THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY
IN AUSTRALIA. 9: THE UNIVERSITY OF TASMANIA’S LLANHERNE
(HOBART AIRPORT) FIELD STATION DURING
THE 1960s–1980s

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Abstract: Beginning in the early 1960s, the University of Tasmania became very involved in low frequency radio
astronomical studies, which was to continue into the 1980s. Although important low frequency arrays were set up at
Penna and Richmond, the main location for this activity by the University was in the vicinity of Hobart Airport, known
as Llanherne. This paper describes the work performed there at frequencies of 30 MHz and below, mainly for
studying radio emission from Jupiter and the Galaxy. The largest of the installations was the Llanherne Low
Frequency Array, a ~640 × 640 m antenna array adjacent to Holyman Avenue; it was well known to the public
because of its high visibility to airport patrons. Other installations were set up closer to the airport runway. Various
researchers, including Graeme Ellis, Hilary Cane and others, made observations at Llanherne.

Key Words: Radio astronomy, Tasmania, Llanherne, low frequency arrays

1 INTRODUCTION

Prior to 1960, several researchers in the field of
low frequency radio astronomy had produced
results, with Australian work being quite signifi-
cant (see, e.g., Higgins and Shain, 1954; Shain,
1951; Shain and Higgins, 1954; Orchiston et al.,
2015a; 2015b). The CSIR (later CSIRO) Divi-
sion of Radiophysics maintained many field sta-
tions, mostly in the Sydney area, beginning in
1946 (see, e.g., Orchiston and Slee, 2017; Rob-
erton, 1992).

However, radio astronomy at low frequencies
is hampered considerably by the absorption of
radio waves by the Earth’s ionosphere; a fre-
quency of approximately 10 MHz is often taken
to be the lower frequency limit under typical
ionospheric conditions.

Graeme Ellis made extensive ionospheric
studies and measurements in Tasmania during
the 1950s both as part of his role with Australia’s
Ionospheric Prediction Service and toward his
Ph.D. degree (Ellis, 1955). His work attracted
the attention of Grote Reber, who had construct-
ed the world’s first purpose-built radio telescope
in the 1930s in Wheaton, Illinois, and continued
his radio astronomy studies. By the 1950s
Reber had turned his attention to low frequency
radio astronomy.

Observations at frequencies less than about
10 MHz become increasingly difficult with de-
creasing frequency. The best conditions occur
when there is the least amount of ionisation: at
solar minimum, at winter, and at night.

Data collected by Reber from many locations
around the world, including those obtained from
Ellis in Tasmania, showed that Tasmania would
be one of two ideal locations for low frequency
radio astronomy, with a lower frequency limit for
transmission of radio waves (foF2) there dropping
to below 2 MHz under ideal conditions (Ellis, 1954). Tasmania is said to be under a ‘mid-
latitude trough’ where the ionospheric ionisation
is relatively quite weak; the other such location
is in the region of the Great Lakes in North
America.

Observations from Cambridge in Tasmania
in 1955 by Reber and Ellis shortly after a deep
solar minimum revealed that it was sometimes
possible to observe down to approximately 1
MHz (Reber and Ellis, 1956). Of relevance to
the Galactic observations at Llanherne with the
Llanherne Low Frequency Array and the 1.6-
MHz array in the mid-1970s and mid-1980s,
respectively, are the solar minima of 1976 and
1986.

Ellis left Tasmania at the end of 1956 to take
up a post in Queensland and subsequently one
in New South Wales. It was on his return to
Tasmania in 1960 as Chair of Physics at the
University of Tasmania that radio astronomy,
in particular low frequency radio astronomy,
blossomed at the University.
The 1960s saw arrays set up by the University at Richmond (George et al., 2016) and Penna (George et al., 2017a), and by Grote Reber near Bothwell (George et al., 2017b). However, it was at the site called Llanherne, in the vicinity of Hobart Airport, that the most extensive work was performed.  

Beginning in the very early 1960s, several arrays and other instruments were set up at the Llanherne site, leading to extensive studies of, in particular, the Galaxy, Jupiter, and the Sun. For the purpose of describing the instrumentation and work performed at Llanherne, this paper is broadly divided into two locations: the site of the Llanherne Low Frequency Array—by far the largest array set up at Llanherne—and the site 1.4 km to its east, much closer to the airport runway and the site of several other installations. In this paper we shall describe these as the ‘Western Site’ and the ‘Eastern Site’ respectively, and the Llanherne Low Frequency Array as the LLFA.

It should be noted that the observing locations mentioned in the various research papers were quoted to low precision and were not accurate. In addition, the location name is often simply given as ‘Hobart’. In this paper, longitudes and latitudes are based on the WGS84 datum and measured from recent Google Earth aerial images.

A fixture at the Eastern Site that almost certainly predates the University’s radio astronomy activities at Llanherne was a hut originally used by the Ionospheric Prediction Service (IPS). It was located at longitude 147° 30’ 42°.94 east, latitude 42° 50’ 35°.24 south (WGS84). This was one of two IPS sites in this vicinity; the other was the site adjacent to Acton Road, to the west of the future location of the LLFA, and which was used by Grote Reber and Graeme Ellis in 1955 for their first observations together (George et al., 2015a; Reber and Ellis, 1956).

This paper covers radio astronomy work at frequencies of up to 30 MHz, but mention also is made of the so-called ‘High Frequency Array’, and a 14-m diameter paraboloidal antenna, both of which were used at the Eastern Site.

The University of Tasmania was also involved, at Llanherne and at other sites, in the study of micropulsations and other geomagnetic phenomena, but as these are not within the scope of this study they are not discussed in detail here.

Figure 1 shows the location of Llanherne and other key radio astronomy sites in Tasmania, and Figure 2 shows a 1973 aerial view of the entire Llanherne site.

2 BIOGRAPHICAL NOTES

It is recognised that the contributions of very many people were important in ensuring the success of the installations and research at Llanherne. In this section, we have selected three people who feature in this paper.

2.1 Graeme Ellis (1921–2011)

Graeme Reade Anthony Ellis (Figure 3) was born in Launceston, Tasmania, in 1921. He was often called ‘Bill’, a name used by his sister in childhood.

After serving in WWII, Ellis completed an Honours Degree in Physics at the University of Tasmania in 1949. He completed a Ph.D. (Ellis, 1955) while working as a Senior Officer with the Ionospheric Prediction Service.

Ellis’ work with Grote Reber in 1955 began a long-term interest in low frequency radio astronomy. After a period of absence from Tasmania, his 1960 return as Chair of Physics at the University of Tasmania began a period of significant research in the field. In particular, his radio astronomy work involved observations of Galactic radiation and radio bursts from the planet Jupiter.

Ellis continued his strong interest in the ionosphere, a subject related to radio astronomy because of its poor transmission at low frequencies.

For many years Ellis lectured in physics at the University of Tasmania, and supervised many B.Sc. Honours and Ph.D. students.

In 1963 Ellis was awarded the Lyle Medal by the Australian Academy of Science, and elected a Fellow of the Academy in 1965. In 1984 he
was honoured when made an Officer of the Order of Australia (AO).

A longer biography of Graeme Ellis appeared in an earlier paper in this series (George et al., 2015b).

2.2 Peter McCulloch

Peter McCulloch (Figure 4) completed a B.Sc. Honours Degree in Physics at the University of Tasmania in 1962, this being only the second year in which Graeme Ellis supervised Honours students. Continuing his interest in radio astronomy, over the following several years he made intensive studies of radio emissions from Jupiter and the Sun, culminating in his 1968 Ph.D. thesis (McCulloch, 1968).

McCulloch made a major contribution to the work on the binary pulsar PSR B1913+16. He designed and built equipment that was used on the Arecibo Radio Telescope in Puerto Rico to test Albert Einstein’s prediction of the existence of gravitational radiation. This equipment was in use on the telescope by March 1979, and the results indeed confirmed Einstein’s prediction; the equipment was used for several more years. The work led to Russell Hulse and Joseph Taylor being jointly awarded the Nobel Prize for Physics in 1993.
Among many other significant contributions to radio astronomy, he has performed significant work on the ‘glitches’ in the rotational period of the Vela Pulsar, and was a member of the team that discovered the first pulsar, PSR 0529-66, in the Large Magellanic Cloud.

For many years, McCulloch taught Physics at the University, beginning as a tutor around 1970 and becoming Professor in 1994. Although having retired in 2002, he continues his work as Emeritus Professor. He is often seen in the University’s School of Mathematics and Physics and, of course, at the Mount Pleasant Radio Observatory near Hobart, the site of the 26-metre radio telescope.

### 2.3 Hilary Cane

Hilary Cane (Figure 5) obtained a B.Sc. Honours Degree in Physics at the University of Tasmania in 1970 and was a key researcher on the LLFA (see Cane, 1975; Cane and Whitham, 1977). Her main work at Llanherne was the assembly of low frequency radio maps of the Galaxy, preceded by a paper on the Gum Nebula (Cane, 1973).

After completing her Ph.D. in 1977, supervised by Graeme Ellis, Cane was employed at the Dominion Radio Astrophysical Observatory in Canada to study low frequency emission from the Galactic polar regions. Later she worked at the Laboratory for Extraterrestrial Physics at NASA’s Goddard Space Flight Center in the USA. There, she made use of data from the International Sun-Earth Explorer 3 spacecraft (ISEE-3) to study very low frequency solar radio bursts. She discovered intense, long-duration Type III radio bursts associated with major solar eruptions (Cane et al., 1981); this was an interest that she maintained for many years. In the 1980s Cane also worked at NASA’s Laboratory for High Energy Astrophysics, where she worked on Galactic and solar particle data obtained by the Interplanetary Monitoring Platform 8 (IMP-8) spacecraft.

In the late 1980s Cane returned to Tasmania, where for many years she worked with husband William Erickson on Bruny Island, establishing the Bruny Island Radio Spectrometer, designed to study low frequency radiation from the Sun (Erickson, 1997).

Cane has continued to be a prolific author and co-author of papers relating to the Sun, the solar wind, cosmic ray modulation and related topics.

### 3 INSTRUMENTATION AND OBSERVATIONS

#### 3.1 The Western Site: The Llanherne Low Frequency Array

The Llanherne Low Frequency Array (LLFA, Figures 6 and 7), which was occasionally called the ‘Ellis Array’, was by far the largest and most prominent radio astronomy installation at Llanherne, and was located at the Western Site. The completed array was approximately square, had 64 rows of east-west dipoles, and had dimensions of 2000 × 2000 ft (610 × 610 m) (Ellis, 1972a).

Other references (e.g., see University of Tasmania, 1969) quote an earlier plan to build the LLFA to the larger dimensions of 2500 × 2500 ft. The initial intention was that it would be used at frequencies of from 5 MHz to 50 MHz (University of Tasmania, 1967). The array was used at frequencies from about 2 MHz to 35 MHz, although principally below 20 MHz, mainly for mapping the radio sky, recording Jupiter radio bursts, and performing ionospheric work.

The Eastern Site at Llanherne had already been in use for several years for low frequency radio astronomy work (see Section 3.2), but the desire for the construction of an array the size of the LLFA necessitated the use of a large plot of land. The receiving hut of the chosen location, on private land owned by Mr George Casimaty, was at longitude 147° 29′ 41.24 E and latitude 42° 50′ 32.56 S; it was 1.4 km to the west and 80 m north of the IPS hut at the Eastern Site.

The array was immediately adjacent to Holyman Avenue (the road leading into Hobart Airport from the Tasman Highway).

#### 3.1.1 Construction and Maintenance of the Array

One of the earliest people to become involved in the LLFA project was Raymond Haynes, who was working on his B.Sc. Honours project at Grote Reber’s Bothwell Array in 1965 (Haynes, 1966). He was told by Graeme Ellis late in that year that he should start his Ph.D. straight away.

Bill [Ellis] proposed that he was going to get a
large grant, without yet having got the large grant, and he proposed to build the Llanherne array ... So he presented this project and I initially said yes, [that] I would be quite interested in working on this new array. But nothing had been done on the design of it at all, except that the principle was that he wanted to broaden the bandwidth of it; he didn’t want it to be narrow band like [the low frequency array at] Penna had been. (Raymond Haynes, pers. comm., 2018).

The Penna Array had been in operation for several years and was used primarily to map the radio sky at 4.7 and 10.02 MHz (George et al., 2017a). To become more acquainted with the radio astronomy that had been in progress at the

Figure 6: Aerial photograph of the LLFA attributed to Vern Reid (after Cane, 1979: 218).

Figure 7: Poles of the LLFA, looking west (courtesy: Estate of Grote Reber).
University, and to prepare him for work on the LLFA, Haynes visited the Penna Array in order to examine its operation in about September 1965 (during his Honours year) and learned more about antenna arrays through these visits and advice from Philip Hamilton (ibid.). Later, he would make important use of the Penna Array (George et al., 2017a).

Although Haynes worked on the design for the LLFA, his association with the project was not long-lived:

[In 1966] we did in the end come up with some sort of design which I recommended … [but] I realised that there was no way I was going to get a Ph.D. out of this Llanerne Array … The money for this array was coming from the Australian Research Council, and was going to come in one-yearly lump sums, for five years—beyond my Ph.D. time. So I had no choice … I moved up in frequency to around 50 megacycles to about 300 megacycles and I spent about six months perfecting these antenna designs, but [then I was] making feeds to go on the Parkes Telescope. (Raymond Haynes, pers. comm., 2018).

Philip Hamilton (pers. comm., 2007) was also connected with the design work, although he never actually used the array

Construction of the LLFA began in 1967 (University of Tasmania, 1967); it was completed in 1972, which became its first year of operation (University of Tasmania, 1972).

George Casimaty ran the site as a farm, and arrangements through an annual lease agreement were made to erect the LLFA there with the stipulation that the sheep could still graze on the site. Casimaty’s son Greg recalled (pers. comm., 2016) that

It was always part of the farm, and I remember that Dad was really happy about it because they paid him—I can’t remember how much—to actually do it, and we still had full grazing rights over it.

Access to the site was through the area where the airport hangars were located, and there was a road that allowed them to get to the array; this ran along the side of a nine-hole golf course.

Barry Wilson, who joined the Physics Department at the University in May 1969, recalled that at that stage, “… about a quarter of the work …” to build the array had been done. He immediately became involved in the construction work:

We used to have drums of copper wire, which were extremely heavy, and we used to have them at one end, and just drag [the wires] to the other end. We’d pull the wire along the ground then put it up on the crossarms and tie it to the insulators. After we’d done that we went along and put these little transformer things in, which I suppose set the wavelengths. (Barry Wilson, pers. comm., 2007).

Interestingly, the choice of dipole design was made empirically, by testing impedance matching and investigating radiation patterns; a small dipole array was built to observe sources as a final test. The dipole design chosen (Figure 8) was a three-wire dipole with the wires in a vertical plane between 15 and 20 feet (between 4.6 and 6.1 m) above the ground (Ellis, 1972a). The transmission lines, which formed the ground screen, were 7 feet (2.1 m) above the ground, allowing sufficient room for people (and sheep) to walk underneath them unless they sagged.

As with other radio astronomy installations—notably the array at Penna—students often were used (particularly during the summer holidays) in the construction of the array.

When I first started there [the golf course] caused problems with the students, because the fellow that was working there before used to let them play golf during the day, and I wouldn’t let them do it. (ibid.).

Philip Whitham (pers. comm., 2012) recalled working on the array beginning at the end of his first year at University in 1968, and performing this work during “… almost all vacations.”

At an early stage during the construction, the plan was to use an ex-army ‘Blitz’ truck to attach the wires to the array. This vehicle had also been used in the construction of the Penna array (George et al., 2017a). However, Kevin Parker, who had been employed by the Physics Department since 1961 but who had little involvement with the LLFA, recalled a Nissan vehicle (Figure 9):

They pensioned off the old Blitz and they bought a Nissan Patrol thing, and used to use that. Because driving around, they needed a 4-wheel drive. The old Blitz was very heavy, and it was only a 2-wheel drive, so it was hopeless in some of those situations. (Kevin Parker, pers. comm., 2009).

Parker recalled that to lay out the wiring, one person would drive and another would stand on the back of the vehicle.

The copper wire used to come on drums about that size, and we had these stands that they used to sit on. We’d just very slowly drive up. [The Nissan vehicle] had a hand throttle
on it. Quite often you could just walk along beside it. [The drums were not carried on] the vehicle. We were pulling the cable[s]; up to 5 or 6 of them. The drums were at one end [of the array]. The work stopped only when it was pouring with rain. But there was not a lot of time lost. But it did get so bad that there was a lot of water. There were one or two drainage ditches... and that did help. If it got too bad we used to dig other drains into it. (ibid.).

The ground was often very wet (Figure 10), this was a suitable condition for radio astronomy, but it caused problems both during the construction of the array and during its use, and was the main reason for the need for a more suitable vehicle (the Nissan). In 1974 the area was badly flooded, and it filled the entire basin with water. My father came out here. He bogged the tractor, he bogged the bulldozer, and he ended up getting the sheep in a dinghy with a seagull on the back.

There were just a couple of high spots that they were stranded on. (Greg Casimaty, pers. comm., 2016).
It was not uncommon for repairs to be necessary. Philip Button (pers. comm., 2009), who joined the Department in 1971, recalled that sometimes you’d get four or five poles in a row that would break and [they would be] swaying in the breeze, and they would be held up by the actual antennas ... It was caused by soggy ground, mainly, but the poles weren’t treated, and they just rotted off at the ground level. Occasionally Prof used to go out there before coming in to work, and he’d say to me ... "There’s three poles in a row. Get out there [and fix them]." ... I’d get my gumboots because there’d be that much water.

The sheep occasionally caused problems:

The problem was that a lot of the wires were sagging. The ground was very marshy, and the poles tend to sag and fall over and occasionally rot. And the lease arrangement with the farmer was that the farmer could still run his sheep on there. And sheep are not very bright, so they’d walk along, until they got caught— and the they go caught en masse as sheep do in a wire: they’d walk in the same direction. They would effectively pull down a whole row of dipoles. And someone, Gordon [Gowland], presumably, or Phil [Button], would have to go out there and sort the lot out and re-string them up again. (Richard Ferris, pers. comm., 2011).

Greg Casimaty (pers. comm., 2016) recalled that The University never complained about [people] walking across the land. To my recollection, the wires—the lowest ones—would have been 6 foot off the ground. Once [in 1975] I went through on my motorcycle, and for some unknown reason I saw a single wire that had dropped below the 6-foot level, and it just clipped the top of my helmet.

The LLFA’s eventual quoted frequency range was ~2 MHz to 20 MHz (Ellis, 1972a). It used a ‘Christmas tree’ feed, and at the equipment building [the hut in the centre of the array; see Figure 11], the signals from each east-west line are combined in different phase relationships to give beams in the meridian. Four simultaneous beams are available, each of which can be moved independently of the others, from 63° north to 62° south of the zenith. (ibid.).

The main work performed with the LLFA was during the 1970s (see Section 3.1.2). By the early 1980s, the array had fallen into disuse and was in a very poor state of repair.

Philip Button recalled a partial dismantling of the array that took place, and that it took four or five months over a summer.

It got to the stage when half the antennas had come down because the wires had snapped and the poles were broken. We removed the whole lot except for the phasing system, but half of that had to go because we only [needed] 32. (Philip Button, pers. comm., 2009).
This recollection that “... we only [needed] 32 ...” referred to the decision to have 32 rows of dipoles instead of 64. According to Button (ibid.), the site would no longer have an array of the original size, but a ‘new’ array was constructed on the site with a quarter the original area. However, this smaller version of the LLFA was short-lived:

We rebuilt the low frequency array, and I think if they used it for 12 months, that would have been ‘it’ — for all the effort that we put in, and all the money that was spent. [Afterwards], Pip [Philip Hamilton] said “You’re going to work for me now, so you’re going to have to start learning about computers”. (ibid.).

The timing of the partial dismantling to which Button referred is not clear, but it is likely to refer to the work performed by John Hudspeth for a Ph.D. project on Z echoes during 1977:

At the time of the [Z echoes] investigation the array was not in use, was in inoperable condition and deteriorating at a fast rate. Over a period of six months I carried out a massive repair program which brought the array into satisfactory operating condition. I estimated that it would not be possible to hold the array in this condition for more than six months. (Hudspeth, 1982).

Eventually, the array was dismantled. Based on a very low-resolution aerial photograph taken in 1983 (not reproduced here) and comments by Graeme Ellis (1985) this took place in the early 1980s, and certainly before 1985. Philip Hamilton (pers. comm., 2007) commented that at the time he took over as Head of the Physics Department about 1982, available ongoing operational funding for the LLFA was only about half of that needed to keep it running. Hamilton visited Max Brennan, who was Chair of the Physics Panel of the Australian Research Grants Committee, 3 to discuss this situation. As a result of that meeting, and partly because the solar activity in the 1970s had not bottomed out enough, he decided it was not worth continuing to try to operate the array.

Barry Wilson (pers. comm., 2007) recalled that they made a device for the back of the Nissan vehicle with a power winch to use in pulling out the star pickets. However, George Casimaty was also quite involved in the dismantling process:

My father bought a backhoe—an old Massey-Ferguson backhoe, that I’ve still got—and the sole purpose of that was to pull the poles out, and pull all of the steel posts out that were driven in as stays or whatever. There were hundreds and hundreds of them. (Greg Casimaty, pers. comm., 2016).

The only pieces of evidence of the LLFA today (2018) are the crumbling remains of the hut, the bases of some of the poles (which were left in the ground during the dismantling process), some insulators, and some scraps of wiring:

We still, after all these years, are picking up copper wire that is still spread all over the paddock and when we put sheep in there still, there is always one that gets copper wire wrapped around its legs. (ibid.).

Although the LLFA was located at the Western Site, a second, much smaller, array measuring $80 \times 80$ m and designed to operate with the LLFA as a swept lobe interferometer, was erected at the Eastern Site (see Section 3.2.4).

### 3.1.2 Astronomical Observations with the LLFA

The LLFA was primarily used for Galactic and Jupiter studies, although at the upper end of its frequency range it also was used to make solar observations.

Initial testing by Ellis included the frequency distribution at declination $-43^\circ$ (the latitude of the array, hence the declination at the zenith) (Figure 12), and recording of the radio source Centaurus A (Figure 13).

Not long after the completion of the array, it was used by B.Sc. Honours student John Hudspeth (1972) for ionospheric studies (see Figure 14). His aim was to investigate travelling ionospheric disturbances, and he found that there were indeed “… electron density motions with...
quasi-periods of 10 to 30 minutes.” (ibid.)

One of the earliest astronomical observations with the LLFA was of the Gum Nebula, by Ellis (1972c; Figure 15) and Cane (1973; Figure 16). The Gum Nebula is named after Australian astronomer Colin Gum, who discovered the Nebula as Gum 12 (Gum 1952; 1955; 1956). This is a very large and complex emission nebula, extending over about 40 degrees of the sky in the constellations of Vela and Puppis. It includes the Vela Supernova Remnant. The much larger Gum Nebula itself may be a much older supernova remnant, but its origin has been debated (see, e.g., Duncan et al., 1996).

Cane’s major project on the LLFA was to produce low frequency maps of the Galaxy. Maps at frequencies lower than 10 MHz had already been produced by earlier observers (see, e.g., Ellis and Hamilton, 1966a; Reber, 1968), and an important result of these observations was that they led to the conclusion that there existed a layer of ionised hydrogen in the plane of the Galaxy (Hoyle and Ellis, 1963; Ellis and Hamilton, 1966b).

The LLFA was used by Cane (Figure 17), and Philip Whitham, to produce maps of Galactic radiation at the frequencies of 3.7, 5.6, 8.3, 13.0 and 16.5 MHz (Cane, 1975; Cane, 1977; Cane and Whitham, 1977; Whitham, 1979). In addition, Cane in her 1977 thesis produced a comprehensive volume of work on the subject, up to that date, of low frequency surveys of the Galaxy. The half-power beamwidths (HPBW) at the zenith were given as 6.8°, 4.5°, 3.0°, 1.9°, and 1.5° at the five frequencies, respectively (Cane and Whitham, 1977).

These observations were greatly facilitated by Philip Whitham’s involvement. He implemented a new method of recording observations using a Digital Equipment Corporation (DEC) PDP-8/E computer (Whitham, 1975). His paper made it clear that before 1974, the contour maps of the radio sky were produced by hand by interpreting the recordings on paper charts. However, from 1974 the array had the use of not only the new DEC computer, but various other important peripherals including a teletype and two DEC tape drives. Other hardware, including an interface to an X-Y plotter, was designed and built locally. Following the observing runs, the magnetic tapes were analysed by using the University’s Elliott 503 computer.

Cane and Whitham (1977) provided maps for all five frequencies centred approximately on galactic longitude 0° and spanning about 70°; the galactic latitude range was approximately +20° to −20°. Interestingly, as Cane and Whitham commented (ibid.), the absorption features were more obvious at the highest two frequencies (13 and 16.5 MHz).
One of the notable features shown in their observations is the dip in intensity near the Galactic Equator between about 30 and 10 MHz (Cane, 1976). The interpretation given by Cane is that this is due to absorption in a ring of ionised hydrogen about 6 kiloparsecs from the centre of the Galaxy. Indeed, rings and partial rings of material and enhanced populations of stars have been studied by many researchers (see, e.g., Thaddeus, 1991; Xu et al., 2015). The feature is not seen at other galactic latitudes, which strongly supported this identification.

Also beginning in 1972 was another major program of observations using the LLFA: a study of the decametric radiation bursts from Jupiter, which occur in several different types.8 Radio bursts from the planet were first identified in 1955 (Burke and Franklin, 1955). In the 1960s Ellis detected emissions using the Penna Array (Ellis, 1962; George et al., 2017a), and (see Section 3.2.2) at the Eastern Site at Llanherne (Ellis and McCulloch, 1966a).

During the early 1960s it became clear that these bursts were associated with the orbital position of Jupiter’s satellite Io (Bigg, 1964). Other analyses showed that they were also related to Jupiter’s rotational phase—that is, the longitude of Jupiter’s central meridian as seen from Earth.8,10 Ellis began observing Jupiter with the LLFA in February 1972, and the initial results of this work appeared in October of that year (Ellis, 1972b; Figure 18). He presented observations of radio bursts at four distinct frequencies between 4 and 16 MHz. Ellis used four spectrum analysers to record the change of frequency of the bursts with time. Three swept through a range of frequencies, while the fourth had 40 channels operating over the range 8 to 8.1 MHz.

The Jupiter observations using the LLFA ran for several years after their commencement in 1972. The observing method was to capture the information on videotape, which allowed excellent time resolution (Figure 19). It is likely that Ellis developed this method as an adaptation of that described by Dowden and Emery (1965), which was used for spectral analysis of audio signals on audio magnetic tapes. The output from the videotapes was displayed on a screen and then photographed by Susan Blackburn (Graeme Ellis’ daughter) and Philip Whitham in the University’s Physics Department, in a room opposite Ellis’ office (Susan Blackburn, pers. comm., 2018).

As mentioned in Section 3.1.1, there was a considerable amount of maintenance that was necessary in order to keep the array in operation. Ellis’ students had an amusing, if not particularly effective, method of minimising problems:

I remember the ‘chair of physics’. The chair was out at the Llanherne array in the shed. It later moved to Dad’s lab [in the physics building at the University] opposite his office. The chair of physics was nothing fancy. It was this high backed old chair probably from about the thirties—Tasmanian oak with very worn upholstery. It wasn’t even really a joke; the students were quite serious about this. They asked Dad to leave his sports jacket hanging on the chair and that would ensure that there wouldn’t be any major equipment breakdowns. (Susan Blackburn, pers. comm., 2007).
An important result of Ellis’ Jupiter work at Llanherne was the production of An Atlas of Selected Spectra of the Jupiter S-Bursts (Ellis, 1979), for which Susan Blackburn provided major support, with assistance from Philip Whitham (Susan Blackburn, pers. comm., 2007; Philip Whitham, pers. comm., 2012). This 198-page publication (Figures 20, 21 and 22) contains a large number of observations of the S-bursts made between 1972 and 1979. Not all of these were made with the LLFA; some were made with the 80 x 80 m array (see Section 3.2.4) and the High Frequency Array (see Section 3.2.6).

Ellis took a great interest in the theoretical aspects of the mechanisms producing decametric radiation from Jupiter. He noted that the bandwidth of the bursts was narrow, and used this to suggest that, depending on the radiation mechanism, it may be that the extent of the source region of the radiation is less than 100 km. He correctly attributed the radiation to being produced by cyclotron emission from electrons in Jupiter’s magnetic field (Ellis, 1973).

Compared with Galactic and Jupiter observations, there is much less published material in relation to solar observations made with the LLFA. However, McCulloch and Ellis (1977) described observations of solar bursts made with “… a broad-band dipole array …” in 1975 and 1976 in two frequency ranges: 21–24 MHz and 26–29 MHz, which is likely to have been the LLFA (Peter McCulloch, pers. comm., 2018). The observations were recorded on videotape and the oscilloscope display photographed, as had been done with the Jupiter observations.

Their 1977 paper included a comprehensive description of the types of bursts that had been recorded, including split pairs—which had been noted much earlier from observations at the Eastern Site (see Section 3.2). Of note was the observation, which they claimed was the first in this frequency range, of ‘fork bursts’, which had been observed by Zaitsev and Zinichev (1974) in the higher frequency range of 96–112 MHz. Both pairs of authors noted that the fork bursts could take two forms, each form starting with a single element (i.e. a single line in the frequency-time plane).

Low frequency solar observations that were made at the Eastern Site are mentioned in Section 3.2.

Finally, there is a brief record of pulsar pulse profiles being measured using the LLFA, but only one reference to this has been located (University of Tasmania, 1974). Robert Allen, who began a Ph.D. degree in 1971, was involved in this study (Hilary Cane, pers. comm., 2018). Allen’s main work was conducted with the Molonglo Aperture-Synthesis Telescope and it must be noted that at Llanherne, pulsar observations were a major purpose of not this Array, but the High Frequency Array (see Section 3.2.6) and the 14-m paraboloid (see Section 3.2.8.3).
3.2 Installations and Astronomical Observations at the Eastern Site

Unlike the Western Site, the Eastern Site was the location of several different instruments. Figure 23 shows the location of some of these.

3.2.1 Waterworth’s Galactic Observations

Michael Waterworth (1940–2014), later well known for his work in optics and optical astronomy, undertook his B.Sc. Honours Degree in Physics in 1961 (Waterworth, 1962). This was shortly after the appointment of Graeme Ellis, who was his supervisor. In his only known published foray into radio astronomy, Waterworth made observations at 4.85 MHz between July 1961 and January 1962, and at 9.7 MHz from August 1961 until January 1962, resulting in chart recordings of parts of the southern sky at these frequencies. The antenna pattern had a half-power beamwidth of 30° (N-S) and 50° (E-W) and was aimed at the zenith, so the central declination was -42° 51′.

In each case Waterworth used a small array of three pairs of dipoles, which he described as electrically identical for the two different frequencies, apart from the halving of the lengths of the dipoles for the 9.7 MHz measurements. The dipoles were supported at one end by attaching them to Oregon poles driven into the ground, and at the other end a supporting wire was run over a pulley to avoid sagging of the dipoles (Figure 24).

Waterworth’s receiving equipment was kept in the building known as the IPS Hut, mentioned in the introduction to this paper and whose position is shown in Figures 2 and 23. Figure 25 shows the interior of the hut, including the chart recorder in the foreground of the image.

In 2008 an identical chart recorder was donated by the University to the Queen Victoria Museum in Launceston (Figure 26). This may have been the actual device used by Waterworth, and is labelled ‘No. 1’.

Waterworth’s results were an important early contribution to low frequency Galactic studies in Tasmania, and were combined with observations at still lower frequencies in a one-page Nature paper the following year (Ellis, Waterworth and Bessell, 1962).
Building considerably on these early Tasmanian radio observations of Jupiter, Ellis and McCulloch (1966a) reported work at 4.7 MHz using the array at Penna (Peter McCulloch, pers. comm., 2018) between June and August 1961 and at Llanherne at five higher frequencies—15.7, 18.7, 21.5, 24.5 (Figure 27) and 28.0 MHz—over several ranges of dates between October 1962 and September 1964. For the frequencies from 15.7 to 24.5 MHz they constructed ...two arrays of four full-wave dipoles separated by twenty wavelengths in an east-west direction. Each array was phased to the declination of Jupiter. The primary beam widths of the antennae were 30° N-S by 60° E-W ... (ibid.)

These arrays were constructed in the vicinity of the IPS hut (Peter McCulloch, pers. comm., 2018). McCulloch (1963) also reported attempted observations made at 4.7 MHz at Llanherne between July and September 1962, as part of his B.Sc. Honours studies; however, interference from transmitting stations precluded definite identification of the records as including observations of Jupiter.11

The observations were conducted using a phase-switching interferometer.12 The large antenna pattern would have produced very low resolution maps of the sky had they been intended for that purpose, but in this case the size of the pattern allowed them to observe Jupiter for about four hours each day: a considerable advantage in this type of observation. However, at 28.0 MHz there were eight full-wave dipoles at each end of the array, halving the E-W beam-width and reducing the observation time to two hours.

The flux level of the emissions was calibrated in two ways. The first method was by calculation, using the envelope of the interferometer pattern and the total observing time, and then comparing these results with a standard noise source. The other was to compare the Jupiter results with the two discrete sources Centaurus A (at 4.7 MHz) and Hydra A (at the other frequencies). This latter method is the radio astronomy equivalent of using standard ‘comparison stars’ in optical photometry.

The observations showed four distinct peaks in the power profile of the bursts, although these were frequency-dependent: three peaks, at system longitudes of 120°, 175° and 335°, were noted at 4.7 MHz, and a fourth at 255° became very apparent at higher frequencies. However, Ellis and McCulloch found that their results were inconclusive with regard to the correlation of the bursts with Io’s position.

### 3.2.3 The Log-periodic Antennas

Installed in the mid-1960s near the IPS hut were at least two log-periodic antennas (Peter McCul-
Several such antennas were made (Peter McCulloch, pers. comm., 2018). An example used for testing was, for many years, seen on the roof of the University of Tasmania’s Physics Building (Figures 28 and 29). Figure 30 shows another log-periodic antenna at Llanherne photographed in 1977; it was also sited close to the IPS hut.

The log-periodic antennas were used with two spectrographs. One had a frequency range from 8 to 230 MHz with a 200 kHz bandwidth and used four spectrographs to cover the range; Peter McCulloch (pers. comm., 2011) felt that this was not as successful as had been hoped. The other had a range from 24 to 28 MHz with a bandwidth of 50 kHz. The method of recording, common for this period, was to photograph the screen of an oscilloscope on moving 35 mm film.

The early observations used two log-periodic antennas at the Eastern Site (Peter McCulloch, pers. comm., 2018), of the type shown in Figures 28 and 29, which resulted in significant research on the Sun. Although splitting of Type II bursts had previously been observed (see, e.g., Roberts, 1959),

We were trying to get observations of Jupiter, which we did, and we said “We may as well look at the Sun.” Because of this, we discovered Type IIib solar bursts. (Peter McCulloch, pers. comm., 2018).

Ellis and McCulloch (1967) began their observations of the Sun in June 1965, and first described their observation of frequency splitting of the Type III solar bursts in a brief paper (Ellis and McCulloch, 1966b). After a routine start during which they mainly observed Type III bursts, an important series of Type I and III bursts ran from 16 to 29 March, 1966, and:

Many narrow bandwidth bursts, apparently of a type not so far recorded, were observed in the frequency range 20–50 Mc/s. ... The rate of occurrence of the burst groups was approximately 10/h during March 17 and 18. With the higher frequency resolution of the 24-28 Mc/s spectrograph, the individual bursts were observed to be made up of two components separated slightly in frequency. (ibid.).

Ellis and McCulloch (1967) observed that the bursts exhibiting frequency splitting lasted between 1 and 2 s, and that their frequency separation was between 0.1 and 1 MHz, with the separation increasing with increasing frequency. They reported using four spectrographs with ranges of 24–28, 28–36, 36–46 and 40–60 MHz, and elaborated on the mid-March 1966 observations:

The bursts were frequently observed in groups or chains distributed in the frequency-time...
plane like a type III burst; that is, a succession of bursts occurred at progressively lower wave frequencies with the frequency-time slope of the whole group in the range 5-10 MHz/sec. The group was sometimes observed to occur within a type III burst. (ibid.)

Figure 31 shows a frequency-time plot of a split pair (Ellis and McCulloch, 1966). (The vertical scale is frequency in MHz, increasing from 25.75 to 26.25 MHz and the horizontal scale is time in seconds, increasing to the right.)

David McConnell (1977) used one of these antennae as part of his B.Sc. Honours studies of solar radio bursts, during which he observed the Sun at frequencies between 20 and 60 MHz. Andrew Klekociuk (1982) used the antenna in Figure 30 for his honours studies of solar radio bursts, although his work below 30 MHz was performed primarily with the Whitham Array (see Section 3.2.5).

3.2.4 The 80 × 80 m Array

This array, mentioned in Section 3.1, allowed the LLFA to be used as a broadband swept-lobe interferometer (Ellis, 1972a). Philip Button (pers. comm., 2009) recalls the construction of this array and that “… it was probably eight rows of eight antennae.”

Andrew Klekociuk (pers. comm., 2007), who worked on his B.Sc. Honours degree in Physics using equipment at the Eastern Site, recalled that this array was constructed close to the IPS hut. Figure 2, an aerial photograph taken in 1973, clearly shows a square, largely cleared, area of these dimensions.

There is little written about the construction and use of this array in the literature, but referring to Ellis’ desire to measure the location of a particular source in about 1975, David McConnell (pers. comm., 2011) recalled:

Bill Ellis had an idea to set up an interferometer to try to see whatever it was [that] was producing [radiation at] low frequencies, like 20 MHz radiation. What he wanted to do was to have an interferometer to look for fringes, so he had the big 2000-foot array, and another array with the same size dipoles over near the IPS hut, but it was all overgrown … it had been there for a while. So suddenly there was this opportunity that came through Phil Whitham that a few of us could go out and spend the weekend and earn real money and clear the scrub out of this little array. So we spent most of two days with axes and hatchets and spades and shovels. I don’t think it astronomically came to anything.

Here, McConnell was clearly referring to the 80 × 80 m array, which had been in existence for several years. The ‘Whitham Array’ (see Section 3.2.5), although built in much the same part of the Eastern Site, was a separate construction.

As mentioned in Section 3.1.2, Graeme Ellis made use of this array for some observations of Jupiter S-bursts (Ellis, 1979).

3.2.5 The ‘Whitham Array’

Philip Whitham’s involvement in the low frequency maps of our Galaxy, using the LLFA, has been mentioned in Section 3.1.2. However, as a separate project, Whitham established a 39 × 39 m low frequency array in 1974–1975 at the Eastern Site in order to study Jupiter S-bursts and their polarisation (Figures 23 and 32). This array is often referred to as the ‘Whitham Array’ (Andrew Klekociuk, pers. comm., 2015).

The array was constructed not far from the IPS hut, near the location of Graeme Ellis’ 80 × 80 m array (Section 3.2.4). Whitham was involved from the outset in the establishment of this array:

I had been to the Himalayas a couple of times and brought back a Gurkha knife. I can remember clearing a space amongst the vegetation for the 39 by 39 metre array. (Philip Whitham, pers. comm., 2012).

The array was a filled-aperture horizontal array, made up of 16 pairs of orthogonal broadband dipoles arranged in a 4 × 4 configuration. Each dipole measured 14 × 1 m, with the intention that the array would be able to operate over the frequency range 4 to 30 MHz. There were two sets of dipoles, oriented NE-SW and NW-SE (Whitham, 1976).

The array was originally phased to match the declination of Jupiter in 1974. Indeed, the array was essentially complete and operational in 1974, but the late arrival of a piece of equipment delayed the start of observations to 1975, by which time the array needed to be re-phased to a declination of +6°. For the 1976 observations the phasing was adjusted to a declination of +9° (Whitham, 1979).

The array was used over the frequency range 11 to 24 MHz. The series of observations of Jupiter in 1975 began on 23 June 1975 and ran to 7 November (ibid.).
The LLFA equipment was used in conjunction with the Whitham Array in two respects. Because of the desirability of recording the output from the 39 × 39 m array on videotape, a transmission line 2.5 km in length was placed between the Whitham Array and the LLFA hut, where the video equipment was located (Whitham, 1976). The other use of the LLFA was to record Jovian bursts between 1972 and 1974, obtained by Ellis, but these covered a wider frequency range.

An important contribution from Whitham’s Jupiter work was the establishment of a correlation between Io and the Jupiter S-bursts below 17 MHz, which had not been noted beforehand (Ellis, 1980; Whitham, 1978; see Figure 33). Another was the first observation of the hyperfine structure of the S-bursts and their polarisation; although many observers had made polarisation measurements, Whitham stated that other than the study by Baart et al. (1966), S-burst polarisation had little coverage in earlier literature (Whitham, 1979: 44).

Whitham’s array was later used by B.Sc. Honours students David McConnell (1977) and Andrew Klekociuk (1982) for polarisation studies of solar radio emissions between about 20 and 30 MHz. For Klekociuk’s work the beam was phased to an altitude of 47° (the altitude of the Celestial Equator) on the meridian. With the Sun’s declination reaching +23°.5 during the winter, this meant that the Sun was several degrees outside the half-power beam. However, Klekociuk was able to observe a number of intense flare events (ibid.: 58).

3.2.6 The ‘High Frequency Array’

Although this paper describes work at frequencies of 30 MHz and below, mention must be made here of the ‘High Frequency Array’, which was also known as the ‘VHF Array’ and the ‘Pul-
sar Array' (Figures 23 and 34). A detailed study of observations at frequencies of 30 MHz and higher is outside the scope of this paper, but would be a suitable topic for a further historical study that would include the work performed by the University through to the present day.

The High Frequency Array initially was planned as a square array 156 m on each side. The first mention of this array in the University of Tasmania Research Reports was in 1968 (University of Tasmania, 1968), in which it is stated that construction was well advanced. By 1973 it had been re-designed to cover half that area, i.e. 78 \times 156 m. It consisted of 4096 dipoles, and was designed to operate over the frequency range 35–150 MHz (Ferris et al., 1980).

The primary purpose of this array was the study of pulsars over this frequency range. Pulsars became an important focus for radio astronomy research at the University, and have remained so through to the present day.

As part of his Ph.D. research David McConnell used this array for solar studies, down to 30 MHz (McConnell, 1980).

In addition, some observations of Jupiter were made in the frequency range of 24–35 MHz (Ellis, 1980; Figure 35). These contributed further to a study of the rate of change of frequency, \( \frac{df}{dt} \), of the bursts. In Figure 35, this rate is approximately \(-20\) MHz/sec.

### 3.2.7 The 1.6-MHz Array

An array, which was designed to operate between 1 and 2.75 MHz and a beamwidth of 25° at 1.6 MHz (Ellis and Mendillo, 1987), was erected at the Eastern Site in 1985 (Figure 36). They described this as having "... eight 180 m broadband dipoles with overall dimensions 330 \times 400 m^2, 12 m above ground ...", but in Ellis et al. (1988) an area of 360 \times 280 m is quoted, closely matching Figure 37 and the layout shown in Figure 36. This array was used for two main purposes: to investigate radio astronomy implications of an expected reduction in foF2 during a burn of the Space Shuttle Challenger's engine over Tasmania during the Spacelab 2 mission, and to measure the radio sky at 1.6 MHz.

That there was a lowering of the ionisation caused by rocket engine burns was known well before 1986. One of the more notable events occurred in 1973, during the launch of the Saturn V rocket that delivered the space station Skylab into Earth orbit, when a considerable reduction in ionisation was observed during the monitoring of ATS-3 (Application Technology Satellite 3) (see Mendillo et al., 1975; Schmerling, 1977).
Figure 36: The layout of the 1.6-MHz array, showing a planned 1.5 to 2.5-MHz array that was likely never constructed (Adapted from a diagram in Papers of Grote Reber, Grote Reber Museum, University of Tasmania).

Figure 37: An aerial photograph taken in March 1986. Locations of identified poles for the 1.6-MHz array are marked with yellow dots. The yellow square measures 370 m × 270 m (base data from theLIST (www.thelist.tas.gov.au), © State of Tasmania).
Plans to make such measurements using a space shuttle were being drawn up in the 1970s. In a letter to Graeme Ellis in early 1977, Michael Papagiannis of Boston University continued a communication with Ellis that had commenced shortly beforehand, requesting several pieces of advice, including information on the most interesting Galactic regions to observe at the low frequencies made accessible by the reduction in ionisation of the ionosphere (Papagiannis, 1977).

Grote Reber (1911–2002) expressed interest in the event, but was generally quite negative about the use of the Space Shuttle, commenting that the ionospheric hole that would be produced would be brief and that the experiment was “... expensive and uncontrolled.” (Reber, 1979).

He added that it seems better to forget the radio astronomy for the time being and do controlled ionosphere experiments. What is really needed is several small injections of hydrogen gas which will not congeal at low temperatures and pressures. (ibid.).

Reber continued by suggesting that the hydrogen could be delivered by “... small inexpensive portable rockets ...” to bring the hydrogen up to the F layer at an altitude of about 250 kilometres.

Despite this, Reber took considerable interest in the eventual Space Shuttle engine burn, suggesting (Reber, 1978) the possible use of his radio astronomy array at Dennistoun, near Bothwell in Tasmania (George et al., 2017b) that he used during the 1960s and 70s.

Reber (1984) also suggested to Ellis that Ellis observe at a range of frequencies between 1.0 MHz and 3.7 MHz, even offering to supply poles for the erection of antennas and assist in other ways. In fact, Ellis did observe the event at a similar range of frequencies.

On 29 July 1985 the Space Shuttle Challenger was launched into orbit for the eighth time, as mission STS-51F. It was the second of the Spacelab missions, and carried several Spacelab components. The significance of this mission to radio astronomy was the ‘plasma depletion experiment’. Fuel was burned on three occasions using its Orbital Maneuvering System (OMS) engines. The exhaust gases, consisting of H₂O, H₂ and CO₂, reacted with O⁺ ions, producing the molecular ions H₂O⁺, OH⁺ and O₂⁺. These then combined with the ambient electrons, thereby reducing the ionisation in part of the ionosphere (Mendillo et al., 1987).

Two of these burns took place over the Massachusetts Institute of Technology Haystack Observatory in the USA, and the third over Llanherne. Studies of plasma physics and the ionosphere were important reasons for conducting this experiment, but at Llanherne, radio astronomy was a major interest.

It was already well established that Tasmania was an excellent location for low frequency radio astronomy due to the relatively high transmission by the ionosphere of low frequency radio waves, but the artificial reduction of ionisation—a so-called ‘ionospheric hole’—would increase its transparency even further.

The plan had been to burn 1797 pounds (815 kg) of fuel over Tasmania, but a failure of one of the main Space Shuttle engines during ascent necessitated the dumping of a significant amount of fuel. As a result, only 539 pounds (244 kg) was burned over Tasmania. The burn lasted only 16 seconds, beginning at 16° 59” 27” Universal Time on 4 August, which was 02° 59” 27” local time in Tasmania (Ellis et al., 1988).

The observations showed that radio astronomy through an artificially created ionospheric hole was indeed possible; at the very least, the lowering of the foF2 value was confirmed. Observations were made at six different frequencies, using two separate antenna systems. Observations at 0.79 and 0.51 MHz were attempted using a single dipole, 560 m in length, whose exact location was not recorded. Observations at 2.75, 2.108, 1.704, and 1.07 MHz were made with the ... 380 m × 280 m telescope ...”, which was designed to operate over a frequency range of 1 to 2.7 MHz (ibid.). This is almost certainly the same array that was used in the 1.6 MHz survey, to be described shortly.

Ionosonde observations, probably conducted by George Goldstone at the IPS station at ‘The Lea’, south of Hobart, clearly showed the drop in foF2 (Figure 38): There was a sudden reduction in foF2 from 1.99 to 1.8 MHz within three minutes of the burn, followed by a slow decrease to less than 1.3 MHz in the next 100 minutes. (ibid.).

Meanwhile, monitoring of celestial radio emission at the various different frequencies showed a marked increase at 1.704 MHz. The reception of higher frequencies (2.75 and 2.108 MHz) remained unchanged, because they were well above the pre-existing foF2 frequencies.

There is no evidence that Reber was present for the eventual observations, but a handwritten
note dated 15 August 1985 suggests that he may have attempted to observe from Dennis-
town:

Burn 16 sec. 300am [sic] over Hobart 310 km altitude. Nothing different from several nites [sic] before and after. foF2 about 1.9 mc at 310 km height. (Reber, 1985).

Observations not specifically related to radio astronomy were also planned for this event, but they had mixed success. Andrew Klekociuk took a receiver to the northern Tasmanian town of Avoca to measure ionospheric echoes from a 1.9 MHz transmitter at The Lea, south of Hobart, and an experiment to detect conjugate point echoes at 1.9 MHz also produced results. However, planned airglow observations could not be conducted because of solid cloud cover over Tasmania on that night (ibid.; Andrew Klekociuk, pers. comm., 2015).

The observations during the Space Shuttle experiment contributed to the 1985–1986 production of a 1.6 MHz map of the sky, using this array, between declinations −12° and −72° (Ellis and Mendillo, 1987; Figure 39). They obtained data on only five nights between May and August 1985, and on six nights between April and July 1986. This is the lowest frequency at which a radio contour map of the sky was obtained at Llanherne, and it was even lower in frequency than the 2.085-MHz map produced earlier by Grote Reber from near Bothwell (Reber, 1968).

Radio observations of the sky at this frequency require exceptional ionospheric conditions. The actual ‘smoothed’ solar minimum occurred in September 1986 (Royal Observatory of Belgium, Brussels, 2018), and the mid-1980s conditions had not been as favourable since the solar minimum of the mid-1950s. Nevertheless, the work was hampered by a limited number of nights on which foF2 was sufficiently low (~1.3 MHz), and the need to find clear channels between radio transmitting stations. For that, they used a minimum detector, with the receivers being swept through a range of 12 kHz every five seconds.

3.2.8 Other Radio Astronomy Installations at Llanherne

3.2.8.1 Jupiter Observations by Richard Dowden

In the second half of 1962 Richard Dowden used an array at Llanherne to record radio bursts from the planet Jupiter (Figure 40) and to study their polarisation. The array was composed of...

... twenty pairs of crossed half-wave dipoles arranged in a 10 by 2 configuration with the long axis in the north-south direction. (Dowden, 1963).

Dowden (pers. comm., 2011) recalled that this array was established in the vicinity of the IPS Hut, where his receiving equipment was set up:

The equipment we used for Jupiter was another [war] surplus thing; it was a receiver and we used a little motor to drive it through that
100 kHz. I think we used a rotating capacitor. It went round and round. (ibid.).

Dowden’s Jupiter studies primarily related to the polarisation of the radio bursts, which Dowden noted had shown little longitude dependency in earlier measurements but were generally dominated by right-handed polarisation (Carr et al., 1961). Dowden, however, was working at 10.1 MHz, and found a quite strong dependency (Dowden, 1963). As noted by other observers (see, e.g., Carr et al., 1961), Dowden (ibid.) clearly demonstrated a System III longitude dependency on the occurrence of the bursts.

Dowden used the original System III longitude system, although this was twice later revised. The use of the older system over a short timespan would not have had a serious detrimental effect on the relative measurements of longitude dependency, as the original System III rotation period was only 0.93s shorter than the eventual 1976 IAU value.

3.2.8.2 Galactic Pole Observations by Hilary Cane

Hilary Cane (1979) made observations of the Galactic Polar regions at 5.2, 9.0, 15.6 and 23.0 MHz from both Llanherne in Tasmania and Penticton in Canada. She was inspired to make these observations because there had appeared to be a difference between North and South Galactic Pole measurements:

There were various observations from various places, and [the polar regions] didn’t look the same. The north and the south were different. So … I organised an experiment. I was able to set up four or five half-wave dipoles out near the smaller array at the airport—the Pulsar Array [at the Eastern Site]. I was able to clear a bit of ground. (Hilary Cane, pers. comm., 2012).

For each frequency, Cane (ibid.) used a single half-wave dipole, oriented in an east-west direction and placed one-eighth of a wavelength above a square ground screen of dimensions one wavelength long on each side.

The dipoles were directed to a declination of $-43^\circ$, this being the latitude of Llanherne; and the measurements were repeated in Canada, with the array directed to declination $+49^\circ$ using the same equipment, which was transported there in order to make the observations.

Despite the earlier indications that the opposite Galactic Poles appeared differently at these frequencies, Cane (1979) found that the intensities of the radiation were essentially the same, to within 10%.

3.2.8.3 The 14-metre 'Dish'

Although not used for low frequency work, we mention here a well-known feature of the Llanherne Eastern Site: a 14-m parabolic dish that was located 150 m southwest of the IPS hut and was used for radio astronomical observations at much higher frequencies. Its main purposes were the observation of pulsars (McCulloch et al., 1987) and, briefly, for very long baseline interferometry. Andrew Klekociuk (1982) used this instrument at 635 MHz for solar studies as part of his B.Sc. Honours project, and at 635 and 954 MHz for observations of the Vela Pulsar (Klekociuk, 1989). Based on an aerial photograph (not reproduced here), the instrument was certainly in place by 1973, and Klekociuk (pers. comm., 2018) is of the opinion that it was probably installed there in the late 1960s. It was moved to the University’s new radio astronomy site at Mount Pleasant, north of Cambridge, in the late 1980s.

4 THE LLANHERNE SITE TODAY

The 1980s heralded the end of the use of the Llanherne site, and very little evidence remains at Llanherne today of the radio astronomy activities that once took place there.

One of us (MG) visited the Eastern Site in 2012 and found that the IPS hut (Figure 41) and the High Frequency Array hut were still standing, but could not be accessed because of their asbestos content. Recent aerial images show that they have now been destroyed.

George also examined the Western (LLFA) Site in 2007 and again in 2016. On both visits the bases of some poles, some pieces of wiring, and the occasional small insulator, could still be found on the site. In 2007 the hut was standing but was in a very poor state, and by 2016 it had collapsed (see Figure 42). For many years, following the removal of the poles and wires, it remained visible from Holyman Avenue as an isolated structure that was a haven for snakes (Greg Casimaty, pers. comm., 2016) in a large, otherwise empty field, memories of its heyday having faded long ago.

5 DISCUSSION

The high level of interest in low frequency radio astronomy at the University of Tasmania began, with little doubt, with the initial association between Graeme Ellis and Grote Reber in the
1950s, Ellis because of his fine record of ionospheric work—a topic strongly connected with the ability to receive low frequency celestial radiation—and Reber, because of his radio expertise and desire to map the sky at the lowest frequencies possible.

Llanherne was a key location because ionospheric work had already taken place there, and the choice of this location was probably influenced by the availability of flat areas of land and the IPS Hut. The hut was important for the housing of recording equipment, an early use of which was made in 1961 by Waterworth.

However, developments would likely have been very different if Ellis had made use of the site at Dennistoun, near Bothwell, where Reber established his 2.085-MHz array in the early 1960s. Clearly, Ellis (1960b) had that site in mind for a large array. Use of the Dennistoun site appears to have been a source of disagreement between the two, with Ellis (1960a) expressing surprise that Reber had made arrangements with landowner Geoffrey Edgell for use of that site. Shortly afterward, giving up on Dennistoun, Ellis (1960b) considered it “... unwise and inconvenient to have two large radio telescopes on the same property.”

But for Reber’s use of the site, therefore, it is likely that the LLFA would instead have been a low frequency array at Dennistoun, and other radio astronomy activities by the University may have taken place there.

The mapping of the southern sky could be regarded as a project with a fairly definite endpoint, because once the contour maps were made at the several different frequencies there was little else that could be done in that regard apart from the possibility of occasional transient low frequency phenomena. Indeed, the High Frequency Array was the one intended for the observation of pulsars.

The Jupiter bursts, however, are still an ongoing topic of study even today. The LLFA was well suited to the lower half of the frequency range over which these bursts occur, and Ellis would have seen that there was no specific endpoint to these observations: the Jovian bursts, in addition to their classification and their characteristics such as the frequency-time relationships, were also important to study from a statistical viewpoint, allowing improved estimates of the effects of the orbital position of Io and the central meridian longitude of Jupiter. In such a study, the more data, the better. However, in light of these significant contributions to radio observations of Jupiter, it seems odd that the Tasmanian observations were not cited by Duncan (1975).

As much as it is an impressive collection of Jovian S-burst records, Ellis’ (1979) An Atlas of Selected Spectra of the Jupiter S-bursts is also somewhat of an anomaly. It has the appearance of being a mixture of a formal University publication and a self-published work; it is unlikely that it would have been completed if not for the invaluable assistance of Susan Blackburn, who recalls even using commercially produced transferable lettering for the cover wording.

Radio astronomy at Llanherne declined in the mid-1980s after Ellis officially retired; as the 1985–1986 1.6 MHz observations were being made, attention shifted to higher frequencies with the 26-m paraboloid being established at Mount Pleasant. It is interesting to wonder what Ellis’ thoughts were in the 1970s about how long research activity would continue at Llanherne. However, by the time of the plasma depletion experiment involving the Space Shuttle, it seems clear that he realised that observations at Llanherne were coming to an end. In relation to the 1.6-MHz survey, he wrote:

... over the past thirty years, the increase in the number of broadcast transmitters below 1.5 MHz has virtually eliminated the possibility of observations in this band ... These observations are likely to be the last in this series and indeed the last to be made from the Earth. Future observations are likely to be made from the Moon or space in the twenty-first century. (Ellis, 1985).

6 CONCLUDING REMARKS

Activities by the University of Tasmania at Llanherne represented the most extensive low frequency radio astronomy observations carried out in Tasmania, and indeed in Australia.

Because it was in Tasmania the site was ideal for low frequency radio astronomy, given the favourable ionospheric conditions, and it was conveniently located within about 30 minutes’ drive of the University campus at Sandy Bay.

Using several antenna systems, including some sensitive to polarisation, a great deal of
work was carried out in Galactic, solar and Jovian radio astronomy. The solar minima of the 1960s, 1970s and 1980s—important because of the resultant low degree of ionisation in the ionosphere—were put to good use.

In particular, the site of the LLFA drew public attention to radio astronomy performed by the University. This was because of its prominent location adjacent to the road leading into Hobart Airport, despite a common misunderstanding that the poles were used for growing hops!

7 NOTES

1. This is the ninth paper in a series that aims to document pre-1980 low frequency (<30 MHz) radio astronomy in Australia. The first two papers overviewed the research by staff from the CSIRO Division of Radiophysics near Sydney (Orchiston et al., 2015a) and the efforts in Tasmania by Grote Reber and staff from the Physics Department at the University of Tasmania (George et al., 2015a). Subsequent papers looked in depth at individual field stations in Tasmania (see George et al., 2015b; 2015c; 2016; 2017a; 2017b) and at Hornsby Valley near Sydney (Orchiston et. al., 2015b).

2. ‘Llanherne’ was the name of the property on which Hobart Airport, opened in 1956, was constructed. Although the airport was named ‘Llanherne Airport’, that name fell into disuse and it is now known as ‘Hobart International Airport’. As McCulloch (1963) pointed out, the airport had an advantage over other sites in that electrical cables were generally placed underground, which minimised electrical noise from such sources. Indeed, in his work at Kempton and Bothwell, Grote Reber (1958; 1968) used batteries instead of mains electricity cables for this reason.

3. Geomagnetic micropulsations are pulsations in the Earth’s magnetic field typically with frequencies from about 0.1 Hz to several Hz; they can be measured by induction loops. At the University of Tasmania, Graeme Ellis, Richard Dowden and Michael Emery took an interest in this phenomenon, which has been studied by many researchers.

4. The Australian Research Grants Committee (ARGC) and the Radio Research Board were important funding bodies for the University’s radio astronomy projects. The ARGC began in 1946 as The Commonwealth Universities Research Grants Committee. It became the ARGC in 1965, and finally the Australian Research Council (ARC) in 1988 (Australian Government, 2016). The Radio Research Board was established in Sydney in 1927 as an Agency of the Commonwealth of Australia, with its function being to “… improve general radio practices in Australia.” It was renamed in 1985 as the Australian Telecommunications and Electronics Research Board (Encyclopedia of Australian Science, 2006).

5. ‘Blitz’ trucks were made in large numbers for use during WWII. The vehicle used by the University appears to have been a Ford model (Hervey Bay Museum, 2017).

6. The ground at Llanherne was susceptible to becoming very wet during the winter months. Related to this may be the interesting observation made in The Mercury newspaper (‘Our Special Correspondent’, 1884): “Excellent water exists at small depth, and there being only one creek, and that of diminutive proportions, numerous waterholes have been sunk, 40 in all.”

7. The ‘half-power beamwidth’ (HPBW) is the angle within the main lobe of coverage of an antenna at which the received intensity is 3 dB below the maximum.

8. Jovian radio bursts are divided into two main types: S (Short) bursts with a typical duration 1–10 ms and L (Long) bursts whose duration is typically 0.5 s up to several seconds. Each type changes frequency as a function of time during the burst; S bursts drift downward in frequency but L bursts can drift either up or down. A subclass of narrow-band L bursts is classified as type N (see, e.g., Riihimaa, 1985). Ellis (1974) also noted a type called a U burst, named after the shape of the frequency-time plot; these reverse their frequency-time slope and occur only below about 9 MHz.

9. A detailed analysis of the decades of observations of Io’s connection with the decimetric Jupiter emission is beyond the scope of this paper, but even at the time of writing (2018), this is still a topic of study (see, e.g., Bhardwaj et al., 2002). Io has been discovered to be a volcanic body, with emitted material becoming ionised in the Io plasma torus. As Jupiter’s magnetosphere sweeps past Io, a strong electrical current is generated between Io and Jupiter, resulting in radio-frequency emission. Three separate sources, based on the orbital position of Io, are called Io-A, Io-B and Io-C.

10. Some of the Jovian radio emissions are independent of Io’s position and are therefore inherent to the planet itself; they are often called ‘Non-Io sources’. These were used to define, and later redefine, the System III longitude system of Jupiter. The initial value of this rotation period was 9h 55m 28.8s (Carr et al., 1958). Douglas (1960) refined this to 9h 55m 29.37s. At its 1976 General Assembly the International Astronomical Union adopted a new System III rotation period of 9h 55m 29.711 ± 0.4 seconds (Duncan, 1975; Seidelmann and Divine, 1977).
McCulloch (1975) had reached a very similar rotation period based on 11 cm (decimetric) emissions.

11. Broadcast stations are a major impediment to low frequency radio astronomy observations. As examples, Reber and Ellis (1956) needed to avoid interference from local radio stations for their attempted observations down to 1 MHz and even below: the majority of AM radio stations operate in the medium-wave (~0.5 to 1.6 MHz) range. Reber was particularly troubled by this problem when attempting his 1.155 MHz observations in the 1970s (George et al., 2017b). However, short wave transmissions, beginning just above the medium wave frequencies and extending to ~30 MHz, cause problems at many other frequencies also. This often necessitated the use of a ‘minimum reading’ apparatus, such as a rotating capacitor, to sweep through a small range of frequencies to find an empty channel.

12. The phase-switching interferometer was invented by Martin Ryle at Cambridge, and it correlated the signals from two antennas to remove uncorrelated noise.

13. A log-periodic antenna is an antenna with, typically, several dipole elements spaced in frequency according to the logarithm of the value of the frequency. Its design allows it to operate as a broadband antenna (covering a wide range of frequencies). The elements become progressively shorter toward one end of the series.

14. Solar radio bursts have been classified into five main types—Types I, II, III, IV and V—and some subtypes. These each have different characteristics, including different observed frequency ranges, rates of change of frequency, and durations. In most cases in which the frequency drifts, the frequency falls during the burst. There is a connection between Type III and Type V: Type V bursts occur only, but not always, following Type III bursts (see, e.g., Space Weather Services, 2017).

15. This was the SA-513 mission to insert Skylab into Earth orbit. It was the final launch of a Saturn V rocket.

16. A ‘variable capacitor’, of the type used with these arrays, allowed fine adjustments to be made to the tuning. It consists of two sets of parallel closely-spaced plates, each normally forming a semicircle, whichmesh together. One can be rotated to change the overlapping area of the two sets, and therefore change the capacitance. It is sometimes called a ‘tuning capacitor’ because of its ability to change the resonant frequency of a circuit.

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9 REFERENCES

The following abbreviation is used:

PGR = Papers of Grote Reber, Grote Reber Museum, University of Tasmania.


George, M., Orchiston, W., and Wielebinski, R., 2017b.


Papagiannis, M.D., 1977. Letter to Graeme Ellis, dated 7 February. In PGR.


Martin George is the Collections and Research Manager at the Queen Victoria Museum and Art Gallery in Launceston, Tasmania, and also is responsible for the Museum’s planetarium and astronomy collections. He is a former President of the International Planetarium Society. Martin has a special research interest in the history of radio astronomy, and is completing a part-time Ph.D. on the development of low frequency radio astronomy in Tasmania through the University of Southern Queensland, supervised by Professors Wayne Orchiston and Richard Wielebinski (and originally also by the late Professor Bruce Slee). Martin is the Administrator of the Grote Reber Medal for Radio Astronomy, and is a member of the IAU Working Group on Historic Radio Astronomy.

Wielebinski is born in Poland in 1936, and moved with his parents to Hobart, Tasmania, while still a teenager. Richard completed B.E. (Hons.) and M.Eng.Sc. degrees at the University of Tasmania. In his student days he met Grote Reber and was involved in the construction of a low frequency array at Kempton. After working for the Postmaster General’s Department in Hobart he joined Ryle’s radio astronomy group at the Cavendish Laboratory, Cambridge, and completed a Ph.D. in 1963 on polarised galactic radio emission. From 1963 to 1969 Richard worked with Professor W.N. (Chris) Christiansen in the Department of Electrical Engineering at the University of Sydney, studying galactic emission with the Fleurs Synthesis Telescope and the 64-m Parkes Radio Telescope. He also was involved in early Australian pulsar research using the Molonglo Cross. In 1970 Richard was appointed Director of the Max-Planck-Institute for Radio-astronomie in Bonn, where he was responsible for the instrumentation of the 100-m radio telescope at Effelsberg. In addition, he built up a research group that became involved in mapping the sky in the radio continuum, studying the magnetic fields of galaxies, and pulsar research. Further developments were the French-German-Spanish institute for mm-wave astronomy (IRAM), and co-operation with the Steward Observatory, University of Arizona, on the Heinrich-Hertz Telescope Project. Richard holds Honorary Professorships in Bonn, Beijing and at the University of Southern Queensland. He is a member of several academies, and has been awarded honorary doctorates by three universities. After retiring in 2004 he became involved in history of radio astronomy research, and is currently the Chairman of the IAU Working Group on Historic Radio Astronomy.

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