UNIVERSITY OF CAMBRIDGE
Estates Division

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Director of Estates

Mr David Hughes
Chief Executive
East West Rail

By email

24 January 2025

Dear Mr Hughes

Non-Statutory Consultation Response

Thank you for the opportunity to engage with East West Rail on the emerging proposal for the railway, through the current non-statutory consultation and through dialogue with your design teams.

The University continues to support the strategic objectives of East West Rail. Development of the railway will enable mass transit movements by sustainable modes, and have a significant beneficial impact in extending the travel to work area for Cambridge including, importantly, the Cambridge Biomedical Campus. The railway will support the continued growth of the Greater Cambridge area, significantly enlarging its travel to work area and providing connection to innovation economies along the route.

There are specific points of details that are raised below. These respond to specific questions in the non-statutory consultation, and are submitted as online responses in addition to this letter.

Croxton to Toft route section (Question 16):

Around 20% of University staff that commute into Cambridge travel along the A428/Madingley Road corridor and the University welcomes the intention to build a new station at Cambourne. It is important that any new station:

- Supports first mile/last mile journeys from/to Cambourne, for the benefit of residents, workers and visitors.

- Is integrated with the proposed Cambourne to Cambridge bus service, which will connect Cambourne to Cambridge via the University's Cambridge West development, a strategically important employment location for which outline planning permission was granted in June 2023 for development of 370,000m2 of academic and commercial

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research space, with up to 170,000m2 commercial research. There is a strategic imperative for East West Rail to integrate seamlessly with Cambourne to Cambridge in order to facilitate travel for work journeys from locations served by train stations to the west of Cambourne.

- Is integrated with other public transport services.

Collaboration between East West Rail and the Greater Cambridge Partnership, Cambridgeshire County Council and bus operators should take place in order to identify design solutions for inclusion in statutory consultation.

Comberton to Shelford route section (Question 20):

The University is concerned about the potential for significant adverse environmental effects that would affect the Mullard Radio Astronomy Observatory (MRAO) and as highlighted in our previous response (view here) and in ongoing discussions with the East West Rail technical teams.

The MRAO is situated at Lord's Bridge on the A603 south of Cambridge, as shown in the plans in Annex A.

National and International Importance of MRAO

The Observatory contains unique radio and optical telescopes which are of international importance and must be safeguarded. The facilities measure signals that are very weak, and hence highly susceptible to many forms of interference, specifically electric-magnetic interference (EMI), light pollution and mechanical vibration from domestic, industrial plant and other sources such as vehicles and aircraft.

The Observatory has been home of some of the largest and most advanced radio astronomy instruments in the world since it opened in 1957. Notably, these instruments have supported research leading to 2 Nobel prizes and countless discoveries which have placed Cambridge and the UK at the forefront of astronomy research. Currently, the observatory is home to a number of state of the art aperture synthesis radio telescopes, such as the Large and Small Arcminute Microkelvin Imager arrays and the 32-m dish part of the e-Merlin national facility. It is also important for a number of internationally leading instrument development projects. In these cases, instruments are developed in Cambridge and via collaboration elsewhere and tested at the observatory before being deployed (often in large numbers) to other sites. Most important of these are the developments that Cambridge leads for the Square Kilometre Array (SKA) which is under construction in South Africa and Australia, and which currently brings ~£3M/year to the university in research funds. The SKA is a €1.2bn construction project in its first phase. Cambridge leads the design of several elements of the telescope including the software and, importantly, the low-frequency telescope which will be deployed to Western Australia. There are two test arrays at Lord's Bridge and a third currently in construction. Furthermore, phase II of the SKA (~ 10x the size of phase I) will start its development phase in the coming years, with the observatory expected again to take a central role in the international development efforts due to its unique characteristics. Other uses of the observatory that could be heavily impact by the EW rail project include the smaller (in comparison to the SKA) wide field instruments used by the radio cosmology group, e.g. the REACH project (a £2.4M ERC/UKRI project).

As well as instrument development for new large radio telescopes, the Observatory also hosts a large vibrationally- and temperature-stable optics laboratory that is used to test and validate optical instruments that support and are used in several large international ground-based telescope projects. As for the radio-focused work, instruments are developed in Cambridge and via collaboration elsewhere, and tested at the observatory before being deployed at other sites abroad.

Further details of MRAO and its operating requirements are attached as Annex B.

The national and international importance of the research undertaken by the Observatory is recognised by the local planning authorities who, for many years in successive Local Plans, have adopted planning policy which protects research from inappropriate development. Details of the current policy for in the adopted South Cambridgeshire Local Plan (2018) are provided below.

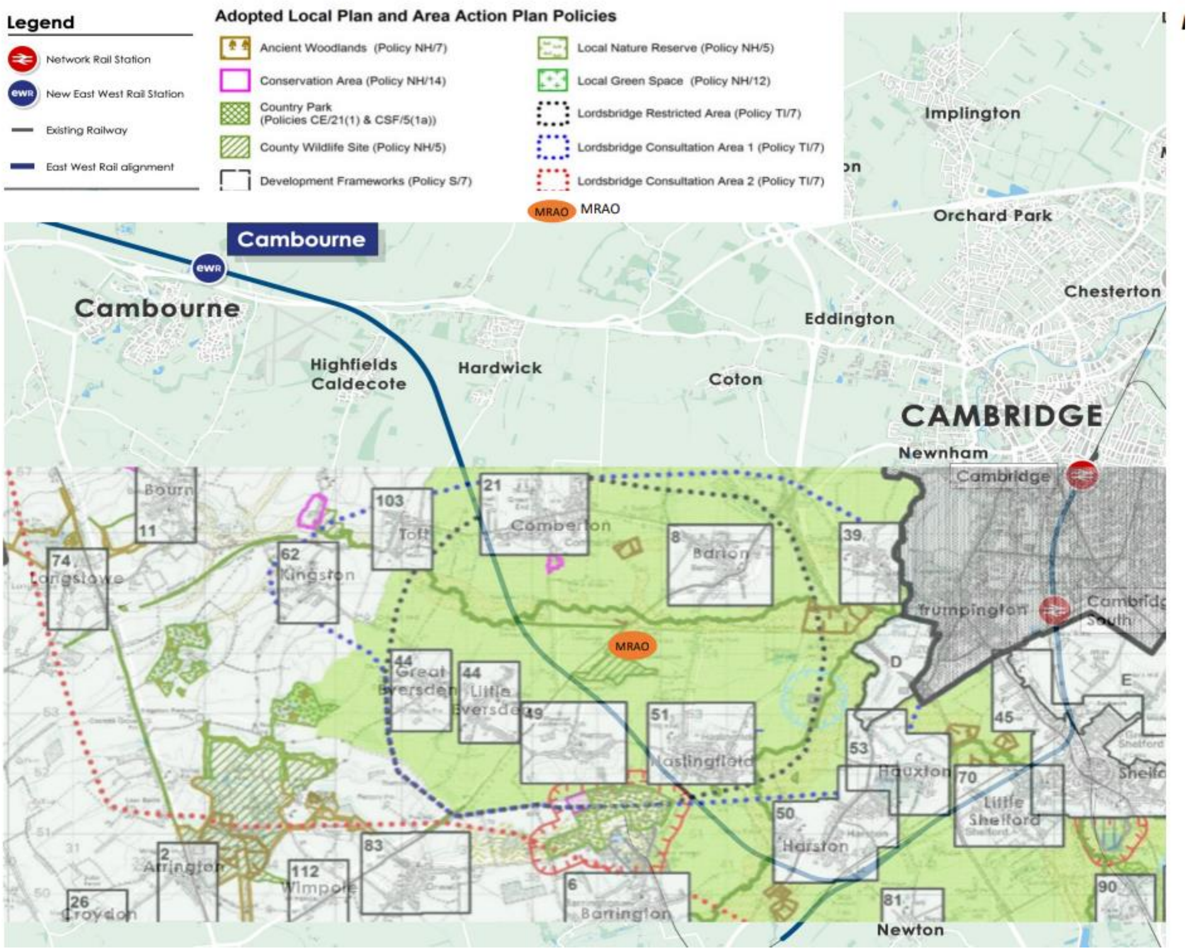
Policy TI/7: Lord's Bridge Radio Telescope

1. Within the 'Lord's Bridge Restricted Area' (defined on the Policies Map), planning permission will only be granted for development that would not result in any risk of interference to the Mullard Radio Astronomy Observatory at Lord's Bridge.

2. Within the 'Lords Bridge Consultation Area 1' (defined on the Policies Map), development proposals that could adversely affect the operation of the Mullard Radio Astronomy Observatory at Lord's Bridge will be subject to consultation with the University of Cambridge, and account will be taken of the risk of interference to the equipment being used at the Observatory. Planning permission will be refused where interference would be caused that could not be overcome by conditions or by the use of planning obligations.

3. Within the 'Lords Bridge Consultation Area 2' (defined on the Policies Map), development proposals for telecommunications and microwave operations that could adversely affect the operation of the Mullard Radio Astronomy Observatory at Lord's Bridge will be subject to consultation with the University of Cambridge, and account will be taken of the risk of interference to the equipment being used at the Observatory. Planning permission will be refused where interference would be caused that could not be overcome by conditions or by the use of planning obligations.

The proposed route for East West Rail will run through the heart of the Lord's Bridge Restricted Area, as shown in the plan below.



Ofcom's publication [Space Science and Meteorology Spectrum Allocations in the UK] (19th August 2022) identifies MRAO as a nationally important radio astronomy site, and sets out global regulations on the allocation and use of certain frequency bands, some of which are specific to Cambridge.

Environmental Assessment

Given the national and international importance of the MRAO, the protection from development as set out in the Cambridge and South Cambridgeshire Local Plans, and the protection of radio frequencies as set out in international regulations, it is essential that effective environmental assessment is undertaken by East West Rail relative to the impact of the proposed railway on radio astronomy research by MRAO at Lord's Bridge.

East West Rail has selected a preferred route, however without having assessed the environmental effects on research at the Observatory, and environmental impacts are not included in the consultation material. The Environmental Update Report merely states at paragraph 11.2.7 that 'The Mullard Radio Astronomy Observatory includes an array of radio telescopes situated near the Bourn Brook crossing, as well as south of the A603. The potential for electromagnetic interference between East West Rail's traction power system and this facility is being assessed, with a view to integrating protective measures within the railway design. Potential vibration impacts may also need to be mitigated.'

East West Rail appear to assume that the actual emissions from the operation of the railway will correspond to the maximum levels permitted by BS EN 50121-2 'Railway applications. Electromagnetic compatibility. Emission of the whole railway system to the outside world.' This is a major concern, as constant emissions at maximum levels would have a significantly detrimental impact on the work of the MRAO, well above the criterion of 'any risk of interference' as set out in Planning Policy T1/7 (1). It is unlikely that the railway would operate to the maximum levels all of the time, however, actual predicted emissions need to be understood in order to assess the likelihood of risk to interference to MRAO and consequently compliance/non-compliance with planning controls.

Despite the absence of any detailed information from the proposed East West Rail, University experts in radio astronomy research and optical instrument development anticipate that the effects from EMI and vibration during the construction and/or operational phases, arising from the unmitigated proposals as set out in the consultation documents, will be significant. There is a clear and obvious risk of interference to research. It is expected, therefore, that the East West Rail consultation proposal will not be compliant with Part 1 of Policy TI/7: Lord's Bridge Radio Telescope in the South Cambridgeshire District Local Plan.

The University urges East West Rail to carry out an assessment of the likely environmental effects arising from the construction and operations of the route and specifically concerning EMI and vibration in the vicinity of Lord's Bridge, so that a conclusion can be reached on the amount of interference likely to be caused, and to identify what measures could be put in place to mitigate harmful effects.

The assessment should be based on:

- measurements of the existing background EMI and vibration levels at Lord's Bridge;

- measurements of EMI and vibration from railway existing infrastructure and rolling hybrid powered rolling stock; this is important as it seems likely that actual EMI emissions may be less than the maximum permitted under BS EN 50121-2. These measurements should be made:

    - On a railway in similarly flat terrain.

- On a railway with similar power supply and rolling stock to that proposed for EWR, with both passenger and freight trains.

- At a range of distances from the railway chosen, to establish the fall off of EMI and vibration disturbances with distance.

- At the full range of frequencies of EMI interest up to at least the upper frequency specified by OfCom.

Measurements of both background and predicted EMI and vibration levels should be shared with the University early in 2025, well in advance of statutory consultation later in the year. When available, potential mitigation can be discussed and a strategy agreed, to identify how EMI can be managed down to a level which would comply with adopted planning policy.

Mitigation Strategy

As set out in Government Guidance on Environmental Impact Assessment, ‘Developers are encouraged to identify any features of their proposed development and any measures envisaged to avoid or prevent what might otherwise have been significant adverse effects on the environment (Paragraph: 023 Reference ID: 4-023-20170728)…and ‘Where alternative approaches to development have been considered, the Environmental Statement should include a description of the reasonable alternatives studied which are relevant to the proposed development and its specific characteristics and provide an indication of the main reasons for the choice made, including a comparison of the environmental effects’ (Paragraph: 035 Reference ID: 4-035-20170728).

Mitigation is important to the process of EIA, as it ensures that adverse impacts of a development are minimised or completely avoided. The Institute of Environmental Management and Assessment (IEMA) Impact Assessment Guidelines (August 2024), describe a ‘mitigation hierarchy’ as follows:

1. Avoid - Identify and avoid potential environmental and social impacts from the outset through considering carefully, for example, the project need, scale, design, location and duration.
2. Prevent - Where impacts from a proposal still pose risk of significant adverse effects to receptor, seek to prevent those effects from occurring by taking action/s to either remove the impact at source or intervene in its pathway to prevent it affecting the receptor.
3. Reduce - If further avoidance and/or prevention are not possible for any remaining aspects, all remaining impacts must be mitigated with guidance from a competent expert with the aim of minimising adverse effects. Mitigation can take many forms and should be specific to the project conditions and context, whilst drawing on good practice and guidance. Mitigation should be reliable, achievable and secured by condition, requirement or legal agreement.
4. Offset - Lastly, any remaining unmitigated or residual impacts should be offset and compensated for.

It is stated in the Guidelines that the mitigation hierarchy can guide decision making at all stages of the project, however, critically, the upper levels of the mitigation hierarchy are most achievable the earlier they are applied, i.e. the **concept, feasibility and site selection phases of the project provide the best opportunities for avoiding a significant environmental impact**. (IEMA’s emphasis).

The consultation proposals for land in proximity to Lord’s Bridge do not include any measures in the priority levels of the hierarchy, however:

1. Avoid – could be achieved by routing the railway further away from MRAO – at least outside the ‘Lord’s Bridge Restricted Area’ as set out in planning policy identified above – or by putting the railway in a tunnel as it passes MRAO. Neither of these options are proposed nor appear to have been explored. Instead, the railway is proposed to run

through the heart of the Lord's Bridge Restricted Area and within 1km of the SKA testing site and the COAST optical laboratory.

2. Prevent – could be addressed by designing the railway at grade, with appropriate vibration suppression, and screened behind an earth bund, neither of which are proposed. Instead, the railway is proposed to operate on an 11m high embankment, without any form of screening, as it passes Lord's Bridge.

We are concerned that East West Rail has assumed reliance on a mitigation strategy that depends solely on measures that would compromise research through the release of radio frequencies up to the maximum levels under BS EN 50121-2, not currently in use, and with no regard to vibration disturbance suppression.

The University does not support the approach to environmental assessment and mitigation being proposed and request that East West Rail urgently consider ways to avoid and prevent adverse impact on the University's nationally and internationally important radio astronomy research.

Until an effective environmental assessment is undertaken, and the operating environment for radio astronomy and other instrument development research is secured and protected for the long-term, to the satisfaction of the University, we are unable to support the current route proposals for the area around Lord's Bridge.

Land Acquisition

It is understood from discussion with officers at East West Rail that land taken for habitat compensation and/or mitigation would initially be permanent land take, but there may be an opportunity for transfers back to original owners subject to agreements securing the ongoing management of habitat created. This includes land within the core of the Mullard Radio Observatory. Control over the future use and occupation of this land is important to secure future research undertaken at the observatory. It is requested that certainty be given that landowners will be given the opportunity to take back land used for habitat creation, subject to appropriate agreements as to the future management of the land, and that landowners will be paid a commuted sum to cover the costs of management required by those agreements. There must be a commitment to a reasonable timescale for such transfers to be made, for example 12 months from the running of the first train, and other than where required to secure future management of habitat no onerous restrictions or covenants should be included in the transfers.

Cambridge Route Section (Question 21)

Anne Maclaren Building

The consultation documents show land acquisition from the University's estate at Cambridge Biomedical Campus, specifically from land around the Anne Maclaren Building and from the adjacent Plot 9 (land parcel references 23144 and 23145). We have since been advised by the design team for the Cambridge route section that East West Rail do not need the additional land beyond which Network Rail has agreed for Cambridge South Station (i.e as per the Transport and Works Act Order Consent), and that University land is not required in order to facilitate the two additional tracks proposed or for the demolition and reconstruction of Long Road Bridge. We have accepted that advice in good faith, for the purpose of this consultation, and ask that amended plans be shared at the earliest opportunity.

The Anne Maclaren Building contains research that is sensitive to vibration impact and to EMI. A Land and Works Agreement (LWA) between the University and Network Rail contains information on vibration and EMC compatibility and management measures that will also apply to the East West Rail proposals. The LWA will be sent under separate cover and is to be treated in confidence.

Cherry Hinton Turnback

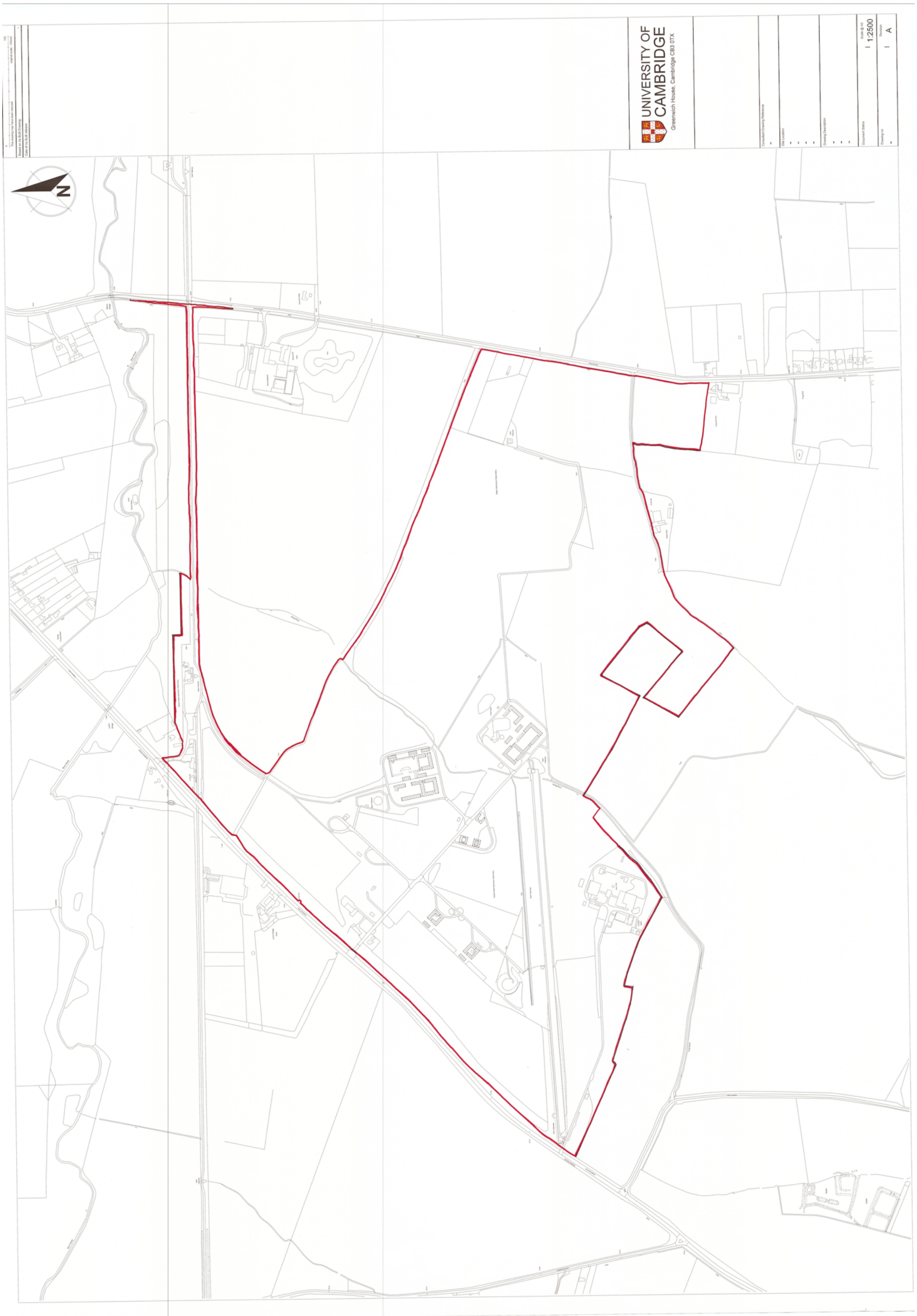
The University supports the proposal to create a turnback at Cherry Hinton. This would create the opportunity to create a new station at Cambridge East, supporting the development of thousands of homes and jobs, and enabling cross-city mass-transit movement.

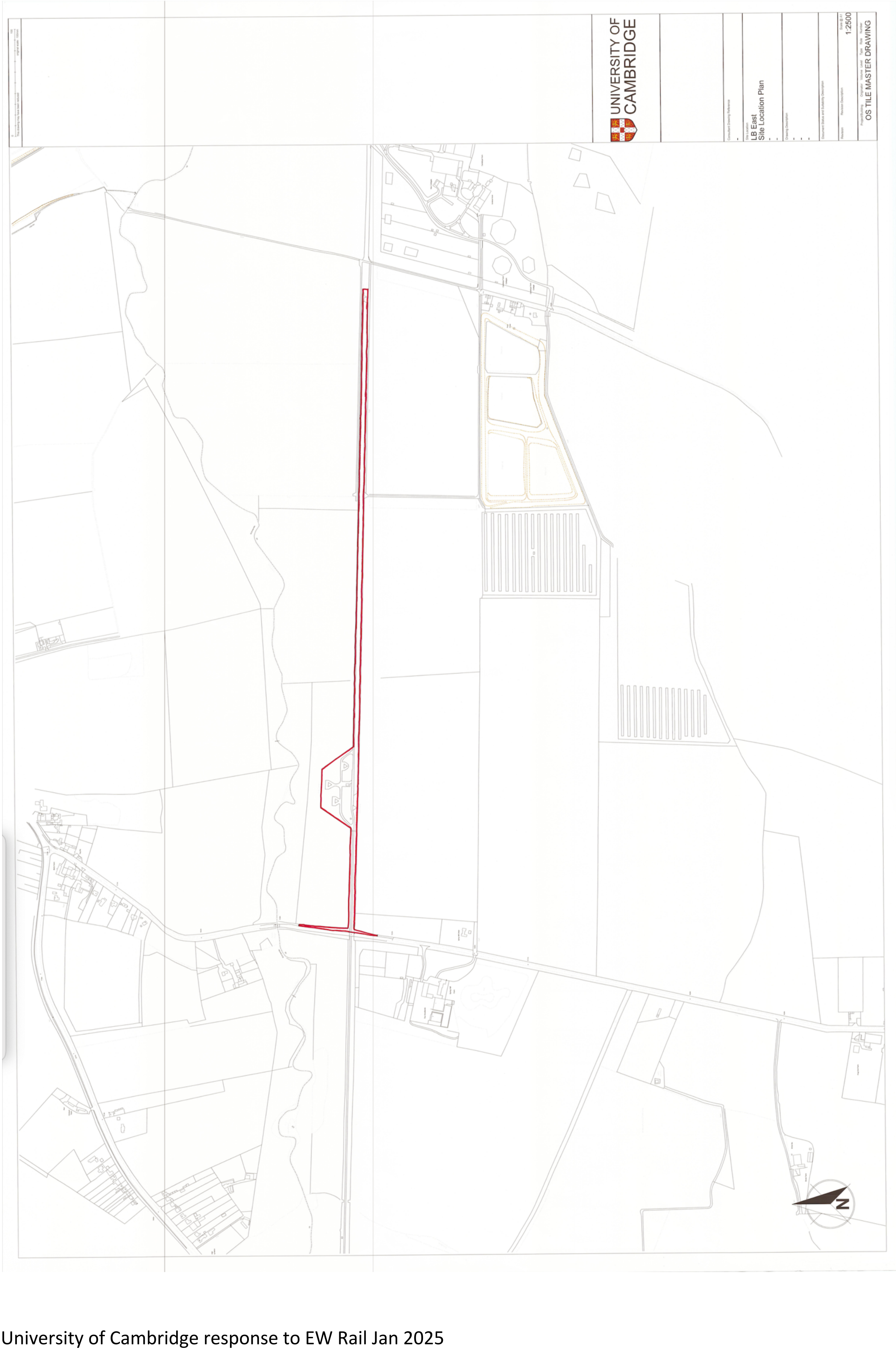
I trust that that this response will be given due consideration and we look forward to working with you in a collaborative spirit to resolve the issues raised, in advance of statutory consultation.

Yours sincerely

Graham Matthews

Annex A Location of the MRAO




UNIVERSITY OF CAMBRIDGE
Consultant Drawing Reference
Site Location
LB East
Site Location Plan
Drawing Description
Document Status and Suitability Description
Revision
Revision Description
Scale @ A1
1:2500
Project/Building Originator Volume Level Type Role Number
OS TILE MASTER DRAWING


UNIVERSITY OF CAMBRIDGE
LB West
Site Location Plan
1:2500
OS TILE MASTER DRAWING

MULLARD RADIO ASTRONOMY OBSERVATORY

1. The role of MRAO in supporting the University's Mission

   The mission of the University of Cambridge is to contribute to society through the pursuit of education, learning and research at the highest international levels of excellence.

   Astronomy and Astrophysics are in a most exciting phase, at the heart of efforts to tackle the great cosmological questions of the origin and nature of the Universe, and also, since the discovery of planets orbiting solar-type stars other than our own Sun in the mid 1990s, questions about the origins of Earth-like planets and life. Cambridge is one of the leading centres globally for this work, and it is centred in three Departments: Physics (the Cavendish Laboratory, including the Mullard Radio Astronomy Observatory, or MRAO), the Institute of Astronomy (IoA), and the Department of Applied Mathematics and Theoretical Physics (DAMTP).

   All three Departments carry out cutting-edge research on these fundamental questions, but the particular strength of the MRAO has long been in the development of ever more sophisticated experimental techniques for astronomical measurements, first at radio wavelengths, and now also at higher frequencies. In short, designing, building and operating ever better radio and other telescopes and their associated receivers and instruments. MRAO is one of only two major centres in the UK (with a handful of equivalent places in the rest of the world), with Jodrell Bank at the University of Manchester being the other.

   The site at Lord's Bridge is central to this work; the quiet environment and proximity to the researchers, with low levels of electromagnetic interference, has allowed this astonishing technical progress since 1957. The current work is still very much at the forefront of science, with the current activity a mixture of scientific observations, and the development of new techniques and instrumentation to be deployed elsewhere in the world. All of this work is part of wide national and international collaborations.

   Not only does this work bring in significant research income, but the MRAO facilities allow Cambridge scientists to stay at the forefront of their fields and take on leading roles in international programmes (such as the SKA) which would not otherwise be possible.

   The MRAO interests and expertise in developing the underpinning technologies required for contemporary astrophysics are focused in the radio and optical/infrared regions of the electromagnetic spectrum. In the radio, a major focus has been towards the detection and study of the Epoch of Re-ionization. The team has been intimately involved in the science planning and technology design of the Square Kilometre Array (SKA) – a €billion scale international radio telescope project – and has participated directly in HERA SKA precursor experiment. The MRAO team were responsible for completing the design of the SKA1-LOW antenna and array systems, and thousands of copies of these critical telescopes elements are currently being constructed and deployed. MRAO researchers also designed a new wideband HERA front-end system, which has allowed exploration of both the Epoch of Re-ionization and the Cosmic Dawn. More recent activity has focused on the REACH global experiment – deployed in South Africa – which aims to detect the 21-cm signal from the

Cosmic Dawn and the Epoch of Re-ionization thereby offering a completely new probe of structure formation in the early Universe.

At optical and near-infrared wavelengths, MRAO staff are world leaders in the design of interferometric array telescopes and their subsystems and are also embedded in several international large-telescope spectrograph projects where skills in precision opto-mechanics, the design and testing of cryogenic systems, and software architecture for instrument control are all deployed. While much of this work takes place at the main Cavendish Laboratory site a specialised thermally and vibrationally stable laboratory located at Lord's Bridge provides a unique large (25m × 5m) environment in which ultra-sensitive equipment can be tested and validated. Current optical/infrared projects include the design and delivery of key elements of the MOONS and ANDES spectrographs for the European Southern Observatory in Chile, the assembly and validation of the HARPS3 ultra-precision spectrograph for the Isaac Newton Telescope in La Palma, and the design and construction of critical subsystems for the $100M-scale Magdalena Ridge Observatory Interferometer in the USA.

2. Scientific achievements by MRAO (past and present ground breaking research)

The story of MRAO is one of scientific success. It is impossible to include all the contributions to our understanding of the Universe that have started at the MRAO. Simply put, the developments that have taken place at the MRAO and Cavendish Astrophysics since World War II have changed the way in which we understand the universe we live in. To name only a few of the most remarkable achievements, one cannot forget about the discovery of pulsars (neutron stars) by Hewish and Brunel (https://en.wikipedia.org/wiki/Pulsar). This is a discovery that not only revealed to the world a completely new type of natural phenomena but opened a world of possibilities to study the universe via interactions of matter and wave, using some of the most accurate natural clocks known to humans: neutron stars. This discovery has been recognised with countless awards, including a Nobel Prize for A. Hewish (https://www.nobelprize.org/prizes/physics/1974/summary/) and many others for JB Brunell (e.g. Copley Medal, etc).

The technique of Earth-rotation Aperture Synthesis (https://en.wikipedia.org/wiki/Aperture_synthesis) is another invention that took place at the MRAO which changed the face of Physics and Astronomy. Developed by M Ryle since the 1950s, it is the main technique used still today by radio telescopes everywhere, as it allows these instruments to survey the sky orders of magnitude faster than other techniques such as mechanical scanning. It was recognized with a Nobel Prize for Ryle in 1974. It led for example the production of the first maps of the radio sky and to the early source counts (also made here at the MRAO) that favoured the Big Bang theory over a steady-state universe. The developments of instrumentation and techniques such as aperture synthesis continue today at the MRAO, adapting the algorithms that Ryle et al developed to modern computing systems such as the ones that will be used by the largest and most powerful radio telescope ever to exist, the SKA. Cambridge holds a world-leading position in the international multi-billion pounds SKA project, head-quartered at Jodrell Bank, Manchester.
Today, the Cavendish Astrophysics group has diversified its research portfolio, but its main strength over others continues to be the strong emphasis on the development of the instruments later used for astronomical observations. This development starts at the conception phase, when our researchers plan what experiment is needed to probe a particular

mystery in Physics, all the way to the actual engineering development, fabrication, testing, etc All happening at our doorstep at the Lords Bridge site of the MRAO. A very current example of this is the REACH telescope, recently awarded 2.4 million pounds by UKRI (https://gtr.ukri.org/projects?ref=EP%2FY02916X%2F1) to study the birth of the very first stars of our Universe, to understand how the universe went from dark and simple to complex and full of light in its most fundamental transformation to date. This discovery, in turn, promises to answer some fundamental questions about the nature of dark matter and its role in the formation of stars, galaxies and the rest of celestial objects. REACH is currently building a radio telescope at the MRAO.

As specific examples of some scientific milestones achieved recently thanks to the instruments at the MRAO, we could cite the follow-up of one of the brightest bursts of electromagnetic radiation in the sky ever recorded (the brightest in history at Gamma Ray frequencies) by the AMI array in October 2022. GRB 221009A was followed since its very early and unexpected appearance in the sky by the AMI telescope (and only by the AMI telescope for a large fraction of time) providing a unique insight in the nature of this cosmological phenomena (https://www.nature.com/articles/s41550-023-01997-9). Another example, on the engineering side, would be the development since 2011 of the SKALA antennas for the SKA1-LOW array, of which 131,000 copies (https://www.skao.int/en/explore/telescopes/ska-low, https://cdr.skatelescope.org/#profiles?lfaa) are currently being built to make the largest and most powerful radio telescope in history.

3. The value of radio astronomy research generally and MRAO specifically to UK and international research

   Radio astronomy has led to many discoveries and insights about the universe, including:
   - Cosmic Microwave Background Radiation: The afterglow of the Big Bang, discovered in the 1960s by astronomers looking for the source of radio antenna interference
   - Pulsars: Rapidly spinning remnants of supernova explosions that emit regular radio waves
   - Quasars: Some quasars are strong radio sources, and were the first radio-emitting objects to be discovered
   - Galaxy structure: Radio astronomers use hydrogen's characteristic emission to map out the structure of galaxies
   - Solar activity: Radio telescopes can observe the Sun and solar activity
   - Planet mapping: Radio telescopes can be used for radar mapping of planets

   Radio astronomy has changed the way we view the universe by providing a different view of the sky that optical instruments like the Hubble Space Telescope cannot see. Radio telescopes allow astronomers to study the radio waves emitted by astronomical objects to learn about their composition, structure, and motion. Radio astronomy data can also be used to create images that show characteristics like temperature, clumpiness, and strength of radio emissions.

   With the development of next-generation radio observatories like the SKAO (www.skao.int), radio astronomy is about to live a second golden age (after the first one already led by researchers at the MRAO). As such, radio astronomy plays a fundamental role in society, by answering some of the most fundamental questions about our universe's past, present and future.

Financially, radio astronomy represents an investment of several hundred million in the UK alone. As an example, the UK's contribution to the SKA project is of the order of £200M (construction and early operations), making the UK the prime funder. For Cambridge, radio astronomy research based at the MRAO and Cavendish Astrophysics currently comes at a rate of ~£3M/year, and expected to continue for the at least the next decade.

It is also worth noting how the technological developments in radio astronomy projects, regularly find their way to the commercial arena and the wider societal impact due to their pioneering nature. A well-known example of this is the invention of WiFi (https://www.csiro.au/en/research/technology-space/it/wireless-lan#:~:text=We%20invented%20wireless%20LAN&text=The%20invention%20came%20out%20of,their%20behaviour%20in%20different%20environments.). Advances in astronomical technology have a direct impact in everyday technology. This includes computers, satellites, GPS, solar panels, digital cameras, airport security scanners, and MRI scanners, amongst others (https://www.cfa.harvard.edu/big-questions/how-can-astronomy-improve-life-earth#:~:text=Computers%2C%20satellites%20and%20the%20smartphones,greatest%20wellsprings%20of%20human%20ingenuity.).

Radio astronomy is considered by many a "British invention" with pioneers in Cambridge and Manchester amongst others. It is certainly a scientific discipline whose early development was led by British scientists, especially here in Cambridge at the MRAO (https://en.wikipedia.org/wiki/Radio_astronomy). This is undoubtedly helping inspire new generations of brilliant and talented engineers, physicist and astronomers across the country. The history of MRAO is full of groundbreaking discoveries and world class research (https://www.astro.phy.cam.ac.uk/about/history). In a few lines one cannot start to make justice to this story, portrayed in history of science books (e.g. https://books.google.co.uk/books/about/The_Early_Years_of_Radio_Astronomy.html?id=v2SqL0zCrwcC&redir_esc=y), countless public talks (e.g. https://talks.cam.ac.uk/talk/index/7600) and science museums (e.g. https://www.sciencemuseum.org.uk/objects-and-stories/astronomy-and-cosmology) across the country and beyond.

4. Research Compatibility

The EMI environment (aka radio spectrum for our purposes) is an ever-changing resource. Below, we show a plot of this environment taken a few years ago at the MRAO Lords Bridge site at frequencies below 500 MHz. This clearly shows some bands that are clean (or cleaner), and some bands contaminated. It is extremely important to understand that this is a snapshot of a situation constantly evolving in time at cadences from seconds to minutes to hours, days, weeks, etc. In radio astronomy, we constantly need to deal with EMI or Radio Frequency Interference (RFI) as we call it. We deploy systems and techniques to either detect and flag (usually to be discarded at some point) contaminated frequency bands, or to equalize the effect of the contamination, depending on how much knowledge of it we have and its nature. As communication systems move to the digital domain (e.g. TV or radio) the nature of the contamination (frequency bands, power levels, etc) change. At the MRAO we aim to leverage a relatively clear existing EMI environment for our research. We adapt our observations when needed and we find workarounds when possible. Typically, knowing specific channels of contamination is the easiest thing to deal with. In other words, wideband noise is our biggest enemy. Knowing that some narrow channels are contaminated, perhaps during only a period, and perhaps only in a certain polarization of the wave, provide us the ability to operate our instruments effectively.

Furthermore, the radio astronomy science done at the MRAO has changed its use of the spectrum all the time since the early days. This is not only because RFI was appearing at certain bands, but also, and most importantly, because the most interesting science required observations at different frequencies. These frequencies have sometimes gone up, typically enabled by modern radio technology, but also sometimes have gone down in frequency. For example, to the MHz regime, where we aim to exploit a particular radio emission from hydrogen to study the infant universe. While ultimately we may need to deploy instruments in far remote locations (where RFI is even lower), the use of the MRAO as a deployment site requires of a radio-quiet spectrum.

In summary, when trying to “protect” a world-class radio observatory like the MRAO, one can not only look at the observation frequencies of the telescopes in operation at a given time but needs to look at the higher-level picture. We therefore come out with requirements (in line with the specifications and standards from the ITU) across large frequency bands, where we expect the science to take place over the next few decades. Otherwise, in the presence of new, permanent, wide-band noise, such as the one that may be introduced by an installation such as the EW rail project, the operations at the observatory would be at risk.

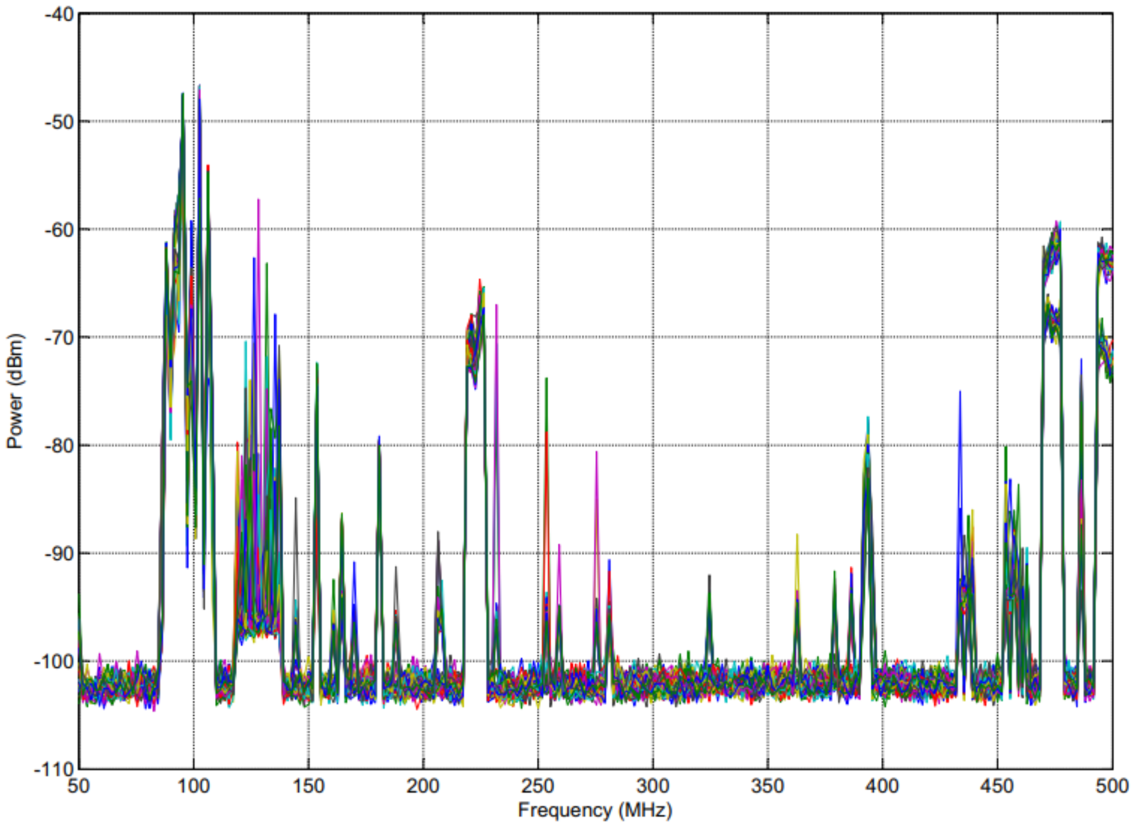


Figure B1. Plot of the EMI environment at the Observatory for frequencies up to 500MHZ.

In the following pages we provide a description of some of the active instruments on site as an example. As described above, this is just a snapshot in time. The observatory continues development (as it has done until now) based on where the science takes it.

Figure B2 - Plan of the observatory and equipment locations (google maps)

Name: Square Kilometre Array (SKA)	
Plan Location: Plan Location A	Date of Installation: 2011, 2015, 2019, 2022
Description: *Phased arrays with 64 and 16 elements each. 2 m tall aerials.*	
Sensitivity: EMI	Frequency Range/Compatibility Requirement: 50-350 MHz
Whether equipment is sensitive in specific directions, and specification: Equipment is sensitive in all directions (widefield instrument)	
Current Research Being Undertaken *These arrays are currently used to develop calibration techniques for the full SKA system in Western Australia.*	
Anticipated Research in the early 2030s and beyond: Aerials will be replaced with new designs. Arrays for SKA Phase II will be built as well.	

Name: AMI Small Array	
Plan Location: Plan Location B	**Date of Installation:** Early 2000s
Description: *10 element dish array inside enclosure (no ceiling)*	
Sensitivity: EMI	**Frequency Range/Compatibility Requirement:** 12-18 HGz
Whether equipment is sensitive in specific directions, and specification: Sensitive in all directions (depending on where the dishes are pointing to), but partially protected by the enclosure walls.	
Current Research Being Undertaken: *Use as a monitor of transient events in the sky.*	
Anticipated Research in the early 2030s and beyond: Unclear at the moment. Transient studies is the most likely application then.	

<table>
<tr><td colspan="2">Name: AMI Large Array</td></tr>
<tr><td>Plan location: Plan Location C</td><td>Date of Installation: Early 2000s</td></tr>
<tr><td colspan="2">Description:

8 dishes, 15.6 m in diameter</td></tr>
<tr><td>Sensitivity:

EMI</td><td>Frequency Range/Compatibility Requirement:

12-18 GHz</td></tr>
<tr><td colspan="2">Whether equipment is sensitive in specific directions, and specification:

All directions according to pointing of the aerials.</td></tr>
<tr><td colspan="2">Current Research Being Undertaken

Use as a monitor of transient events in the sky.</td></tr>
<tr><td colspan="2">Anticipated Research in the early 2030s and beyond:

Use as a monitor of transient events in the sky.</td></tr>
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<table>
<tr><td colspan="2">Name: COAST Bunker</td></tr>
<tr><td>Plan Location and Coordinates:

Plan Location D

52° 09’ 49.4” N

0° 02’ 26.3” E</td><td>Date of Installation:

Circa 1990, as part of the infrastructure needed to house the optical delay lines and correlator for the Cambridge Optical Aperture Synthesis Telescope.</td></tr>
<tr><td colspan="2">Description:

This is a laboratory building, covered with an earth berm, and with approximate external dimensions of 25m x 10m. The long axis of the building is oriented North-South. The bunker is at ground level.</td></tr>
<tr><td>Sensitivity:

Ground vibrations</td><td>Frequency Range/Compatibility Requirement:

Vibration Criterion D (VC-D)

The experiments now undertaken in the COAST bunker are most sensitive to ground vibrations in the 0.1-200 Hz frequency range

One of our current projects requires continuous stable periods of up to 48 hours

Other experimental tests of equipment usually run for shorter periods (2-8 hours) and so can normally be scheduled to be run during “quiet” periods, e.g. at night time or early mornings.</td></tr>
<tr><td colspan="2">Whether equipment is sensitive in specific directions, and specification:

The COAST Bunker is sensitive to all sources of ground vibration, from all directions</td></tr>
<tr><td colspan="2">Current Research Being Undertaken:

The COAST bunker was decommissioned for use as part of the Cambridge Optical Aperture Synthesis Telescope in the mid 2000s but since then has been used as a thermally and seismically quiet laboratory space where optical instruments for astronomical telescopes are characterised and tested. These instruments (and their testing set-ups) typically employ interferometric methods, and so require vibrationally-stable laboratories for their testing to take place.

The large size of this space (25m × 5m) allows for very large instruments and test assemblies to be validated: such a large stable environment is not available in the main Cavendish site.

Currently there are two projects that use the COAST bunker as a vibration-quiet laboratory space. The first of these is collaboration between scientists at the MRAO and staff at the New Mexico Institute of Mining and Technology (NMT) in the USA to design, construct and test the world’s largest imaging synthesis telescope operating at optical/near infrared wavelengths. The collaboration to design this telescope (the Magdalena Ridge Observatory Interferometer) has been ongoing since 2003, and is currently supported by a 4.5 year $3.7M contract extending to Q4</td></tr>
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2026. Should the demonstrator telescope under construction perform as expected, NMT anticipate bidding for an additional $100M to complete the array over a subsequent 5-7 year period. Were that to happen, MRAO researchers would expect to secure an additional $7M-10M of grant funding to deliver/upgrade hardware components to the array. A second project, currently supported by a £1M grant from the EPSRC, that exploits the COAST bunker is focused on designing and prototyping a 2d optical lithographic engine capable of patterning substrates with nm-level accuracy over metre-sized substrates. The rationale for such an instrument is to overcome the current impasse in making large echelle diffraction gratings, where there exist only a single manufacturer worldwide that can produce gratings over 0.2m in size, and none which can fabricate metre-sized gratings. Our current grant extends until Q4 2025, but we anticipate a further 3 years of work will be needed to confirm an appropriate level of performance. The scale of funding needed for that further development would be or order £2M-4M.
Anticipated Research in the early 2030s and beyond: It is difficult to anticipate the needs of the astronomical community beyond 5 year timescales, as the desire for future instrumentation is contingent on the discoveries that will be being made over the next 5 years. What is clear, though, is that the development of instrumentation for the currently planned next-generation of ground-based telescopes is a strategic theme of the Cavendish Astrophysics Group, and so we anticipate needing VC-D stability for at least the next 5-10 years.

Name: 32-m e-Merlin dish

Plan Location and Coordinates: Plan Location E

Date of Installation: 1990

Description:

The e-MERLIN telescope at Lords Bridge, Cambridge is a high performance, high sensitivity 32m diameter radio telescope operated by The University of Manchester as part of e-MERLIN on behalf of the UK Science and Technology Facilities Council for radio astronomy research. e-MERLIN combines signals from 7 radio telescopes across the UK, with a maximum separation of 220km in order to produce high resolution radio images of a wide range of astrophysical objects and phenomena from nearby stars to the most distant galaxies and quasars. Crucially, this telescope provides the maximum separation in the e-MERLIN array and hence the most resolution.
See www.e-merlin.ac.uk

Sensitivity:

EMI

Frequency Range/Compatibility Requirement:

Currently: 1.25-1.75 GHz, 4-8GHz, 18-24 GHz. Future plans would also cover 2-4 GHz and 8-16 GHz.

Whether equipment is sensitive in specific directions, and specification:

The 32-m telescope is fully steerable and is used to observe objects all over the sky including those at low elevation (down to 2 degrees above the horizon). It is used 24hrs/day and up to 365 days/year, except for any maintenance activities. The thresholds for harmful interference should be based on ITU-R RA.769-2, which forms an internationally accepted definition of harmful interference to radio telescopes. Since the telescope can also be used in single dish mode, compatibility calculations should be made on that basis. Compatibility calculations should include out-of-band emission and unintended electromagnetic radiation coming in to protected radio astronomy bands (eg 1400-1427 MHz).

We stress that radio telescopes are extremely sensitive (they are equipped with cryogenic receivers) and are routinely used to detect extremely faint signals, often using long integration times. We routinely and frequently study objects fainter than 1E-29 W/Hz/m^2 and our most sensitive observations can be 100x below this.

Current Research Being Undertaken:

e-MERLIN is used by hundreds of researchers across the UK and around the world, including almost all UK university astrophysics groups for a wide range of science projects including planet formation around nearby stars, star formation and evolution, galaxy formation and evolution, cosmology including dark matter and dark energy via weak gravitational lensing observations, and fundamental physics. It is also used for bi-static radar observations of asteroids, satellites and space debris including contributions to NATO research task groups.

e-MERLIN is a UK National Facility and provides a world-leading unique capability for high resolution radio astronomy. It is also part of the European VLBI Network which combines all e-MERLIN telescopes with 10-15 of the largest radio telescopes in Europe, Asia and South Africa to provide milli-arcsecond resolution. (see www.evlbi.org)

e-MERLIN is operated by the University of Manchester on behalf of UKRI-STFC. STFC are the principal funders. The total capital investment in e-MERLIN would be >~£40m, not including the 76-m Lovell Telescope at Jodrell Bank. The current annual operating costs exceed the STFC

contribution of £2.7m/yr. e-MERLIN has operated since 1980 and the Cambridge 32-m telescope was added in 1990. Current operational funding is typically provided on a 5-yr rolling contract.
Anticipated Research in the early 2030s and beyond: We are currently developing a (~£50m) proposal to extend e-MERLIN by adding multiple smaller dishes across the UK. This would greatly increase the sensitivity, resolution, imaging capability and flexibility of e-MERLIN. This project has been positively reviewed by STFC and we await further decisions on funding. If supported this would create a major UK facility for high resolution radio astronomy, space weather monitoring and prediction, and space situational awareness from ~2030 for another 20+years.

Name: REACH antenna	
Plan Location: 150 m south of plan Location D	**Date of Installation:** Q1 2025
Description: *30 x 30 m aerial, 2 m tall.*	
Sensitivity: EMI	**Frequency Range/Compatibility Requirement:** 10-250 MHz
Whether equipment is sensitive in specific directions, and specification: Yes, all directions.	
Current Research Being Undertaken: *Attempting a detection of the 21-cm line from cosmic hydrogen averaged across all directions of the sky.*	
Anticipated Research in the early 2030s and beyond: Unclear.	

Name: SKA MFAA array	
Plan Location: Plan Location G	**Date of Installation:** Circa 2015
Description: Small array prototype useful for early developments for SKA Phase II	
Sensitivity: EMI	**Frequency Range/Compatibility Requirement:** 300-1500 MHz
Whether equipment is sensitive in specific directions, and specification: All directions	
Current Research Being Undertaken: *Engineering prototype*	
Anticipated Research in the early 2030s and beyond: The plan is to it make it larger to make it a transient detector.	