has effectively had a Buffer Zone since 1973, when the UK Parliament passed the 'Jodrell Bank Direction'. This has protected the property from developments (e.g. housing, industrial units etc) which might had impacted adversely on the radio interference environment around it and impaired its science.

This has also had the effect of protecting the property from inappropriate visual intrusion over this period. In future, this will be reinforced further by the designation of the property Buffer Zone, which follows the boundaries of the original zone set up in 1973 and covers an area of 18569.22hectares.

3.1.d

Statement of Authenticity

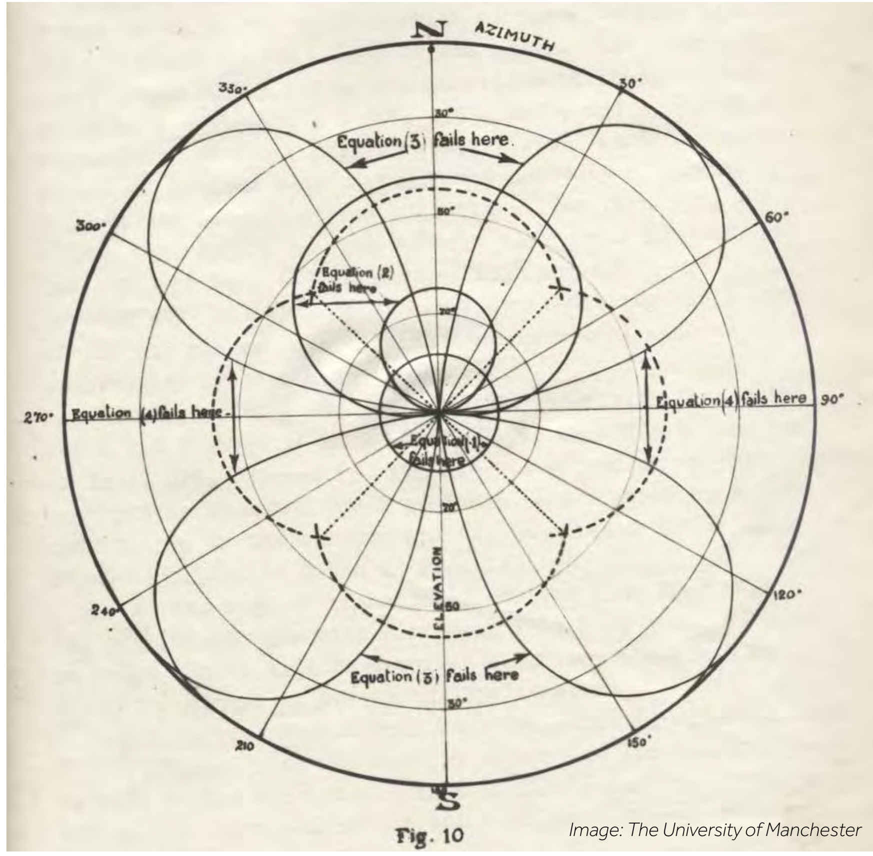


Figure 3.7: Extract from the Blue Book – Memorandum on a 250ft aperture Steerable Radio Telescope – the 1951 design proposal for the Lovell Telescope held in the Jodrell Bank archive.

Image: The University of Manchester

Despite the rapid and continuing developments at Jodrell Bank, the site preserves good evidence for the emergence of the science of Radio Astronomy and retains a high level of authenticity due to its continuing function as an observatory. Sites of all the major phases of development survive, even if in some cases only as archaeological evidence and major structures are preserved in working order. The authenticity of this is supported by a very strong body of associated documentation, including many thousands of international research papers, a variety of archives and a huge number of archived media reports. The contributions of the property to the science of astronomy are documented extensively in scientific literature from its emergence to the present day.

The Jodrell Bank Observatory is a working site, rather than solely a scientific monument. This has a strong influence on identification of its attributes and on assessment of its integrity and authenticity. Indeed, as the authors say, in the introduction to the Thematic Study on Astronomy, 'In terms of scientific sites, the use of instruments and the buildings that encompass them could be key attributes of OUV, in which case authenticity relates to how well they still display those uses[6]'.

For this property, the Authenticity is therefore considered in terms of:

- Use & Function
- Form & design
- Material and Substance
- Traditions, techniques & management systems
- Location & setting
- Quality of documentation

These are described below.

Use and Function

The Jodrell Bank Observatory and its component elements are in daily use for world leading radio astronomy research, i.e. their original function. This continuity of function, from its inception to the present day is a key element of the OUV of the site. The authenticity of this is apparent in many thousands of formal scientific papers published in international journals, archived professional and personal accounts and photographs, which continue to be produced.

The elements of the property fall into a number of different groups. Some are scientific instruments, such as the Lovell and Mark II Telescopes, which are still very much in use and maintained and operated primarily for that purpose.

[6] ICOMOS-IAU: 'Astronomy and Archaeoastronomy in the context of the UNESCO World Heritage Convention – A Thematic Study': June 2010 **Introduction** : *Michel Cotte and Clive Ruggles*

Some are buildings that are still in daily use (e.g. the main Control Building), whereas others have had a slight change of function (e.g. Radiant Hut is currently used to store records). However, this dynamic change of function is within the tradition of the ongoing use of the site as a working Observatory.

Some smaller buildings (e.g. the Botany Huts) are now disused, and conserved in order to preserve the heritage of the property.

The high value of the use and function of the property can be seen from:

- its current role as the home of the UK National Radio Astronomy Facility, e-MERLIN (see Section 2.b). The e-MERLIN network is operated from the Control Building and the signals from the telescopes across the UK are brought together in a supercomputer (the 'correlator') housed in the building. The Lovell and Mark II Telescopes are used as part of the wider e-MERLIN network.
- its role as a founder member of the network of major European (and worldwide) radio astronomy observatories ('EVN') that schedule observations of the same object in space simultaneously so that they operate as an 'interferometry' instrument that spans continents (again, see Section 2.b for a fuller description of this). As part of this, signals from the Jodrell Bank telescopes (particularly the Lovell and Mark II Telescopes) are brought together in the Control Building together with accurate timing information from the Observatory's atomic clock, (currently housed in Cosmic Noise Hut), prior to combination with the rest of the EVN observations.
- the many astronomers worldwide that use the Lovell and Mark II Telescopes (and the e-MERLIN network) for their own research observations.

Form and Design

The landscape and arrangement of the Observatory and of its component elements is little changed since the 1960s, by which point it was established.

The site and its buildings are configured in a way that is oriented around its ongoing research, and records (photographs, architectural drawings, site surveys and even, to some extent, intangible online resources such as Google Maps) indicate the authenticity of this.

The Lovell Telescope and the Mark II Telescope are, in one sense, architectural monuments, but their form and design, (as with all the radio telescopes on the site) were and are determined solely by function, i.e. they work as radio telescopes. The authenticity of this is, again, partly demonstrated by their outputs (i.e. scientific results), and also by engineering design drawings and plans held in the Jodrell Bank engineering archive and in archives elsewhere.

The Lovell Telescope and Mark II Telescope are also regarded as beautiful structures in themselves, and are popular landmarks in the area and the country, appearing widely in representations of the landscape of the area. The Lovell Telescope, in particular, is an international icon of science and appears, for example, on the postage stamps of a number of nations.

Materials and substance

As noted in the section on Integrity, much of the original fabric of the site remains and there are clear records of which instruments have been removed or modified. Despite the rapid and continuing developments at Jodrell Bank, the site preserves good evidence for the emergence of the science of Radio Astronomy. Sites of all the major phases of development survive, even if in some cases only as archaeological evidence.

Major instruments, from the Lovell Telescope onwards, are still primarily in daily use and have undergone repairs and upgrades over the years.

The current maintenance and inspection regime works to:

1. maintain the function of Jodrell Bank as a working scientific establishment and
2. maintain evidence of Jodrell Bank's history and role in the development of radio astronomy

The original bowl of the Lovell Telescope was made of welded mild steel. The bowl rotates on bearings that were recycled from gun turrets of two navy warships, HMS Royal Sovereign and HMS Revenge, which were both decommissioned at the end of World War II. The authenticity of this is well-documented in written accounts of the day, and also in film and photographic records.

The Mark II Telescope demonstrates innovative and spectacular use of concrete whilst being the first large telescope in the world (and one of the first large instruments) to be controlled by digital computer. Its design was also used in Goonhilly I, which pioneered transatlantic TV via the Telstar satellite. Full documentation of both these examples of the interchange of ideas is held in archives.

Figure 3.8: Artist's impression of the Lovell Telescope from its design study, the Blue Book, showing the mesh surface originally proposed.

Traditions, Techniques and Management Systems

Previously, the sole priority for the Jodrell Bank Observatory was research rather than conservation of its heritage. Paradoxically, the management systems for this have ensured that the Lovell Telescope has been preserved as a 'living' structure for six decades (extremely rare for a scientific instrument), and that the site has not suffered from redevelopment. The evolution of structures at the property is documented in the Jodrell Bank engineering archive.

Management systems have evolved with changes of, for example, technology, scientific focus etc, but have focused largely on the operation of the property as an observatory. One major change is that management systems are now in place to maintain the heritage of the property as well as its science

Location and Setting

Jodrell Bank is located at
N 53° 14' 05" W 2° 18' 18".

The nature of the site and its setting, have changed little since the Observatory was created, which is important for its continuing functioning. The setting of the site is wide, as it stands out in the Cheshire Plain as an iconic landmark between the Pennines and the coast.

One important element of the setting is the 'radio silence' of the area around Jodrell Bank. This is an area that allows the Observatory to challenge developments which might produce excessive radio frequency interference, so that it can pick up very faint signals from distant objects far away in space. This was formalised by Parliament in the 'Jodrell Bank Consultation Zone' directive in 1973 and was recently re-addressed by the UK's Secretary of State for Communities and Local Government in a judgment of November 2016 which stated that "Jodrell Bank Observatory as an established world class facility should be afforded reasonable protection". The Consultation Zone has acted as a 'de facto' Buffer Zone since its establishment.

Quality of Documentation

The scientific knowledge produced by the work of the Observatory is mainly intangible, but has been (and is) recorded both by scientists and engineers connected with the property and by external observers. In fact, in science, there is a continuous cycle between tangible and intangible work, where published findings have direct impact on the next generation of instruments or facilities to be built.

One example of this, at Jodrell Bank, is the surface of the Lovell Telescope. Originally designed to be a mesh dish (following on from the Transit Telescope), new discoveries were published as it was being built that changed the plan. The original mesh design (Figure 3.8) was replaced with a solid steel dish, increasing the weight of the bowl, which in turn required extra support. This was also partly the reason for the cost overruns in the Telescope construction – but a good example of how an intangible output of a scientific process (published information) can affect very tangible aspects of a site itself.

The authenticity of the Observatory is demonstrated by a wealth of documentation in a large number of archives and collections held in various institutions across the UK and worldwide. These include written documents, images and film.

In addition, its scientific achievements, which are significant, and have had global impact, are documented exhaustively in many thousands of international scientific papers and articles, which are now universally available online, as well as in academic libraries worldwide.

As the Introduction to the Astronomy Thematic Study of 2010 mentions,

> *'The scientific corpus that represents the core heritage of astronomy comprises the material sources of the history of astronomy: its archives and documents, in the broadest sense.'*

And again, as the Thematic Study adds,

> *'...the production and retention of archives could be considered the very heart of the scientific productivity of a laboratory or observatory... one measure of the importance of a given site could be how influential were the data contained in its archives. The scientific OUV of a site could certainly be demonstrated in this way.'*

An Archive Survey has recently been completed (2017). In summary, primary sources of documentation include:

- Many thousands of scientific and technical papers (from inception to the present day) published in international journals;
- Many thousands of citations of its papers by scientists at other Observatories worldwide (a measure of its influence);
- The Jodrell Bank Engineering Archive (which documents all changes to the Lovell Telescope, the Mark II Telescope and other instruments);
- Papers and images held at Jodrell Bank, including records of observations and events; physical images and information (photos, spectra, radio maps etc);
- The Jodrell Bank National Archive (in the University of Manchester Library, includes papers relating to all stages of development, correspondence between scientists, engineers and others, etc);
- Sir Bernard Lovell's personal papers (held by the Royal Society in London, these include his diary of the construction of the Lovell Telescope);
- Sir Bernard Lovell's wartime papers (held in the Imperial War Museum in London, including records of his first detection of radio echoes from meteors);
- A/V recordings of interviews with Sir Bernard and colleagues (e.g. in the Web of Stories Archive, the BBC, the Jodrell Bank Observatory archive);
- National records of and objects related to the development of Jodrell Bank (e.g. in the UK's Science Museum Group, the NASA archive and archives in countries of the former USSR);
- Press and broadcast media records (e.g. archives of the BBC and Pathe News);
- Books by many of the scientists and engineers who worked at Jodrell Bank and others elsewhere.

There are other archives held elsewhere, and work is currently underway to uncover these (e.g. in the archives of companies such as Tata who now own the steelworks which supplied the original materials for the Lovell Telescope).

This high level of documentary support, within the Observatory archives, in many thousands of scientific publications, and in contemporary media records, is an extremely valuable demonstration of the authenticity of the property.

3.1.e

Protection and management requirements

Framework for Protection and Management

The Lovell Telescope was awarded Grade I Listed status in 1988 and therefore enjoys full statutory protection under this and other Planning regulations. In 2017, the Mark II Telescope was also Grade I listed and five other historical structures at the site were also listed at Grade II. All new developments at the property are also controlled through the spatial planning system. Both local planning authorities have included specific policies for the protection of Jodrell Bank and its buffer zone in their Local Plans.

The Buffer Zone for the property (which is 18569.28 hectares in area) has been set up using the radio telescope protection zone around the Observatory, which was established by the Jodrell Bank Radio Telescope Direction (1973). (This is similar to an area protecting a 'dark night sky' around an optical observatory, and has acted as a de facto buffer zone since 1973).

The Jodrell Bank site is relatively small (17.38 hectares), has clear boundaries and a single owner. All elements expressing the OUV of the site lie within the boundaries of the property.

The property benefits from being solely owned by The University of Manchester, which has a robust and successful management system in place, including a site Governance Group, that takes oversight of all activities. The property has a completed World Heritage Management Plan.

The property has a number of levels of protection, which safeguard it against future threats.

The first of these is the national legal framework of heritage and landscape protection set out in Section 5.

The principal elements of these are:

1. Designation: applies to specific assets, which in the case of the property are listed structures (e.g. the Lovell Telescope and Mark II Telescope are Grade I listed, the Control Building and a number of other structures are Grade II listed).
2. Spatial Planning policy: a legal framework established by 4 Acts of Parliament and the consolidated National Planning Policy Framework and Planning Practice Guidance.

This is reinforced by further protection at a local level, particularly in the Cheshire East and Cheshire West and Chester Local Plans and Strategies.

In addition, at both national and local level, further protection is afforded by specific rulings and policies that pertain to the property itself – in particular, the Jodrell Bank Direction (1973), which created a zone around the Observatory in order to protect the radio interference environment within which it operates.

Within this framework, the property itself has a single owner, which is one of the UK's leading Universities. This affords it very strong protection, as can be seen from the protection of the site from encroachment since its inception.

The University has responsibility for the management, coordination, presentation and promotion of the property, in collaboration with a wide range of stakeholders (described in Section 5). This, together with the modest size of the property, means that the task of protection and management is less onerous than that for larger sites in, for example, multiple ownership, or crossing significant land boundaries.

The property has been in existence, as an entity, for many decades, and its management systems are well-developed and resourced. Until recent years, as described in Section 4, the focus of these has been the operation and presentation of the Observatory as a world-leading science institution. However, since the process of Nomination has been undertaken, this has been widened to include the conservation and preservation of the OUV of the heritage of the site.

This has been underpinned by the preparation of the site's first Conservation Management Plan and Gazetteer (the first site inventory), which has also set out the foundation for the Management Plan for the property, including its monitoring and reporting.

The University will be responsible for both of these, with the advice of national bodies and relevant consultants.

In order to bring together all management of the property under one body, the University has established a site Governance Group, which includes members from the bodies that work on the property itself and also other areas of the Jodrell Bank site that are under University control (and form part of the property Buffer Zone).

Specific Long-Term Expectations

A Steering Committee including all stakeholders will oversee the management of the World Heritage Site. It is also planned to develop a deemed strategy of consent with all relevant stakeholders in 2018.

The University of Manchester, owner of the property, is investing £15million in conservation of the property, in order to provide a good basis for future management.

The property also benefits from a very successful visitor facility, the Jodrell Bank Discovery Centre, which already attracts 180,000 visitors each year, including 26,000 school pupils on educational visits. The visitor facility has plans in place for the sustainable management of future visitation levels and recently secured commitment of £20.5million towards the delivery of these, with one gallery focused on the heritage of the site.

The wider management of the site, including its presentation and promotion, will be overseen by the World Heritage Site Steering Committee. This will include representatives from all major stakeholder groups, as set out in Section 5.

Conversations (both formal and informal) have taken place with many of the potential Steering Committee members in the course of preparing the nomination dossier. Consultations with local communities have also been carried out.

The interpretation and management of the statutory protection explained above will be strengthened, in 2018/19, by the development of a deemed strategy of consent including all relevant statutory bodies and the property managers.

Current investment in the conservation of the attributes of the property and in facilities for sustainable visitor management is underway. Summary documentation of all the relevant changes is included in the dossier and full documentation is archived at the property itself.

The Management Plan, which is developed from the foundation of the Conservation Management Plan (CMP) sets out future conservation plans, including specific archaeological projects that will be put in place.

Additional promotion and presentation of the property is planned should the nomination for inscription on the World Heritage list be successful.

3.2 Comparative Analysis

This section compares the nominated property to other similar properties, whether on the World Heritage List or not. First, there is a discussion of Astronomy and World Heritage, enabling identification of the list of properties for comparison. The criteria for comparison are discussed and the various properties are then compared according to each of these criteria, identifying where the nominated property stands out, and its importance in a national and international context.

3.2.a Astronomy and World Heritage

In order to identify a list of potentially comparable properties, it is important to set the discussion in the wider context of astronomy in World Heritage.

Similar sites on the World Heritage List and Tentative Lists

The Thematic Study identified sites on the World Heritage List with possible connections to astronomy (listed in full on their website[7] along with an interactive 'Astronomical Heritage Finder'). They noted that, *"what perhaps stands out most is that the great majority of the sites listed are not related to modern scientific astronomy or its history."* The second volume (2017) of the Thematic Study notes, *"there are very few historical observatories on the World Heritage List and no observatories from the 20th Century (whether or not still undertaking active science). The most recent example on a National Tentative List at the time of writing is Jodrell Bank (UK), founded in the late 1940s."*

It is important to note that the properties currently on the World Heritage Site with connections to astronomy are concerned either with 'pre-scientific' cultural interactions with astronomical phenomena, or with traditional visible-light astronomy or its application.

There are certainly no sites associated with the development of radio astronomy and the way in which the study of the 'invisible' universe, beginning in the mid-twentieth century, has transformed our understanding and contributed to our collective culture.

This is also true of the Tentative Lists, except for the case of the 'Astronomical Observatories of the Ukraine', submitted in 2008. This includes the Crimean Astrophysical Observatory, which operates a 22-metre radio telescope (the RT-22) at Katsiveli. This site will be compared with Jodrell Bank Observatory, along with other sites worldwide, in the following sections.

Other similar sites related to radio astronomy

The first volume of the Thematic Study contains a useful chapter on the theme 'The Development of Radio Astronomy' by Richard Wielebinski (Emeritus Director, Max-Planck-Institut für Radioastronomie, Bonn, Germany) and Tom Wilson (Head of Radio, Infra-Red and Optical Sensor Branch at the US Naval Research Laboratory, Washington DC, USA). This has been used to derive a list of radio astronomy sites for comparison. It has been supplemented with information from the comprehensive and authoritative work by American astronomer and historian of science Woodruff T. Sullivan III – *Cosmic Noise: A History of Early Radio Astronomy* (published 2009, too late for consideration in work on the initial Thematic Study review) – and other sources in the bibliography, including *Observatories and Telescopes of Modern Times: Ground-Based Optical and Radio Astronomy Facilities since 1945* by Leverington (2017).

[7] http://www2.astronomicalheritage.net/index.php/world-heritage-list

3.2.b Values for comparison


Image: Anthony Holloway

The Thematic Study takes on the formidable task of summarising the whole history of radio astronomy from the earliest experiments in the USA in the 1930s, through the growth driven by technological developments in radar, to its spread across the world, up to 2009 (the time of writing).

The description includes a large number of individual telescopes, mentioning in many cases their current condition, and also summarising the scientific and technological developments. However, it does not (almost certainly for reasons of space) focus a discussion on individual observatory sites, which elsewhere in the Thematic Study are described via an important concept, as monuments or machines of science, *"encapsulating the idea that an astronomical observatory is an integrated system linking fixed, movable and intangible heritage, and where change and development is inevitable"*. The extended Case Study on the Royal Observatory, Cape of Good Hope (South Africa), has also been useful in considering the concept of the observatory as a site.

The Jodrell Bank Observatory has an iconic and influential telescope (the Lovell Telescope), which is referred to by Wielebinski and Wilson as the world's largest reflector in 1957. But it also shows unique integrity and influence as an observatory site from the earliest developments in radio astronomy immediately after the Second World War, to the present day – and with physical evidence of all these stages. Much of this wider story of Jodrell Bank, particularly the relation to the remaining physical evidence, has been collated during the last several years as part of developing a conservation management plan and the process of nomination, and so was unavailable at the time the Chapter was written, and to some extent, beyond its scope.

The nominated property has a number of important values expressed in its attributes, and which contribute to its Outstanding Universal Value.

- Jodrell Bank Observatory is the earliest radio astronomy observatory in the world that is still in existence. The character of the site, as an operational professional observatory, is a key element of its value.
- The Observatory had a pioneering role in the emergence of radio astronomy.
- It has made major contributions to radio astronomy research for a long period of time, from the very beginning of this new science to the present day.
- Considerable physical evidence of the Observatory's contribution to radio astronomy remains at the property.
- It is the location of an iconic radio telescope.

Site as an operational radio astronomy observatory

Much of the early work on radio astronomy and on developing new instruments took place at sites that are now no longer used for this purpose. Where radio astronomy observatories were established, this often occurred after a move from an initial site, which resulted in fragmentation, and in many cases, loss, of the physical evidence of the developmental work that had taken place. Later sites were also established once radio astronomy had gained credibility as a new branch of science.

Some early sites still work as leading radio astronomy institutes, and some of these also retain their instruments, but operate them for education activities rather than research. Although such sites can still play an important role in managing and carrying out research with remote telescopes, they do not operate research instruments that are co-located with their original scientific buildings. Such sites are not categorised here as operational radio astronomy observatories.

Pioneering role in the emergence of radio astronomy

As Wielebinski and Wilson describe, the earliest successful experiments in radio astronomy took place in the USA in the 1930s. Following this, the field of radio astronomy rapidly developed in the years immediately after the Second World War driven by the technological developments in radar. Sullivan notes that "The undisputed leaders in post-war radio astronomy" were in England (in Jodrell Bank and Cambridge) and Australia (in Sydney), where physicists who had worked on radar returned to peacetime research. However, this work also grew rapidly in other countries, becoming a global, and often collaborative, endeavour.

Although radio astronomy continued to develop significantly from the 1950s onwards, the period of the 1930s and 1940s can therefore be taken to define the emergence of the new science of radio astronomy. The term 'radio astronomy' was first used in around 1948 and Bernard Lovell was appointed to the world's first Chair in Radio Astronomy in 1951. This aspect of comparison therefore deals with radio astronomy sites up to the end of the 1940s, in order to identify those that genuinely brought this new field to birth.

Period over which the site carried out radio astronomy research

Part of the value and significance of a particular site in the science of radio astronomy is the period of time over which it operated. This is because, in general (and as the Thematic Study points out), a longer period of operation generally leads to an increase in the numbers of people involved, the diversity of work, perhaps even the influence of that work, and the likelihood that physical remains exist. This is an essential measure of the value of the site and its authenticity.

Of course, as the Thematic Study also points out, for these 'monuments of science', change and development is inevitable. In some of the sites already discussed, this change was as radical as the abandonment of a site altogether, sometimes for external or personal reasons, sometimes because the scientific goals indicated that course of action. Abandonment, in general, is likely to have had a negative impact on the heritage of the site.

Extent of remaining physical evidence of contribution to radio astronomy

In order to assess the value of each site, it is essential to consider the extent and condition of any tangible, immoveable heritage that may be present. Some sites that were active at the very emergence of radio astronomy are now not in existence, and very few traces of their work remain. For newer sites (which may not have been present at the very emergence of the field) there is good tangible evidence for their work, but this is more recent and is not evidence of an early role in the science.

Presence of one or more iconic radio telescopes

Undoubtedly, a significant part of the OUV of a radio astronomy facility is the presence of an iconic telescope, where iconic can be defined in terms of its size, supported by authenticity of scientific use. Here it is important to consider observatories/telescopes dating from a later period than the emergence of radio astronomy to ensure the largest radio telescopes are included. This section compares various iconic instruments listed by Wielebinski and Wilson and other sources.

Table 3.2 lists the biggest single dish telescopes in the world at the time in succession, ordered chronologically and separating fully-steerable telescopes from transit instruments. Table 3.2 lists the biggest single-dish telescope of either type, operating in 2017, ordered by size.

Table 3.1: The largest single dish radio telescopes in the world.

Dates in brackets indicate either a move in location or the end of research operation.

1. Largest transit telescopes in succession			
	Diameter	Date	Period largest (years)
Reber Telescope, Wheaton, USA	9.6m	1937-(47)-(54)-	10
218ft Transit Telescope, Jodrell Bank, UK	66.4m	1947-62	15
300ft Transit Telescope, Green Bank, USA	91.4m	1962-88	1
400ft Telescope, Vermilion River, USA	183m x 122m	1963-70	1
Arecibo Telescope, Puerto Rico	305m	1963-	53
FAST, China	500m	2016-	>1
2.Largest fully-steerable dishes in succession			
	Diameter	Date	Period largest
Naval Research Laboratory, USA	3m	1946	2
Wurzburg, Kootwijk, Netherlands	7.5m	1948-56	1
30-ft Telescope, Jodrell Bank, UK	9.1m	1949-77	3
Naval Research Laboratory, USA	15.2m	1952-(<98)-	4
Agassiz Telescope, Harvard, USA	18.3m	1956-91	<1
Dwingeloo Telescope, Netherlands	25m	1956-(98)-	1
Stockert Telescope, Germany	25m	1956-(95)-	1
Lovell Telescope, Jodrell Bank, UK	76.2m	1957-	15
Effelsberg Telescope, Germany	100m	1972-	29
Robert C. Byrd Green Bank Telescope, USA	110m x 100m	2001-	>16

Table 3.2: Largest single-dish telescopes (>60m in diameter) in operation as of 2017 by size.

Largest single-dish telescopes in operation 2017 by size		
	Diameter	Date completed
FAST, China	500m	2016
Arecibo Telescope, Puerto Rico	305m	1963
Robert C. Byrd Green Bank Telescope, USA	110m x 100m	2001
Effelsberg Telescope, Germany	100m	1972
Lovell Telescope, Jodrell Bank, UK	76.2m	1957
Goldstone, USA	70m	1988[1]
Robledo, Spain	70m	1987[2]
Tidbinbilla, Australia	70m	1987[2]
Galenki, Russia	70m	1984
Yevpatoria, Ukraine	70m	1978
Sheshan, China	65m	2012
Sardinia, Italy	64m	2011
Kalyazin, Russia	64m	1992
Bear Lakes, Russia	64m	1983
Parkes Telescope, Australia	64m	1961

[1] Upgraded from a 64m dish completed in 1966
[2] Upgraded from a 64m dish completed in 1973

3.2.c
The sites compared

Consideration of the values discussed in the previous section, lead to selection of the sites potentially comparable to the nominated property.

The sites are:

1. Bell Telephone Laboratories, USA
2. Wheaton, USA
3. Richmond Park, UK
4. Jodrell Bank Observatory, UK
5. Sydney Field Stations, Australia
6. Cambridge 'Rifle Range Site', UK
7. Naval Research Laboratory, Washington DC, USA
8. Kootwijk, Netherlands
9. Tokyo Astronomical Observatory, Japan
10. Astronomical Observatories of the Ukraine
11. Nançay Observatory, France
12. Dwingeloo, Netherlands
13. Stockert, Germany
14. Green Bank, West Virginia, USA
15. Lord's Bridge, Cambridge, UK
16. Parkes, Australia
17. Arecibo, Puerto Rico
18. Effelsberg, Germany
19. FAST, China

Each of the selected sites is discussed in turn in relation to the values set out earlier in this section.

Bell Telephone Laboratories, USA

image: lsst.org

The location of Karl Jansky's 1930's telescope in Holmdel, New Jersey, USA, now marked by a sculpture and an interpretation board.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Bell Telephone Laboratories site is not an observatory. Jansky's work was carried out for a short period of time on the laboratory premises.

Period over which the site carried out radio astronomy research

1931-1934

Jansky was employed as a communications engineer and studying radio emissions from space was not his job. Despite wanting to do more work on the subject, he was directed to other tasks, which occupied all his time and so from the early part of 1934 he undertook no more practical radio astronomy work at the site.

Extent of remaining physical evidence of contribution to radio astronomy

As Wielebinski and Wilson note, the historical instrument of Jansky no longer exists on its original site. There is now a monument at the site of Jansky's original experiment and a replica of his antenna has been constructed at the National Radio Astronomy Observatory, Green Bank, West Virginia.

Presence of one or more iconic radio telescopes

None.

There is a replica of Jansky's antenna at the Green Bank Observatory in West Virginia, USA.

Wheaton, USA

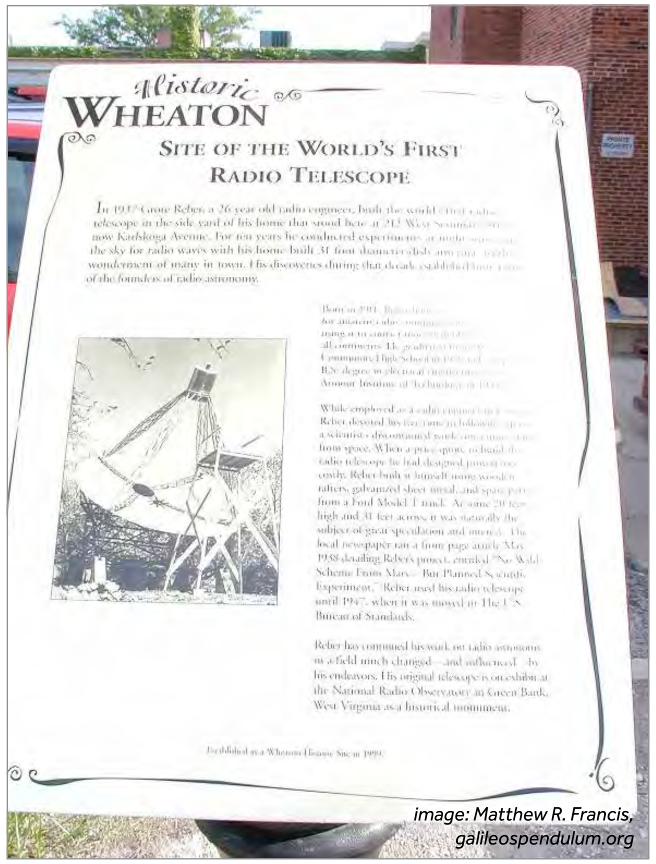


image: Matthew R. Francis, galileospendulum.org

The interpretation board at the approximate location of Grote Reber's telescope in Wheaton, Illinois, USA.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

Reber famously worked at home, in his own back yard, in what was effectively an amateur observatory. However, the site does not now have the character of an observatory, as he left it in 1947 and it is now a parking area.

Period over which the site carried out radio astronomy research

1937-1947

Reber worked in his backyard, making improvements to his receivers and mapping the sky at different radio frequencies, throughout the war. Radio interference in the environs of Chicago gradually worsened encouraging him to begin looking elsewhere for a site to conduct observations. When his mother died in 1945, he had to look at selling the family home. Finally, in June 1947 he dismantled the telescope and moved to the National Bureau of Standards in Washington DC. He reassembled the dish, making it fully steerable, and complemented it with three Wurzburg dishes.

Little was published and he moved on to Hawaii in 1951 and then a few years later to Tasmania, where he remained. Sullivan points out that Reber's idiosyncratic boldness and amateur spirit, whilst helping his initial pioneering work, in the end restricted his long-term impact.

Extent of remaining physical evidence of contribution to radio astronomy

None.

There is no trace of Reber's work at this location, now a parking area although it is designated as a local historic site and there is an information plaque. The original telescope was moved to Washington DC and then transferred to Green Bank where it was refurbished and reconstructed for display.

Presence of one or more iconic radio telescopes

None.

Reber's telescope could be considered iconic as it was the first parabolic dish telescope and the first to make extensive radio maps of the sky, albeit relatively small at 9.6m diameter when compared to those that came later.
However, it is no longer at its original site, having been moved several times before being refurbished and reconstructed for display at Green Bank, USA.

Richmond Park, UK

Part of Richmond Park, London, where J.S. Hey's Army Operational Research Group sited their mobile antennas at the end of the war.

Site as a radio astronomy observatory
(research telescopes co-located with scientific buildings)

The Richmond Park site was never an observatory. It was the location of work using mobile instruments for a short period of time. No traces of this now remain.

Period over which the site carried out radio astronomy research

1945-1947/48

Military requirements, particularly the cold war, led to this army group being directed away from work on radio astronomy after just a few years in 1947/48.
(J.S. Hey did eventually return to radio astronomy elsewhere at the Royal Radar Establishment, Malvern, UK).

Extent of remaining physical evidence of contribution to radio astronomy

None.

Work was conducted from mobile army trailers. By mid-1947 the site was closed and no remains exist.

Presence of one or more iconic radio telescopes

None.

Jodrell Bank Observatory, UK

The Green and Mark II Telescope at Jodrell Bank, UK

Site as a radio astronomy observatory
(research telescopes co-located with scientific buildings)

Jodrell Bank Observatory is the earliest surviving radio astronomy observatory in the world. It retains this character to the present day and is one of the world's leading radio astronomy observatories.

Period over which the site carried out radio astronomy research

1945 – present day

Jodrell Bank Observatory is still operational as a world-leading radio astronomy facility. As a mature research station of The University of Manchester operating seven large radio telescopes as part of e-MERLIN (the UK's National Radio Astronomy Facility), it is expected to remain so for the foreseeable future. All elements of the Jodrell Bank work from the location of the very earliest work in 1945 to the present day are still part of the Observatory and on a single site.

Extent of remaining physical evidence of contribution to radio astronomy

As described in detail in Section 2, there is a significant physical record of the work carried out from 1945 to the present day.
This includes:

- The landscape and layout of the site (which have been determined by the emergence of radio astronomy)
- Lovell and Mark II Telescopes
- Control Building
- The Green and associated Observatory buildings
- Site of the Transit Telescope
- Sites and remains of early instruments (e.g. the Searchlight Telescope, Helical Antenna base, 30ft Telescope base etc)
- Botany Huts (where the first experiments were conducted)

Presence of one or more iconic radio telescopes

The nominated property has several iconic telescopes.

The *Lovell Telescope*, constructed between 1952-57, was by far the largest telescope in the world when it was completed, almost a factor ten times larger in collecting area than the Dwingeloo Telescope and the Stockert Telescope which had begun operations the year before. It is still, 60 years later, the third-largest fully-steerable telescope in the world. It is still a world-leading research instrument and has carried out a range of astronomical observations as well as space tracking, doing significant work in pulsars, quasars, masers and in interferometers such as e-MERLIN and the European VLBI Network.

The 38m x 25m *Mark II Telescope* constructed in 1964 is also still in research operation as part of the e-MERLIN array of telescopes. It has a unique concrete mount and was the first in the world to be controlled by a digital computer.

The Lovell Telescope took over the mantle of worlds largest telescope from the 66m *Transit Telescope*, also at Jodrell Bank, which, although not fully steerable, was the biggest in the world when it was completed in 1947. It was the largest in the world for 15 years and dismantled in 1962. Archaeological remains of this still exist.

Sydney Field Stations, Australia

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Sydney Field Stations were spread over many kilometres and operated as a set of observatories. However, these no longer exist and work that was carried out at the sites was transferred elsewhere

Period over which the site carried out radio astronomy research

(various from) 1945 - (various to) 1998

The work of the Radiophysics Laboratory was not conducted at a single site, but over a large number of field stations within about 50km of Sydney, beginning with existing coastal radar stations.

Their dates of operation are listed by Sullivan: Collaroy (1945-47); Dover Heights (1945-54); North Head (1945-46); Georges Heights (1946-48); Potts Hill (1946-63); Hornsby (1947-55); Penrith (1949); Badgerys Creek (1950-56); Dapto (1952-65); Fleurs (1953-63[-98]); Murraybank (1956-61); Wallacia (1957-60).

Significant work was undertaken at several of these sites but in all but one case this did not extend beyond the early 1960s, largely as a result of the gradual move towards larger instruments and the completion in 1961 of the 64m Parkes Telescope 300km to the west.

As Wayne Orchiston describes in his 2004 paper, the exception is Fleurs, which operated for 10 years and then transferred its work to the University of Sydney in 1963, closing down the original site.

After the move, it remained in operation, becoming the site of the Fleurs Synthesis Telescope (based on the historical Chris Cross telescope) until 1988 when the new Australia Telescope Compact Array near Narrabri, New South Wales, was completed. The Fleurs site was transferred to the Engineering Faculty who refurbished some of the antennas, although others were removed.

The site was finally closed in 1998.

A replica of one of the original antennas at Dover Heights, Sydney, Australia, standing alongside the rusting mount of the original.

Extent of remaining physical evidence of contribution to radio astronomy

The Field Station sites are now all closed.

Fragmentary remains exist at some sites, for example, at Dover Heights a telescope replica sits alongside the mount for the original.

At Potts Hill, Harry Wendt notes in his 2008 PhD thesis, *"Nearly all traces of the occupation by Radiophysics have gone. Only the remains of some foundations and two small huts remain."*

In 2015, one of these huts was saved by the Sydney water company when it was realised it was used on the radio astronomy station. In 2004, Orchiston argued for protection of the historic Chris Cross antennas at Fleurs and similar remains, only to find that later the same year, the last 12 were bulldozed so that as of 2009, all that remained were 4 rusting dishes from the later Fleurs Synthesis Telescope.

Presence of one or more iconic radio telescopes

None.

Cambridge – 'Rifle Range Site', UK

The location of the Cambridge 'Rifle Range' site overlaid on a recent aerial image of the site.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Rifle Range site was the location of some very early experiments in radio astronomy, and can be said to have operated as an observatory for around 10 years. However, it transferred its activities to the Lord's Bridge site in 1957 and now no longer retains its character as an observatory.

Period over which the site carried out radio astronomy research

1946-1956

When more space was need for radio astronomy research, the 'Rifle Range' site was closed in 1956 and is not maintained as a working observatory or heritage location. (Activities moved to a site at Lord's Bridge, about 6km to the southwest, where the Mullard Radio Astronomy Observatory was opened in 1957 and continues today).

Extent of remaining physical evidence of contribution to radio astronomy

The site is no longer maintained as an observatory or heritage site. Part is still the Cambridge University Rugby Union Club, as it was then, and other parts are open fields. There appear to be no significant items but there may be some merit in an archaeological survey for any fragmentary remains, for example of the footings for interferometers.

Presence of one or more iconic radio telescopes

None.

Naval Research Laboratory, Washington DC, USA

The main administration building of the U.S. Naval Research Laboratory in Washington DC, showing the 50-foot telescope on its roof.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

While the Naval Research Laboratories (NRL) carried out radio astronomy research from 1946, this was within the auspices of the NRL, rather than as an observatory per se. The physical elements that remain do not have the character of an observatory.

Period over which the site carried out radio astronomy research

1946-present

NRL became the USA's leading radio astronomy group in the mid 1950s combined with military applications. They occupied another site at Maryland Point I in the late 1950s, erecting a 26m telescope there in 1958, and another in 1965. Radio astronomical observations became focused on the remote sites, including a 46m telescope at Sugar Grove, West Virginia. They were involved in the creation of the US National Radio Astronomy Observatory and eventually shifted to using those facilities with the Maryland Point Observatory closed down in 1994. The 50ft telescope in the main building at Washington DC has not been used for many years, since at least the mid-1990s. There are a group of radio astronomy specialists still working at the NRL, focusing particularly on new technology for long wavelength astronomy and observations are carried out at other sites.

Extent of remaining physical evidence of contribution to radio astronomy

At the main NRL site, observations first began soon after the war and were conducted from the roof of the building. The 50ft (15.2m) telescope still stands in that location as a monument to their work in the 1950s. The two 26m telescopes at Maryland Point are also still standing, although the site has been closed for decades.

Presence of one or more iconic radio telescopes

The 50ft (15.2m) radio telescope is still in existence and a popular local landmark. However, it would not now be regarded as iconic, in global terms. The Maryland Point site dates from much later.

Kootwijk, Netherlands

An information board at the site of the Kootwijk radio telescope being unveiled in 2011 by Prof. Hugo van Woerden (Emeritus Professor of Astronomy at the University of Groningen) and Ari Hin (Retired Technician of ASTRON).

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

As is often seen with early radio astronomy locations, the Kootwijk site was closed down when astronomers moved elsewhere. It now no longer operates as a professional observatory.

Period over which the site carried out radio astronomy research

1948-1955

The Kootwijk site was abandoned in 1955, when the Dutch astronomers moved to work with their new 25m radio telescope at Dwingeloo. The 7.5m Wurzburg dish was left behind at the site unused.

Extent of remaining physical evidence of contribution to radio astronomy

Van Woerden and Strom (2006) have done extensive research into the current status of the Dutch 7.5m Wurzburg dishes, including the one left behind at Kootwijk following the move to Dwingeloo. They presumed it lost, apparently scrapped around 1956. Further research was done for a film project *Spiral Galaxy, the Milky Way unravelled*[8], highlighting the contribution of Dutch scientists between 1886 and 1955 to astronomy and, following contact from a local resident, an information board was placed at the now empty site in 2011 on the 60th anniversary of its use to detect the hydrogen line.

Presence of one or more iconic radio telescopes

None.

[8] http://www.lightcurvefilms.com/spiralgalaxy/en/html/locaties_kootwijk.html

Tokyo Astronomical Observatory, Japan

Site of the original 'radio astronomy precinct' at Mintaka, Tokyo, indicated on an aerial view of the modern National Astronomical Observatory of Japan.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Tokyo Astronomical Observatory hosted radio telescopes from 1949 to 1969. It now has none in operation at the site, so cannot be regarded as a radio astronomy observatory.

Period over which the site carried out radio astronomy research

1949-1969

Although the Tokyo Astronomical Observatory was established in 1924, it was principally a traditional optical observatory and radio astronomy observations did not begin until 1949.

The observatory still exists and the location is now the headquarters of the National Astronomical Observatory of Japan, but radio observations are now conducted at other sites, notably the Nobeyama Radio Observatory which began operations in 1969.

Extent of remaining physical evidence of contribution to radio astronomy

Ishiguro et al (2012) note that none of the early Japanese radio telescopes at Tokyo Astronomical Observatory, not even foundations, or at Toyokawa Astronomical Observatory, have survived. There is a replica of an early dipole array at the modern Nobeyama Radio Observatory using the original polar axis mount moved from the Tokyo Observatory site.

Presence of one or more iconic radio telescopes

None.

Astronomical Observatories of the Ukraine

The 22-m radio telescope in Katsiveli (near Simeiz) operated by the Crimean Astrophysical Observatory.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The observatory at Katsiveli still has a radio telescope, which began operating in 1967. It can therefore be said to be a radio astronomy observatory.

Period over which the site carried out radio astronomy research

1953-present

In the 1950s, a 31m 'hole-in-the ground' concrete transit telescope was built at Katsiveli, a separate site than the original 1940s location on Mount Koshka. Although the RT-22 Telescope included in the submission on the Tentative List has been used in VLBI observations linked to others in the European VLBI Network, it was only completed at Katsiveli in 1967 and so does not belong to the period of the early development of radio astronomy considered here. Observations using this telescope, and another 70m telescope at a separate location at Yevpatoria, do continue to the present day.

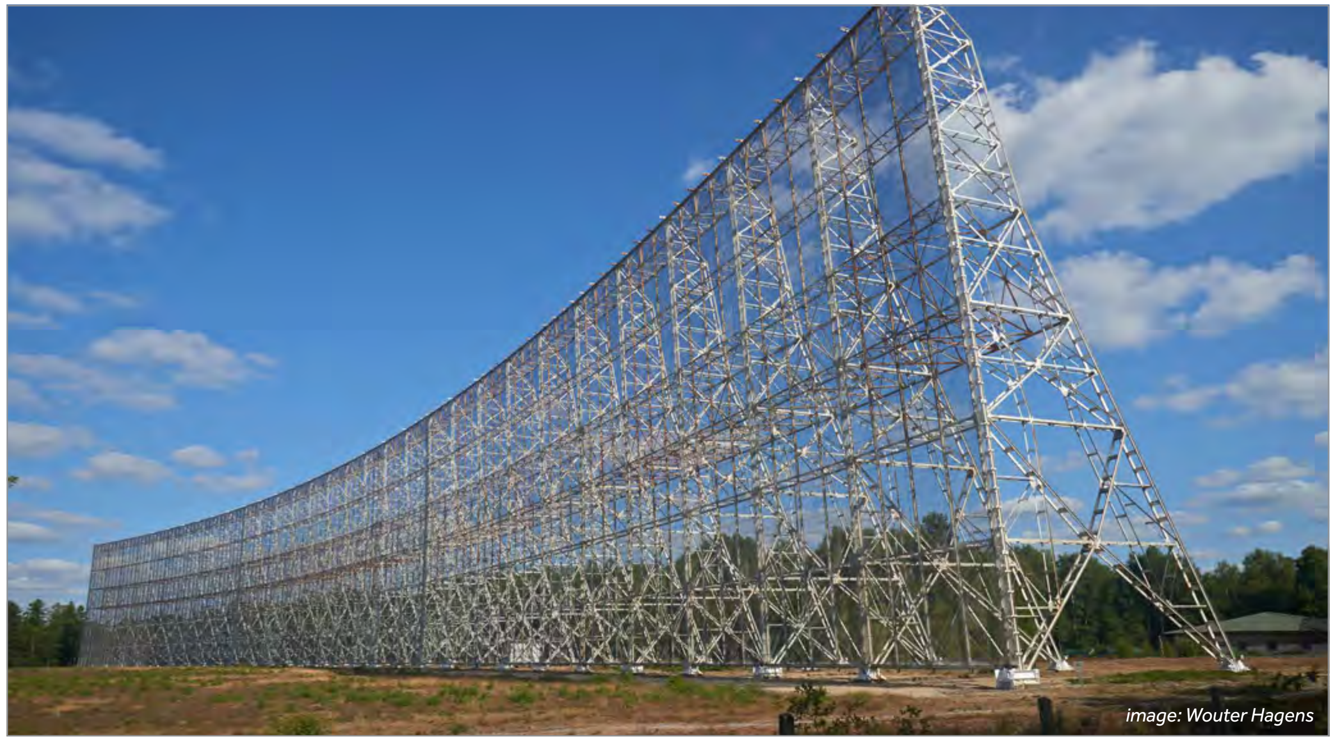
Extent of remaining physical evidence of contribution to radio astronomy

A 22m radio telescope (completed in 1967) does still exist at Katisveli and a 70m at Yevpatoria (completed in 1978). However, it is not clear whether any other remnants exist at the Katisiveli site established in 1953 or the earlier 1940s site on Mount Koshka.

Presence of one or more iconic radio telescopes

The 22m telescope is not large enough to be deemed iconic, and the 70m came later than the emergence of the field of radio astronomy, and was smaller than others that had been built long before.

Nançay Observatory, France



The large secondary reflector of the Nançay Radio Telescope.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Nançay observatory is still in operation as a radio astronomy observatory.

Period over which the site carried out radio astronomy research

1955-present

A number of different radio telescopes have been built at Nancay, including arrays of small dishes and two of the ubiquitous Wurzburg dishes (transferred from one of the earlier sites at Marcoussis). There continued to be an emphasis on solar radio astronomy but some work was also done on more distant radio sources. The large Nançay Radio Telescope, built in the years 1958 to 1966, was based on a design used earlier by Kraus at Ohio State University in the USA. It consists of a plane mirror (200m x 40m – equivalent to the area of a 100m dish) that reflects the radio waves to a section of spherical reflector (pictured; 300m x 35m), which in turn reflects them to a focal point. The limitations of the fixed secondary reflector mean it is a transit telescope, albeit one of the largest in the world. This instrument, originally built for the observation of hydrogen and constantly improved since, now observes a range of astronomical sources including galaxies, envelopes of stars, comets and pulsars.

Extent of remaining physical evidence of contribution to radio astronomy

The Nançay Radio Telescope and several others, including the Decameter Array, a Radio Heliograph and a station of the international LOFAR telescope are all still in operation.

Presence of one or more iconic radio telescopes

The Nancay large radio telescope is, by collecting area, one of the largest telescopes in the world, equivalent to a 100m dish, albeit only a transit instrument. It can therefore be deemed iconic in terms of scale.

Dwingeloo, Netherlands

The Dwingeloo Telescope in the Netherlands.

Site as a radio astronomy observatory
(research telescopes co-located with scientific buildings)

The Dwingeloo telescope ceased operation for research in 1998. The site is now home to ASTRON, the Netherlands Institute for Radio Astronomy, one of the world leaders in the field.
However, its radio telescopes are based on sites elsewhere, which means that the Dwingeloo site, alone, therefore does not have all the characteristics of a working radio astronomy observatory.

Period over which the site carried out radio astronomy research

1956-present

The Dwingeloo Telescope was operated for research for 1956 through to 1998.
The site is now the home of ASTRON, the Netherlands Institute for Radio Astronomy, one of the world's leading radio astronomy research institutes. ASTRON operates the Westerbork Synthesis Radio Telescope and the International LOFAR Telescope, both located at separate sites. It also hosts the Joint Institute for VLBI in Europe (JIVE) which operates the correlator for the European VLBI Network.

Extent of remaining physical evidence of contribution to radio astronomy

Since 2009, the Dwingeloo radio telescope has been maintained as a designated Industrial Heritage Monument in the Netherlands. It was refurbished in 2012-14 and is now operated by a volunteer group (the Foundation CAMRAS) and is used for outreach to the public and schools.

Presence of one or more iconic radio telescopes

The Dwingeloo radio telescope has a diameter of 25m and a collecting area around 10% of that of the Lovell Telescope at Jodrell Bank. It was, along with Stockert, the largest steerable telescope in the world for around a year from 1956 until the completion of the Lovell Telescope. It was clearly important but would probably not now be regarded as one of the most iconic, worldwide.

Stockert, Germany

The 25m Stockert Telescope in Germany

Site as a radio astronomy observatory
(research telescopes co-located with scientific buildings)

The Stockert Telescope is currently operated for education and the public, rather than research, so cannot be regarded as a working radio astronomy observatory.

Period over which the site carried out radio astronomy research

1956-1995

Originally used from 1956 to 1966 by the University of Bonn, the Stockert site was taken over by the Max-Planck-Institut in 1966. In 1978, when the iconic Effelsberg radio telescope was completed, ownership reverted back to Bonn University, which sold the site in 1995. The telescope was used to carry out a range of radio astronomical observations.

Extent of remaining physical evidence of contribution to radio astronomy

The site is dominated by the 25m radio telescope, which has a novel support structure that includes several stories of technical rooms. The site also includes another 10m radio telescope, a laboratory/workshop, a residence for observers and a house for the site manager.
The Stockert Telescope was designated a historical monument in 1999. The site was sold again in 2005 and funds allocated for refurbishment of the telescope from 2007-10. The Nordrhein-Westfalen-Stiftung Foundation operate it for education and the public.

Presence of one or more iconic radio telescopes

The Stockert Telescope is included as a case study in the ICOMOS/IAU Thematic Study. However, as with Dwingeloo (also 1956), its collecting area is only about 10% that of the 76-metre Lovell Telescope completed the following year. Its research use ended in 1995, although in recent years it has been refurbished and is now used for education and outreach. Although, along with Dwingeloo, it was the largest steerable telescope in the world for about one year, it would not now be regarded as one of the most iconic on a global stage.

Green Bank, West Virginia, USA


image: NRAO/AUI/NSF

Two of the large radio telescopes in Green Bank, West Virginia. In the foreground, the largest steerable telescope in the world, the 110m x 100m Robert C. Byrd Green Bank Telescope (completed 2001), and the 43m equatorially-mounted telescope (1965).

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Green Bank Observatory in West Virginia is one of the world's leading radio astronomy observatories.

Period over which the site carried out radio astronomy research

1956-present

Following the opening of the 26m Tatel Telescope in 1959, the Green Bank site grew rapidly and several large telescopes were sited there: for example, the famous 300-foot (90m) Transit Telescope (1962; moveable in elevation but not azimuth); another 26m to form an interferometer (1964); and a 43m telescope equatorially-mounted telescope (1965). The site became one of the world's leading radio astronomy observatories. The 90m Telescope collapsed in 1988 and was replaced by the world's largest steerable telescope, the 110m x 100m Robert C. Byrd Green Bank Telescope, completed in 2001.

In 2012, with the pressures of having to operate several sites elsewhere (the Very Large Array in New Mexico and ALMA in Chile) the National Radio Astronomy Observatory decided to recommend the withdrawal of national funding from the Green Bank site. The astronomers responded by setting up an independent Green Bank Observatory, inaugurated in 2016, to operate the telescopes using a combination of government and private funding.

Extent of remaining physical evidence of contribution to radio astronomy

A large number of the telescopes at Green Bank are still in existence and many are still operating, although there is obviously some concern over future operations with the recent changes to funding.

Presence of one or more iconic radio telescopes

The Green Bank site is now dominated by the 110m x 100m Robert C. Byrd Green Bank Telescope, completed in 2001. This is the largest fully-steerable radio telescope in the world and is truly iconic. However, it is a relatively recent instrument. There are other large telescopes which have a longer history, including a 43m telescope, the largest equatorially-mounted telescope in the world dating from 1965, and the first large telescope at the site, the 26m Tatel Telescope.

Lord's Bridge, Cambridge, UK


image: Cmglee

One antenna of the One-Mile Telescope (left), two of the Half-Mile Telescope (centre) and the remains of the 4C Array (right) at Lords Bridge in 2014.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Mullard Radio Astronomy Observatory at the Lord's Bridge site, is one of the world's leading radio astronomy observatories.

Period over which the site carried out radio astronomy research

1956-present

A number of important instruments were constructed at Lords Bridge through the 1960s and 70s and beyond: the One-Mile Telescope, the Half-Mile Telescope, the 5-km Telescope (later the Ryle Telescope, now reconfigured as the Arcminute Microkelvin Imager – AMI) and more. A four-acre (1.6 hectare) Interplanetary Scintillation Array was built in 1967 and used to detect the first pulsars. It is also home to Jodrell Bank's 32m Telescope, part of e-MERLIN.

The site, known as the Mullard Radio Astronomy Observatory, became and remains one of the world's leading sites for radio astronomy.

Extent of remaining physical evidence of contribution to radio astronomy

There are telescopes still in operation at Lords Bridge, and extensive remains of some of the early instruments. This incudes the first main instrument, the 178 MHz interferometer used to produce the 4C survey (pictured) and remnants of the Array used by Bell and Hewish to detect the first pulsars, along with sheds and other buildings used in their operation.

Presence of one or more iconic radio telescopes

The largest telescopes still on site – the eight 13m dishes of the 5-km Telescope (1972), the 18m dishes of the One Mile Telescope (1964) and the 32m dish of Jodrell Bank's e-MERLIN array (1990) – are impressive but do not compete in scale with the world's largest instruments. It could be argued that the remnants of the pulsar array and the early aperture synthesis interferometer, are more important in radio astronomy terms, but they perhaps do not possess the iconic qualities of the very large instruments elsewhere.

Parkes, Australia

The 64m Parkes Telescope in Australia.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Parkes Observatory is one of the world's leading radio astronomy observatories.

Period over which the site carried out radio astronomy research

1961-present

The Parkes Telescope has been used to do significant work including in the areas of radio sky surveys, quasars and pulsars. It has also been used in interferometers including the Australia Telescope comprising the Compact Array (ATCA; six 22m dishes at Culgoora) and another 22m dish at Mopra, which could be combined with Parkes. The full array became operational in 1990. VLBI work has included the Australian Long Baseline Array and global VLBI. The Telescope has received a number of upgrades over the years, including resurfacing, and is operated by the Australian national science funding agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Extent of remaining physical evidence of contribution to radio astronomy

The Parkes Telescope is maintained and operated as a leading research instrument. It is in excellent condition, and shows good evidence, which is well-documented, of its history and use in radio astronomy.

Presence of one or more iconic radio telescopes

The Parkes Telescope has iconic status and significant cultural impact, for example in its use during the Apollo 11 Moon landings. It has also been featured in films and on TV etc.

Arecibo, Puerto Rico

The 305m Arecibo Telescope in Puerto Rico.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Arecibo Observatory is one of the world's leading radio astronomy observatories.

Period over which the site carried out radio astronomy research

1963-present

Like the 66-metre Transit Telescope at Jodrell Bank, it is not 'steerable' and is a fixed transit telescope. It is a major research instrument and in daily use. It has contributed to a wide range of research projects, from imaging the Moon, planets and asteroids with radar, to detecting and observing pulsars, as well as the Search for Extra-Terrestrial Intelligence. It has been significantly upgraded a number of times, including installation of a new surface and secondary reflector system. It was initially a Cornell University telescope, before passing to the National Science Foundation (NSF) in 1969, although until 2011, still operated by Cornell. As of 2017 there are new concerns over continued NSF funding.

Extent of remaining physical evidence of contribution to radio astronomy

The Arecibo Telescope is in good condition as it is a working research instrument.

Presence of one or more iconic radio telescopes

The Arecibo Telescope is a vast instrument at 305 metres in diameter, and certainly iconic.

It was the world's largest telescope until the inauguration of the 'FAST' Telescope in China in 2016.

Effelsberg, Germany

The 100m Effelsberg Telescope near Bonn, Germany.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The Effelsberg Observatory is one of the world's leading radio astronomy observatories.

Period over which the site carried out radio astronomy research

1972-present

The Effelsberg Telescope was the first in the world to adopt an innovative homologous design in which the self-compensating dish structure remains free of gravitational distortion as it tips to different elevations. It is only marginally smaller than the later Robert C. Byrd Telescope at Green Bank, USA, and remains one of the world's leading radio astronomy observatories.

The telescope has been involved in a wide-range of observations from pulsars to interstellar gas and dust, to star formation and radio galaxies. It is also used as part of interferometers such as the European VLBI Network.

There have been many upgrades over the years, including a new reflecting surface.

Extent of remaining physical evidence of contribution to radio astronomy

The Effelsberg Telescope is currently maintained and operated by the Max Planck Institute for Radio Astronomy at Bonn as a working research instrument and is in excellent condition.

Presence of one or more iconic radio telescopes

The Effelsberg Telescope is one of the largest radio telescopes in the world, and can be regarded as iconic.

FAST, China

The 500m FAST telescope in Guizhou, China.

Site as a radio astronomy observatory (research telescopes co-located with scientific buildings)

The FAST telescope is set to become one of the world's leading radio astronomy observatories, given its ambitious size.

Period over which the site carried out radio astronomy research

2016-present

FAST (Five hundred metre Aperture Spherical Telescope) was inaugurated in 2016. With a diameter of 500m, it is now the world's largest telescope, although like Arecibo it is a fixed dish, with limited steering only by moving the instruments at the focus.

Extent of remaining physical evidence of contribution to radio astronomy

Fully present at site as commissioning is still underway in 2017.

Presence of one or more iconic radio telescopes

The FAST Telescope has been included in this analysis as it is now the world's largest telescope and therefore clearly iconic. Apparently, it is already attracting millions of tourists, mainly from within China. However, it is a very young instrument and has yet to contribute to the field of radio astronomy.

3.2.d
Conclusion

Jodrell Bank Observatory stands out in comparison with other similar places in the world in a number of ways (also summarised in Table 3.1):

- Jodrell Bank Observatory is the earliest radio astronomy observatory in the world that is still in existence, carrying out world-leading research. It has a particular character as a working observatory, which is not shared by other historic sites.
- It is unique in being a world-leading radio astronomy site used continuously from the pioneering years of the emergence of this new science to the present day. As discussed in Section 3.1.d, this authenticity is borne out by a weight of evidence (scientific papers, government documents, media records etc).
- Although there are other historic sites dating from that emergence, none have the quality of tangible immoveable heritage present at Jodrell Bank, where the landscape is marked with the history of radio astronomy. Many of the earliest features of the site or their locations are extant and recognisable.
- The site has two major telescopes, listed at Grade I by Historic England for their significance. One of these is clearly iconic, the first very large steerable telescope, and the largest fully-steerable telescope in the world for 15 years. There are also remains of the previous largest telescope, the Transit Telescope. Although some other sites have iconic telescopes, they are either more recent, or are not presented on a site with a similar rich history dating back to 1945.


Image: The University of Manchester

Figure 3.9: In the bowl of the iconic Lovell Telescope.

This comparative analysis has shown that Jodrell Bank Observatory is a world-leading site, graced by iconic telescopes, which has, uniquely, recorded the story of the emergence of radio astronomy and its development to maturity, continuing to the present day.

TABLE 3.3: Summary of values for sites worldwide that might compare to the nominated property

Site	Character as an operational radio astronomy observatory	Pioneering role in emergence	Date from which used	Period contributed to research (years)	Integrity of site	Presence of iconic telescope(s)
Bell Telephone Laboratories, USA		✔	1931	3	None	
Wheaton, USA		✔	1937	10	None	
Richmond Park, UK		✔	1945	3	None	
Jodrell Bank Observatory, UK	✔	✔	1945	>72	Good	✔
Sydney field stations, Australia		✔	1945	≤43	Poor	
Cambridge 'Rifle Range', UK		✔	1946	10	None	
Naval Research Laboratory, USA		✔	1946	>71	Mixed	
Kootwijk, Netherlands		✔	1948	7	None	
Tokyo Astronomical Observatory, Japan		✔	1949	20	None	
Astronomical Observatories of the Ukraine	✔		1953	>64	Mixed	
Nançay Observatory, France	✔		1955	>62	Good	✔
Dwingeloo, Netherlands	✔		1956	>61	Good	
Stockert, Germany			1956	39	Good	
Green Bank, West Virginia, USA	✔		1956	>61	Good	✔
Lords Bridge, Cambridge, UK	✔		1956	>61	Good	
Parkes Telescope, Australia	✔		1961	>56	Good	✔
Arecibo Observatory, Puerto Rico	✔		1963	>54	Good	✔
Effelsberg Telescope, Germany	✔		1972	>45	Good	✔
FAST telescope, China	✔		2016	>1	Good	✔

3.3

Proposed Statement of Outstanding Universal Value

a. Brief Synthesis

Jodrell Bank Observatory is the earliest radio astronomy observatory in the world that is still in existence.

It is the one remaining site, worldwide, that includes evidence of every stage of the post-1945 emergence of radio astronomy, and, as such, played a pioneering role in a revolution in our understanding of the Universe.

Radio astronomy showed that there is far more to the Universe than meets the human eye, and that entirely new information can be obtained by using radio waves – a revolution exemplified by a range of features across the site.

Located in rural Cheshire in northwest England, the Observatory, which is part of the University of Manchester, is dominated by the iconic Lovell Telescope, the first very large fully-steerable radio telescope in the world. Constructed between 1952 and 1957, its first act was to track the carrier rocket for Sputnik 1, the first satellite ever launched into orbit and humanity's first step into space. The Telescope was the largest of its kind in the world for 15 years and inspired the construction of many other instruments worldwide.

The property encompasses a number of other radio telescopes, including the Mark II Telescope, and functional buildings on a 17.38-hectare site. Many of these are original structures and instruments, while remnants of earlier structures also persist, some of them below ground.

The character of the Observatory has been determined by the evolution of radio astronomy. Scientists first arrived at the southern boundary of the site in 1945, and then moved northwards as they made new discoveries, creating new equipment and experiments, thereby imprinting the development of the science on the landscape of the site.

The Observatory is not solely a scientific monument as it still carries out world-leading research. It currently hosts the UK's national array of 7 radio telescopes, and collaborates with many other radio telescopes worldwide.

The scientific importance of the property is demonstrated by the influence of its work, evidenced by the data and scientific publications in its archive, and its continuing research.

b. Justification for Criteria

Criterion (i) represents a masterpiece of human creative genius

Jodrell Bank Observatory is an outstanding example of supreme scientific and technical achievement, which revolutionised our understanding of the Universe. The post-1945 emergence of the science of radio astronomy was a turning point in the progress of 20th century astronomy. At Jodrell Bank, evidence of every stage of this is present in the property. This includes: the early use of recycled radar equipment; the construction in 1947 of the Transit Telescope (then the world's largest telescope); and the creation of the iconic Lovell Telescope in 1957 (superseding the Transit Telescope as the world's largest). The development of the Observatory, as a whole, was driven by the vision, determination and creative scientific genius of Sir Bernard Lovell and the team that gathered around him.

Criterion (ii) exhibits an important interchange of human values

The Jodrell Bank Observatory contains numerous examples of physical evidence of the international interchange of ideas at a significant time in history, as the new science of radio astronomy and the space age developed during the 1940s-60s. This is epitomised by the structures of the iconic Lovell Telescope and the Mark II Telescope, which dominate the site and effectively 'bracket' the property. It is also embodied in the character of the landscape itself and the structures that housed and exemplify the work that was at the heart of this unique flowering of international cooperation and exchange of values and ideas. These included developments in astronomy, but also extended more widely to include, for example, quantum optics; interferometry; spacecraft tracking and satellite communications.

Criterion (iv): an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history

Jodrell Bank Observatory is the unique technological and landscape ensemble, globally, that exemplifies, through its surviving physical evidence, the transition from traditional optical astronomy to modern multi-wavelength astrophysics that took place during the 1940s and the years that followed. Developments at all stages of this history took place within its boundaries, with many of the earliest features, or their locations, extant and recognisable. This was a significant stage in the history of understanding our place in the Universe.

It was also a significant stage in the peacetime development of 'Big Science', which followed the Second World War, and was characterised by a leap in the scale of projects, paralleled by a leap in scale of funding and in numbers of collaborating scientists and engineers. While the size of the Lovell Telescope means that it is the most obvious feature of the site, it is, in fact, the Observatory as an ensemble that is at the heart of the property. The character of the landscape and the interrelation between buildings and structures speaks of the revolutionary developments that took place there, and represent this significant stage in human history.

Criterion (vi) directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance

Jodrell Bank Observatory is inextricably linked to the fundamental concept underpinning modern astronomy: that we live on a planet orbiting a star, one in a galaxy of several hundred billion stars, itself only one of a hundred billion galaxies in the observable universe.

When radio telescopes were first pointed at the sky, it became apparent that there were whole aspects of the Universe, including exotic objects previously unimagined, which ordinary (optical) telescopes cannot see.

Jodrell Bank Observatory is intrinsically linked to this discovery – that there is far more to the Universe than meets the human eye, and that entirely new information can be obtained by using 'invisible' light, beyond the usual 'rainbow' of visible colours. Modern Astrophysics now uses this 'invisible light' as a matter of course, to examine the Universe, but the first major step towards this was taken by radio astronomy.

c. Statement of Integrity

All the tangible attributes of the property sit within the site boundaries. The nominated property is solely owned by the University of Manchester, and the boundaries of the site are clearly identifiable in the Deeds of Ownership of the land. The property is generally in a good state of conservation. The integrity of some elements of the property is compromised (for example, only 5-10% of some of the original scientific instruments remain, as traces below ground). However, most of the buildings in the property are in good condition and the Grade I listing and continued research use of the Lovell Telescope and the Mark II Telescope has ensured that the integrity and function of the most iconic elements of the property have been retained.

d. Statement of Authenticity

Despite the rapid and continuing developments at Jodrell Bank, the site preserves good evidence for the emergence of the science of Radio Astronomy and retains a high level of authenticity due to its function as an observatory. The character of the Observatory landscape persists, major structures are preserved in working order and sites of all the major phases of development survive, even if in some cases only as archaeological evidence. The authenticity of this is supported by a very strong body of associated documentation, including many thousands of international research papers, a variety of archives and a huge number of archived media reports. The contributions of the property to the science of astronomy are documented extensively in scientific literature from its emergence to the present day.

e. Requirements for Protection and Management

The Lovell Telescope was awarded Grade I Listed status in 1988 and therefore enjoys full statutory protection under this and other Planning regulations. In 2017, the Mark II Telescope was also Grade I listed and five other historical structures at the site were also listed at Grade II. All new developments at the property are also controlled through the spatial planning system. Both local planning authorities have included specific policies for the protection of Jodrell Bank and its buffer zone in their Local Plans.

The Buffer Zone for the property (which is 18569.28 hectares in area) has been set up using the radio telescope protection zone around the Observatory, which was established by the Jodrell Bank Radio Telescope Direction (1973). (This is similar to an area protecting a 'dark night sky' around an optical observatory, and has acted as a de facto buffer zone since 1973).

The Jodrell Bank site is relatively small (17.38 hectares), has clear boundaries and a single owner. All elements expressing the OUV of the site lie within the boundaries of the property.

The property benefits from being solely owned by The University of Manchester, which has a robust and successful management system in place, including a site Governance Group, that takes oversight of all activities. The property has a completed World Heritage Management Plan.

A Steering Committee including all stakeholders will oversee the management of the World Heritage Site. It is also planned to develop a deemed strategy of consent with all relevant stakeholders in 2018/19.

The University of Manchester, owner of the property, is investing £15million in conservation of the property, in order to provide a good basis for future management.

The property also benefits from a very successful visitor facility, the Jodrell Bank Discovery Centre, which already attracts 180,000 visitors each year, including 26,000 school pupils on educational visits. The visitor facility has plans in place for the sustainable management of future visitation levels and recently secured funding of £20.5million (from various sources) for a new visitor gallery that will be constricted in the buffer zone.

4. State of Conservation and Factors Affecting the Property

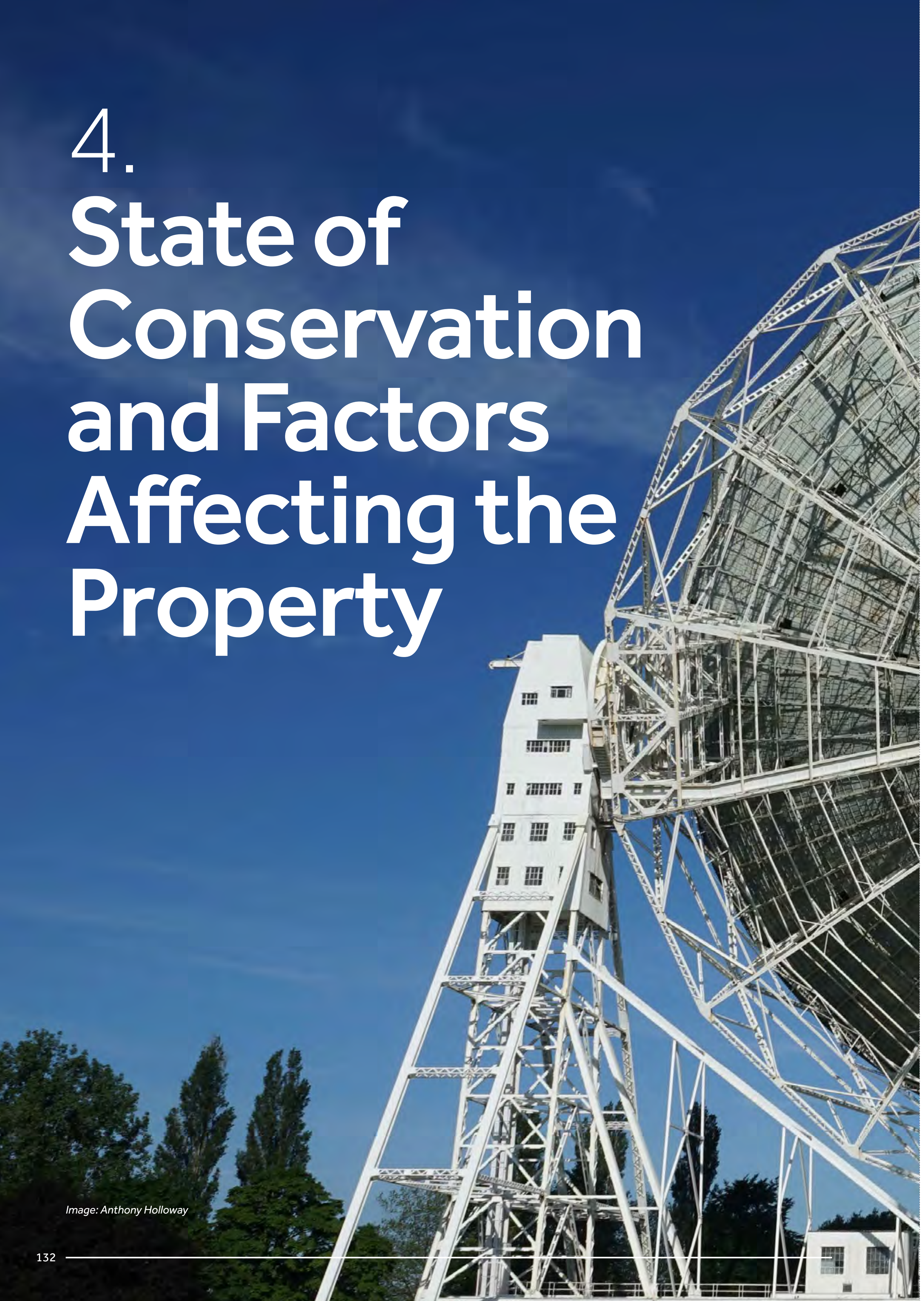


Image: Anthony Holloway

4.a Present State of Conservation

4.a.(i) Introduction

The attributes of OUV of the nominated property fall into a number of different groups. Some are scientific instruments, such as the Lovell Telescope and Mark II Telescope. These are still very much in use as scientific research instruments and are maintained primarily for that purpose. A number of the buildings are also still in use and are therefore well-maintained.

Other buildings are used less frequently, or not at all, and will need some intervention to maintain them. The Transit Telescope and some other features survive only as archaeological monuments. The overall layout of the site, which is an important attribute of the OUV of the property, since it shows how research developed here, remains very clear.

Some structures on the site are not attributes of OUV, either because they are very recent, or because they were not associated with radio astronomy, (such as the vehicle shed, or Blackett's Hut). Decisions on whether to retain or remove these buildings will be taken on the basis of whether or not they have a useful function.

A full Conservation Management Plan (CMP) was completed in 2016 and provides a baseline assessment of the condition of the property and its attributes. It will also provide guidance on future management.

In particular, the CMP sets out 4 main policy aims:

1. Conserve and enhance the site's science heritage and maintain its role as a world leading centre for scientific research.
2. Conserve and enhance the site's innovative public engagement with scientific discoveries and the site's heritage.
3. Conserve and enhance the site's spirit of place.
4. Ensure effective governance, resources and monitoring are in place to support implementation of the plan.

The aims cover the entire University estate at the site, which is larger than, but encompasses the nominated property.

Aims 1, 3 and 4 are key to the management of the nominated property, while Aim 2 relates to responsible visitation (see Section 4.b.(iv)), visitor facilities and infrastructure (see Section 5.h) and the presentation and promotion of the property (see Section 5.i).

The CMP is included in the Nomination Dossier, as is the associated CMP Gazetteer (i.e. the first inventory of all aspects of the site) (Annexes x and y).

The current inspection and maintenance regime is well-established. Its two primary functions, in line with the two primary aims of the CMP, are:

1. to maintain the function of Jodrell Bank as a working scientific establishment concentrated on research in radio astronomy
2. to maintain evidence of Jodrell Bank's history and role in development of radio astronomy.

Within these two primary objectives, it is recognised that the best way to conserve a building or structure is to keep it in beneficial use. This means that a degree of change to these is accepted, provided that the contribution of each attribute to OUV is not diminished (e.g. office interiors can be redecorated etc; office equipment can be changed; instrument racks will be updated). In fact, this is entirely within the spirit of place of Jodrell Bank, which is one of pioneering science and engineering, where scientists dare to conceive audacious new projects that then set high aspirations for new engineering developments.

The site's raison d'être lies in exploring the frontiers of knowledge by carrying out world-leading radio astronomy research. This is reflected in the southern half of the Site having evolved in an ad hoc fashion, which responded to no considerations other than those associated with the implementation of different scientific experiments (e.g. space and associated equipment, buildings and structures needed).

The removal, adaptation and re-use of scientific structures and equipment strongly echo the spirit of innovation and modification that are traditional and essential in science and the development of technology.

In some cases maintaining the function of an attribute of OUV may therefore mean accepting changes to its fabric e.g. the refurbishing of the dish of the Lovell Telescope, replacement of broken bearings etc, updating of electronics. This practice is well-established at the Observatory, with the guidance of Historic England. In fact, change to building interiors and the structure of scientific instruments has happened throughout the history of the site, while maintaining the elements of external appearance that give a clear picture of the site as it has developed. Continued use of the property is seen as a key part of the property's authenticity.

Some building interiors are iconic, especially the Control Room at the heart of the Control Building. This will therefore be maintained at least visually, even if electronic instrumentation is modified.

In 2014, the University committed a budget of £15million to the conservation and restoration of the Lovell Telescope, the Control Building and the Green.

In 2015, a further £12million was secured from the Heritage Lottery Fund to contribute to this restoration work and, in addition, create a new visitor gallery in which to present and promote the heritage of the candidate site. An additional £8.5million has been raised towards this project in anticipation of delivering the project in 2019/2020.

In 2017 an additional £1.8million was secured to fund the expansion of the car park and the construction of a new arrivals plaza. All new visitor facilities are being created outside the boundaries of the property, and do not impact on the attributes that carry the OUV.

The following paragraphs summarise the state of conservation of the attributes of OUV.

The attributes are summarised according to the groups set out in Section 2a, with some grouping in this section where similar measures apply to similar structures.

The sections used here are:

1. The Landscape and Layout of the Site
2. The Lovell Telescope and The Mark II Telescope
3. The Control Building
4. The Green, associated Observatory buildings and the Botany Huts
5. The site and remnants of the Transit Telescope and other early scientific instruments

Fuller descriptions of each attribute, together with plans and illustrations, can be found in the Site Gazetteer of the Conservation Management Plan included in the nomination dossier.

The Gazetteer reference numbers for each group of attributes are listed in each section to enable easy reference to these longer descriptions. In addition to a description of each attribute, the CMP Gazetteer comments in detail on its state of repair and on desirable works.

4.a.(ii) Landscape of the nominated site

(Gazetteer reference numbers: L03, L05, L06, L07, L08)

1. A particular feature of Jodrell Bank is the way in which radio astronomy developed across the site from south to north. This has greatly aided the survival and retention of evidence of the development of the site.
2. When Lovell first arrived here, the land was largely in use for agriculture and botanical research. Adaptation and development of landscape has resulted in differing character of landscape units across the University estate. These are classified in the Conservation Management Plan Gazetteer into eight landscape units (L01 to L08). Of these, L03, L05, L06 – L08 constitute the nominated property. The remaining zones in University ownership are part of the buffer zone.
3. The different zones have developed in very different ways. Some are intensively used, others less so. Over the years, there has been much tree planting on areas not required for operational work.
4. The maintenance policy is to maintain the differing characters of these various landscape zones, while recognising that landscapes change continuously, and with due regard for the conservation and enhancement of the site's natural heritage. A particular priority is to maintain the landscape of the Green in keeping with its character as a key element of the Observatory.

4.a.(iii) The Lovell Telescope and Mark II Telescope

(Gazetteer reference numbers: B07; B21)

1. An important part of the overall significance of Jodrell Bank Observatory is its continued use for radio astronomy research. It would lose important parts of its worth if this work ceased.
2. The property has two major radio telescopes which, despite being Grade I listed structures, operate at the forefront of radio astronomy research, improving human understanding of the Universe. This in itself is a tribute to the designers, builders and users of these instruments, as it has proved possible to adapt them to changing observational needs. It is also a glowing testament to the maintenance programme and team, which have kept the Telescopes operating in peak condition.
3. Function and use is a strong component of the authenticity of these instruments; to maintain functionality and use requires changes and repairs and these are carried out with full regard for maintaining, as far as possible, the historicity of the telescopes and their control processes. For example, the installation of a new working surface for the Mark II Telescope in 1987 and the like-for-like replacement of the Lovell Telescope wheel bogies in 2007 and subsequently.
4. In addition to such necessary changes, working instruments and their control facilities are maintained to very high levels.

4.a.(iv) The Control Building

(Gazetteer reference number: B05)

1. The Control Building, which houses the Control Room for the Lovell Telescope and the Mark II Telescope, offices and laboratories is well-used and therefore well-maintained and generally in good condition
2. Regular maintenance schedules are in place and in use as part of the routine maintenance of the University Estate.
3. The Control Building has had modest changes many times over the years, in response to changing needs in the operation of site. Since 1988, when the Lovell Telescope was Grade I listed, modifications to the building have been done with due regard to its historicity. This practice will continue in future, especially as the building was itself awarded Grade II listed status in 2017.

4.a.(v) The Green, associated Observatory buildings and the Botany Huts

(Gazetteer reference numbers: L05, B11, B13, B17, B19, B20, B23, B25, B26, B28, B29, B30)

1. Jodrell Bank Observatory has a large number of buildings of historic interest and attributes of OUV, which are spread across the nominated area. As working practices have changed and evolved, some of these buildings have become underused or even unused. Inevitably this means the condition of some of these have deteriorated, although recent surveys have indicated that they are still in good condition.
2. The CMP Gazetteer summarises their condition, which is good, overall, for the landscape, but mixed elsewhere. The CMP itself makes proposals for their conservation and for more sustainable use, including conservation works on the Botany Huts.
3. A major programme of repair and maintenance began in 2017, in order to put the buildings into good condition as a basis for future maintenance. This will continue until 2021. After this point, the buildings will be maintained as part of the University's rolling programme of repair and maintenance of its estate.
4. As part of this programme of review and repair, modern additions of low historical value to some buildings may be removed. Appropriate experts at Historic England and Cheshire East Council will be consulted on such proposals.

4.a.(vi) The site and remnants of the Transit Telescope and other early scientific instruments

(Gazetteer reference numbers: A01, A02, A04, A05, A06, A11, A13, A25)

1 A number of items of early scientific equipment survive only as archaeological sites, whether entirely buried, or as ruinous reinforced concrete. The Transit Telescope is an example of the former and the base of the 30ft Telescope of the latter.

2. These remains are important attributes of OUV since they are often the only record of early phases of the development of radio astronomy at Jodrell Bank.

3. Sites of below-ground remains have been largely identified in the CMP Gazetteer. They will be protected from disturbance by new development. Some non-intrusive survey to establish their full extent may be needed. Appropriate conservation measures will be taken, as will work on presenting these important locations on the site to visitors.

4. Above ground concrete features are largely stable. Vegetation affecting them will be controlled/ removed as appropriate and their condition will be regularly monitored. If possible, a walking tour of these features will be created, using virtual reality technologies to marry the physical elements of the site with the historical structures of which they are relics.

5. A plan will be developed for the conservation of the remains of the Searchlight Telescope, which was given Grade II listed status in 2017.

4.a.(vii) University Estate outside the boundaries of the nominated property

(Gazetteer reference numbers: L01, L02, L04, B01, B02, B04, B04a, B09, B09a)

1. A significant part of the University of Manchester's land at Jodrell Bank is outside the boundaries of the nominated property, but included within its buffer zone. This includes two parcels of land:

a. Landscape Zone L04 which is leased to the Square Kilometre Array project and managed by them under an agreement with the University

b. Landscape Zones L01 and L02 which occupy the northern part of the University property and contain the main access to the site, visitor facilities and the Arboretum

2. It is important that these areas are managed so that they remain harmonious to the character of the nominated property. New buildings in both areas will respect the character of the nominated property. L01 and L02 also need to retain their landscape character, in part created by Sir Bernard Lovell, to complement the OUV of the nominated property.

3. The University also owns all the farmland adjoining the Jodrell Bank estate along its western boundary. It therefore has control over change of use of that land (from farming to other uses) through the tenancy agreements with its tenants.

4.a.(viii) Conservation measures

1. The review of the state of conservation above shows that the overall state of the nominated property is satisfactory. However, the condition of individual components, summarised in the CMP Gazetteer does vary from excellent to moderate or even poor for some unused structures.

2. As owner of the site, the University of Manchester is committed to the continued operation of the establishment and also to the conservation of its historic significance. The University is wholly supportive of the nomination of Jodrell Bank as a World Heritage property.

3. The property is protected through the UK planning system and particularly through listing of a number of key components (also see Section 5.b):

Table 4.1: Designation of elements of Jodrell Bank Observatory

Designation	Component	Date of designation
Grade I	The Lovell Telescope	1988
Grade I	The Mark II Telescope	2017
Grade II	The Control Building	2017
Grade II	Cosmic Noise Hut	2017
Grade II	Electrical Workshop	2017
Grade II	Park Royal	2017
Grade II	Remains of the Searchlight Aerial	2017

4. The CMP sets out the state of individual components and of landscape units and proposes measures for conservation as necessary.

5. The Management Plan for the property sets out processes for identifying and implementing necessary works to conserve and maintain attributes of OUV within the nominated property and within the remainder of the University's Jodrell Bank estate.

6. The University has a range of management priorities and strategies for conserving the components of the site, in line with the CMP Policies and Action Plan. Resourcing for the conservation of the two major Telescopes is ensured as part of keeping them as operating instruments. Buildings and landscapes are maintained and conserved in line with University Estates Division policies.

7. In 2014, the University committed a budget of £15million of its own resources in order to put the elements of the site that carry its OUV in a very good state of repair, as a basis for future sustainable maintenance. Work on this long-term project is now underway, with the guidance of Historic England and Conservation Officers from the local authority, Cheshire East.

8. Strategy of deemed consent is to be put in place in 2018/19, in order to manage the heritage of the site in a way that includes all stakeholders (See Section 5).

Image: Anthony Holloway

4.b

Factors Affecting the Property

4.b(i) Development Pressures (e.g. encroachment, adaptation, agriculture, mining)

The candidate property has a single owner, the University of Manchester, and has been in this ownership since its inception. This affords it good protection from development pressures in general. Specific factors are examined below

Potential future alterations/ additions to the nominated property

Jodrell Bank is still, and will remain, an operational research establishment. This will mean that it is likely that there will need to be changes to individual buildings and that there may be a need for new buildings and facilities to provide new functions or support to research activities. New structures may also be needed to support public access and interpretation of the property, although these are likely to be created in the area that the University owns in the Buffer Zone, rather than in the property itself.

The addition of new buildings and facilities has been happening throughout the site's history. With virtually no exception these have been of one or two stories at most and, as such, they have fitted well into the overall character of the property. This approach is enshrined in the needs of the scientific priorities of the site, as taller buildings would obscure parts of the sky, making them impossible to observe with the telescopes, so are not desirable. The nature of the site itself therefore affords it an additional level of protection.

All new buildings and facilities will require planning consent and will be subject to the policies of the newly adopted Cheshire East Local Development Plan which contains a specific policy for the protection of the proposed World Heritage property (see Section 5.d.(i)). They will also be subject to national policies on new construction within the setting of a Listed Building since the Lovell and Mark II Telescopes are listed Grade I, and the Control Building, Cosmic Noise Hut, Electrical Workshop and Park Royal are all listed Grade II, as are the remains of the Searchlight Aerial. All proposals for new development will be the subject of Heritage Impact Assessment according to the methodology proposed by ICOMOS (ICOMOS 2011).

Proposals for alterations to existing buildings will also be subject to a level of Heritage Impact Assessment appropriate to the proposed change. Changes and additions to buildings will in many cases require planning consent and be subject to national and local planning policies. Any proposals for change to a listed historic building (such as the Lovell telescope) will require Listed Building Consent.

As far as possible new buildings will be sited away from the areas with the largest concentrations of attributes of OUV. As with the new headquarters of the Square Kilometre Array, it may well be possible to place new buildings outside the actual nominated property but still on land belonging to the University. The southern and eastern parts of the nominated property contain wooded areas which could conceal necessary new build or other facilities such as parking, which are required for operational reasons. New visitor facilities, if required, are likely to be sited in the publicly accessible area at the north end of the University estate close to the existing facilities.

New development within the Buffer Zone

New development is always possible outside the boundaries of the Jodrell Bank estate. This is, however, a largely agricultural area and pressure for development is unlikely to be great. Some areas immediately adjoining the Jodrell Bank estate are owned by the University, which therefore has more direct control over proposed developments on that land.

In particular, the new car park and visitor facilities will be developed in the Buffer Zone (on land owned by the University) in a way that is entirely under the University's control. In recent years, for example, the new HQ for the SKA Organisation has been located in an area of the site owned by the University, but which does not contain any of the attributes that carry the OUV of the site.

Developments to date have been controlled by national planning policies and by the policies of the Cheshire East Local Development Plan, which includes a specific policy to protect both the efficiency of the Lovell Telescope and the historic environment and visual landscape setting of Jodrell Bank. This will continue in future. Cheshire West and Chester also has a policy to protect the part of the Jodrell Bank Radio Telescope Consultation Zone, which falls in its territory.

The property is in any case well-screened by woodland around its boundaries. Views of the site from outside are principally of the Lovell Telescope and, from some angles, of the Mark II Telescope. The likelihood of development outside the property having an adverse impact is low.

Lack of maintenance and decay of attributes of OUV

Overall Jodrell Bank is well maintained and in good condition. The condition of individual structures within the site is more varied. Operational elements such as the telescopes are maintained to the highest standard because they remain in use. At the other extreme, elements which are now archaeological require comparatively little maintenance since they are largely in a stable condition. Some of the surviving buildings are however in relatively poor repair because they have been under-used or not used at all.

The University has been successful in rasing £20.5 million towards its *First Light at Jodrell Bank* project. Part of this project is to put attributes of OUV into good order. This is in addition to the £15 million of its own resources it has committed towards the repair and renovation of the Lovell Telescope and the Control Building. These programmes of work are currently underway and will ensure that all attributes of OUV are in good condition for the foreseeable future.

4.b(ii) Environmental Pressures (e.g. pollution, climate change, desertification)

No major environmental pressures pose a threat to the fabric of the OUV of the nominated property.

Weather related impacts

There are no major weather-related threats to the OUV of the site. Weather monitoring (wind speed and direction, temperature, precipitation) has been carried out at the site 24 hours a day for over 50 years (and is still done at present) and is assessed for increased risk. To date, there is no evidence of increased risk due to extreme weather. This will be monitored in case of change.

The Lovell Telescope, one of the key attributes of the property, is an immense metal structure exposed to the elements, which inevitably cause corrosion. However, its management and operation are predicated upon these facts, and the fact that it is still operating, having had a forecast lifetime of 10 years at the time of construction, is testament to the outstanding and sensitive maintenance and inspection programme that it receives.

The Lovell Telescope is also managed in order to minimise the risk of damage in high winds (see Table 4.2).

Vegetation Management

There are no significant issues with vegetation management, although there is some encroachment by invasive species (principally Himalayan Balsam) in some of the less-used landscape areas.

These are not a threat to the OUV of the site and are addressed by the management plan.

Table 4.2: Operating Wind Limits for the Lovell Telescope

Wind regime	Action
Continuous wind speed over 30miles/hour (48km/hour)	Operate the Lovell Telescope above 30degrees elevation
Persistent gusts over 35miles/hour (56km/hour)	
Continuous wind speed over 35miles/hour (56km/hour)	Park the Lovell Telescope at the zenith
Persistent gusts over 45miles/hour (72km/hour)	

4.b(iii) Natural Disasters and Risk Preparedness (earthquakes, floods, fires etc)

Management of risk is a normal part of the management of any scientific facility, visitor facility or other facility. The University of Manchester has well-developed risk management plans and systems, as part of its overall responsibility for the whole University Estate (which includes the nominated property, as well as the rest of the University land around it in the Buffer Zone).

In addition, the candidate property is relatively small (17.38 Hectares) and has similar topographic features across its entire area. This means that a single approach to risk management can be applied across the whole site.

The area in which it lies is not in a seismic zone and not at risk from flooding by inundation. Consequently, it is not subject to a high level of risk from natural disasters. Man-made risks to the OUV are therefore considered to be higher than natural risks.

Man-made risks

Of the man-made risks, fire is considered the most significant. The Observatory has a comprehensive fire plan, which sits within the University's overall fire plan. The property has access routes to all relevant structures and a recently renewed network of fire hydrants. More detail on this is given in the property Management Plan.

An additional risk, under consideration because of recent events, is terrorist attack. Consultation on this has taken place with the police force in the region and they have begun a training programme with site staff.

An emergency management plan is in place for all major incidents and includes the following measures:

- Telescope Controller on duty 24 hours a day
- Security patrols and guards overnight
- Vehicle barriers at all entrances
- Site-wide CCTV system
- Counter-terrorism training for staff by police

Image: Anthony Holloway

4.b(iv) Responsible Visitation at World Heritage Sites

Overview

The property has well-established facilities and programmes for accommodating visitors, a tradition that goes back to the mid 1960s. In 2011, the University opened the new 'Jodrell Bank Discovery Centre' in order to welcome visitors to the site and act as a gateway to manage them.

The 'Discovery Centre' area includes part of the nominated property (see map), but the majority of it is situated in the Buffer Zone (on land owned by the University) (See Section 5.h for a more detailed description of the visitor facilities).

A project is underway to enable a limited number of people to visit the Green on pre-booked guided tours, subject to the operational requirements of the Observatory.

The property has a well-developed visitor management plan, which sets the framework for the sustainable operation of its visitor facilities. It also has a well-developed plan for presentation and promotion, which includes engagement activities directed at specific groups, such as Schools, Volunteers and local communities. The Centre is one of the University's 'Cultural Institutions' and its visitor policies and strategies are supported by a full range of University structures (e.g. promotions and communications; financial management; emergency planning etc).

The visitor programme is also integrated into and supported by appropriate regional and national policies and by the relevant tourism agencies.

Visitor numbers

Visitors are admitted to the property by ticket only, and to its ancillary spaces via areas covered by electronic door counters. This means that visitor numbers are reliable.

Visitor numbers have grown from circa 60,000 per annum since the current facility was opened (in 2011) to circa 180,000 in 2017 (Figure 4.1). These numbers include around 26,000 school pupils on educational visits.

The property managers carry out regular Market research, in order to ensure that visitor management is based on accurate data. As part of the preparatory work for inscription, a major study on potential increase in numbers was commissioned in 2017. This indicates, as might be expected, a sharp rise in visitor numbers of around 30% (50,000) following inscription and then a gradual rise following the initial surge of interest. Figure 4.2 combines actual data to 2017 with forecast growth subsequently.

Figure 4.1

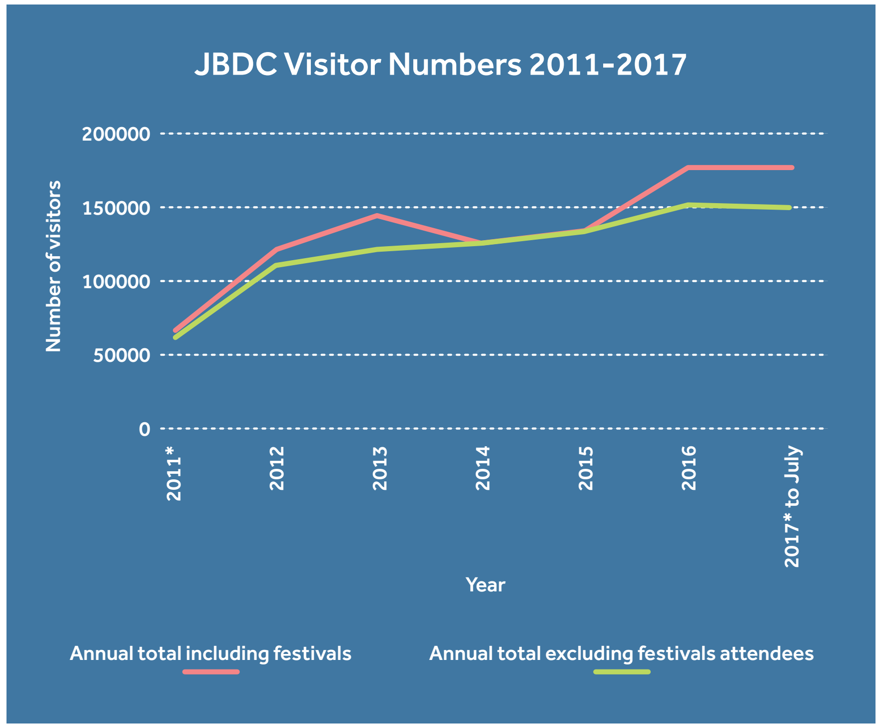
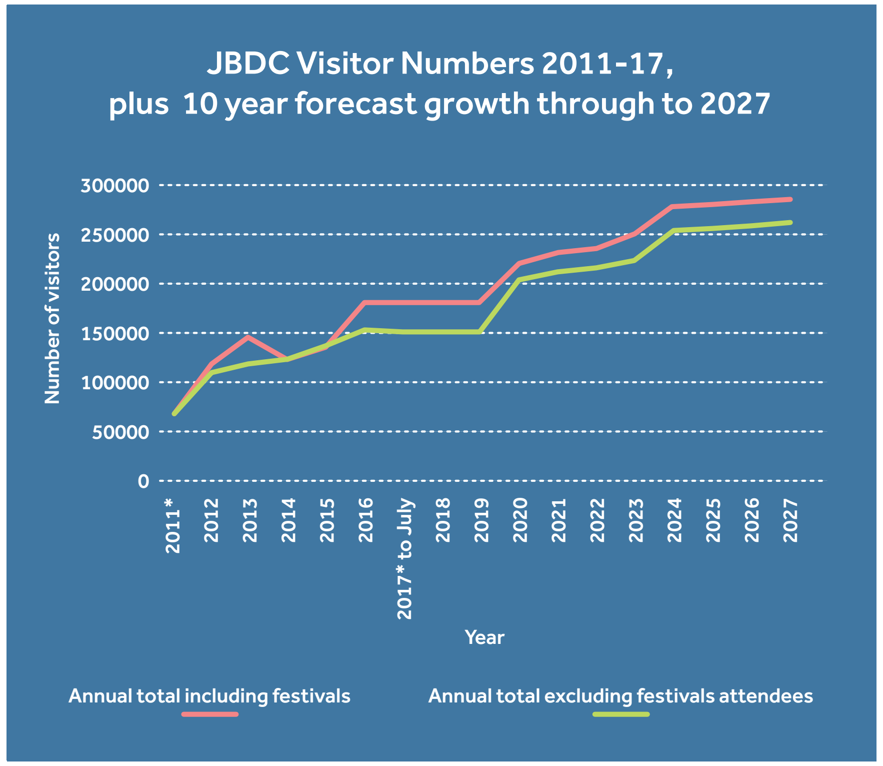


Figure 4.2



Carrying Capacity

Current visitor arrival and accumulation patterns show peak days have an accumulation of around 1,000 people on site at any one time. The forecast increase for total numbers of visitors is around 60% over the next 10 years, which suggests a peak accumulation of around 2,000 people on site at any one time (the peak numbers do not relate linearly to overall numbers).

An expanded car park and new arrival plaza and ticket booths are currently being constructed in order to accommodate this increase. This construction is taking place in the Buffer Zone, outside the property, but on land owned and controlled by the University.

The carrying capacities of visitor buildings are determined by their design architects and fire officers (who set limits on building capacities). The carrying capacity of the overall area accessible to visitors is much larger, as it includes the outdoor zone mentioned above, including a network of hard-surface pathways, which are suitable for all weathers. Because the University owns the site and controls access, it would be able to take appropriate measures to restrict visitor numbers if carrying capacity is exceeded at some point in the future.

The University is about to begin a £20.5million project dedicated to the presentation and promotion of the site. This project is designed to include the creation of additional visitor buildings including a new gallery building (the 'First Light Pavilion') that engages visitors with its heritage and history.

The project also includes an element of conservation and restoration to the Green, together with a plan for guided, pre-booked walking tours of this area for a limited number of visitors. Additional fundraising is underway for this project.

For future considerations, it is helpful to note that, as part of its normal operations, the Centre hosts large-scale festivals of music, culture and science each summer (usually on a weekend in July) in which around 15,000 to 20,000 visitors attend the site as a whole. Surrounding farm fields (including those to the west of the property owned by the University) are used for stages and presentation areas, as well as parking and camping for around 8,000 people. The Jodrell Bank visitor site is modified for these events with pathways temporarily widened and increased visitor facilities (such as food outlets, toilets etc) installed for the weekend.

The area of the property accessed by the festival attendees is closely managed, with high concentrations of visitors located in the surrounding areas, rather than the nominated property itself. This management ensures that, although the festival has a high level of engagement with the public, it has negligible impact on the condition of the property and facilities. From this it can be inferred that the carrying capacity of the area is considerably larger than that required by the forecast increase in visitor numbers over the next 10 years, and gives comfort that any future increases after that time can be accommodated without harming the OUV of the property.

Visitor management

The property has a well-developed Tourism Action Plan, included in this dossier, which sets the framework for the sustainable operation of its visitor facilities.

General visitors receive orientation when they arrive and then are directed towards a range of presentation opportunities, including galleries, outdoor display areas, the landscape area around the Lovell Telescope itself

(landscape area L03) and the Gardens (referred to in the Conservation Management Plan as the Arboretum: landscape area L01).

A proportion of people come purely to visit the Café and Shop, and do not enter the visitor area of the nominated property itself. These numbers are assessed using an automatic door counter linked to a computer.

Visitors are asked to switch off mobile phones when visiting the site as these cause radio interference which could be picked up by the radio telescopes (all staff who work at the site switch off their mobile phones as a matter of course).

The Centre works hard to ensure that its facilities are as inclusive as possible. This includes measures for people with accessibility issues and work to extend engagement with the property.

Schools visits

There is a well-developed schools programme, governed by a Schools Programme Strategy, which currently welcomes around 26,000 school pupils per year. The education team at the Centre provide age-appropriate learning sessions that are developed in discussion with curriculum advisors and sector experts. School visitor numbers are monitored and analysed and the programme is evaluated regularly with teachers and participants. More detail on this can be found in Section 5.

Public Programme

In addition to the Schools Programme, which operates during the day in term-time, the property runs a range of events and activities designed to engage particular groups of visitors in the evenings at weekends and during school holidays.

These include:

- **Family events:** During the school holidays, staff organise 'science shows' that tell the story of the site and its work. They run at multiple times during each day and are also used to spread visitor arrival times across the day in order to manage visitor accumulation.
- **Craft workshops:** Families are encouraged to participate in 'hands-on' craft workshops, which allow younger children to engage with the themes of the property. For example, the 60th Anniversary of the Lovell Telescope was celebrated with a memory wall and Telescope hats.
- **Lectures:** The Discovery Centre organises a range lectures, delivered each month by a University academic, on topics related to the science research of the site, its heritage or other related subjects.
- **Volunteer Programme:** The Centre has a volunteer programme that works on both the landscape of the site and also on communicating the wonder of Astronomy to the visiting public.
- **Bluedot Festival:** As the visitor profile for the property shows a 'dip' around the 'Young Adult' age range, the Centre decided to address this by running a series of music festivals, which typically attract the 'missing' age range. These festivals act as an 'attractor' for groups that would not traditionally visit and widen the diversity of the engagement with its messages.

Further details on visitor management and visitor programmes are given in Section 5 and in the Tourism Action Plan.

4.b(v) Number of Inhabitants Within the Property and the Buffer Zone

Estimated population located within:

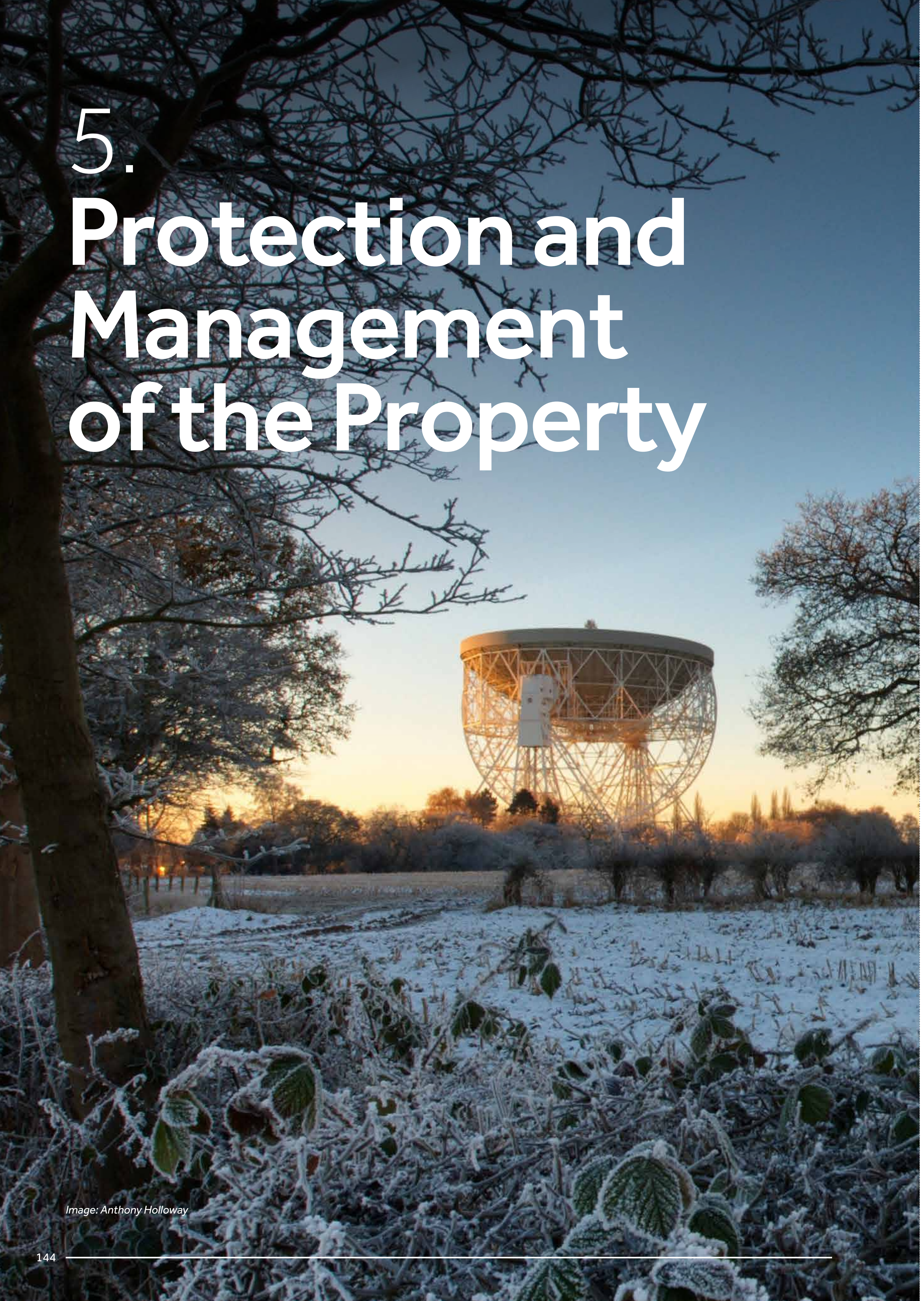
Area of nominated property
________0____________

Buffer zone
___20,000____________

Total
___20,000____________

Year
___2011*____________

* The Population Estimate for the Buffer Zone is taken from the population statistics from the 2011 census (population data at an appropriately small scale is not available in more recent estimates). Output Areas that intersect the buffer zone were selected, and those Output Areas where the population centres lay outside the buffer zone were then manually removed. This gives a population estimate of 20,000 for the area.



5. Protection and Management of the Property

Image: Anthony Holloway

5.a Ownership

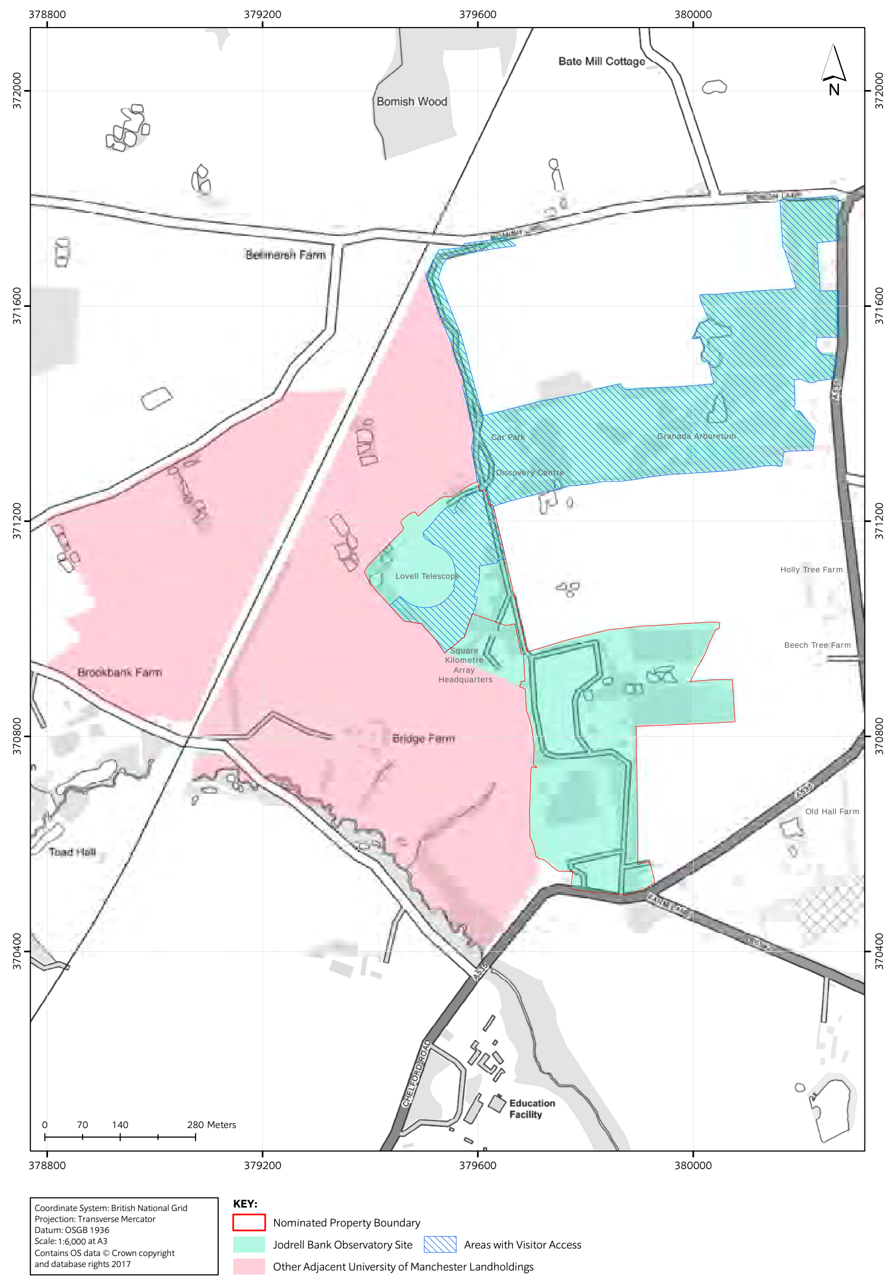
The nominated property is entirely owned by The University of Manchester, who also own much of the immediately adjoining land around the property. The total area of the Jodrell Bank site is 35 hectares. The property (17.38 hectares) sits within this.

The part of the University site outside the property includes area (and a building) leased to the Square Kilometre Array Organisation and an area and buildings that the University uses for the sustainable management of visitors (known as the 'Jodrell Bank Discovery Centre').

The University's approval is needed for any works, such as new buildings, carried out on any area of its land. The University's approval would also be needed for any significant changes of use to the farmland owned by them adjacent to Jodrell Bank.

Ownership is a key element of the protection of the OUV of the site. Indeed, the University's ownership since the inception of the Observatory is one of the major factors that has ensured its protection.

Figure 5.1: The University of Manchester Land Holdings at Jodrell Bank Observatory



5.b
Protective Designation

The nominated property, Jodrell Bank Observatory, is fully protected through ownership, legislation and planning policy.

5.b.1
Ownership

The whole nominated site, together with land around it, is owned by The University of Manchester who are committed both to continuing the scientific use of the site and to the conservation of its heritage interest (see Section 5.a above for details and map).

What happens within the nominated property is entirely controlled by the University. The University also controls land around the nominated property either directly or through legal agreements with the occupiers. This gives a strong level of protection and proactive management.

Image: Anthony Holloway

5.b.2
Legal protection

In England there are two interlocking legal approaches to the protection of heritage – designation, and spatial planning policy.

Designations

Heritage designation applies to specific assets. These can be scheduled ancient monuments, listed buildings, conservation areas, historic parks and gardens, and battlefields. These are designated under varying powers and consent must be granted for works to be carried out to them.

Ancient monuments are scheduled under the terms of the 1979 Ancient Monuments and Archaeological Areas Act (as amended). Consent for works to them is granted by the Secretary of State for Culture, Digital, Media and Sport, advised by Historic England, the government's statutory advisor on the historic environment.

Listed Buildings and Conservation Areas are designated under the Planning (Listed Buildings and Conservation Areas) Act 1990. Listed Buildings are buildings of special architectural or historical interest and can be graded I, II*, or II. Listed Buildings are listed by the Secretary of State for Culture, Digital, Media and Sport, advised by Historic England. Once a building is listed, consent is needed from the relevant local authority for any works that might change its character. For a building listed at Grade I or II*, the local authority should seek the comments of Historic England when considering an application for listed building consent.

Conservation Areas are designated by the relevant local authority, or in exceptional circumstances by the Secretary of State for Communities and Local Government.

The only designated assets within the Jodrell Bank nominated property are a number of listed buildings. The Lovell Telescope has been listed at Grade I since 1988. In August 2017 further buildings were listed: The Mark II Telescope (Grade I); The Control Building (Grade II); The Cosmic Noise Hut (Grade II); The Electrical Workshop (Grade II); The Park Royal Building (Grade II) and the remains of the Searchlight Telescope (also known as the Searchlight Aerial) (Grade II). This establishes a high level of control since listed building consent is required for any changes to the structure. This consent is normally granted by the local authority who should seek the advice of Historic England on any listed building consent application for a Grade I or II* structure. Developments within the setting of the Lovell Telescope also have to be considered with regard to their impact on its character. Setting is discussed further below. Here it should be noted that the scale and height of the Lovell Telescope mean that its setting is extensive.

World Heritage properties are not in themselves designations under English law and there is therefore no specific consent procedure similar to that for listed buildings. They are therefore protected through the spatial planning system and through the designation of specific assets within them. National planning advice (see Section 5.c below) says that, as an international designation, they should be treated as the equivalent of national designations of the highest significance and that they should be protected to a high level.

Spatial Planning system

England has a plan-led spatial planning system. The basic legal powers are provided by primary legislation.

The legal framework is established principally by four Acts of Parliament[1]:

- Town and Country Planning Act 1990 – this consolidated previous town and country planning legislation and sets out how development is regulated
- Planning and Compulsory Purchase Act 2004 – this made changes to development control, compulsory purchase and the application of the Planning Acts to Crown land.
- Planning Act 2008 – this set out the framework for the planning processes for nationally significant infrastructure projects and provided for the community infrastructure levy
- Localism Act 2011 – this provides the legal framework for neighbourhood planning powers and the duty to cooperate with neighbouring authorities.

National Planning Policy

In 2012 the Government consolidated virtually all national planning policy guidance into one National Planning Policy Framework (NPPF). This is supported by national Planning Practice Guidance (PPG), first published online in 2014 and updated as necessary. The relevant provisions of the NPPF and PPG are described in Section 5.c below. At the local level, policies for protection of the historic environment are set in the local development plan (see Section 5.d below).

[1] Graham Winter, Louise Smith, Suzie Cave, Alan Rehfisch Comparison of the planning systems in the four UK countries Commons Library Briefing Paper 07459

5.b.3
Buffer Zone

Jodrell Bank is on the whole well screened by woodland along its boundaries which means that there is not much intervisibility between the site and its surrounding context.

The major exception to this is the Lovell Telescope. 76m in diameter and 89m high, it dominates the surrounding Cheshire plain and it is visible from considerable distances west from the Pennines out to the coast.

Protection of a considerable zone around Jodrell Bank has in fact been in place since 1973 because of the importance of minimising radio interference to protect the operation of the Lovell Telescope. The Town and Country Planning (Jodrell Bank Radio Telescope) Direction 1973, issued under the powers of the Town and Country General Development Order 1973, imposes considerable restriction on new development within an area of just over 18,500 ha within an approximate six-mile radius (9.656kms) of Jodrell Bank. This is known as the Jodrell Bank Radio Telescope Consultation Zone. It lies mainly in Cheshire East with a smaller part in Cheshire West and Chester. The buffer zone shape was determined by the characteristic of the landscape and local population needs, and the fact that the Lovell Telescope (which is the most sensitive instrument at the site) largely observes the southern sky (as this is where there is more variation in the objects in the Universe that pass through its view).

It is proposed that this will form a buffer zone for the nominated property since it already has a degree of protection over and above the standard planning policies of the District Council. (see map in Section 5.d).

A major tall development beyond that radius could still interfere with views of the Lovell Telescope. It is considered, though, that such applications could be effectively handled through the local planning authorities' policies to protect Jodrell Bank (see Section 5.d) and the general policies on the protection of the setting of a Grade I listed building (see Section 5.c). For such an interference with views, at a distance of more than six miles, it would have to be a very major structure indeed.

Image: Anthony Holloway

5.c
Means of implementing protective measures

5.c.1
Ownership

Image: Howard Barlow

Figure 5.2: The single-storey Planet Pavilion at the Jodrell Bank Discovery Centre with the Lovell Telescope in the background.

The ownership of the whole nominated property and of the surrounding land is a very strong element of the protection of Jodrell Bank.

The University is wholly committed to supporting the management of Jodrell Bank as both a World Heritage property and a world-leading site for science. It is developing a holistic approach to management, which recognises the needs of astronomical research, heritage conservation, and improvement of public access and understanding. In recent years it has spent considerable amounts on the conservation of the site and is committed to continuing to do so.

In the past, for example, the University has observed design principles that restrict developments at Jodrell Bank to low-profile buildings (single storey etc) that do not obstruct telescope views of the sky and do not impinge upon the setting of the site. Examples of these include visitor facilities (Figure 5.2) and the HQ for the Square Kilometre Array Organisation.

5.c.2

The protection of listed historic buildings

As noted in Section 5.b, certain heritage designations have specific consent regimes.

The only designation of this type at Jodrell Bank are listed historic buildings. Apart from the need for planning consent for developments when they are proposed, any change to a historic listed building requires listed building consent. The listed buildings at Jodrell Bank are key attributes of Outstanding Universal Value.

Listed building consent is required for all works of demolition, alteration or extension to a listed building that affect its character as a building of special architectural or historic interest. The requirement applies to all types of works and to all parts of those buildings covered by the listing protection (possibly including attached and curtilage buildings or other structures), provided the works affect the character of the building as a building of special interest. An application for listed building consent is made to, and determined by, the local planning authority. Where the works have an impact on the external appearance of the building, planning permission may also be required and if so should be applied for at the same time. The local planning authority must consult Historic England and the National Amenity Societies (for Jodrell Bank Observatory, the 20th Century Society is the most relevant) on certain listed building consent applications.

Image: Anthony Holloway

Figure 5.3: The Grade-II listed Electrical Workshop.

Apart from the Listed Building Consent process, listed buildings also have settings. Impact on their settings is something that must be considered in coming to decisions on planning applications (see next section). This may require the preparation of some kind of assessment of the potential impact of the proposed development on the setting of the listed building. It is proposed that a deemed strategy of consent is developed for the property in 2018/19, with the participation of all relevant stakeholders.

5.c.3

Development Control through the spatial planning system

How spatial planning powers, established by national legislation, should be used is set out in national policy, and in more detail in local development plans for each local authority area. For almost all developments, it is necessary to obtain planning consent. Most planning decisions are taken by the local authorities. Their role is central to effective spatial planning.

There are two exceptions to this.

Firstly, there is provision for appeals against refusal of consent for development by the relevant local authority. The decision is then taken by or on behalf of the Secretary of State for Communities and Local Government (the government department responsible for spatial planning). The Secretary of State can also 'call in' planning applications for his own decision if matters of significant national interest or policy are affected. This power is used very sparingly. In both appeal and call-in cases the application will be examined in a public inquiry by a Planning Inspector who will, for most appeals, take the decision himself. For the remaining appeals and for all call-in cases the Inspector will make a report to the Secretary of State, who will then take the final decision.

The second exception is for nationally significant infrastructure projects. These are large-scale developments relating to energy, transport, water, or waste. These are dealt with by a separate process. Applications for a Development Consent Order are submitted directly to the relevant Secretary of State. They are then examined by the Planning Inspectorate principally by means of written submissions from all concerned parties. The Planning Inspectorate can hold a public hearing if necessary. After the examination is completed, a report is submitted by the Inspectorate to the Secretary of State who will take the final decision.

The basis of the spatial planning system is that it is plan-led and that decisions are taken within a democratic system, either by local councillors or by government ministers. Applications must be submitted for most development proposals and consent should be granted or refused in accordance with agreed policies. Detailed policy for each local authority area is set by its council in a local development plan. Relevant local plans are covered in Section 2.d below. As noted above there are circumstances when the decision will be taken by the Secretary of State or his nominee.

Local plans have to conform to national policy, now contained primarily within the National Planning Policy Framework (NPPF). At the heart of the NPPF is a presumption in favour of sustainable development. Sustainability is recognised to have three dimensions – economic, social, and environmental. These are defined as:

- an economic role – contributing to building a strong, responsive and competitive economy, by ensuring that sufficient land of the right type is available in the right places and at the right time to support growth and innovation; and by identifying and coordinating development requirements, including the provision of infrastructure;
- a social role – supporting strong, vibrant and healthy communities, by providing the supply of housing required to meet the needs of present and future generations; and by creating a high quality built environment, with accessible local services that reflect the community's needs and support its health, social and cultural well-being; and
- an environmental role – contributing to protecting and enhancing our natural, built and historic environment; and, as part of this, helping to improve biodiversity, use natural resources prudently, minimise waste and pollution, and mitigate and adapt to climate change including moving to a low carbon economy. (National Planning Policy Framework para 7)

Protection and enhancement of the natural, built and historic environment is therefore recognised as a key part of the government's goal of sustainable development.

NPPF contains more detailed advice on the protection and sustainable use of the historic environment (paras 126 – 141). Paragraphs relevant to Jodrell Bank are quoted below:

> *126. Local planning authorities should set out in their Local Plan a positive strategy for the conservation and enjoyment of the historic environment, including heritage assets most at risk through neglect, decay or other threats. In doing so, they should recognise that heritage assets are an irreplaceable resource and conserve them in a manner appropriate to their significance. In developing this strategy, local planning authorities should take into account:*
>
> - *the desirability of sustaining and enhancing the significance of heritage assets and putting them to viable uses consistent with their conservation;*
> - *the wider social, cultural, economic and environmental benefits that conservation of the historic environment can bring;*
> - *the desirability of new development making a positive contribution to local character and distinctiveness; and*
> - *opportunities to draw on the contribution made by the historic environment to the character of a place.*
>
> *128. In determining applications, local planning authorities should require an applicant to describe the significance of any heritage assets affected, including any contribution made by their setting. The level of detail should be proportionate to the assets' importance and no more than is sufficient to understand the potential impact of the proposal on their significance. As a minimum the relevant historic environment record should have been consulted and the heritage assets assessed using appropriate expertise where necessary. Where a site on which development is proposed includes or has the potential to include heritage assets with archaeological interest, local planning authorities should require developers to submit an appropriate desk-based assessment and, where necessary, a field evaluation.*
>
> *129. Local planning authorities should identify and assess the particular significance of any heritage asset that may be affected by a proposal (including by development affecting the setting of a heritage asset) taking account of the available evidence and any necessary expertise. They should take this assessment into account when considering the impact of a proposal on a heritage asset, to avoid or minimise conflict between the heritage asset's conservation and any aspect of the proposal.*
>
> *131. In determining planning applications, local planning authorities should take account of:*
>
> - *the desirability of sustaining and enhancing the significance of heritage assets and putting them to viable uses consistent with their conservation;*
> - *the positive contribution that conservation of heritage assets can make to sustainable communities including their economic vitality; and*
> - *the desirability of new development making a positive contribution to local character and distinctiveness.*
>
> *132. When considering the impact of a proposed development on the significance of a designated heritage asset, great weight should be given to the asset's conservation. The more important the asset, the greater the weight should be. Significance can be harmed or lost through alteration or destruction of the heritage asset or development within its setting. As heritage assets are irreplaceable, any harm or loss should require clear and convincing justification. Substantial harm to or loss of a grade II listed building, park or garden should be exceptional. Substantial harm to or loss of designated heritage assets of the highest significance, notably scheduled monuments, protected wreck sites, battlefields, grade I and II* listed buildings, grade I and II* registered parks and gardens, and World Heritage Sites, should be wholly exceptional.*
>
> *133. Where a proposed development will lead to substantial harm to or total loss of significance of a designated heritage asset, local planning authorities should refuse consent, unless it can be demonstrated that the substantial harm or loss is necessary to achieve substantial public benefits that outweigh that harm or loss, or all of the following apply:*
>
> - *the nature of the heritage asset prevents all reasonable uses of the site;and*
> - *no viable use of the heritage asset itself can be found in the medium term through appropriate marketing that will enable its conservation; and*
> - *conservation by grant-funding or some form of charitable or public ownership is demonstrably not possible; and*
> - *the harm or loss is outweighed by the benefit of bringing the site back into use.*
>
> *134. Where a development proposal will lead to less than substantial harm to the significance of a designated heritage asset, this harm should be weighed against the public benefits of the proposal, including securing its optimum viable use.*
>
> *135. The effect of an application on the significance of a non-designated heritage asset should be taken into account in determining the application. In weighing applications that affect directly or indirectly non designated heritage assets, a balanced judgement will be required having regard to the scale of any harm or loss and the significance of the heritage asset.*
>
> *137. Local planning authorities should look for opportunities for new development within Conservation Areas and World Heritage Sites and within the setting of heritage assets to enhance or better reveal their significance. Proposals that preserve those elements of the setting that make a positive contribution to or better reveal the significance of the asset should be treated favourably.*
>
> *138. Not all elements of a World Heritage Site or Conservation Area will necessarily contribute to its significance. Loss of a building (or other element) which makes a positive contribution to the significance of the Conservation Area or World Heritage Site should be treated either as substantial harm under paragraph 133 or less than substantial harm under paragraph 134, as appropriate, taking into account the relative significance of the element affected and its contribution to the significance of the Conservation Area or World Heritage Site as a whole.*

The NPPF is supplemented by on-line Planning Practice Guidance (PPG) which amplifies the guidance on World Heritage provided in NPPF (paras 026 to 038). The most relevant paragraphs are produced below.

> ***How are World Heritage Sites protected and managed in England***
>
> *England protects its World Heritage Sites and their settings, including any buffer zones or equivalent, through the statutory designation process and through the planning system.*
>
> *The Outstanding Universal Value of a World Heritage Site, set out in a Statement of Outstanding Universal Value, indicates its importance as a heritage asset of the highest significance to be taken into account by:*
>
> - *the relevant authorities in plan-making, determining planning and related consents (including listed building consent, development consent and Transport and Works Act Orders)*
> - *and by the Secretary of State in determining such cases on appeal or following call in*
>
> *Effective management of World Heritage Sites involves the identification and promotion of positive change that will conserve and enhance their Outstanding Universal Value, authenticity, integrity and with the modification or mitigation of changes which have a negative impact on those values.*
>
> *Paragraph: 026 Reference ID: 18a-026-20140306*

How does the terminology used by UNESCO relate to the policies of the National Planning Policy Framework?

The international policies concerning World Heritage Sites use different terminology to that in the National Planning Policy Framework. World Heritage Sites are inscribed for their 'Outstanding Universal Value' and each World Heritage Site has defined its 'attributes and components' the tangible remains, visual and cultural links that embody that value. The cultural heritage within the description of the Outstanding Universal Value will be part of the World Heritage Site's heritage significance and National Planning Policy Framework policies will apply to the Outstanding Universal Value as they do to any other heritage significance they hold. As the National Planning Policy Framework makes clear, the significance of the designated heritage asset derives not only from its physical presence, but also from its setting.

Paragraph: 031 Reference ID: 18a-031-20140306

What principles should inform the development of a positive strategy for the conservation and enjoyment of World Heritage Sites?

In line with the National Planning Policy Framework, policy frameworks at all levels should conserve the Outstanding Universal Value, integrity and authenticity (where relevant for cultural or 'mixed' sites) of each World Heritage Site and its setting, including any buffer zone or equivalent. World Heritage Sites are designated heritage assets of the highest significance. Appropriate policies for the protection and sustainable use of World Heritage Sites, including enhancement where appropriate, should be included in relevant plans. These policies should take account of international and national requirements as well as specific local circumstances.

When developing Local Plan policies to protect and enhance World Heritage Sites and their Outstanding Universal Value, local planning authorities, should aim to satisfy the following principles:

- *protecting the World Heritage Site and its setting, including any buffer zone, from inappropriate development*
- *striking a balance between the needs of conservation, biodiversity, access, the interests of the local community, the public benefits of a development and the sustainable economic use of the World Heritage Site in its setting, including any buffer zone*
- *protecting a World Heritage Site from the effect of changes which are relatively minor but which, on a cumulative basis, could have a significant effect*
- *enhancing the World Heritage Site and its setting where appropriate and possible through positive management*
- *protecting the World Heritage Site from climate change but ensuring that mitigation and adaptation is not at the expense of integrity or authenticity*

Planning authorities need to take these principles and the resultant policies into account when making decisions.

Paragraph: 032 Reference ID: 2a-032-20140306

What approach should be taken to assessing the impact of development on World Heritage Sites

Applicants proposing change that might affect the Outstanding Universal Value, integrity and, where applicable, authenticity of a World Heritage Site through development within the Site or affecting its setting or buffer zone (or equivalent) need to submit sufficient information with their applications to enable assessment of impact on Outstanding Universal Value. This may include visual impact assessments, archaeological data or historical information. In many cases this will form part of an Environment Statement. Applicants may find it helpful to use the approach set out in the International Council on Monuments and Sites' Heritage Impact Assessment guidelines and Historic England's guidance on setting and views.

World Heritage Sites are 'sensitive areas' for the purposes of determining if an Environmental Impact Assessment is required for a particular development proposal. Lower development size thresholds apply to the requirement for Design and Access Statements within World Heritage Sites as compared with the norm.

Paragraph: 035 Reference ID: 18a-035-20140306

What consultation is required in relation to proposals that affect a World Heritage Site

The World Heritage Committee Operational Guidelines ask governments to inform it at an early stage of proposals that may affect the Outstanding Universal Value of the Site and "before making any decisions that would be difficult to reverse, so that the Committee may assist in seeking appropriate solutions to ensure that the Outstanding Universal Value is fully preserved". Therefore, it would be very helpful if planning authorities could consult Historic England (for cultural Sites) or Natural England (for natural Sites) and Department for Culture, Media and Sport (DCMS) at an early stage and preferably pre-application.

Planning authorities are required to consult the Secretary of State for Communities and Local Government before approving any planning application to which Historic England maintains an objection and which would have an adverse impact on the Outstanding Universal Value, integrity, authenticity and significance of a World Heritage Site or its setting, including any buffer zone or its equivalent. The Secretary of State then has the discretion as to whether to call-in the application for his/her own determination. Further information on the Secretary of State's involvement in deciding an application can be found in the 'Determining a planning application' section of guidance.

Paragraph: 036 Reference ID: 18a-036-20140306

Are permitted development rights restricted in World Heritage Sites?

World Heritage Sites are defined as article 2(3) land in the Town and Country Planning (General Permitted Development) Order 2015. This means that certain permitted development rights are restricted within the Site. Planning authorities can restrict further development by using article 4 and article 5 (minerals operations) directions under the 2015 Order.

Paragraph: 037 Reference ID: 18a-037-20140306

The effect of the NPPF is to place a high level of protection on World Heritage properties, which should ensure that planning applications are handled correctly within the planning system. The PPG, as noted above, amplifies the requirements of the NPPF and makes them more operational. In particular it makes abundantly clear that World Heritage properties are designated assets of the highest significance and should be treated as such. Helpfully, the PPG also relates the terminology used by UNESCO to that used in the English planning system so that there should be no problem over the interpretation of terms such as Outstanding Universal Value.

Protection of the Outstanding Universal Value, including its integrity and authenticity, should be the key objective of the application of the planning system to the protection to Jodrell Bank. Outstanding Universal Value is the reason why a property is inscribed on the World Heritage List. Failure to maintain Outstanding Universal Value could jeopardise the future status of the property. Loss of Outstanding Universal Value would result in the deletion of the property from the World Heritage List.

Authenticity and integrity are seen as part of the overall definition of Outstanding Universal Value. Integrity is about the wholeness (all the necessary attributes are included within the boundaries) and completeness (all the attributes are still present without loss or significant damage or decay) of the property. Authenticity is about the truthfulness and credibility of the evidence (attributes) that demonstrates Outstanding Universal Value. Damage to either integrity or authenticity may also adversely affect the status of a property.

In response to this requirement of the World Heritage Convention, the NPPF and PPG together place great weight on the importance of positive conservation and enhancement of World Heritage properties and make clear that any damage to OUV should be wholly exceptional. They also set out clearly that the English planning system is value-led with regard to heritage. This ties in well with the UNESCO approach to the definition and protection of Outstanding Universal Value. A key element of the English approach is that the local planning authority must be provided, or provide itself, with adequate information on the impact of the significance of a heritage asset to determine the degree of damage which might be caused by a proposed development (NPPF paras 128 – 129; PPG para 035). This ties in well with the requirement of the UNESCO World Heritage Committee that impact assessments for all interventions are essential for all World Heritage properties (OG para 110). The PPG has incorporated advice from the UNESCO World Heritage Committee to use Guidance on Heritage Impact Assessments for Cultural World Heritage Properties published by ICOMOS in 2011 for such assessments. This defines the character of heritage impact assessment (HIA) and sets out guidance on carrying out HIA, which will be used at the nominated property as appropriate. In some circumstances, proposed developments affecting a World Heritage property may require a formal Environmental Impact Assessment in accordance with the terms of The Town and Country Planning (Environmental Impact Assessment) Regulations 2017.

Setting

The PPG also advises use of Historic England's guidance on setting and its protection, The Setting of Heritage Assets. Setting of heritage assets is defined in the NPPF as the area in which the heritage asset can be experienced. This experience is not necessarily solely visual, though this is often the dominant aspect of consideration of setting issues. Setting does not have fixed boundaries and may need to be defined for each proposed development, which might affect a heritage asset. It can be closely related to views of a heritage asset, whether planned or fortuitous. The importance of setting lies in what it contributes to the significance of its heritage asset.

In the case of Jodrell Bank, one aspect of setting is clearly visual since the Lovell Telescope is a dominant feature in its landscape. Another aspect is the need for minimal radio interference to the operation of the radio telescopes. This is similar to the requirement for a 'dark night sky' around an optical observatory (and is protected by the Jodrell Bank Direction of 1973 – see sections 5.b.(iii), 5.d.(i) and 5.d.(ii)).

To some extent the areas affected by these considerations are very similar. The Historic England publication provides useful definitions of setting and related concepts and practical guidance on the analysis of the impact of proposed developments on the setting of a heritage asset.

Finally, the PPG collects together references to other aspects of World Heritage properties within the planning system. These include the restriction of permitted development rights, and the definition of World Heritage properties as sensitive areas for Environmental Impact Assessment

5.c.4
Conclusion

Sections 5.c.1 to 5.c.3 demonstrate three strands to the effective protection of the Jodrell Bank nominated property

1. Firstly there is the ownership of Jodrell Bank by the University of Manchester who have promoted this nomination. This will ensure the continued sympathetic and active management of the nominated property. The University are establishing a management system based on a World Heritage Management Plan which will ensure a fully participative approach to the overall management of the nominated property. The basis of this approach is already established by, for example, the well-established partnership between the University and bodies such as Cheshire East Council, the local planning authority, and Historic England, the government's lead advisor on the historic environment.

2. The system of control through designation of listed historic buildings provides a further strand of effective protection. Listed Building Consent exists to protect designated buildings, of which Jodrell Bank has several, including the Lovell Telescope and Mark II Telescope. This also brings into play the need to protect their setting.

3. Finally, the general spatial planning system places great emphasis on the protection and sustainable use of the historic environment. There is specific reference to the need to protect World Heritage properties. There is emphasis on the need to manage World Heritage properties to protect their Outstanding Universal Value, and to use the types of tools, such as Heritage Impact Assessment, recommended by the UNESCO World Heritage Committee. The local authority, Cheshire East, have recently adopted a new local development plan (see Section 5.d), which contains specific policies to protect the nominated property.

This combination of ownership, designation, and the spatial planning system with its agreed local plan provides a strong and effective basis for the ongoing protection of the nominated property.

5.d
Existing plans related to municipality and region in which the proposed property is located
(e.g., regional or local plan, conservation plan, tourism development plan)

Image: Anthony Holloway

5.d.(i)
Cheshire East Local Plan and Strategy

The principal plan currently affecting the nominated property is the Cheshire East Local Plan Strategy, which was adopted in July 2017, having been in draft for several years before that.

The nominated property itself now lies wholly within the boundaries of Cheshire East, as does most of the Jodrell Bank Radio Telescope Consultation Zone. Prior to the creation of Cheshire East in April 2009, it was divided between the Borough of Congleton and the Borough of Macclesfield. The two parts of the nominated property were therefore previously subject to different local plans. Part of the six-mile radius protected zone extended into a third local authority area, Vale Royal Borough, now part of Cheshire West and Chester.

All their local plans contained policies for the protection of the historic environment, including archaeological remains. The open character of the site and the visual setting of the Lovell Telescope were also protected by specific policies (Policy PS8 of the Congleton Borough Local Plan, Policies GC5 and GC6 in the Macclesfield Borough Local Plan, and Policy BE20 in the Vale Royal Local Plan). Restriction on development in the wider vicinity was provided by Policy PS10 of the Congleton Borough Local Plan, and Policies GC14 in the Macclesfield Borough Local Plan.

Both the Congleton and Macclesfield Plans have now been superseded by the new Cheshire East Local Plan Strategy 2010 – 2030, adopted by the Council on 27th July, 2017. This builds on the policies of the previous Congleton and Macclesfield Local Plans to provide clear protection for Jodrell Bank, its setting and archaeological features.

Policy SE14: Jodrell Bank *states:*

1. Within the Jodrell Bank Radio Telescope Consultation Zone, as defined on the Proposals Map, development will not be permitted if it:

i. Impairs the efficiency of the telescopes; or

ii. Has an adverse impact on the historic environment and visual landscape setting of the Jodrell Bank Radio Telescope.

2. Conditions will be imposed to mitigate identified impacts, especially via specialised construction techniques.

3. Proposals should consider their impact on those elements that contribute to the potential outstanding universal value of Jodrell Bank.

In addition, there is general protection for heritage sites.

Policy SE7: Historic Environment *states:*

1. Cheshire East has an extensive and varied built heritage and historic environment, described in the justification text to this policy. The character, quality and diversity of the historic environment will be conserved and enhanced. All new development should seek to avoid harm to heritage assets and make a positive contribution to the character of Cheshire East's historic and built environment, including the setting of assets and where appropriate, the wider historic environment.

2. Proposals for development shall be assessed and the historic built environment actively managed in order to contribute to the significance of heritage assets and local distinctiveness. Where a development proposal is likely to affect a designated heritage asset (including its setting) the significance of the heritage asset, including any contribution made by its setting, must be described and reported as part of the application.

3. The council will support development proposals that do not cause harm to, or which better reveal the significance of heritage assets and will seek to avoid or minimise conflict between the conservation of a heritage asset and any aspect of a development proposal by:

a. Designated Heritage Assets:

i. Requiring development proposals that cause harm to, or loss of, a designated heritage asset and its significance, including its setting, to provide a clear and convincing justification as to why that harm is considered acceptable. Where that case cannot be demonstrated, proposals will not be supported.

ii. Considering the level of harm in relation to the public benefits that may be gained by the proposal.

iii. The use of appropriate legal agreements or planning obligations to secure the benefits arising from a development proposal where the loss, in whole or in part, of a heritage asset is accepted.

b. Non-Designated Assets:

i. Requiring that the impact of a proposal on the significance of a non-designated heritage asset should be properly considered, as these are often equally valued by local communities. There should be a balanced consideration, weighing the direct and indirect impacts upon the asset and its setting, having regard to the scale of any harm or loss. The presumption should be that heritage assets should be retained and re-used wherever practicable and proposals that cannot demonstrate that the harm will be outweighed by the benefits of the development shall not be supported. Where loss or harm is outweighed by the benefits of development, appropriate mitigation and compensation measures will be required to ensure that there is no net loss of heritage value

4. For all heritage assets, high quality design should be achieved. It should aim to avoid poorly executed pastiche design solutions and should foster innovation and creativity that is sensitive and enhances the significance of heritage assets in terms of architectural design, detailing, scale, massing and use of materials.

5. Cheshire East Council will seek to positively manage the historic built environment through engagement with landowners/asset owners and other organisations and by working with communities to ensure that heritage assets are protected, have appropriate viable uses, are maintained to a high standard and are secured and have a sustainable future for the benefit of future generations. Proposals that conserve and enhance assets on the Heritage at Risk register will be encouraged.

The Cheshire East Local Plan has a strong focus on sustainability, including policies that extend protection to the countryside.

Policy SE3: Biodiversity and Geodiversity *sets out protection measures for areas of high biodiversity and geodiversity. In general, this deals with areas that have special protection under the NPPF, although it does also say:*

5. All development (including conversions and that on brownfield and greenfield sites) must aim to positively contribute to the conservation and enhancement of biodiversity and geodiversity and should not negatively affect these interests. Where appropriate, conditions will be put in place to make sure appropriate monitoring is undertaken and make sure mitigation, compensation and offsetting is effective.

Policy SE4: The Landscape *requires the conservation of landscape character and quality. In particular, it says:*

1. The high quality of the built and natural environment is recognised as a significant characteristic of the borough. All development should conserve the landscape character and quality and should, where possible, enhance and effectively manage the historic, natural and man-made landscape features that contribute to local distinctiveness of both rural and urban landscapes.

Policy SE5: Trees, Hedgerows and Woodland *sets out protection measures for these features. It says that:*

The council will seek to ensure:

1. The sustainable management of trees, woodland and hedgerows, including provision of new planting within the infrastructure of new development proposals to provide local distinctiveness with the landscape; enable climate adaptation resilience, and support biodiversity;

2. The planting and sustainable growth of large trees within new development as part of a structured landscape scheme in order to retain and improve tree canopy cover within the borough as a whole.

5.d.(ii)
Cheshire West and Chester Local Plan

The Cheshire West and Chester local plan, adopted in 2015, is also relevant as part of the Jodrell Bank Consultation Zone lies within its boundaries. The Consultation Zone is proposed as the nominated property's Buffer Zone.

The Cheshire West and Chester Local Plan (part 1) Strategic Policies has a saved policy from the Vale Royal Local Plan BE20 on Jodrell Bank which continues the policy to protect the Referral Zone around Jodrell Bank on its territory. This policy says:

> ***Jodrell Bank***
>
> ***Policy BE20***
>
> *WITHIN THE JODRELL BANK RADIO TELESCOPE CONSULTATION ZONE, AS DEFINED ON THE PROPOSALS MAP, DEVELOPMENT WHICH CAN BE SHOWN TO IMPAIR THE EFFICIENCY OF THE JODRELL BANK RADIO TELESCOPE WILL NOT BE ALLOWED.*

Reasons and Explanations

(i) The radio telescopes at Jodrell Bank are of international importance for Radio Astronomy. Their value depends upon being able to receive radio emissions from space with a minimum of interference from electrical equipment. Despite technological advances, protection from local sources of interference is still of utmost importance.

(ii) The Town and Country (Jodrell Bank Radio Telescope) Direction 1973 requires the Local Planning Authority to consult with the University of Manchester before granting planning permission on any application for development (subject to the exceptions specified in the schedule).

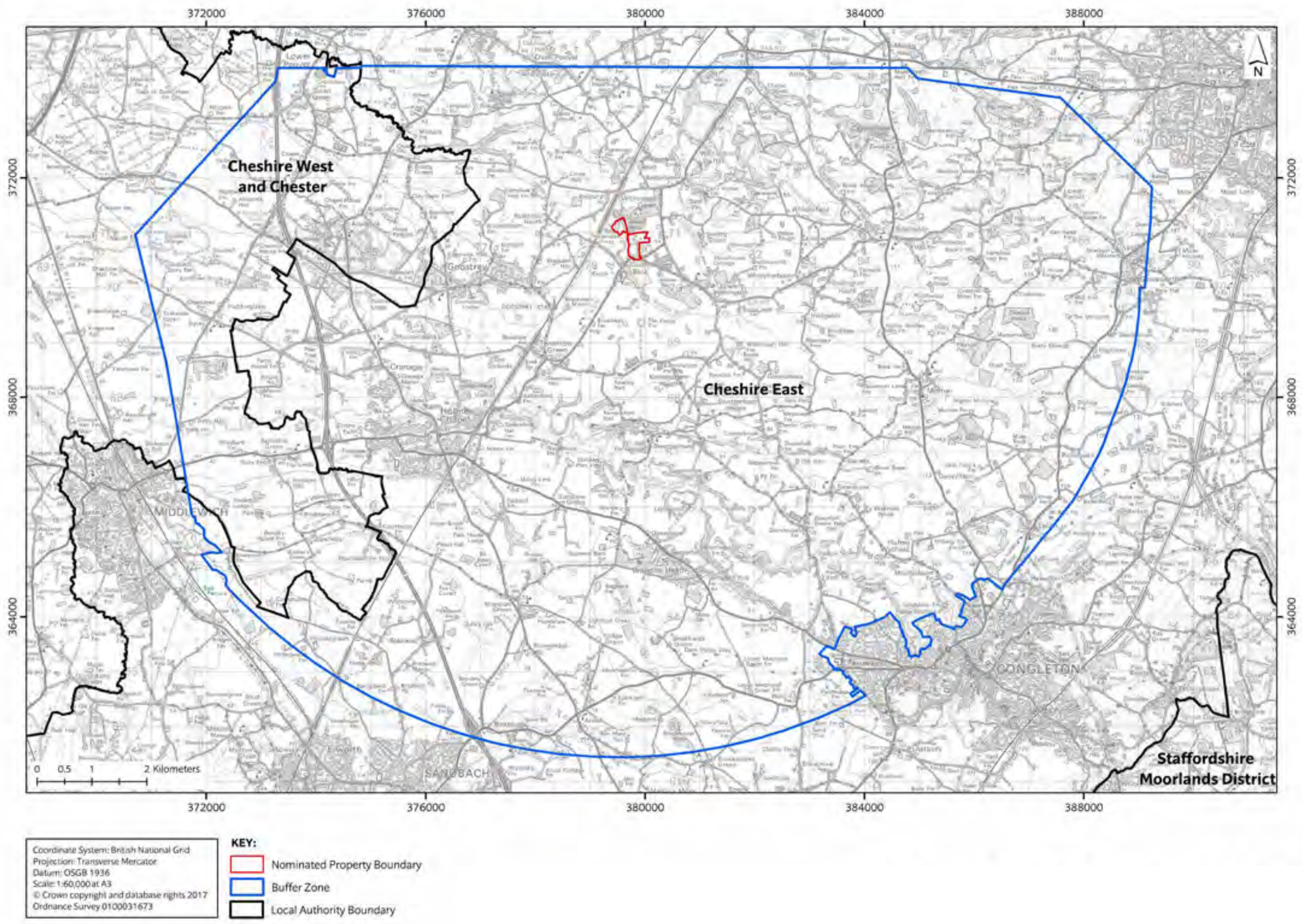

Image: Anthony Holloway

5.d.(iii)
Conclusion

While the Cheshire East and Cheshire West and Chester Local Plans now provide excellent protection for the property, they build on several decades of protection afforded by previous local policies, which set up, in effect, a Buffer Zone for the site from 1973 (following the creation of the Jodrell Bank Direction).

See Map of Buffer Zone, showing boundaries of Cheshire East and Cheshire West local authorities.

Map of Property and Buffer Zone, showing boundaries of local authorities 'Cheshire East' and 'Cheshire West and Chester'



5.d.(iv)
Tourism policies and plans

Cheshire East Local Plan

The Jodrell Bank site authorities contributed to the development of the Cheshire East Local Plan, adopted in 2017, which refers to Tourism at Jodrell Bank in several places.

Paragraph 1.42

The borough's heritage and cultural assets are key to the future as well as a trail to the past. They provide a vital contribution to the overall visitor economy, which has a turnover of £700m per year. They are also treasured by residents, and provide a valuable overall contribution to quality of life in the borough. Key considerations incorporated in this plan include continued protection of over 76 conservation areas, 47 grade 1, 179 grade 2 and 2,412 grade 2 listed buildings, and supportive policies in relation to the cutting edge science research and worldwide heritage associated with Jodrell Bank.*

Paragraph 11.31

The visitor economy covers a wide range of activities across a variety of themes and locations in Cheshire East. Attractions such as Tatton Park, Jodrell Bank and Little Moreton Hall may be considered visitor destinations in their own right; leisure based visits might cross the borough over a variety of canal, cycle or public footpath networks; and culture and recreational activities may take visitors to parks and gardens, market towns, and festivals across the borough.

Paragraph 13.64

Key assets include Macclesfield's silk and industrial heritage, Little Moreton Hall, Crewe's railway heritage, Tatton Park, Lyme Park, Quarry Bank Mill, Tegg's Nose Country Park, the canal network, historic towns and parts of the Peak District National Park, amongst others. Specific unique attractions include a wealth of historic parks and gardens and the Lovell Telescope at Jodrell Bank. The area's stately homes and historic parks and gardens are a particular feature of Cheshire East and pose particular challenges as well as opportunities. There are 76 conservation areas and 2,638 listed buildings including 47 grade 1 and 179 grade 2 listed buildings.*

The property is also included in the major tourism policies and plans for the area, including the Cheshire East Visitor Economy Strategy and the Marketing Cheshire Destination Management Plan.

Cheshire East Visitor Economy Strategy 2016-2020

The Cheshire East local authority (in which the proposed property lies) has a policy in its Visitor Economic Strategy (2016-2020), which identifies that tourism is of key economic value within the region and supports all economic development related to this.

Its aims include: '*To promote Cheshire East's Key Attractors*' and '*To significantly increase Leisure and Business visits from International Visitors*' (particularly from the US, China, Australia and Europe) to a number of locations, including Jodrell Bank.

Marketing Cheshire Destination Management Plan 2015-2018

Marketing Cheshire is the Tourism Agency for Cheshire (both East and West) and Warrington. It operates within the oversight of both Visit England and Visit Britain.

Its Destination Management Plan says: '*We will enhance the image of the region using our strongest brands, explore new communication methods, encourage dialogue and feedback through the ever changing world of digital media, strengthen the visitor experience and improve its brand positioning. We will reach new niche growth markets that will allow us to differentiate our destination*'.

The plan identifies Jodrell Bank as one of the strongest brands (indeed, uses images of the Lovell Telescope on its documents) and the Destination Management team work closely with the visitor team at the property.

5.e
Property management plan or other management system

Figure 5.4: Members of the site management team with external stakeholders in the bowl of the Lovell Telescope.

5.e.(i)
The current position

A full Management Plan is attached to this nomination document.

The property is fortunate in that it already has a well-established management framework, which has been in existence since its inception. That said, the management has, to date, prioritised its world-leading science and engineering research, rather than focussing on its heritage. Alongside the management of research activities, visitor management has also been developed in a way that is sympathetic to both scientific operations and heritage. Management of the heritage of the property has, to date, been more informal.

The nomination process has, for the first time, initiated the development and implementation of management practices that bring the three important elements of science, visitors and heritage together. In doing so, the wide group of site stakeholders (both site users and others) has been involved in the process.

This section sets out the pre-existing management framework and external stakeholder relationships at the point of nomination.

5.e.(ii)

Stakeholders

Internal Stakeholders

The Jodrell Bank site is wholly owned by The University of Manchester, the main stakeholder.

The site is used by three distinct groups:

1. The Jodrell Bank Centre for Astrophysics (JBCA) – a Division of the University of Manchester's School of Physics and Astronomy comprising research activities at Jodrell Bank Observatory and in the Alan Turing Building on the main University campus in Manchester;
2. The Jodrell Bank Discovery Centre (JBDC) – one of the University of Manchester's Cultural Institutions and responsible for visitors to the site;
3. The Square Kilometre Array Organisation (SKAO) – an international research organisation, collaborating with the Jodrell Bank Centre for Astrophysics and many other similar institutions worldwide and leasing land at Jodrell Bank from the University on which their international headquarters is sited (see, for example, Figure 2.5). The SKAO is due to become an Inter-Governmental Organisation, by International Treaty, in 2018/19.

External Stakeholders

The property has a number of external stakeholders. These include local and national communities; the wider scientific community and associated governing bodies and funders; the planning authority and Heritage bodies. The SKAO can also be seen as an external stakeholder. However, it is a special case as it is located adjacent to the property and access to its site is via the property, hence it is dealt with above as a site user.

The main external stakeholders are:

- *Local communities:* These are, in general, represented by local Parish Councils. In the case of Jodrell Bank, the main Parish Councils are those for Lower Withington and Goostrey.
- *Retired and former staff & students:* There is a significant community of people who have worked and/or studied at Jodrell Bank and who have relevant heritage knowledge and experience.
- *National and regional communities of interest:* These include amateur astronomers, history of science and engineering groups etc. The main group linked to Jodrell Bank in this category is the Macclesfield Astronomical Society, which has a strong relationship with the site. Group members participate in astronomy and heritage events at the Jodrell Bank Discovery Centre.
- *The international astronomy research community*, including national/international users of the telescopes operated by Jodrell Bank, the European VLBI Network (EVN), the Large European Array for Pulsars (LEAP) etc. JBCA astronomers are leading members of this community and are in daily contact with others across these networks.
- *UK Science and Engineering Research Councils* (especially the Science and Technology Facilities Council, STFC): JBCA staff are involved in work with the Research Councils at all levels and JBDC staff sit on STFC public engagement panels.
- *Cheshire East Council:* Interactions range from high level strategic links concerned with the benefit to Cheshire of the world leading heritage, research and profile of Jodrell Bank, to more practical links concerned with particular issues (especially planning and conservation).
- *Cheshire West Council:* Interactions are linked mainly to planning issues.
- *Historic England:* Jodrell Bank and University staff have strong working relationships with Historic England at many levels, particularly relating to listed status of various structures and buildings.
- *The Royal Astronomical Society* (RAS): As the professional body for UK astronomy, the Observatory and Discovery Centre have relationships at several levels of the RAS, including its Heritage Committee.
- *The International Astronomical Union* (IAU) and the IAU/ICOMOS Working Group on Astronomy and World Heritage: Jodrell Bank has already begun dialogue with the Working Group on Astronomy. A 'Case Study' on Jodrell Bank is under preparation for inclusion on the ICOMOS/IAU website on Astronomy and Heritage.
- *Marketing Cheshire:* The Discovery Centre has a strong working relationship with this agency, which is responsible for strategic support and promotion of tourism in Cheshire and for facilitating wider benefits from the visitor economy.
- *Marketing Manchester:* The Discovery Centre also has a strong working relationship with this agency, which is responsible for strategic support and promotion of tourism in Greater Manchester, a significant catchment area for visitors but also the location of the main campus of the University of Manchester.

Consultation about the Jodrell Bank application for World Heritage Site status has taken place with representatives of all stakeholders and dialogue takes place with them on a regular basis.

As described in the Management Plan, representatives of appropriate groups from the above list are included in the World Heritage Site Committee.

In addition to the groups above, the general public are also key stakeholders of the site. Consultation with them, including general visitors and groups (conservation organisations, bee keepers etc) has taken place over the last 3 to 5 years, while the process of preparing the nomination dossier has been underway. Formal consultation and involvement of these groups will take place at regular intervals in future (see the Action Plan in the Management Plan).

Image: Chris Gleave

Figure 5.5: Current and retired staff share memories at a reunion to celebrate 60 years of the Lovell Telescope in 2017.

5.e.(iii)

Current Management

The current management structure is represented in Figure 5.6 and described below.

Site Coordination Level

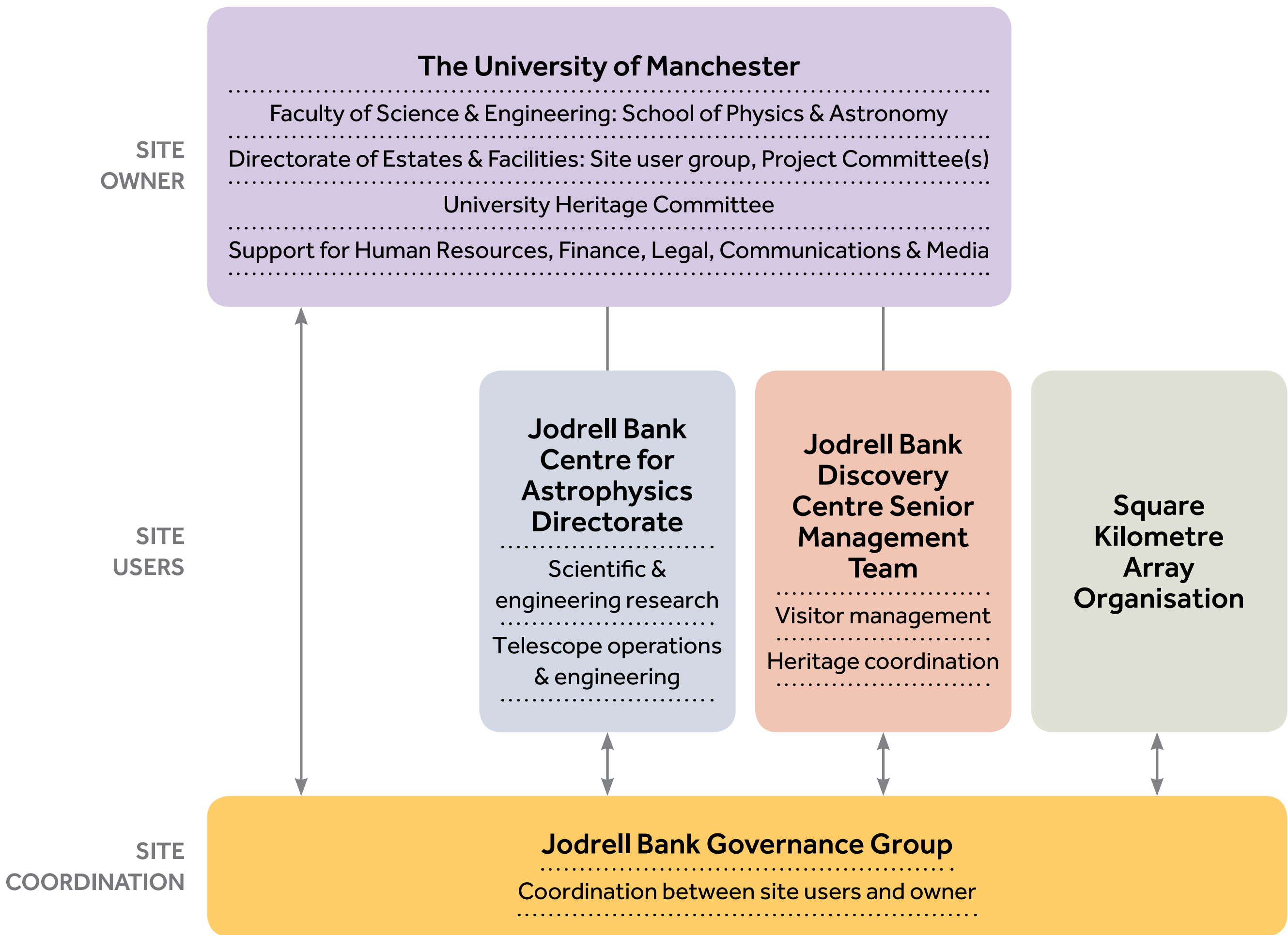
Coordination of activities on the Jodrell Bank property is currently undertaken by a University committee, the Jodrell Bank Site Governance Group, which includes all key internal stakeholders including representatives of the three main site user groups. The Group meets 2-3 times per year and takes a strategic overview of work, events and developments at the Jodrell Bank site with particular focus on where interests of the three user groups overlap. This has, to date, also included discussion of the World Heritage Site process.

Operational Level

In addition to the coordination exercised by the Governance Group, each of the three site user groups has its own well-developed and independent management and operational structures. There are however cross-links between each team and also links from various points to external stakeholders.

These management structures are concerned primarily with their function at Jodrell Bank (e.g. scientific research and development, telescope engineering and operations, public engagement etc). Roles managing the heritage of Jodrell Bank are integrated into the day-to-day work of the Observatory element of JBCA and the JBDC, supported by other management groups within the University of Manchester. This ensures that responsibility is taken for the protection and enhancement of the heritage aspects of the site, including the due care of archaeological remains.

Figure 5.6: Current management structure at Jodrell Bank site



The local management structures currently include:

The Observatory: Managing Science and Engineering

- The Jodrell Bank Centre for Astrophysics Directorate has oversight of the research and engineering functions of Observatory and the wider research division, including the e-MERLIN National Facility and the relationship with the SKA Organisation.
- The JBCA Engineering team is responsible for maintenance and conservation of the Telescopes both at Jodrell Bank and elsewhere in the UK's e-MERLIN network.
- The day-to-day management of the Observatory Estate and buildings is undertaken by the Observatory team working alongside the University's Directorate of Estates and Facilities. These areas include all the major heritage Attributes of the site.
- One of the JBCA Associate Directors is tasked with managing the heritage of the Observatory.
- Academic and Engineering staff also collaborate with the Discovery Centre to deliver Education and public engagement ('presentation') activities.

The Jodrell Bank Discovery Centre: Managing Visitors, oversight of Heritage

- The Discovery Centre team coordinates the World Heritage Site process.
- It has responsibility for management of Estate and Buildings open to the public
- It provides visitor services and support
- The property's Education, Exhibition and Events teams are part of the Discovery Centre
- It takes a lead on managing the gardens, sustainability, green policies and biodiversity on behalf of the University and has a gardens team that focus on this.
- The Heritage Officer for the property is part of the Discovery Centre team.

University support structures

- The University of Manchester Heritage Committee (Chaired by the University's Deputy President and Deputy Vice Chancellor), has representation from all relevant University areas, including Jodrell Bank. The University's Historian and Heritage Manager is also supporting the process of Nomination to UNESCO and will be part of the Steering Group.
- The University Estates site 'User Group' coordinates ongoing Estates matters at the site for all stakeholders.
- Any major capital projects are overseen by a Project Committee established by the University Directorate of Estates and Facilities with senior representation from the site users.
- The University's Sustainability and Green Travel Plan Group provide support on sustainability.
- The University also provides functional support from its Professional Support Services (PSS) team, including the Finance Division; Legal team; HR team; Communications team etc.

Planning Cycle

In addition to the requirements of the process of maintenance engineering, planning of activities and developments at Jodrell Bank Centre for Astrophysics and the Jodrell Bank Discovery Centre is managed through the University's planning cycle, which combines elements of yearly, 5-yearly and long-term planning. The cycle includes teaching, research and public engagement commitments as a matter of course, and sets out the framework for resourcing all the various activities that take place. Overlaid on this are the planning cycles of other key stakeholders, such as Government research councils (particularly STFC – the Science and Technology Facilities Council which is a major funder of research and observatory operations) and external bodies such as the European VLBI network with which telescope observations are regularly coordinated.

This process sits alongside management of the heritage and the attributes that carry the Outstanding Universal Value of the property, which are described in more detail in the Management Plan.

5.e.(iv)
Future Management

The future management of the property will be taken forward by existing University structures described above, augmented by the World Heritage Site Steering Committee, see Figure 5.7.

WHS Coordination will be managed by the Director of the Discovery Centre and an appropriate Steering Committee as described in Section 1.3, that will include all stakeholders, will oversee the way in which the site is managed. It is expected that additional costs of management will be managed via existing budget structures, offset in part by increased revenues generated by increased visitor activity.

It is not anticipated that visitor numbers will increase due to inscription to the extent that major works will be required on the local highways etc. However, an estimated increase of around 30-50% will be accommodated in the new visitor facilities funded by the national Heritage Lottery Fund, UK Government, the University of Manchester and other donors. The operation of this will be supported via a full Business Plan (see Tourism Management Plan) based around visitor numbers in a similar way to the current operation, ensuring its sustainability.

Guiding Principles

The Management Plan for the Jodrell Bank Observatory World Heritage Site has the following guiding principles:

1. Protection, conservation and maintenance of the Outstanding Universal Value, Integrity and Authenticity of the property, including the identification and promotion of change that conserves and enhances these qualities; and the modification and/or mitigation of development and change that might damage them.

2. The Jodrell Bank Observatory continues to perform its function as a radio astronomy facility. It is important to conserve and enhance the heritage of the site whilst maintaining this role as a world-leading scientific research facility, thus retaining its authenticity of use and function.

3. Sustainable use for the benefit of the local population and economy.

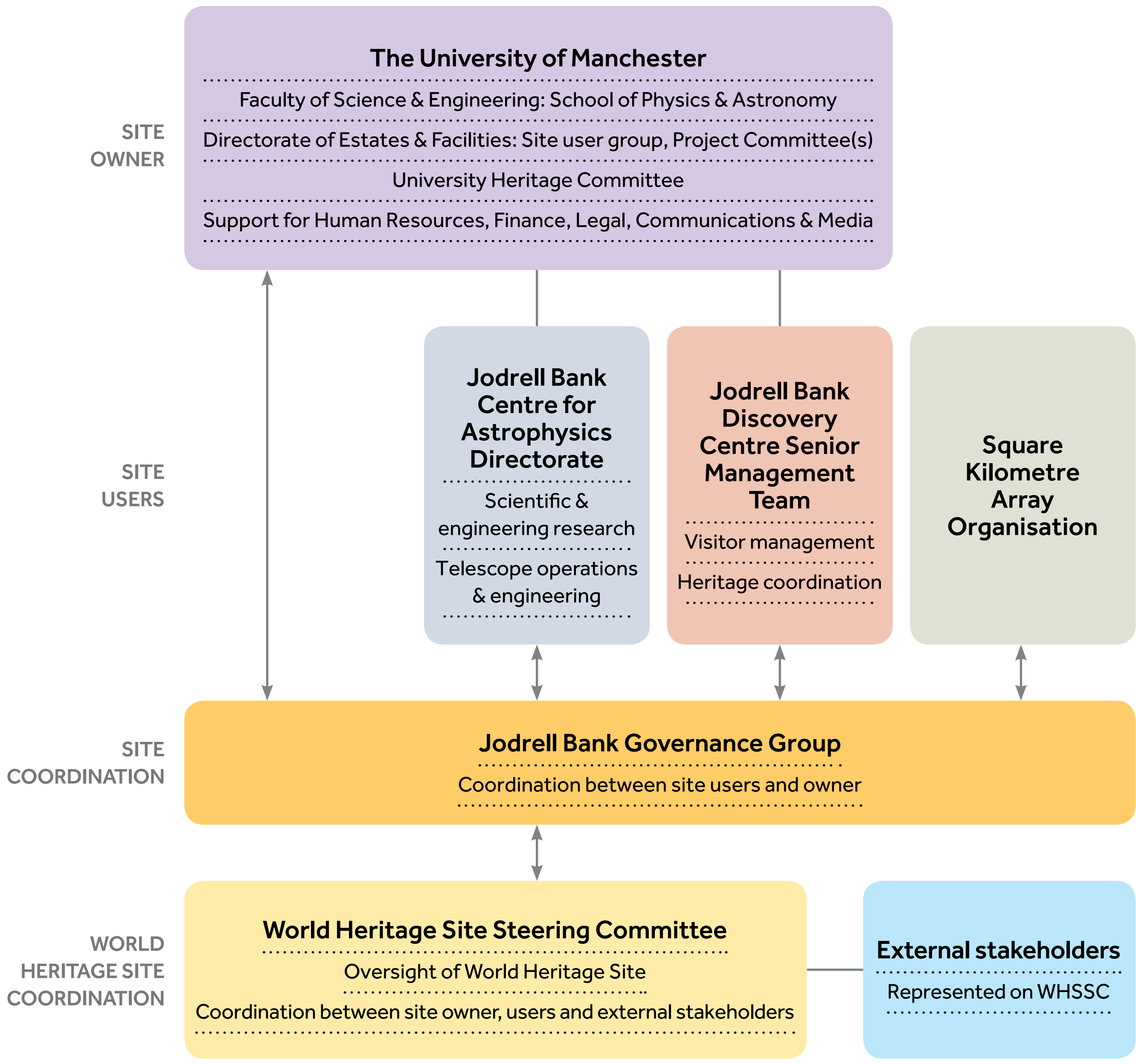
4. Commitment to a comprehensive programme of presentation and education, including a commitment to sustainable visitation.

5. Importance of gathering all stakeholders in a shared understanding of the property; in a commitment to developing and implementing the management plan; and to furthering the obligations of the World Heritage Convention.

6. Commitment to ensuring effective governance, resources and monitoring are in place to support implementation of the plan, including a commitment to capacity building and to the planning, implementation, evaluation and feedback cycle.

The guiding principles lead to a number of Policies, together with an Action Plan designed to meet the policy objectives. These are presented in Section 5 of the Management Plan. The new Management Structure is shown in Figure 5.7. The new World Heritage Site Steering Committee is described in the subsequent section.

Figure 5.7: Post-inscription management structure at Jodrell Bank site



World Heritage Site Steering Committee

The World Heritage Site (WHS) Steering Committee will bring together all stakeholders in a shared understanding of the property and embody a commitment to further the obligations of the World Heritage Convention. It will continue to develop and implement the management plan, oversee the delivery of the Action Plan, ensuring that it is fit for purpose and that it contributes to all the policy objectives for the property. The WHS Steering Committee includes representatives of all stakeholder groups, including the site owners and users, local communities, local authorities, national authorities and communities of interest.

The group membership is set out below.

Body	Committee Members
Site owner: The University of Manchester	• University Registrar and Chief Operating Officer (Chair) • Vice President for Social Responsibility • Director of Estates • Director of Communications • University Historian and Heritage Manager
Site user: Jodrell Bank Discovery Centre	• Director of Jodrell Bank Discovery Centre (World Heritage Site Coordinator) • Deputy Director of Jodrell Bank Discovery Centre (coordinating Presentation and Sustainable Visitation) • Head of Education and Interpretation at Jodrell Bank Discovery Centre (coordinating Education and Interpretation)
Site user: The Jodrell Bank Centre for Astrophysics	• Director of Jodrell Bank Centre for Astrophysics, with overall responsibility for science and engineering • Associate Director of Jodrell Bank Centre for Astrophysics (Public Engagement) with responsibility for Scientific Heritage • Associate Director of Jodrell Bank Centre for Astrophysics (Observatory) with responsibility for Observatory operations
Site user: The SKA Organisation	• Director General or their representative
Local Community	• Representative of Lower Withington Parish Council • Representative of Goostrey Parish Council
Local Authority (Cheshire East)	• Executive Director Place or representative • Senior Conservation Officer
Local Authority (Cheshire West and Chester)	• Senior Planning representative
Tourism bodies	• Chief Executive of Marketing Cheshire • Head of Marketing of Marketing Manchester
Historic England	• Principal, Historic Places Team, North West • Head of International Advice
DCMS	• Representative of Heritage team in Government Department for Digital, Media, Culture and Sport
ICOMOS UK	• Representative of ICOMOS UK
UK World Heritage Site Community	• Representative of UK World Heritage Site Community
Astronomy Heritage Community	• Representative of Astronomy Heritage Community (from Heritage Committee of Royal Astronomical Society and/or ICOMOS IAU working group on the heritage of astronomy on the World Heritage list)
UNESCO UK	• Representative of UNESCO UK

5.f Sources of Finance

5.f.(i) Overview


Image: The University of Manchester

Existing areas of activity at Jodrell Bank are resourced from a variety of sources.

The science and engineering research is currently funded by the UK Science and Technology Facilities Council, the University of Manchester and various other research funders. Resourcing for visitor facilities and engagement is part-funded by the University of Manchester and part-funded by the operation of the Discovery Centre as a not-for-profit business.

The resourcing required for the management of Jodrell Bank as a World Heritage Site is in addition to this and includes investment both pre- and post-Nomination) and ongoing running costs (post-Nomination). This section examines this in the context of the resourcing of existing operations.

Observatory – Operations and Maintenance

The bulk of the management, operation and maintenance of the Observatory, and of the Lovell Telescope, in particular are already borne by the research budgets at the property, because the Observatory will remain in operation and a working science site.

In addition to this, The University of Manchester contributes £200,000 per annum to the 'heritage' costs of the site, which include non-staff costs related to particular repairs and painting etc. This sum is largely spent on the Lovell Telescope, which is the major structure on site.

The University has recently invested in a major project to restore all the heritage elements of the site, in order to put these on a firm basis for future conservation and maintenance. (See Section 5.f.(iii) for further details).

Discovery Centre – Visitor Management, Education and Engagement

The Discovery Centre is responsible for managing visitor access to Jodrell Bank, which it facilitates on a 7-day/week basis. The Centre is open most days, with the exception of Christmas and New Year's days. It has a closure week just prior to Christmas to allow for essential maintenance.

The Director oversees around 50 staff (allowing for seasonal variation), who work on a rota basis, covering around 29FTE roles. Additional staff will be recruited in the near future as part of the University's strategy to manage the heritage of the site in a planned way.

The Discovery Centre is a not-for-profit visitor facility and is part-funded (around 20%) by the University of Manchester. It generates the remainder of its income from ticket sales, Cafe commission, shop revenue and event hire etc. It currently has an operating budget of just under £1.7million per annum.

The Centre opened in April 2011 and since then (at the time of writing) has increased visitor numbers from around 60,000 (prior to opening) to around 180,000 per annum.

This includes just over 26,000 school pupils per annum, who all receive high quality curriculum-linked learning sessions when they visit.

The revenue the Centre generates is directly related to visitor numbers, as are the Centre's operating costs.

5.f.(ii)
Future Management of the nominated property

The future day-to-day management of the property will be taken forward by existing University structures, described in the sections above, with the guidance and oversight of the World Heritage Site Steering Committee.

Coordination will be managed by the Director of the Discovery Centre, and an appropriate World Heritage Site Steering Group, that will include all stakeholders, will oversee the way in which the site is managed. It is expected that additional costs of management will be managed via existing budget structures, offset in part by increased revenues generated by increased visitor activity.

It is not anticipated that visitor numbers will increase due to inscription to the extent that major works will be required on the local highways etc, as the PWC study notes. However, an estimated increase of around 30-50% will be accommodated in the new visitor facilities funded by the HLF and by the University of Manchester. This will be supported by the operation of a full Business Plan (see Tourism Management Plan).

Image: Howard Barlow

5.f.(iii)
Major Capital Expenditure

The University has committed £15million capital investment into the Jodrell Bank site.

This is funding an ongoing major conservation and restoration project on the Lovell Telescope, as well as some work on the Control Building and other elements of the property yet to be completed.

In addition, in 2018 an investment of £1.8million will be made in extending the current car park, creating a new arrivals plaza and new ticket booths. These are being created in an area in the Buffer Zone, adjacent to the property, and will be complete by June 2018.

The University is working on a major project ('First Light at Jodrell Bank') to create new visitor facilities. The project has an overall value of £20.5million and is fully funded, including an award of just over £12million from the UK's Heritage Lottery Fund and £4million from the UK national Budget. This work will take place in the Buffer Zone at some distance from any attributes of the OUV of the property and shielded from view by trees. It is due for completion in 2020/21.

This project will further develop the management of the site; will resource 'heritage' staff to work on overseeing the Property's heritage assets and engage visitors in appropriate history projects; underpin the development of a new heritage education offer and, most importantly, create a new gallery in which visitors will be able to learn about and engage with the heritage of the property for the first time.

5.g
Sources of expertise and training in conservation and management techniques

Image: John Kitching

5.g.(i) Expertise and Training available from national authorities

The property managers work closely with advisors at Historic England and Cheshire East local authority.

These external experts provide advice and guidance on work on maintenance and conservation of the fabric of the site. They also provide advice on 'addressing the gaps' in terms of skills needed as the property implements its action plan for the future.

5.g.(ii) Expertise and Training present at the property and the University

Management, Maintenance and Conservation

The Observatory, working alongside the University's Division of Estates and Facilities, is responsible for the management, maintenance and conservation of the telescopes on the property (i.e. the Lovell, Mark II, 42ft and 21ft telescopes). They are also responsible for the telescopes at remote e-MERLIN sites (Pickmere, Darnhall, Knockin, Defford and Cambridge, plus the link sites), which are part of the Observatory's current operations.

The team also maintains and manages associated scientific equipment (e.g. signal processing equipment, supercomputers etc).

Weekly engineering meetings are chaired by the Associate Director of the Observatory and attended by all lead engineers. This team is responsible for the maintenance and conservation of telescopes, all of which are inspected and maintained regularly (Figure 5.8). Conserving and enhancing the authenticity/integrity of telescopes and scientific equipment, as far as practicable, is key to management and maintenance regimes, alongside their scientific priorities.

The Lovell Telescope is inspected daily during operations by highly specialised staff (this is critical to prevent damage). A more detailed inspection and regular maintenance is carried out weekly (involving approximately 8 hours downtime) and reported to weekly engineering meetings.

A rolling programme of repairs, upgrades and maintenance is in place for all telescopes on site (covering weekly, monthly, three-monthly schedules etc). Major proactive and reactive maintenance tasks and painting are planned on an annual basis.

The Lovell Telescope is taken out of service for up to 2-3 months each summer so that major tasks can be delivered when the weather and daylight conditions are most favourable.

Astronomical Heritage Management

As the Thematic Study of 2010 mentions, it is essential that '*the specificities of astronomical heritage management*' are addressed in the Management Plan for an astronomical property.

In the case of Jodrell Bank Observatory, this is relatively simple to address. The team of engineers, technicians and astronomers working at the property address these as a matter of course. This is one advantage of the fact that the property is a working Observatory.

The University Estates team manage the non-technical 'Observatory' estate and buildings, in collaboration with Observatory staff. Contractors currently maintain the landscape elements according to a Grounds Maintenance Specification. Buildings are maintained and inspected on a continuing basis.

Managing Visitors, Presentation and Promotion

The staff team in the Jodrell Bank Discovery Centre has all the appropriate expertise required for promotion and presentation, including first degrees in appropriate subjects, alongside post-graduate and professional qualifications in public engagement, education, marketing etc, as well as many years experience working in this sector.

New staff are recruited to very high standards and training is provided for any new staff members with skills or experience gaps. The University has a well-developed and diverse Staff Training and Development scheme.

The new 'First Light at Jodrell Bank' project includes the recruitment of a specialist heritage manager.

Support from University Departments

The University provides support for many tasks and issues at the property (and the wider Jodrell Bank site). The support includes legal expertise; financial management; Human Resources; Risk Management; Security; Risk preparedness; Communications; Computing and Information Technology; Health and Safety, Estates and Facilities.

The University also has a large Staff Training and Development Unit, which provides free training to staff via many hundreds of courses each year.

Archives and collections management

Skills required for managing archives and collections, as well as training, advice and support, are provided by colleagues within the University. Chief amongst these are the University's Historian and Heritage Manager, the Keeper of Collections at the University Library and Curators at Manchester Museum (which is part of the University).

The National Jodrell Bank Archive is kept in archive conditions in the University Library and Manchester Museum has some objects related to Jodrell Bank kept in its storage spaces.

5.g.(iii) Expertise and Training sourced externally

Management, Maintenance and Conservation

Significant repairs to the Lovell Telescope are typically carried out by external teams of specialist structural engineers, working to specifications defined by the Observatory's team of engineers and astronomers.

All painting of the Lovell Telescope is carried out by an external project team, which works in planned phases each summer.

External contracts are overseen by the University's Directorate of Estates, which engages a full project team including contract administrators, CDM coordinators, principal contractor and sub- contractors.

Industrial and Technological Archaeology

The most significant 'gap' in terms of the skills required to uncover, conserve, maintain and celebrate the heritage of the property is in Archaeology.

In order to address this, the property managers, with the advice of Historic England and Cheshire East Conservation Officers, commission archaeologists as needed, to provide advice; supervise and carry out activities (e.g. the resistivity survey of the Transit Telescope site); and document progress and findings.

Figure 5.8: Jodrell Bank engineers maintaining one of the bogies of the Lovell Telescope.

5.h
Visitor facilities and infrastructure

Image: Feilden Clegg Bradley

5.h.(i)
Visitor Facilities

The property has attracted visitors since the Lovell Telescope first tracked Sputnik in 1957 and has built up its experience and expertise in meeting the needs of visitors since that time.

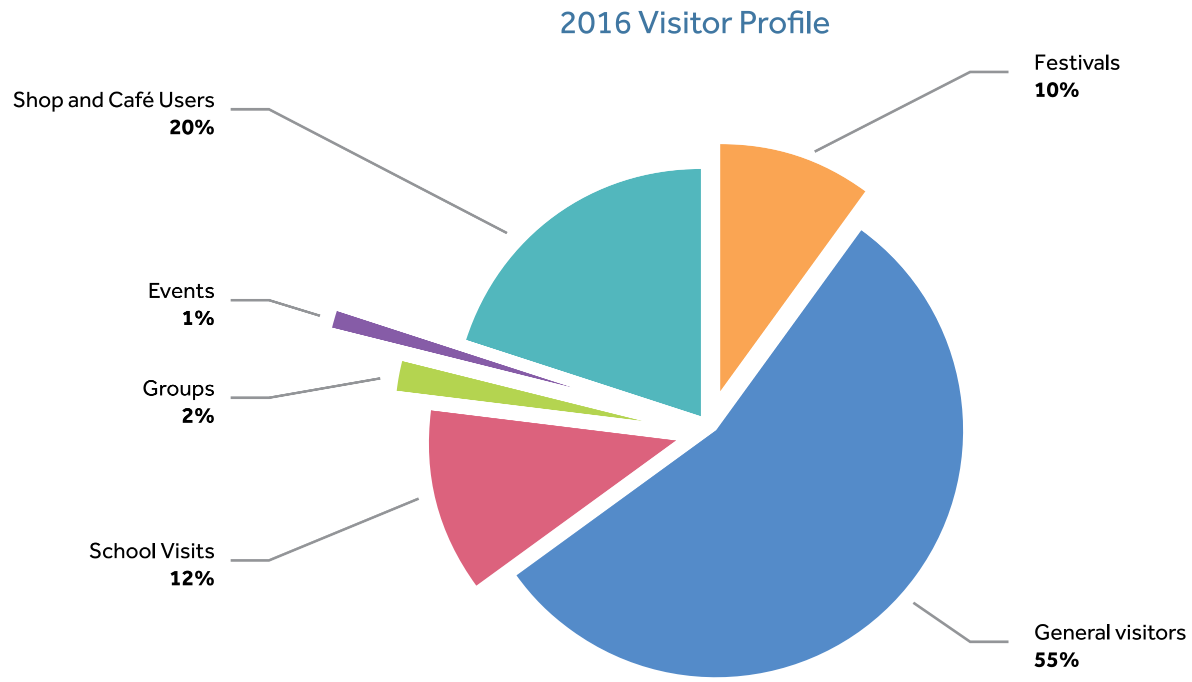
The first purpose-built visitor centre opened in 1966 and visitors were then welcomed there until its demolition in 2003. In 2011, new facilities were opened, backed by a new visitor strategy and financial support plan. These were expanded in order to meet the needs of the property's Education Programme for schools and now constitute 3 main buildings that provide visitor reception, modest galleries, a classroom, two larger teaching/events spaces, a Café, Shop, offices, and visitor facilities such as toilets and First Aid room etc. There are some further ancillary buildings in the Centre (e.g. huts in the gardens etc)

The Centre's car park (which lies in the Buffer Zone, outside the boundaries of the property) has recently been expanded, after a full analysis of parking needs based on a range of scenarios for forecast increased visitation. This required an investment of £1.8million.

Visitors, (who make day visits to the property, rather than staying overnight) can access the landscape area around the Lovell Telescope (Landscape Zone L03) via a range of tarmac pathways, which are furnished with interpretation signs and some 'interactive' outdoor displays.

The Centre also includes 35 acres of gardens, which were planned and planted at the behest of Sir Bernard Lovell, founder of the observatory, in the 1970s. These include resin-bound, tarmac and concrete pathways, which make the gardens accessible even in poor weather and mitigate any potential damage to the site during times of high visitor footfall.

Visitor footfall varies on a seasonal basis, with a mix of visitor groups arriving at different times and using the site in different ways (see chart). These are described briefly in the following section.



5.h.(ii)

The Visitor Experience

Image: Howard Barlow

Figure 5.9: Guided tours along the Lovell Telescope pathway.

General Visitors

All visitors (including the General Public) are welcomed via the 'Jodrell Bank Discovery Centre', which is the property's visitor facility. This is open 7 days per week, almost every day of the year (including public holidays), apart from a short closure period just before Christmas.

As well as services such as the car park, toilets and information points, this gives public access the area of the property around the Lovell Telescope, which includes a walkway around the Telescope Compound.

The visitor facilities also include the Gardens and the Discovery Centre's galleries and interpretation initiatives such as information boards and leaflets, 'hands on' and digital exhibits, display screens etc – and also knowledgeable staff, who are on hand during opening hours to speak to visitors and answer any questions that they may have.

During the summer months, which are peak visitor periods (and the weather is better), the Centre also organises guided walks around the perimeter of the Lovell Telescope compound.

In general, these measures are very popular with visitors and work well. Surveys of visitor satisfaction are carried out on a regular basis, in order to ensure that the visitor facilities, interpretation and activities are engaging and well-received.

Digital Presentation

The Centre also has a lively website dedicated to visitor management (**www.jodrellbank.net**) which sits alongside the website of the Jodrell Bank Centre for Astrophysics research group (**www.jodrellbank.manchester.ac.uk**) which is focused on the science research work.

The Jodrell Bank Centre for Astrophysics research group is part of the University of Manchester's School of Physics and Astronomy.

The property Action Plan includes updates to both websites in order to promote and present the OUV to diverse audiences.

Schools

The property has a well- established and well-staffed Education programme, which welcomes over 26,000 school pupils per year to the property.

The education team at the Centre provide age-appropriate learning sessions that are developed in discussion with curriculum advisors and sector experts.

School visitor numbers are monitored and analysed (Figure 5.11) and the programme is evaluated regularly with teachers and participants.

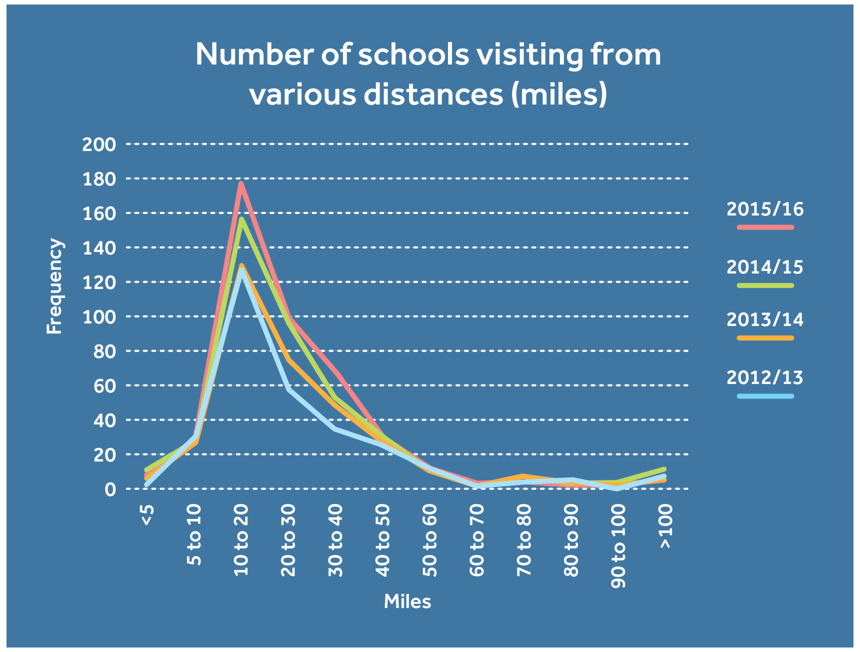
Shop and Café users

The Discovery Centre car park and much of the nearby 'Planet Pavilion' building, which contains the Café and Shop, are open to visitors who do not pay to enter the main part of the property. This group of visitors includes many local residents and members of special interest groups (such as cyclists), who make repeat visits to the site because of the amenity value it affords to the local area. The property managers regard this as a key part of the relationship with local communities, (members of which are often well-known to staff) as it provides a well-developed channel for feedback and dialogue.

Image: Howard Barlow

Figure 5.10: Schools workshop exploring Jodrell Bank heritage.

Figure 5.11



Events and Festivals

In addition to the Schools Programme, which operates during the day in term-time, the property runs a range of events and activities designed to engage particular groups of visitors in the evenings at weekends and during school holidays.

These are described briefly below.

- **Family events:** During the school holidays, staff organise 'science shows' that tell the story of the site and its work. They run at multiple times during each day and are also used to spread visitor arrival times across the day in order to manage visitor accumulation.
- **Craft workshops:** Families are encouraged to participate in 'hands-on' craft workshops, which allow younger children to engage with the themes of the property. For example, the 60th Anniversary of the Lovell Telescope was celebrated with a memory wall and Telescope hats.
- **Lectures:** The Discovery Centre organises a range of public lectures, delivered to audiences of over 200 attendees each month by a University academic, on topics related to the science research of the site, its heritage or other related subjects.
- **Volunteer Programme:** The Centre has a volunteer programme that works on both the landscape of the site and also on communicating the wonder of Astronomy to the visiting public.

Figure 5.12: Lovell Telescope 60th anniversary.

Figure 5.13: Luna 9 50th anniversary.

- **Arts Engagement events:** The Centre creates specific events in order to explore the connections between art, heritage and science, in order to present and promote the property and its heritage to as wide an audience as possible. One example of this was the 'Watch the Skies' outdoor film festival, created in 2014, in partnership with the British Film Institute and AND digital Arts Agency. The film festival showed films projected onto an outdoor screen over a weekend, and also included new film works commissioned especially for the festival, which were projected onto the surface of the Lovell Telescope itself.
- **Bluedot Festival:** The visitor profile for the property shows a 'dip' around the 'Young Adult' age range.

  In order to address this and attempt to be as inclusive as possible, the Jodrell Bank Discovery Centre runs a series of music festivals each summer, which typically attracts the 'missing' age range.

  These festivals act as an entry point for groups that would not traditionally visit and widen the diversity of the engagement with its messages.

5.h.(iii) Inclusivity and Accessibility

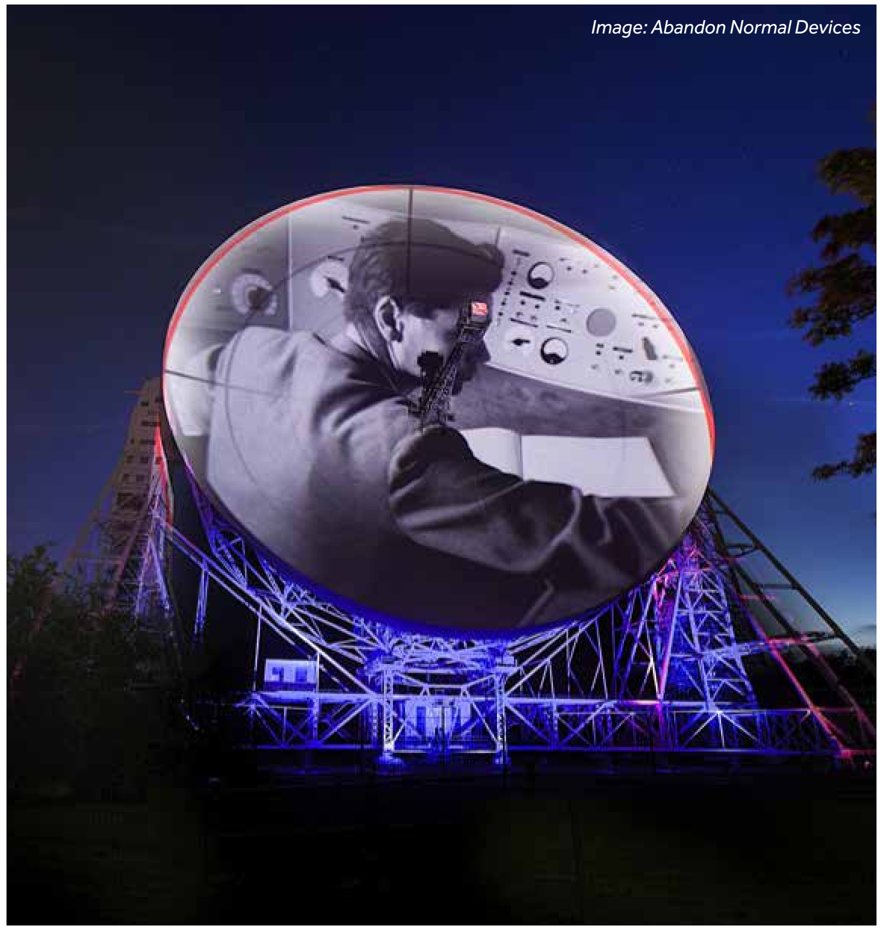


Figure 5.14: Operations in the Control Room in 1957, projected onto the surface of the Lovell Telescope during an outdoor film festival in 2014.

Figure 5.15: bluedot festival 2016, including art installation by Brian Eno and performance by Jean-Michel Jarre.

The Centre pays particular attention to ensuring that it is as inclusive as possible.

All the visitor facilities have level access for wheel-chair users and have accessible toilets. The Centre reception, exhibition areas and auditoriums all have induction loops.

All exhibits are at wheel-chair height and, where possible, include either subtitles (in the case of video) for those who are hard of hearing or audio commentary (in the case of some exhibits) for those who are sight-impaired. Many of the current exhibits are 'hands on'.

Future exhibits will also follow these principles.

The Centre also pays particular attention to achieving gender balance in both its staff team and visitor body, running several events each year in order to encourage female visitors and participants.

It is guided in these activities by several University of Manchester policies and guidance documents.

5.i
Policies and programmes related to the presentation and promotion of the property

The property has a plan to present and promote the heritage of the site, which is included in the Tourism Management Plan.

This includes:

- A new gallery building focused entirely on the OUV of the property, including a new exhibition presenting its stories in a variety of engaging ways.
- New, pre-booked, guided tours of the 'Green' area of the site, giving the public access to this area for the first time.
- New interpretation points within the area between the Lovell Telescope and the Control Building, using digital technologies where possible
- New website areas and content focused on the OUV of the property.

In addition, the property has an Audience Development Plan (included in Dossier), commissioned from specialist consultants, which sets out its approach to building future audiences using the new gallery and guided tours. This has underpinned the preparation of a Marketing Plan, which sets out promotion activities for the first few years following inscription.

In preparation for inscription, the visitor facility has also devised a project that will be funded by Visit Britain, which will promote the science heritage of the UK to overseas visitors. This project, called, 'Brilliant Science' was launched in 2017/18. The Director of the Discovery Centre chairs the project board for this.

The team at the property is committed to promoting the wider purpose of UNESCO and works to foster good relations between nations (e.g. it will be creating the opportunity for live link-ups between schools from different countries in its new gallery and associated Education Programme).

Image: HASSELL

Figure 5.16: Artist's impression of the proposed new gallery focused on the OUV of the property.

5.j
Staffing levels and expertise (professional, technical, maintenance)

The staffing levels at the property are adequate for all its requirements.

Observatory staff comprising approximately 30 technicians, engineers and astronomers work directly on or with the Lovell and Mark II Telescopes on a daily basis. Their maintenance and conservation regimes have been developed over decades, and the fact that the telescopes are in superb condition is evidence of the high level of skill in this team.

In addition to this, there is a group of academic astronomers (the Jodrell Bank Centre for Astrophysics, which has around 150 members), some of whom also use the telescopes for their research. Astronomers worldwide also use the Observatory instruments, either on their own or in collaboration with Jodrell Bank scientists. Time on the telescopes is allocated competitively between the various potential users. Operations are typically carried out by observatory staff with data being accessed remotely by astronomers across the world.

The visitor facilities (the Jodrell Bank Discovery Centre) have approximately 50 staff (29 FTE). These numbers are supplemented by casual staff during busy holiday periods. There is a growing group of volunteers, who help with the maintenance and management of the gardens.

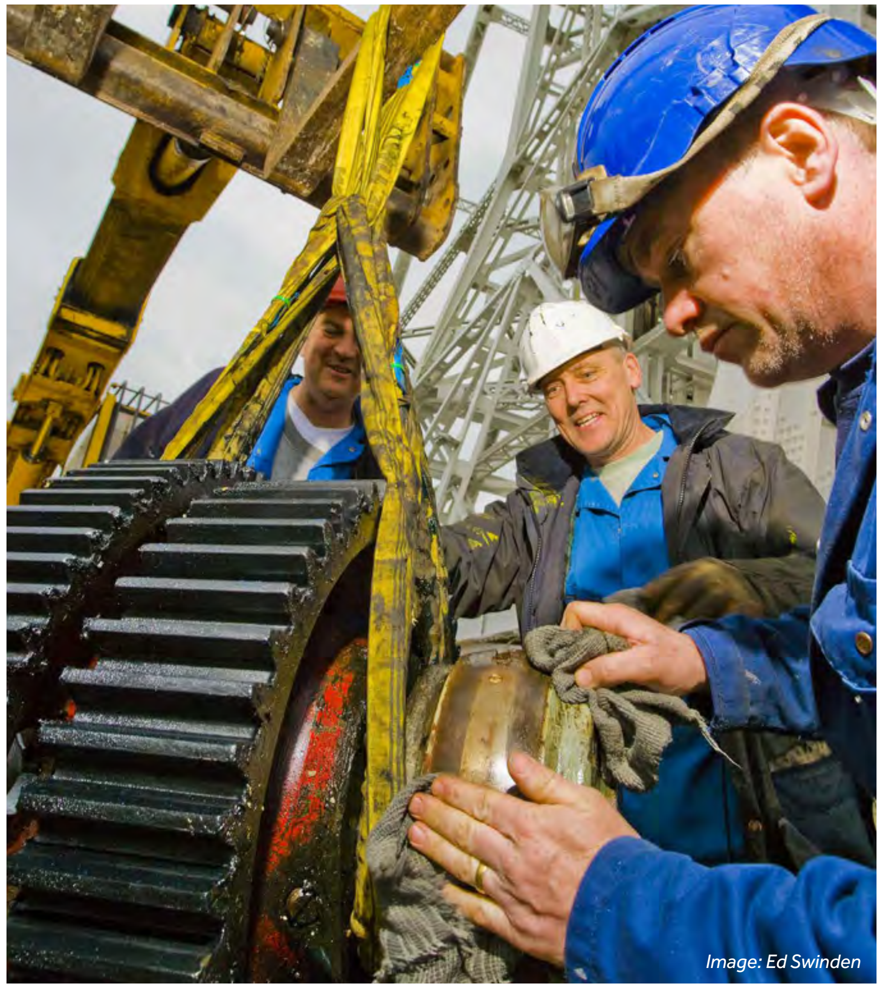


Image: Ed Swinden

As mentioned in Section 5.g. (iii), the property also benefits from contributions in expertise and time from colleagues in the University for many tasks and issues. This includes legal expertise; financial management; Human Resources; Risk Management and preparedness; Security; Communications; Computing and Information Technology; Health and Safety.

It is estimated that this contribution adds up to circa 4 FTE additional staff per year (as these inputs are provided as needed). These contributions free up staff based at the property and its associated visitor facilities to concentrate on work specific to the site.

In addition, colleagues also provide expertise and guidance on many areas related to the heritage of the property. Including the dedicated Heritage Officer at the property, it is estimated that this adds up to specialist inputs of around 2.5FTE per year.

In addition, the University is preparing to launch a Masters degree in Heritage Skills, which will collaborate with the property, in order to provide student placements and training opportunities, thus building the heritage skills of future generations.

6. Monitoring

Image: Anthony Holloway

6.a
Key Indicators for Measuring State of Conservation

Jodrell Bank Observatory has the advantage of having been in single ownership since its inception.

The property owner, the University of Manchester oversees all activities within its boundaries, and is responsible for the maintenance and upkeep of all its elements.

This means that all Attributes that carry the OUV of the property are within its control.

The Observatory is responsible for the operation and maintenance of the telescopes on the Site (Lovell, Mark II, 42ft and 21ft telescopes) and at the remote e-MERLIN sites (Pickmere, Darnhall, Knockin, Defford and Cambridge, plus the link sites) and the associated scientific equipment. Weekly engineering meetings are chaired by the Associate Director (Observatory) and attended by all lead engineers. This team is responsible for the maintenance and conservation of telescopes, all of which are inspected and maintained regularly. Conserving and enhancing the authenticity/integrity of telescopes and scientific equipment, as far as practicable, is key to management and maintenance regimes.

A staff of approximately 30 technicians, engineers and scientists work directly on or with the Lovell Telescope and Mark II Telescope on a daily basis. Both are inspected daily during operations by highly specialised staff (this is critical to prevent damage). A more detailed inspection and regular maintenance is carried out weekly (involving approximately 8 hours downtime) and reported to the weekly engineering meeting. A rolling programme of repairs, upgrades and maintenance is in place (covering weekly, monthly, three-monthly schedules etc). Major proactive and reactive maintenance tasks and painting are planned on an annual basis and carried out every summer, when the Lovell Telescope is taken out of service for up to 2-3 months, dependent on the nature of the work being undertaken. All significant repairs to the Lovell Telescope are carried out in consultation with external structural engineers and all painting is carried out under the aegis of the University's Estates Directorate, who engages a full project team including contract administrators and CDM coordinators to manage the principal contractor and their sub- contractors.

The Observatory also works alongside the University Estates team to manage the 'Observatory' Estate, including the Telescopes and buildings. Contractors currently maintain the landscape elements according to a Grounds Maintenance Specification. Buildings are maintained and inspected on a continuing basis.

Working with the University Directorate of Estates, the Jodrell Bank Discovery Centre (JBDC) manages and maintains the estate and buildings open to the public. Contractors carry out maintenance works relating to buildings and look after part of the soft landscape (including boundary hedges, grassed areas, weed control and litter clearance). Other soft landscape features (e.g. the gardens) are managed and maintained by members of the Discovery Centre Team. Landscape infrastructure components (fences, interpretation boards, paths, picnic tables etc.) are currently managed and maintained on an informal basis. Staff from the University of Manchester's Arboricultural Team inspect trees onsite and carry out and/or commission necessary arboricultural works.

A condition survey for the property, which will use the original Conservation Management Plan and Gazetteer as a baseline, will be commissioned every 5 years from external consultants.

A table of key indicators is provided below categorised according to the elements of the property being addressed. The periodicity of the review of each of these indicators is also included.

Category	Periodicity	Indicator
Condition of the Lovell and Mark II Telescopes	Annually	• Days lost to planned maintenance • Days lost to unplanned maintenance • Days lost to high wind • Days lost for other reasons (to be specified) • Description of maintenance tasks undertaken, including engineering specification if relevant, budget, time taken, illustrated by photographs as appropriate, comments by conservation officer and Historic England as appropriate
Any major conservation projects on the Lovell and Mark II Telescopes	Annually	• Reports on any major conservation projects underway, to include: - Description of work including extent of structure concerned, engineering specifications - Heritage Impact Assessments - Comments from conservation officer and Historic England as appropriate - Time before the project is due to be completed - Estimated budget required - Illustrated by photographs as appropriate • Reports on any major conservation projects which appear likely to be required in future, to include: - Description of work including extent of structure concerned, engineering specifications - Comments from conservation officer and Historic England as appropriate - Estimated timescale before work to start - Estimate of time required to complete - Estimate of budget required
Repairs and maintenance to Observatory Buildings	Annually	• General update on use of building • Description of any works carried out, including budget, estimate of time taken, illustrated by photographs as appropriate • Relevant Heritage Impact Assessments • Report from conservation officer on any works to listed buildings (Control Building, Cosmic Noise Hut, Electrical Workshop, Park Royal) • Description of any future work identified to be required, including estimated budget and time required, illustrated by photographs as appropriate • Photographs of building from several specified external and internal locations, for comparison to previous years
Conservation and maintenance to archaeological remains	Annually	• Description of any works carried out, including budget, estimate of time taken, volunteer days, illustrated by photographs as appropriate • Heritage Impact Assessments • Report from conservation officer and County Archaeologist on any works to listed building (Searchlight Aerial) • Description of any future work identified to be required, including estimated budget and time required, illustrated by photographs as appropriate • Photographs of remains from several specified locations, for comparison to previous years
Maintenance to Landscape areas	Annually	• Description of any works carried out, including budget, estimate of time taken, volunteer days, illustrated by photographs as appropriate • Description of any future work identified to be required, including estimated budget and time required, illustrated by photographs as appropriate • Photographs of landscape from several specified locations, for comparison to previous years • Heritage Impact Assessments
Level of visitation	Annually	• Visitor numbers, • Evaluation of visitor satisfaction • Education programme numbers • Evaluation of education programme • Assessment of level of impact on property
Condition survey of property	5 yearly	Condition survey report to collate the annual reporting and provide update to the conservation management plan.
Conservation Management Plan	5 yearly	Updated version of Conservation Management Plan.

6.b Administrative Arrangements for Monitoring Property

The property is entirely in the ownership of the University of Manchester, which is also responsible for all maintenance of the property.

The reports outlined in the table of key indicators will be presented to the Steering Committee and records will be kept in the University as part of the papers for that Committee.

The contact for monitoring is:

Professor Teresa Anderson MBE
Director
Jodrell Bank Discovery Centre
The University of Manchester
Macclesfield
Cheshire
SK11 9DL
UK

Tel:
+44 (0)161 306 9586

E-mail:
teresa.anderson@manchester.ac.uk

6.c Results of Previous Reporting Exercises

There have been no previous formal reporting exercises for the property.

However, a complete Conservation Management Plan (CMP) together with a full Gazetteer of all elements of the site with was prepared in 2014 and updated in 2016. This provides the baseline for the state of conservation of the property. The CMP and Gazetteer form part of this Nomination Dossier.

Image: Howard Barlow

7. Documentation

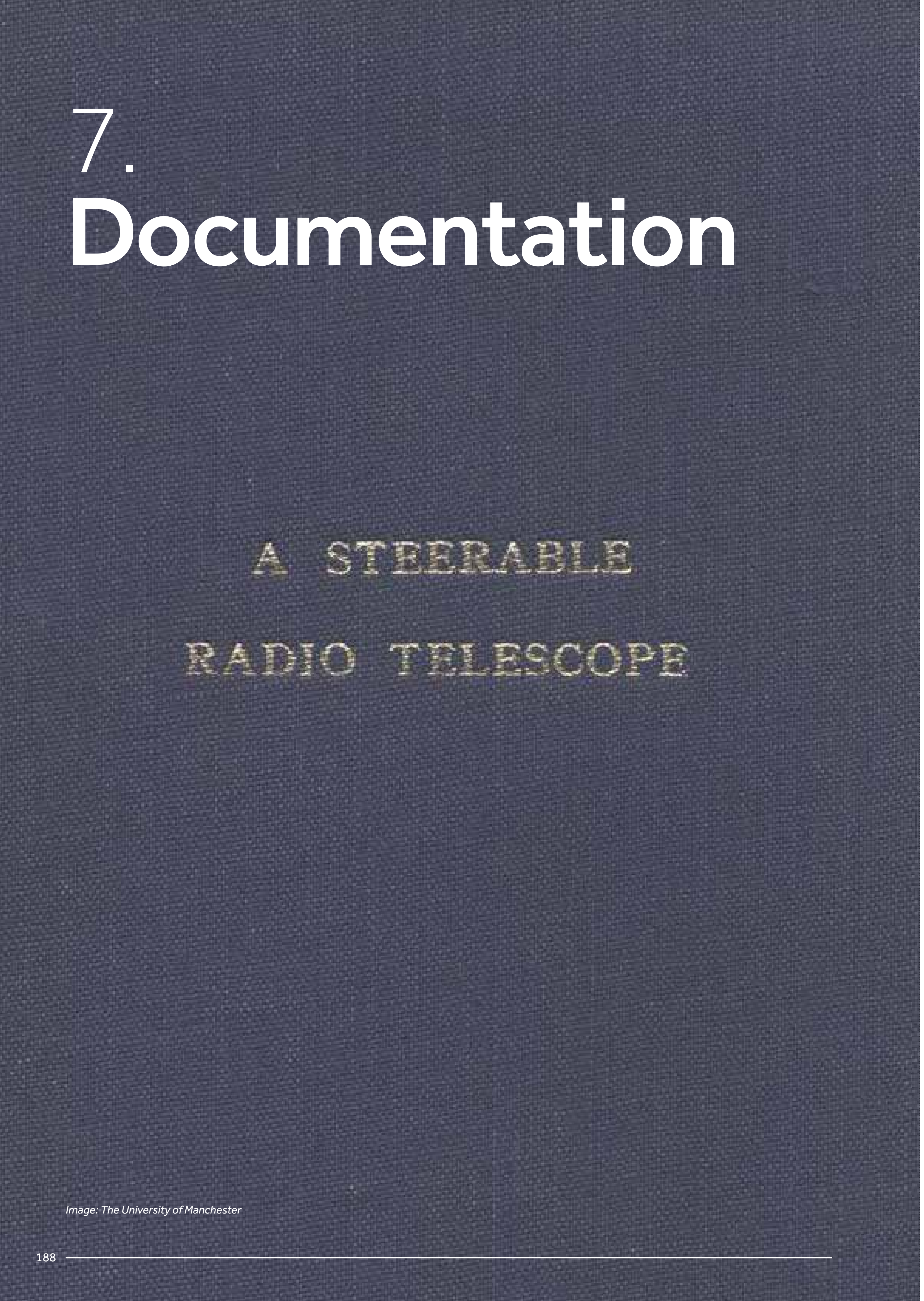


Image: The University of Manchester

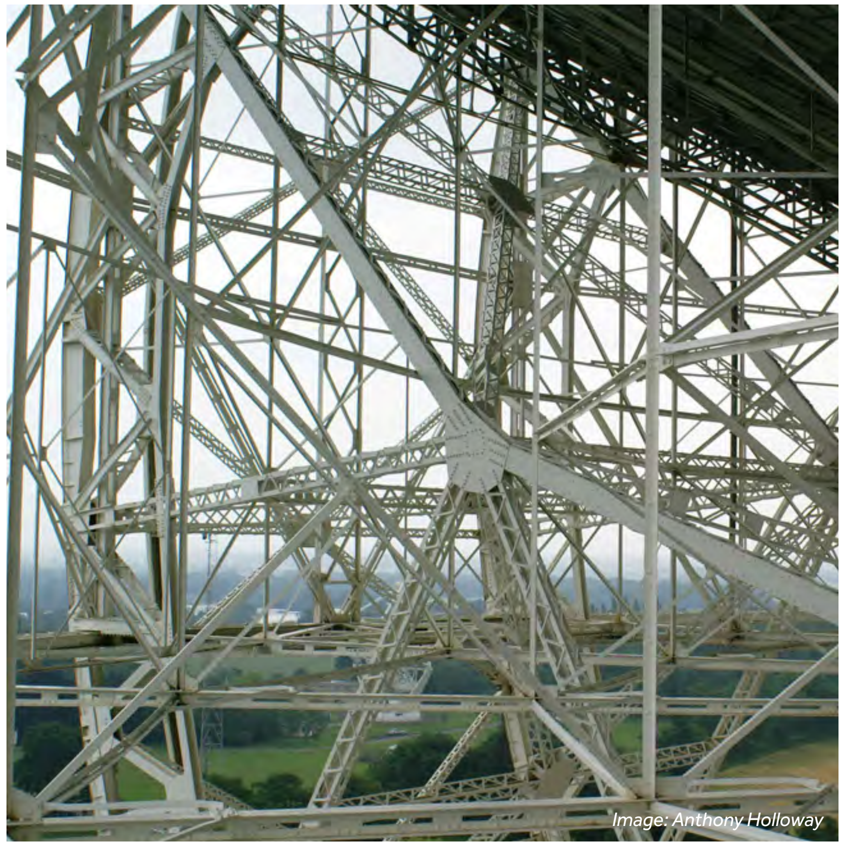
7.a
Photographs and Audiovisual Image Inventory and Authorisation Form

PHOTOGRAPHS AND AUDIOVISUAL IMAGE INVENTORY AND AUTHORIZATION FORM

id No.	Format (slide/ print/ video)	Caption	Date of Photo (mo/yr)	Photographer/ Director of the video	Copyright owner (if different than photographer/director of video)	Contact details of copyright owner (Name, address, tel/fax, and e-mail)	Non exclusive cession of rights
	JPEG	Lovell Telescope		Anthony Holloway	Use is allowed if credit is given to photographer/ director		Y
	JPEG	Mark II and Lovell Telescopes		Anthony Holloway	Use is allowed if credit is given to photographer/ director		Y
	MP4	Lovell Telescope at Sunset Drone video		Tim O'Brien	Use is allowed if credit is given to photographer/ director		Y
	MP4	Timelapse of Lovell Telescope		Tim O'Brien	Use is allowed if credit is given to photographer/ director		Y
	JPEG	Lovell View Arboretum		Anthony Holloway	Use is allowed if credit is given to photographer/ director		Y
	JPEG	Lovell at sunset		Anthony Holloway	Use is allowed if credit is given to photographer/ director		Y
	JPEG	Lovell Trails		Anthony Holloway	Use is allowed if credit is given to photographer/ director		Y
	JPEG	Lovell from Roaches View		Anthony Holloway	Use is allowed if credit is given to photographer/ director		Y
	JPEG	Lovell Fields of Wheat		The University of Manchester	Use is allowed if credit is given to photographer/ director		Y
	JPEG	Lovell Bluedot 2016 projection		Howard Barlow	Use is allowed if credit is given to photographer/ director		Y
	JPEG	Lovell Bluedot 2017 Projection		Scott Salt	Use is allowed if credit is given to photographer/ director		Y

7.b

Texts Relating to Protective Designation, Copies of Property Management Plans or Documented Management Systems and Extracts of Other Plans Relevant to the Property



Primary legislation

- Ancient Monuments and Archaeological Areas Act 1979 (as amended)
- Localism Act 2011
- Planning Act 2008
- Planning and Compulsory Purchase Act 2004
- Planning (Listed Buildings and Conservation Areas) Act 1990
- Town and Country Planning Act 1990
- Enterprise and Regulatory Reform Act 2013

Secondary legislation

- The Town and Country Planning (Environmental Impact Assessment) Regulations 2017
- The Town and Country Planning (General Permitted Development) Order 2015
- The Town and Country Planning (Jodrell Bank Radio Telescope) Direction 1973

National Policy and Guidance

- National Planning Policy Framework 2012
- Planning Practice Guidance
- The Setting of Heritage Assets (Historic Environment Good Practice Advice in Planning: 3)
- Historic England Advisory Note on World Heritage (forthcoming)
- The Costs and Benefits of UK World Heritage Site Status: a literature review for the Department for Culture, Media and Sport. (2007) PriceWaterhouseCoopers
- The Costs and Benefits of World Heritage Site Status in the UK: Case Studies. (2007) PriceWaterhouseCoopers

ICOMOS Guidance

- Heritage Sites of Astronomy and Archaeoastronomy in the context of the UNESCO World Heritage Convention: A Thematic Study. Ruggles, C. and Cotte, M., 2010.
- Heritage Sites of Astronomy and Archaeoastronomy in the context of the UNESCO World Heritage Convention: Thematic Study no. 2. Ruggles, C. and Cotte, M., 2017.
- Guidance on Heritage Impact Assessments for Cultural World Heritage Properties, ICOMOS, 2011

Local Plans

- Cheshire East Local Plan Strategy (2017)
- Cheshire West and Chester Local Plan (Part One) Strategic Policies (2015)
- Cheshire East Visitor Economy Strategy 2016-2020
- Marketing Cheshire Destination Management Plan 2015-2018

Key documents

- World Heritage Site Management Plan
- Tourism Management Plan
- Jodrell Bank Observatory Conservation Management Plan (2016)
- Jodrell Bank Observatory Conservation Management Plan Site Gazetteer (2014)
- Archive Survey (2017)
- Audience Development Plan (including Market Research)
- Biodiversity Action Plan

The University of Manchester Policies and Plans

- The University of Manchester Estates management plan
- The University of Manchester Risk Management Strategy
- The University of Manchester Landscape strategy and plan
- The University of Manchester. (2014) The Presence of Our past: Strategic Framework for University History and Heritage
- The University of Manchester. (2013) Environmental Sustainability Plan
- The University of Manchester. (2009) Carbon Management Plan 2009-14.
- The University of Manchester. (2012) Sustainable Travel Plan 2012-15.
- The University of Manchester. (2012) Sustainable Waste Plan 2012-2015.
- The University of Manchester. (2010) Equality and Diversity Policy.
- The University of Manchester. (2005) Staff Training and Development Policy.

7.c

Form and Date of Most Recent Records or Inventory of Property

Current and recent records for the property are all held by its owner, the University of Manchester, both at the property itself and on the University computer systems.

The most recent up-to-date records of the property are contained in the Jodrell Bank Observatory Site Conservation Management Plan (2016) and Site Gazetteer (2017), which are submitted as part of this dossier.

7.d

Address where Inventory, Records and Archives are Held

Jodrell Bank Observatory
The University of Manchester
Macclesfield
Cheshire
SK11 9DL, UK

7.e.1

Bibliography

Agar, J. (2014). Science and Spectacle: The Work of Jodrell Bank in Postwar British Culture. Harwood Academic Publishers.

Allen, L. R.; Anderson, B.; Conway, R. G.; Palmer, H. P.; Reddish, V. C.; Rowson, B. (1962) Observations of 384 radio sources at a frequency of 158 Mc/s with a long baseline interferometer. Monthly Notices of the Royal Astronomical Society,124, 477

Allen, L. R.; Brown, R. Hanbury; Palmer, H. P. (1962) An analysis of the angular sizes of radio sources. Monthly Notices of the Royal Astronomical Society, 125, 57

Anderson, T., O'Brien, T.J., Garrington, S. The Balance Between Recent Heritage and Ongoing Research: the Case of Jodrell Bank Observatory. In Boyle, A., Hagmann, J-G., (Volume editor) (2017) Challenging Collections: Approaches to the Heritage of Recent Science and Technology, doi: 10.5479/si.9781944466121

Aspinall, A., Clegg, J. A., Hawkins, G. S. (1951) 'Radio-Echo Apparatus for the Delineation of Meteor Radiants', Phil. Mag., 42, 504–514, 1951.

Benton, R.A. (1982) 'The Granada Arboretum', The Garden, 181-185.

Blackett, P.M.S (1952) 'A Negative Experiment Relating to Magnetism and the Earth's Rotation, Philosophical Transactions of the Royal Society of London'. Series A, Mathematical and Physical Sciences, Volume 245, Issue 897, pp. 309-370.

Broten, N.W. et al. Long baseline interferometer, observations at 408 and 448 MHz-I. The observations, Monthly Notices of the Royal Astronomical Society, Vol. 146, 313

Brown, R. Hanbury, Hazard, C. (1950) Radio-frequency Radiation from the Great Nebula in Andromeda (M.31). Nature, 166 (4230) 901-902

Brown, R. Hanbury, Lovell, A.C.B (1955) Large radio telescopes and their use in radio astronomy, Vistas in Astronomy 1, 542–560

Brown, R. Hanbury; Palmer, H. P.; Thompson, A. R. (1955) Polarization measurements on three intense radio sources. Monthly Notices of the Royal Astronomical Society, Vol. 115, 487.

Brown, R. Hanbury; Palmer, H. P.; Thompson, A. R. (1954) Galactic Radio Sources of Large Angular Diameter. Nature, 173 (4411) 945-946

Brown, R. Hanbury; Palmer H.P; Thompson, A.R. (1955) XCVII. A rotating-lobe interferometer and its application to radio astronomy. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science: Series 7. 46 (379) 857-866

Brown, R. Hanbury (1991). Boffin: a personal story of the early days of radar, radio astronomy and quantum optics. Taylor & Francis Group.

Browne, I.C., Evans,J.V., Hargreaves, J.K. and Murray, W.A.S. (1956) Radio Echoes from the Moon. Proceedings of the Physical Society. Section B, Vol 69, N.901

Cheshire Region Biodiversity Partnership (2008) Cheshire Region Biodiversity Action Plan [www.document]. http://www.cheshire-biodiversity.org.uk/background/ (accessed June 2014).

Davies, J.G. and Lovell, A.C.B. (1955) Radio echo studies of meteors. I. Vistas in Astronomy, 585-598.

Davies, R. D and Williams, D.R.W. (1955) 'An Alternative Identification of the Radio Source in the Direction of the Galactic Centre'. Nature 175, 1079 – 1081.

Davies, R. D and Williams, D.R.W. (1955) An Alternative Identification of the Radio Source in the Direction of the Galactic Centre Nature 175, 1079 – 1081

Elgaroy, O.; Morris, D.; Rowson, B. (1962) A radio interferometer for use with very long baselines. Monthly Notices of the Royal Astronomical Society, 124, 395

Grahn, S. (2008) 'Spaceflight History, Space Radio Tracking and Space Technology' [www.document]. http://www.jb.man.ac.uk/history/tracking/part1.html and http://www.jb.man.ac.uk/history/tracking/part2.html (accessed June 2014).

Greenhow, J.L. and Neufeld, E.L. (1957) The variation of ionization along a meteor trail. Monthly Notes of the Royal astronomical Society, Vol 117, 359.

Hanbury Brown, R., and Lovell, A.C.B. (1955) 'Large radio telescopes and their use in radio astronomy'. Vistas in Astronomy. Volume 1, 542–560.

Jennison, R. C. (1994) High resolution imaging forty years ago. Proceedings of the 158th International Astronomical Union (IAU) Symposium, edited by J. G. Robertson and William J. Tango., 337

Leverington, D., 2016. Observatories and Telescopes of Modern Times. Cambridge University Press.

Lovell, A.C.B.; Banwell, C.J.; and Clegg, J.A. (1947) 'Radio Echo Observations of the Giacobinids Meteors'. MNRAS, 107 (2): 164-175.

Lovell, B. (1951) Memorandum on a 250ft Aperture Steerable Radio Telescope (Blue Book). Available online from http://www.jodrellbank.manchester.ac.uk/aboutus/lovell/bluebook (accessed June 2014).

Lovell, B. (1968) The Story of Jodrell Bank. London, Oxford University Press. Lovell, B. (1973) Out of the Zenith. London, Oxford University Press.

Lovell, B., 1973. Out of the zenith: Jodrell Bank: 1957-1970. Oxford University Press.

Lovell, B. (1985) The Jodrell Bank Telescopes. New York, Oxford University Press.

Lovell, B. (1990) Astronomer by Chance. New York, London, Macmillan.

Lovell, B., 1991. Echoes of war: The story of H2S radar. Adam Hilger Publishing.

Matzner, R. A. (2001) Dictionary of Geophysics, Astrophysics, and Astronomy, CRC Press

Morris, D.; Palmer, H. P.; Thompson, A. R. (1957) Five radio sources of small angular diameter. The Observatory, 77, 103-106

Munns, D.P. (2012). A single sky: How an international community forged the science of radio astronomy. MIT Press.

Palmer, H. P.; Rowson, B.; Anderson, B.; Donaldson, W.; Miley, G. K.. (1967) Radio Diameter Measurements with Interferometer Baselines of One Million and Two Million Wavelengths. Nature, 213, (5078), 789-790.

Portal to the Heritage of Astronomy. (2017) World Heritage List. https://www3.astronomicalheritage.net/index.php/world-heritage-list (accessed November 2017)

Research Excellence Framework. (2014) Impact Case study: Public Engagement with the Research of Jodrell Bank.

Royal Astronomical Society. (2012) Sir Bernard Lovell, 1913-2012 [www.document]. https://www.ras.org.uk/news-and-press/219-news-2012/2159-sir-bernard-lovell-1913-2012 (accessed July 2014).

Spiral Galaxy: The Milky Way Unravelled. (2009) Directed by Maarten Roos and Pieter-Rim de Kroon. [DVD] Lightcurve Films, DKW FILM.

Sullivan, W.T. (1984). The early years of radio astronomy: reflections fifty years after Jansky's discovery. Cambridge University Press.

Sullivan, W. T. (2009) 'The History of Radio Telescopes 1945-1990'. Exp Astron, review article.

Sullivan, W. T. (2009) Cosmic Noise. New York, Cambridge University Press.

The Royal Society Archive. (date uncertain) Papers and correspondence of Robert Hanbury Brown (ref: GB 117 RHB) [www.document] https://royalsociety.org/library/collections/#archive (accessed October 2014)

Thomson, J. H (1963) 'Planetary Radar', Quarterly Journal of the Royal Astronomical Society, Vol. 4, p.347.

Wendt, H., 2008. *The contribution of the division of radiophysics Potts Hill and Murraybank field stations to international radio astronomy* (Doctoral dissertation, James Cook University).

Wielebinski, R. and Wilson, T., 2010. The development of radio astronomy. *Heritage Sites of Astronomy and Archaeoastronomy*, pp.213-220.

7.e.2 Digital Resources

National Heritage List for England Listings

The Lovell Telescope:
https://historicengland.org.uk/listing/the-list/list-entry/1221685

The Mark II Telescope:
https://historicengland.org.uk/listing/the-list/list-entry/1443087

The Control Building:
https://historicengland.org.uk/listing/the-list/list-entry/1443868

Cosmic Noise Hut/Link Hut:
https://historicengland.org.uk/listing/the-list/list-entry/1443486

Electrical Workshop:
https://historicengland.org.uk/listing/the-list/list-entry/1444238

Park Royal:
https://historicengland.org.uk/listing/the-list/list-entry/1443093

Remains of Searchlight Aerial:
https://historicengland.org.uk/listing/the-list/list-entry/1443133

Archives relating to Jodrell Bank

The University of Manchester Jodrell Bank Archive :
http://www.library.manchester.ac.uk/search-resources/guide-to-special-collections/atoz/jodrell-bank-archive

The Blue Book (proposal for the funding of the Lovell Telescope):
http://www.jb.man.ac.uk/aboutus/lovell/bluebook/

The Royal Society 'Turning the Pages' website for Lovell's diary of the construction of the Lovell Telescope:
http://ttp.royalsociety.org/ttp/ttp.html?o=1&id=c67c8ad6-ab9d-46e9-a050-29775c377832&type=book

NASA History record of Moon Relay Experiments at Jodrell Bank:
https://history.nasa.gov/SP-4217/ch3.htm

Film & TV Resources

Pathe News footage 'The Jodrell Bank Radio Telescope':
https://www.britishpathe.com/video/jodrell-bank-radio-telescope

Pathe News Reel 'Listening to the Stars':
https://www.britishpathe.com/video/listening-to-the-stars/query/Jodrell+bank

Pathe News Reel 'Moon Next Time?':
https://www.britishpathe.com/video/moon-next-time/query/Jodrell+bank

BBC website:
http://www.bbc.co.uk/science/space/universe/exploration/jodrell_bank_observatory

Audio Resources

'Web of Stories' Interviews with Sir Bernard Lovell:
https://www.webofstories.com/play/bernard.lovell/1

7.f
Glossary

Anisotropies: Used to describe direction-dependent properties of materials.

Astrometry: The measurement of the location and movement of celestial bodies.

Attributes: Aspects of the property which are associated with or express the Outstanding Universal Value (OUV).

Authenticity: Those characteristics that most truthfully reflect and embody the cultural heritage values of a place and attest to its veracity.

Azimuth: The angle of direction, usually measured in relation to north (North, East, South, and West on the compass are, in turn, at 0°, 90°, 180°, and 270° azimuth). A telescope that moves in azimuth can point in different directions along the horizon line.

Buffer Zone: Area surrounding the nominated property afforded special protection, in order to prevent development pressures damaging the OUV of the property.

Celestial Maser: intense radio emission from an interstellar cloud of gas (acronym for 'microwave amplification by stimulated emission of radiation').

Comet: An object composed of ice and rock which orbits the sun, usually in a highly elliptical orbit. They often have two tails, one of dust, and a bright, ionized gas tail that points away from the sun.

Cosmic Rays: High energy subatomic particles. Many cosmic rays are produced in the sun, but the highest-energy rays are produced outside the solar system, perhaps associated with **supernova** explosions.

Dipole: A simple and widely used class of antenna, made up of two identical conductive elements.

Einstein Ring: Refers to the deformation of the light from a source, such as a galaxy or star, into a ring through **gravitational lensing** of the source's light by an object with an extremely large mass.

e-MERLIN: The upgraded MERLIN programme, including improved receivers and telescope electronics, and an optical fibre network connecting the constituent telescopes to Jodrell Bank Observatory.

Gravitational Lens: An object (in observational practice usually a **quasar**, galaxy, or cluster of galaxies) whose gravitational field deflects the light rays emitted by another object (usually a galaxy or a quasar) so strongly that some of the rays intersect behind the deflector.

Hubble's Constant: Refers to the estimated value of the rate of expansion of the Universe.

Hydrogen Line/21cm Line: Spectral line emitted in the radio domain, at a wavelength of 21 cm, due to the transition between two energy states in the hydrogen atom. The hydrogen line/21-cm emission line was first detected in 1951; since then it has been used to map the distribution of neutral hydrogen within the galaxy, and in external galaxies, with radio telescopes and interferometers.

Integrity: A measure of the wholeness and completeness of the natural or cultural heritage and its attributes.

Interferometer: An astronomical interferometer consists of two or more separate telescopes that combine their signals, offering a resolution equivalent to that of a telescope of diameter equal to the largest separation between its individual elements.

Listed Building: Building of special architectural or historic interest that has been afforded legal protection.

Long Baseline Interferometry/Very Long Baseline Interferometry (VLBI): A technique used to improve the resolution of a radio telescope by using a number of synchronized antennas very far apart.

MERLIN: Multi Element Radio Linked Interferometer Network (predecessor to **e-MERLIN**), which linked 7 telescopes across the UK including the Lovell Telescope and Mark II at Jodrell Bank, and telescopes at Cambridge, Defford, Knockin, Pickmere and Darnhall.

Meteor: The glowing track of a meteoroid (metallic or rocky small body orbiting the sun) as it travels through the air. Such meteors also are often called shooting stars or falling stars. Most of the debris creating meteors is small (dust to sand-sized) and burns up during the atmospheric passage.

Nebula: A diffuse mass of interstellar dust and gas.

Outstanding Universal Value: Cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations for all humanity.

Pulsar: A neutron star in which a rapid rotation and a strong magnetic field result in radio waves or other forms of electromagnetic radiation being emitted primarily along narrow beams.

Quasar: Refers to a compact, star-like (hence the name quasar, from quasi-stellar) celestial body which emits huge amounts of energy (generated from the gravitational field of a supermassive black hole).

Radiant Point (of meteors): The point in the sky from which a meteor shower appears to originate.

Radio Interference: A number of products generate radio waves, either intentionally as a part of their workings (mobile phones, wireless alarms), or as a by-product of operation (computers, microwave ovens, etc.). This background 'noise' generated, is radio interference which can impact upon the ability of highly sensitive instruments such as radio telescopes to detect tiny signals from space.

Scintillation: Random fluctuations in the amplitude, phase, and direction of arrival of an electromagnetic signal.

Spectrohelioscope: A solar telescope which allows the Sun to be viewed in a selected wavelength of light, designed by George Ellery Hale in 1924.

Supernova: The death explosion of a massive star, resulting in a sharp increase in brightness followed by a gradual fading.

Transit Telescope: a telescope mounted so as to point only at objects transiting the local meridian (the arc linking the zenith and the celestial poles).

Yagi Aerial: a directional antenna consisting of multiple parallel **dipole** elements in a line, usually made of metal rods.

Zenith: The point directly vertically above a given location (usually the direction directly away from the Earth's centre).

Figure 7.1: The e-MERLIN correlator which combines signals from the seven telescopes in the network.

Image: Anthony Holloway

8. Contact Information of Responsible Authorities

Image: Anthony Holloway

8.a Preparer

Name:
Professor Teresa Anderson MBE

Title:
Associate Director,
Jodrell Bank Centre for Astrophysics

Address:
Jodrell Bank Observatory,
The University of Manchester

City, Province/State, Country:
Macclesfield, Cheshire, UK

Tel:
+44 (0)161 306 9581

E-mail:
teresa.anderson@manchester.ac.uk

Name:
Professor Tim O'Brien

Title:
Associate Director,
Jodrell Bank Observatory

Address:
Jodrell Bank Observatory,
The University of Manchester

City, Province/State, Country:
Macclesfield, Cheshire, UK

Tel:
+44 (0)161 306 9581

E-mail:
tim.obrien@manchester.ac.uk

8.b Official Local Institution/Agency

Jodrell Bank Observatory
The University of Manchester
Macclesfield
Cheshire
SK11 9DL, UK

8.c Other Local Institutions

Marketing Cheshire
Riverside Innovation Centre,
1 Castle Dr,
Chester CH1 1SL, UK

Marketing Manchester
Lee House,
90 Great Bridgewater St,
Manchester
M1 5JW, UK

Cheshire East Council
c/o Municipal Buildings,
Earle Street,
Crewe CW1 2BJ, UK

Tatton Park Gardens
Mereheath Dr,
Knutsford
WA16 6QN, UK

Macclesfield Town Council
Town Hall,
Market Pl,
Macclesfield
SK10 1EB, UK

Macclesfield Silk Museum
Park Ln,
Macclesfield
SK11 6TJ, UK

8.d Official Web Address

www.jodrellbank.manchester.ac.uk
www.jodrellbank.net

Contact name:
Professor Teresa Anderson

E-mail:
teresa.anderson@manchester.ac.uk

9. Signature of Behalf of the State Party

Image: Anthony Holloway

NAME:
Giles Smith

TITLE:
Deputy Director

ADDRESS:
Heritage Tourism and Cultural Diplomacy
Department for Digital, Culture, Media and Sport
4th Floor, 100 Parliament Street, London SW1A 2BQ

SIGNATURE ....

DATE ....

10. Acknowledgements

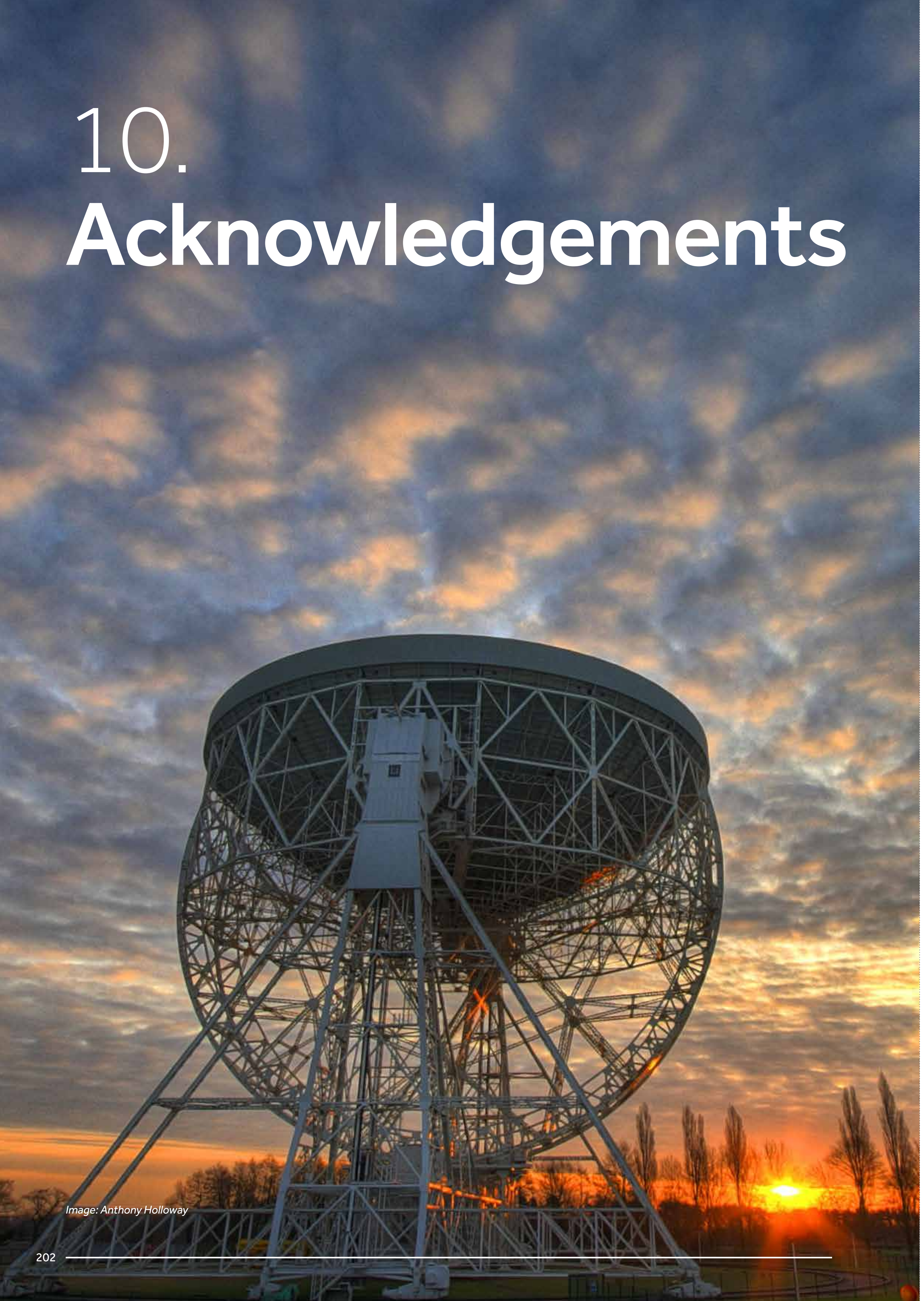


Image: Anthony Holloway

The authors would like to extend heartfelt thanks to a number of people and organisations, who have made the preparation of this dossier possible. The journey from preparing the application to the UK Tentative List to the point of nomination has taken eight years. Many people have been involved in this journey.

First of all, the help of Christopher Young, in preparing the dossier, has been completely invaluable and we are very grateful to him for his advice, suggestions and work.

Historic England, and particularly Henry Owen-John, Karl Creaser and Anna Boxer, have provided guidance and support to the authors over many years.

Crispin Edwards and the Historic England listing team have also worked very hard to support the preparation of this case.

Many thanks to DCMS, and particularly Enid Williams and Hannah Jones, in overseeing the formal process of nomination.

The UK's Technical Evaluation Panels of 2013, 2015 and (in particular) 2017 have provided guidance on the development of this case for nomination since 2013. The authors have learned much from their advice and know that the final dossier has benefited hugely from this. It isn't possible to list all Panel Members here, but the authors are particularly grateful to Helen Maclagan, Chair of the Evaluation Panel, for years of helpful counsel. Kate Clark, Chief Executive of Cadw, also provided some very useful inputs in recent months, as did Miles Oglethorpe, Head of Industrial Heritage at Historic Environment Scotland and the Forth Rail Bridge Team.

Chris Blandford Associates consultants have supported the development of the heritage management at Jodrell Bank for some time, including the preparation of the superb first draft of its Conservation Management Plan by Chloe Cava and Dominic Watkins. Since then they have helped with many other elements and the authors would like to thank them for their speedy and professional support, especially as the nomination deadline approached.

Marketing Cheshire, and particularly Katrina Michel, CEO, have supported the renaissance of the visitor experience at the property since 2011.

We are grateful to Cheshire East Council for formal support for the nomination, and for the work of both their Conservation Officer, Andrew Ramshall, and their Tourism Lead, Brendan Flanagan.

The University of Manchester has supported the preparation of this dossier from many quarters, including colleagues in:

- the Jodrell Bank Observatory (particularly Associate Director of the Observatory, Professor Simon Garrington; Telescope Maintenance Supervisor and Design Technician, Phil Clarke; Former Director of the Observatory, Emeritus Professor Sir Francis Graham-Smith) and the Jodrell Bank Centre for Astrophysics (particularly its Director, Professor Mike Garrett);
- the Jodrell Bank Discovery Centre, particularly Keir Powell-Lewis, Lorna Harper, Amy Bishop and Liz Bruton
- the University's Division of Estates, particularly Diana Hampson, Director; Steve Jordan, Deputy Director; Steve Mawhinney, Capital Project Manager; Mike Billington, Head of Estates for the Faculty of Science and Engineering