Journal of Astronomical History and Heritage, 18(2), 177–189 (2015).

THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 3: ELLIS, REBER AND THE CAMBRIDGE FIELD STATION NEAR HOBART

Martin George, Wayne Orchiston
National Astronomical Research Institute of Thailand, 191 Huay Kaew Road, Suthep District, Muang, Chiang Mai 50200, Thailand, and University of Southern Queensland, Toowoomba, Queensland, Australia.
Emails: martingeorge3@hotmail.com; wayne.orchiston@narit.or.th

Bruce Slee
CSIRO Astronomy and Space Sciences, Sydney, Australia.
Email: Bruce.Slee@csiro.au

and

Richard Wielebinski
Max-Planck-Institut für Radioastronomie, Bonn, Germany, and University of Southern Queensland, Toowoomba, Queensland, Australia.
Email: rwielebinski@mpifr-bonn.mpg.de

Abstract: Low frequency radio astronomy in Tasmania began with the arrival of Grote Reber to the State in 1954.[1] After analysing ionospheric data from around the world, he concluded that Tasmania would be a very suitable place to carry out low frequency observations. Communications with Graeme Ellis in Tasmania, who had spent several years studying the ionosphere, led to a collaboration between the two in 1955 during which year they made observations at Cambridge, near Hobart. Their observations took place at four frequencies between 2.13 MHz and 0.52 MHz inclusive, with the results at the higher frequencies revealing a clear celestial component.

Keywords: Australian low frequency radio astronomy, Tasmania, Grote Reber, Graeme Ellis, Cambridge.

1 INTRODUCTION

The science of what would later be termed radio astronomy began in 1931 with the discovery by the American physicist Karl Jansky (1905–1950) of radio-frequency radiation of celestial origin. Grote Reber (1911–2002) followed this up, and in 1937 he constructed the world's first dedicated radio telescope at Wheaton (Illinois, USA) and used it to create a 160 MHz map of the sky (Reber, 1940; 1944).

After WWII, Reber maintained a strong interest in this field of research, and was aware of the important work being performed in Australia, in and near Sydney by staff from the CSIR's Division of Radiophysics (Orchiston and Slee, 2005; Robertson, 1992; Sullivan 2009). By the early 1950s Reber was working atop Mount Haleakala in Hawaii, attempting to observe discrete sources using a sea interferometer (see Reber, 1959). His inspiration came mainly from the pioneering work carried out at Dover Heights in Sydney and sites near Auckland, New Zealand, by John Gatenby Bolton (1922–1993; Robertson, 2015), Gordon John Stanley (1921–2001); Kellermann et al., 2005) and Owen Bruce Slee (b. 1924; Orchiston, 2004; 2005b). Their research revealed that the concept of 'radio stars' was a misnomer, and that these discrete sources were associated either with prominent optical objects in our own Galaxy (such as the remnant of SN 1054) or with anomalous extragalactic objects (see Bolton et al., 1949; Robertson et al., 2014).

Reber's interest turned increasingly to low frequency radio astronomy (Reber, 1977), but he was well aware that the ionosphere imposed a lower limit, albeit a variable one, on the frequencies that could be observed. He therefore collected ionospheric data from many locations around the world, which made it clear to him that

> The lowest electron density was found to be near the minimum [of] solar activity, during winter at night between latitudes 40° and 50°, near the agonic line where [the] compass points true north. (ibid.).

Tasmania (Figure 1), therefore, offered excellent prospects for making low frequency observations of celestial sources. Although similar conditions existed in the USA and Canada in the region of the Great Lakes, the fact that the Galactic Centre was at a southerly declination clearly was appealing to Reber (ibid.). As early as 1949 he had indicated that he was interested in making observations in the Southern Hemisphere (Reber, 1949), and the fact that the best observing conditions occurred during winter would have been an additional factor in selecting Tasmania rather than the USA-Canada region as Tasmanian winters, even at sites well inland, were far less severe.

In Tasmania, the seeds of a potential future

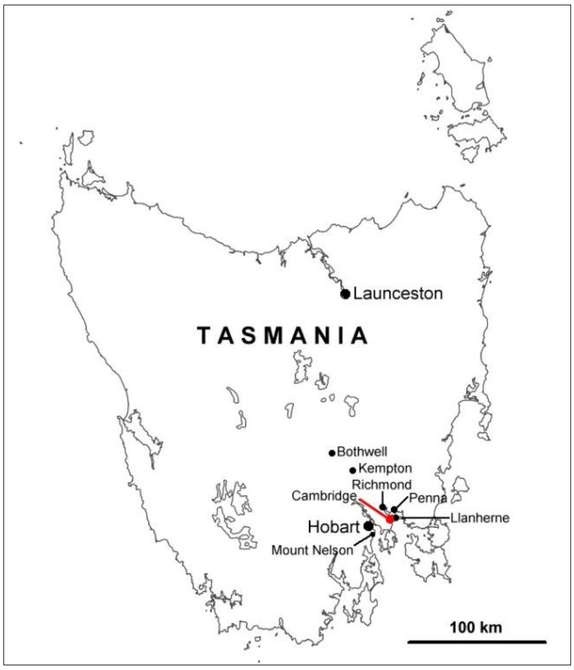


Figure 1: The Australian island State of Tasmania, showing the two largest cities (Hobart and Launceston) and important radio astronomy sites.

in radio astronomy were already being sown. By about 1952, Gordon Newstead (1917–1987), then a Senior Lecturer in Electrical Engineering at the University of Tasmania, had succeeded in making observations at about 90 MHz from a site on Mount Nelson, near Hobart (Ellis, 1954a; Haynes et al., 1996), and Graeme Ellis (1921–2011) was performing important ionospheric research as an officer of the Ionospheric Prediction Service (IPS) and at the same time working toward a Ph.D. Ellis' collaboration with George T. Goldstone (1925–2012) from the IPS was of major importance in ionospheric studies in Tasmania; indeed, Susan Ellis (pers. comm., 2007) recalled that Goldstone

> … assisted him [Ellis] during his Ph.D. work, and was at the Physics Department all those years and even after they both retired, Dad and George used to go to The Lea [a later IPS station].

Reber (1954a) was prompted to contact Ellis after reading Ellis' (1953) research paper on 'Z echoes', and during the first half of 1954 they exchanged several letters. It seems that the first suggestion of a cooperative effort in Tasmania came in a letter by Reber (1954b) in which he discussed the conditions in which 'cosmic static' of exceptionally low frequency would easily pass through the ionosphere via an ionospheric Z hole. Clearly, was aware that at frequencies of around 1 MHz or even lower, the best chance was to observe through such a hole. He concluded that the declination from which the radiation would most easily reach observers on the ground was equal to the latitude of the observer plus the dip of the Earth's magnetic field less 90°. For Hobart (latitude S 43°, dip angle 72°), this is equal to 25°—that is, a declination of –25°. This was close to the declination of the Galactic Centre (–28° 55′ in 1950.0 coordinates). Reber (1954c) described this as a 'Z hole experiment', referring to the mode by which this radiation would reach the ground,[2] in addition to offering the opinion that observations at 2 to 2.5 MHz would be possible in general when f0F2[3] was sufficiently low. Reber then made a clear request to Ellis:

> If the circumstances look auspicious, I will be interested in making some arrangement with the University of Tasmania to conduct experiments for measuring Cosmic Static from the galactic center at frequencies in the range 0.5 to 1.5 megacycle. My sponsor, the Research Corporation, will cover the expenses of the proposed tests.

Ellis' reply (1954a) was very welcoming and positive. Reber made further detailed enquiries to Ellis about the scientific equipment that was then

Figure 2: The Ionospheric Prediction Service building on Mount Nelson, erected in 1954 (after *The Mercury*).

available at the IPS field station, and conditions at the site.

This amicable correspondence between Reber and Ellis, and Reber's acceptance of the suitability of making observations from Tasmania, led him to decide to spend a period of time in the island State from late 1954. During his initial correspondence with Ellis (which began in January 1954) and up until the time he travelled to Tasmania, Reber was living in Hawaii.

Although the IPS field station had recently been transferred to Mount Nelson (Figure 2),[4] the site to which Ellis referred in his correspondence with Reber was the original one at Cambridge, close to Hobart Airport.[5] Further details of the site, and the observations made by Reber and Ellis, are discussed below in Sections 3 and 4.

2 BIOGRAPHICAL NOTES

2.1 Grote Reber

Grote Reber (Figure 3) was born in Chicago, USA, on 22 December 1911. At an early age he developed a great interest in radio and obtained his amateur radio licence, W9GFZ, at the tender age of 16 (Kellermann, 2005). He also showed an aptitude for mechanics, as evidenced by a note written at the age of 13 giving instructions to his father as to how to repair his bicycle. He graduated from the Armour (now Illinois) Institute of Technology in 1933 with a degree in electrical engineering.

Reber took a great interest in the work of Karl Jansky, who in the early 1930s was employed by the Bell Telephone Laboratories to investigate radio interference in transatlantic telephone links. In the process he serendipitously discovered radio emission from our Galaxy (see Sullivan, 1983; 1984b).

There was very little progress in this field in the 1930s and Reber decided to investigate the phenomenon further (Sullivan, 1984b). To this end, in 1937 he constructed the world's first purpose-built radio telescope. It was built with his own funds adjacent to his home in Wheaton, Illinois, just west of Chicago, and it was of the now-familiar paraboloid 'dish' design. It was such an unusual object that local residents would walk along different streets in order to avoid getting too close to it.[6]

Reber (1940; 1944) used his radio telescope, which had a diameter of 9.75 metres (32 feet), to map galactic emission at a frequency of 160 MHz—a wavelength of 1.9 metres. This was the first detailed radio map of the sky. It showed the Milky Way, and revealed for the first time the presence of the Galactic Centre in Sagittarius, and the radio source which later became known as Cassiopeia A.

Reber maintained his interest in radio emission from celestial sources and he published several papers on the subject in the 1940s. For example, in September 1943 he succeeded in detecting radio emission from the Sun (Reber, 1944), which was first identified by the British radar researcher, James Stanley Hey (1909–2000), in 1942 but made public only after the war (see Hey, 1946).

After leaving Wheaton in early 1948, Reber (1983) worked for a while at the National Bureau of Standards in Washington, before moving to Hawaii and conducting radio astronomy experiments from the summit of Mount Haleakala, on the island of Maui. Then in 1954 he moved to Tasmania, and began to observe at lower frequencies. Although he returned to the USA on many occasions, he effectively made Tasmania his home for the second half of his life. Accordingly, in 1982 he wrote:

Figure 3: Grote Reber in 1957 (courtesy: George Swenson).

> During the past quarter century I have greatly enjoyed Tasmania, and its mild climate. I've travelled around the state, engaged in projects in botany, archaeology and cosmic rays. The natives have been very friendly. (Reber, 1982).

Reber involved himself in many other scientific pursuits. Among his activities, he built an energy-efficient house in Bothwell; he was fascinated by plants, in particular the direction in which beans entwined themselves around poles; and he was particularly keen on studying energy-efficient transport, being very proud of his electric car, which he called *Pixie*.

Reber was well known for his independent thoughts and activities, and he held controversial views on various topics, including his opposition to the widely-accepted Big Bang Theory.

He was awarded a number of prizes, including the Astronomical Society of the Pacific's 1962 Bruce Medal, and an honorary D.Sc. from Ohio State University in the USA.

Grote Reber died in Tasmania on 20 December 2002, two days before his 91st birthday.

2.2 Graeme Ellis

Graeme Reade Anthony Ellis (Figure 4) was born in Launceston, Tasmania, on 20 December 1921. During his early childhood he came to be called 'Bill' by his sister, and the name stayed with him for the rest of his life (Susan Ellis, pers. comm. 2007).

Ellis took a great interest in science from an early age, experimenting with gunpowder and flying model aeroplanes (McCulloch and Delbourgo, 2013). During WWII he enlisted in the army, but not long after joined the Royal Australian Air Force, following which went to England and served as a navigator with the Royal Air Force.

Figure 4: Graeme Ellis at the Ionospheric Prediction Service Station on Mount Nelson, near Hobart, in 1954 (courtesy: *The Mercury*).

After the war, Ellis returned to Tasmania and enrolled at the University of Tasmania, completing a B.Sc. with First Class Honours in 1949. While working as a Senior Officer with the Ionospheric Prediction Service, he worked on his Ph.D., submitting his thesis in 1955. His work with Grote Reber, in 1955, began a long-term interest in low frequency radio astronomy.

After a brief period in Queensland and then New South Wales, Ellis returned to Hobart in 1960 to take up the Chair of Physics at the University of Tasmania. His great interest in radio astronomy led to significant developments in the field in the ensuing years, with many installations in the Hobart area and several of his honours and Ph.D. students excelling in the subject. These aspects will be discussed in later papers in this series.

Ellis also maintained a keen interest in the properties of the ionosphere—a subject closely aligned to low frequency radio astronomy because of the ionosphere's poor transmission of low-frequency radiation. Indeed, in his physics lectures at the University, he would often include a mention of the subject, which was an important part of the courses on "Electrodynamics" and "Advanced Electrodynamcs" that he taught third-year and fourth-year physics students.

As well as being an eminent physicist, Ellis was a very practical person who liked to ensure that equipment was working efficiently and without undue fuss. His aim was to obtain results quickly and perform a rigorous analysis.

Ellis was a driving force behind radio astronomy in Tasmania, making important contributions especially to ionospheric physics, low frequency Galactic radio astronomy, and the study of Jovian decametric radio emission. He continued his work well beyond his official retirement in 1982. He was also supportive of amateur astronomy, serving as Patron of the Astronomical Society of Tasmania from 1960 for two decades. He attended many meetings of the Society, and presented talks on his research work and occasionally on other topics. The latter included the search for intelligent life in the Universe, which was of special interest to him.

In 1963 Ellis was awarded the Thomas Ranken 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 (OA).

3 INSTRUMENTATION

The installation at Cambridge used by Reber and Ellis in 1955 was at the former IPS station, which was relocated to Mount Nelson in 1954. In reference to the Cambridge site, in March 1954 Ellis informed Reber:

> Should you wish to make your measurements here, I shall be pleased to assist all I can. I have available a 10 acre site about 11 miles from Hobart. There is a 10′ × 10′ building with power and telephone, and some aerials, including a full wave 2.2Mc/s Berkner dipole.[7] The site is not at present being used and was originally established for the P′f recorder[8] which is now situated nearer Hobart. (Ellis, 1954a).

In addition, Ellis (1954b) wrote to Reber:

> The site is about 650′ square and is oriented N.E-S.W. It is flat and the land slopes gently upwards S.W of it, ending in a row of hills a couple of miles away.

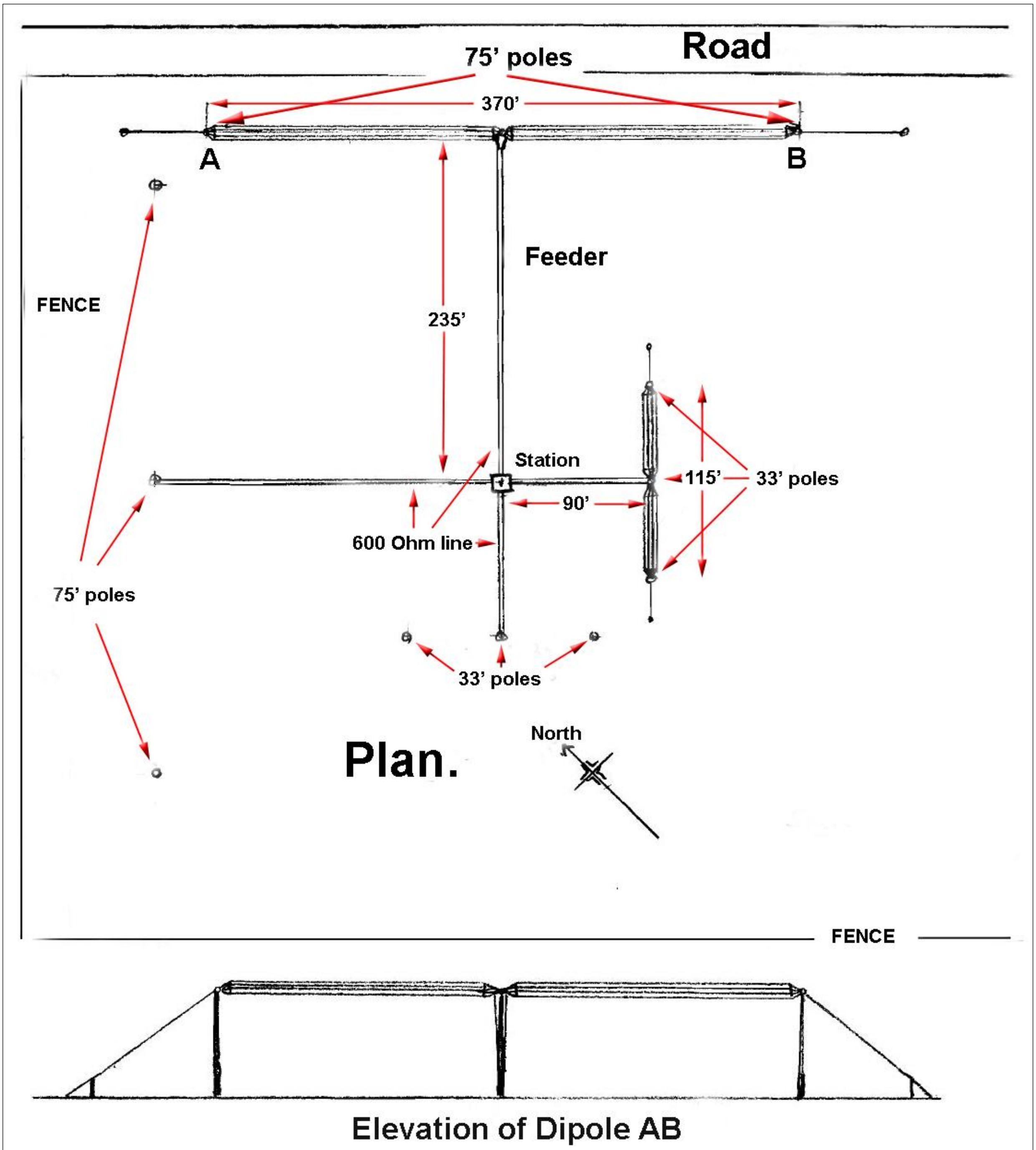


Figure 5: A plan (top) of the Cambridge site as at mid-1954, and an elevation drawing (bottom) of the 374-foot dipole (adapted from a diagram in Ellis, 1954c).

From an interview with Dr Geoff Fenton (pers. comm., 2008) in combination with a diagram (see Figure 5) in Ellis (1954c) and the only known surviving image of the site—an aerial photograph taken in 1957 (Figures 6a, 6b)—one of us (MG) has identified the location of the Cambridge site as being at longitude 147° 28.6′ E and latitude 42° 50.7′ S, adjacent to what is now known as Acton Road. MG visited the site on 21 September 2013 and noted, as expected, that the area has been subdivided into modern blocks of land that contained post-1950s houses. No trace could be seen, or imagined, of the 1955 setup.

Reber was pleased with the proposed site and that some equipment remained there, but he brought some of his own to supplement what was available. His letters to Ellis during 1954 made this intentions clear, but his arrival in Sydney on 1 November 1954 (after leaving Honolulu 17 October) was far from satisfactory:

> Eventually I arrived in Sydney on 1st November, 1954 aboard the *"Orion"* with ten cases of electronic apparatus in the hold. The wharfies promptly struck. Only passengers and personal baggage were unloaded by the crew and the *"Orion"* left for New Caledonia with my cases. I reached Hobart toward the end of November and my cases followed in a few weeks. (Reber, 1982).

Figure 6a: The Cambridge field station (centre), photographed on 27 May 1957 (two years after the 1955 observations discussed in this paper). The relatively new Hobart Airport (Llanherne) is at the extreme upper left. The photograph was found amongst Reber's collection and was probably taken by Reber himself (courtesy: Archives, National Radio Astronomy Observatory/Associated Universities, Inc.).

Reber's enthusiasm for the observations and his clear intention to make the most of his visit to Tasmania were evident in his questions to Ellis about the local conditions (Reber, 1954c), as he was naturally keen—because of the low frequencies at which he and Ellis would be observing—to understand the likely level of artificial radio interference. He also enquired as to the possibility of extending the aerials onto adjacent land. Ellis' reply (1954b) included maps, and a comment that adjacent land to the south and west could indeed be used if necessary.

To record their observations, Reber and Ellis (1956) made use of a cathode ray indicator.[9] The indicator was photographed with a film moving at a rate of 1.5 inches (3.8 cm) per hour. At such low frequencies, this was far preferable to using a pen recorder. The advantage of the cathode ray indicator method was that its smaller time constant resolved the appearance of atmospherics[10] so that the background celestial signal could be isolated.

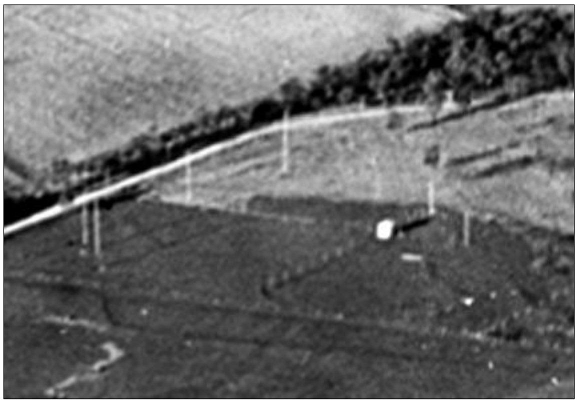


Figure 6b: A close-up of the central region of Figure 6a, enhanced to show the remaining artefacts on the site. North is to the left. The position of the white shed in relation to several poles clearly matches the diagram by Ellis (cf. Figure 5).

4 THE OBSERVATIONS: RADIO ASTRONOMY AT CAMBRIDGE IN 1955

Because Reber had arrived in Australia in the lead-up to the summer of 1954–1955, he and Ellis decided to wait until mid-March 1955 to commence their observations (Reber, 1982). This was, of course, because of the well-understood advantage of observing during winter when the conditions for low-frequency radio astronomy would be best. However, although there are no detailed records of their activities between November 1954 and March 1955, Reber and Ellis would in any case have needed to use this time to set up and test equipment at Cambridge and plan their observations. In particular, Reber (1954c) had mentioned to Ellis that before any observations could be commenced or more poles erected, he wished to carry out 'listening tests' to ensure that man-made electrical interference did not dominate.[11]

Originally, Reber (ibid.) had told Ellis that he intended to observe at two main frequencies:

> I expect to bring with me duplicate equipments (*sic*) and make simultaneous recordings at two main frequencies. One frequency will be in the region of 500–1000 kc where the Z hole phenomenon should occur. The other frequency will be in the region 2000 to 2500 kc where the ionosphere should be reasonably transparent when f0F2 is between 1000 and 1500 kc.

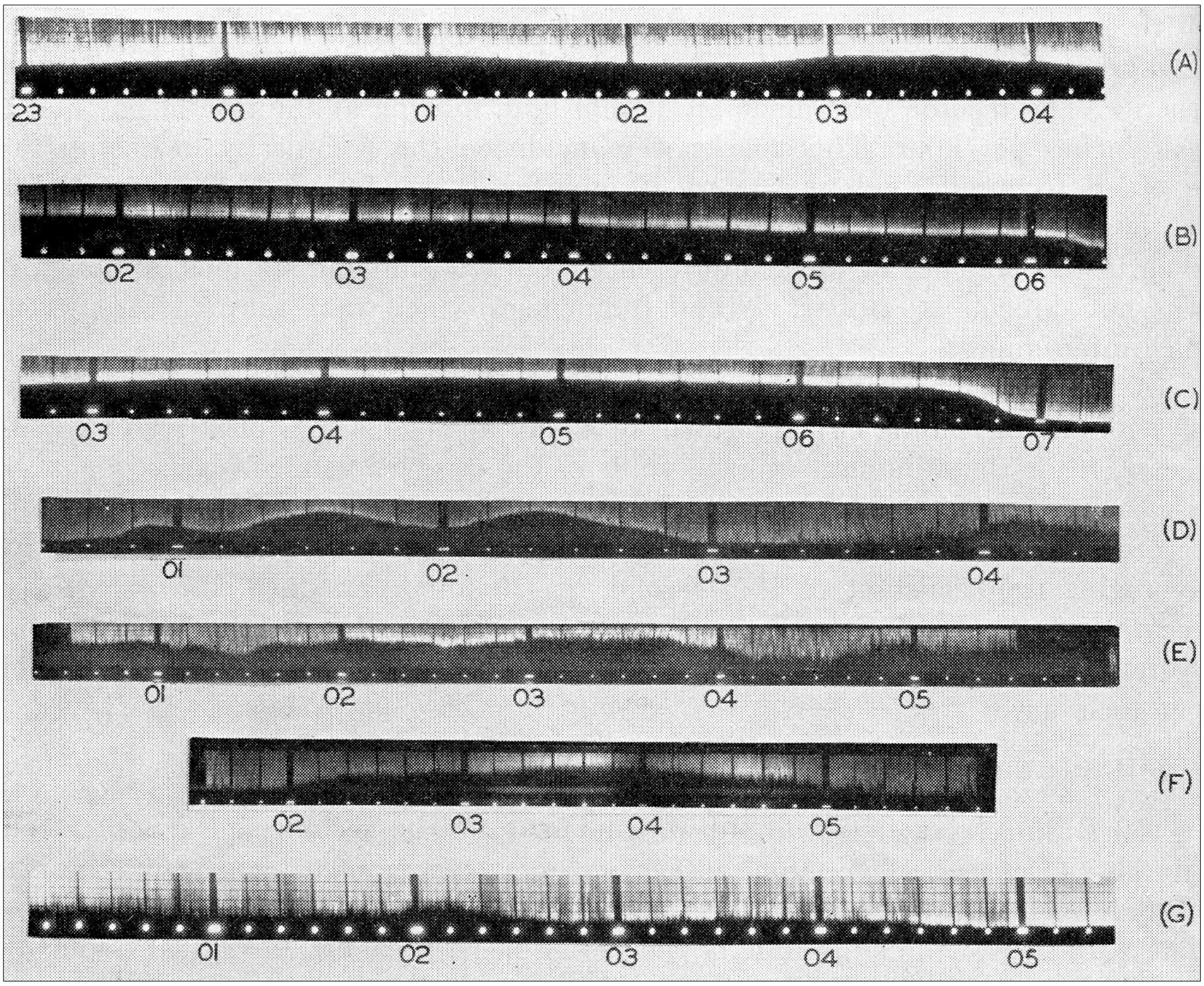


Figure 7: Records of observations made at Cambridge in 1955. The upper three (A, B and C) were at 2.135 MHz, followed by two (D and E) at 1.435 MHz, and one each at 0.9 MHz (F) and 0.52 MHz (G), respectively (after Reber and Ellis, 1956).

However, the 1955 observations were actually made at four different frequencies: 2.13, 1.435, 0.9 and 0.52 MHz (see Figure 7). Note that at the time these were by far the lowest frequencies ever attempted in radio astronomy: prior to this, the lowest frequency at which celestial radio emission had been observed was 9.15 MHz by Higgins and Shain (1954) at the Radiophysics Hornsby Valley field station near Sydney (see Orchiston et al., 2015).

In mid-March 1955, Reber and Ellis set the equipment to an "… apparently empty frequency near two megahertz …" (Reber, 1982), using a pen recorder. It was left operating for three days. Over that period they noticed that

> Daytime readings showed low level station interference which increased in magnitude along with atmospherics toward evening. About 1 a.m. on the first night, the electron density decreased enough so that a transparent hole in the ionosphere appeared at that frequency. The pen on the chart rose to a high level, about three-quarters full scale, and continued there until sunrise when the hole closed due to increasing electron density ... During the first night, when the hole was open, all man-made interference and atmospherics went out through the hole into space. Luckily for us the cosmic static came in without attenuation and had unexpectedly great strength. Here was a new and interesting aspect of radio astronomy which should be followed up. (Reber, 1982).

In their landmark paper titled "Cosmic Radio-Frequency Radiation Near One Megacycle", Reber and Ellis (1956) describe the results of the observations made at the four different frequencies.

4.1 The 2.13 MHz Observations

This series of observations ran from March to October, and includes the very first trial observations mentioned above. At this frequency, the 374-foot cage dipole was used (see Figure 5a). The authors mention (ibid.) that at this frequency and at 0.52 MHz (see 4.4 below), "… specially built battery-operated receivers with a bandwidth of 6 kc/sec were used." However, they do not indicate whether Reber brought these with him when he came to Australia, or whether he built them in Hobart.

In relation to the 2.13 MHz observations, Reber and Ellis (ibid.) noticed that

> On almost every night, strong continuous radiation was observed for periods which ranged from approximately one hour to 12 hours.

Both researchers were in no doubt that the radiation was of extraterrestrial origin. They also noted that when the critical frequency was lower than about 1.6 MHz, the amplitude increased to a limiting value. The clear implication of this is that the ionosphere was by then so transparent (at this frequency) that they were observing relatively, or nearly completely, unattenuated radiation.

4.2 The 1.435 MHz Observations

These, and the observations at 0.9 MHz, ran from April to September 1955 and were conducted using single half-wave dipoles placed 60 feet above the ground. Although the researchers make no other reference to the particular antenna used, it is reasonable to assume that they constructed new dipoles for this purpose, as Ellis (1954c) in his diagram of the site makes no reference to 60-foot poles, and Reber (1954c) discusses the possibility of erecting extra poles.

On only five nights, when the critical frequency was ~1MHz, did the radiation reach a limiting value. Nevertheless, Reber and Ellis (1956) still were able to identify a maximum at ~17h right ascension (close to the Galactic Centre), although the results were clearly less distinct than at 2.135 MHz.

4.3 The 0.9 MHz Observations

A significant difference now existed with the observations, as the equipment used to measure the critical frequency operated only down to 1 MHz. Therefore, the important observation of extraterrestrial radiation reaching a maximum when the critical frequency dropped below a certain level was not possible with these observations, nor was it possible at the lowest frequency of 0.52 MHz (see Section 4.4 below). However, based on the observations they did obtain between June and October 1955 the critical frequency was *inferred* to have been below 1 MHz on four occasions.

Nevertheless, at this frequency the cosmic component of the radiation was far less clear. Reber and Ellis (ibid.) commented that they did observe a rise and fall in the cosmic radiation, but that it also was characteristic of the rise and fall in the transparency of the ionosphere.

4.4 The 0.52 MHz Observations

This was the lowest of the four frequencies at which Reber and Ellis attempted observations. They observed on 80 nights between late May and early September 1955, and noted that only three nights produced records that could "… reasonably be interpreted as cosmic radiation." However, their comment that on two of these same nights they also observed radiation at 0.9 MHz (which, they imply, was assumed to be cosmic radiation), is an indication that they were convinced that they had observed extraterrestrial radiation at this frequency. Indeed, they commented that

> Although observations were made at lower frequencies at various times, 520 kc/sec was the lowest frequency on (*sic*) which there was any reason for believing that the cosmic radiation was detected. (ibid.).[12]

They came to the interesting conclusion that it was possible that all the records at 0.52 MHz were due to a region of low electron density passing overhead.

5 DISCUSSION

5.1 Reber and Ellis' Cambridge Observations

This was the first time that radio astronomers had attempted to observe at such low frequencies. From the letters exchanged by Reber and Ellis, and in particular Reber's assessment of the Z hole situation and his appreciation of Ellis' understanding of the subject, it is clear that Reber saw the potential for making observations at these frequencies being twofold. Firstly, the observations at the lower frequencies would make use of the Z hole phenomenon, and secondly, at the higher frequencies (particularly at 2.13 MHz) use would be made of the generally low values of the critical frequency.

As it turned out, Reber and Ellis made their observations a little later than the optimum time. The solar minimum of the 1950s, which occurred in June 1954, was very deep (e.g. see Hathaway, 2015; Meeus, 1983), with the mean Zurich sunspot numbers for both January and June 1954 reaching as low as 0.2.[13]

The mean of the Zurich sunspot numbers for the whole of 1955 was 38.0, with the lowest value of 4.9 occurring in March. It may therefore have been quite fortuitous that Reber and Ellis began their observations in March, rather than in the following months. This would have been a major factor that allowed the researchers to detect strong radiation on "… almost every night …" (see Section 4, above).

In their 2.13 MHz results, Reber and Ellis (1956) show a clear rise and fall centred on the region between 16h and 20h right ascension, and they noticed a similar maximum at 1.435 MHz. Later, when high-resolution low frequency arrays were utilised, the centre of our Galaxy showed up in absorption (e.g. see Shain, 1957), but we would not expect to see this with the wide-field Cambridge antenna, where the radiation was observed through an ionospherioc hole of ~1°, so the maximum in emission observed between 16h and 20h right ascension almost certainly was real.

There is little doubt that from amongst their selected frequencies, Reber and Ellis' 1.43 MHz results would have been close to the lower limit of reliable and consistent results. So the fact that they claim to have seen a possible celestial component at 0.9 MHz, and even at 0.52 MHz, is remarkable. Rather than being a record of the intensity as a function of right ascension, the success or otherwise of any such observations would have been very strongly dependent on ionospheric conditions, including the existence and size of an ionospheric hole. Supporting this view is the suggestion by Reber and Ellis (1956) that when regions of low electron density were passing overhead it was possible that all of the records obtained at 0.52 MHz were due to phenomena of that kind.

We can only speculate as to what the result would have been had Reber and Ellis chosen to carry out their initial observations during the exceptional year of 1954 instead of in 1955. Today this may be viewed as a 'lost opportunity', but at the time neither Reber nor Ellis made any comment about this. Indeed, although Reber was aware that solar activity was increasing, this did not deter him from making further low frequency observations before the consistent level of solar activity became too high. When they detected strong signals in March 1955, Reber and Ellis (1956) made the point that "… here was a new and interesting aspect of radio astronomy which should be followed up." This clearly resonated with Reber, whose subsequent research—and especially at Kempton in 1956–1957—will be the focus of a future paper in this series.

We also should note the comment by Reber and Ellis (1956) that their 1.435 and 0.9 MHz observations were made between 1 am and 5 am in order to avoid interference from local radio stations. At the time, and for some years afterwards, it was common for these radio stations to cease operating around midnight and start again at 6 a.m. or 7 a.m. (see Table 1). Even by the early 1970s, Hobart radio station 7HO, an AM station broadcasting at 0.86 MHz, and possibly others, still did not recommence their daily transmissions until 5 a.m.

In November 1955, not long after the completion of the observations at Cambridge, Reber (1955) left Australia, only to return a few months later so that he could begin observing at Kempton.

5.2 Other Early Observations

In addition to the observations made by Reber and Ellis at Cambridge, two research papers were published that relate to low frequency observations made after Reber's departure. One was by Ellis alone (1957) and the other by Ellis and Newstead (1957). As we saw on page 178, Gordon Newstead (Figure 8) from the Department of Electrical Engineering at the University of Tasmania was the first local person to conduct radio astronomical research in Tasmania, in 1952,[14] and it is interesting to see him team with 'Bill' Ellis from the Physics Department and carry our further research in this exciting new field after a hiatus of several years.

Unfortunately, as with many of the Tasmanian low frequency radio astronomy papers, the exact location of these observations by Ellis and Newstead is not recorded. It is a matter of speculation as to whether they were made at Cambridge or the IPS station on Mount Nelson, but Ellis (1957) states that a dipole was directed 38° east of north. Measurements along Acton Road at Cambridge show that the section of the road immediately adjacent to the Cambridge field station and parallel to the large antenna had an azimuth bearing of 127°. A line perpendicular to this has an azimuth of 37°, very close to the angle mentioned, and from both the diagram by Ellis and the aerial photograph of the site, it is significant that the dipoles

Table 1: The broadcast times of Hobart radio stations in 1954 (after *The Mercury*, 1954).

Station	Daily Broadcast Times	
	Start	End
7HO	6 a.m.	11 p.m.
7HT	6 a.m.	11 p.m.
7NT	6 a.m.	not listed
7ZL	7 a.m.	not listed
7ZR	6 a.m.	not listed

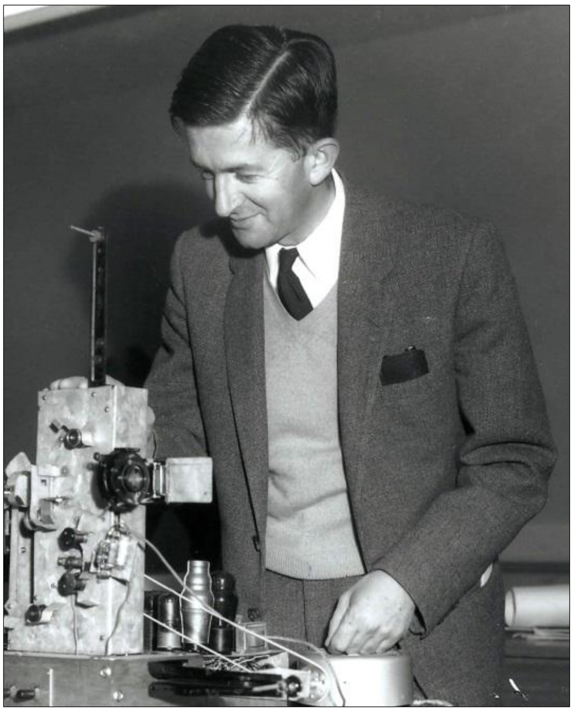


Figure 8: Gordon Newstead in the 1950s (courtesy Kim Newstead).

were very close to being parallel to or perpendicular to the road.

Regardless of the site of these observations, it is clear that although they were made at low frequencies, they were not made at the *extremely* low frequencies employed by Reber and Ellis in 1955. Indeed, Ellis and Newstead (1957: 185) reveal that their joint observations were made at 10.05 and 18.3 MHz, and that

> Six [discrete] sources were observed at both frequencies. Four of the sources were weaker at 10.05 Mc/s than at 18.3 Mc/s and two were stronger.

Although these observations did not form part of the collaboration by Reber and Ellis discussed in this paper, nonetheless they are an important component of early Tasmanian radio astronomy.

Figure 9: Examining a test recording at Eaglehawk Neck immediately prior to the 1949 partial solar eclipse. From left to right are John Murray (Division of Radiophysics), Graeme Ellis (standing) and N. Gerrard. At the time Ellis and Gerrard were research students in physics and electrical engineering at the University of Tasmania (courtesy: *The Mercury*).

6 CONCLUDING REMARKS

The 1955 observations at Cambridge by Reber and Ellis were a successful pioneering attempt to demonstrate that celestial radiation could be detected at significantly lower frequencies than had previously been thought possible, and they were aided by relatively low solar activity even though this was one year after the very deep solar minimum of that decade.

The combination of Reber and Ellis' ionospheric knowledge and Reber's drive to investigate this exciting new area of radio astronomy worked well, the eventual outcome being a very significant paper that they published in 1956. Although Reber knew that Tasmania was ideally located for such research, and this influenced his decision to relocate to Hobart, his appreciation of the ionospheric research carried out by Ellis clearly also was a contributing factor.

Future papers in this series will show that the success of the 1955 research by Reber and Ellis led to the blossoming of low frequency radio astronomy in Tasmania during the 1960s as Reber and Ellis went on to build a succession of new low frequency radio telescopes and Ellis developed a vibrant graduate program at the University of Tasmania.

7 NOTES

1. This is the third paper in a series that aims to document the early history of low frequency radio astronomy (<30 MHz) in Australia. The first paper (Orchiston et al., 2015) overviewed the activities of the CSIRO's Division of Radiophysics in Sydney at the Hornsby Valley and Fleurs field stations, and the second paper (George et al., 2015) summarised the research carried out in Tasmania during the 1950s and 1960s.
2. The O, X and Z modes are the three wave propagation modes that can pass through the ionosphere (Reber and Ellis, 1956). The 'Z hole', described by Ellis (1955), is a relatively small ionospheric region that allows the Z mode to pass through. Ellis had found that for Hobart this region had an angular diameter (as observed from the ground) of <0.84°. Despite the interest in this hole, Ellis and Reber (1956) note that only the O mode was important in the observations they recorded.
3. The term f0F2 refers to the lowest frequency that will pass through the F2 ionospheric layer at vertical incidence. It is also called the *critical frequency*. The F2 ionospheric layer is the most important layer limiting the detection of low-frequency celestial radiation. The value of f0F2 varies according to location, time of day and season.
4. This new site was located on University of Tasmania property on Mount Nelson, near the road known as Olinda Grove, at longitude 147° 18.9′ E and latitude 42° 54.8′ S. Ellis (1954b) comments that the Mount Nelson site includes "… the usual equipment of an ionospheric station, supplemented by close co-operation with the University."
5. Until 1956, Hobart's airport was located close to the small township of Cambridge. The current Hobart Airport (now known as Hobart International Airport), is several kilometres to the east and began operations in 1956. It is also known as 'Llanherne Airport' after the name of an important local property.
6. This comment is based on discussions one

of us (MG) had with Wheaton (Illinois) residents on 16 August 2008. Some of these residents were children at the time when Reber built his 'dish', and they recalled that in walking home from school they used a route that by-passed Reber's radio telescope.

7. When Reber asked Ellis what a 'Berkner dipole' was, Ellis (1954c) explained that it was a cage dipole, as shown in the diagrams he sent to Reber (see Figure 5).
8. A P′f record for an ionospheric layer is a plot of virtual ionospheric height against frequency. By 'virtual height' is meant the equivalent (single) altitude from which reflection appears to come.
9. These bore some similarity to cathode ray oscilloscopes, but were simple display devices that often were dedicated to particular applications.
10. The term 'atmospherics', sometimes simply called 'spherics', is used to describe radio noise arising from atmospheric sources, rather than external radio-frequency radiation that passes through the ionosphere. It occurs most predominantly at low frequencies. Lightning is the main cause.
11. Reber was always keen to optimise his use of time. Therefore it is clear that his arrival date in late 1954 was planned in order to allow sufficient time to prepare for the winter 1955 observations, including conducting the 'listening tests.' Indeed, he commented (Reber, 1954c) that "The earliest I can leave here [Hawaii] will be October or November ..." Later, he thanked the University of Tasmania's Vice-Chancellor, Professor T. Hytten, for the use of laboratory and shop facilities, which "... greatly expedited the work, particularly in its early stages." (Reber, 1955).
12. As far as is known, no further records or comments about attempted observations below 0.52 MHz were made, probably because they produced no useful results other than to show that these frequencies were far too low to produce anything meaningful.
13. The Zurich Relative Sunspot Number for an observer is calculated using the formula

$$R = k(10g + f) \qquad (1)$$

where k is a constant which is dependent on the observer (to remove systematic differences between observers), g is the number of sunspot groups and f is the number of individual sunspots. A typical value of R at the time of solar maximum is between 100 and 200. The monthly mean of 0.2 was an exceptionally low value; indeed, 1954 as a whole saw the lowest yearly mean (4.4) since 1901. A lower monthly mean value was not documented until a value of 0.0 was recorded in August 2008 during the unexpectedly prolonged solar minimum.

14. It is important to note, however, that Newstead was not the first to carry out radio astronomy experiments in Tasmania, as teams from the CSIR's Division of Radiophysics observed partial solar eclipses from Strahan (on the west coast) and Eaglehawk Neck (near Hobart) in 1948 and 1949 respectively (see Orchiston et al., 2006; Wendt et al., 2008). The former eclipse was observed at 600 MHz, and the latter at 1,200 MHz. It is interesting that Bill Ellis was a member of the 1949 eclipse team (see Figure 9). At the time he was completing his B.Sc. Honours degree, and this was his very first escapade in radio astronomy.

8 ACKNOWLEDGEMENTS

We wish to thank Elizabeth Ellis, Susan Ellis, Dr Geoff Fenton (University of Tasmania), David Goldstone (Hobart), Dr Ken Kellermann (National Radio Astronomy Observatory, USA), Kim Newstead and Dr Harry Wendt (Sydney) for assisting with this project. We also are grateful to the National Radio Astronomy Observatory, Kim Newstead, George Swenson and *The Mercury* newspaper for kindly supplying Figures 2–4, 6, and 8.

9 REFERENCES

Bolton, G., Stanley, G.J., and Slee, O.B., 1949. Positions of three discrete sources of Galactic radio-frequency radiation. *Nature* 164, 101–102.

Ellis, G.R.A., 1953. F-region triple splitting. *Journal of Atmospheric and Terrestrial Physics*, 3, 263–269

Ellis, G.R.A., 1954a. Letter to Grote Reber, dated 28 March. In Archives, National Radio Astronomy Observatory/Associated Universites Inc., Green Bank.

Ellis, G.R.A., 1954b. Letter to Grote Reber, dated 29 April. In Archives, National Radio Astronomy Observatory/Associated Universites Inc., Green Bank.

Ellis, G.R.A., 1954c. Letter to Grote Reber, dated 6 July. In Archives, National Radio Astronomy Observatory/Associated Universites Inc., Green Bank.

Ellis, G.R.A., 1955. The Z propagation hole in the ionosphere. *Journal of Atmospheric and Terrestrial Physics*, 8, 43–54.

Ellis, G.R.A., 1957. Cosmic radio-noise intensities below 10 mc/s. *Journal of Geophysical Research*, 62, 2, 229–234.

Ellis, G.R.A., and Newstead, G., 1957. Discrete sources of cosmic radio noise at 18.3 and 10.5 Mc/s. *Journal of Atmospheric and Terrestrial Physics* 10, 185–189.

George, M., Orchiston, W., Slee, B., and Wielebinski, R., 2015. The history of early low frequency radio astronomy in Australia. 2: Tasmania. *Journal of Astronomical History and Heritage*, 18, 14–22.

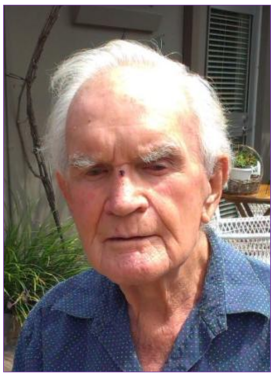
Haynes, R., Haynes R.D., Malin, D., and McGee, R., 1996. *Explorers of the Southern Sky: A History of Australian Astronomy*. Cambridge, Cambridge University Press.

Hathaway, D., 2015. The sunspot sycle. NASA. At: http://solarscience.msfc.nasa.gov/SunspotCycle.shtml. Retrieved May 2015

Hey, J.S., 1946. Solar radiations in the 4–6 metre radio band. *Nature,* 157, 47–48.
Higgins, C.S., and Shain, C.A., 1954. Observations of cosmic noise at 9.15 Mc/s. *Australian Journal of Physics*, 7, 460–470.
Kellermann, K., and Sheets, B. (eds.), 1983. *Serendiptious Discoveries in Radio Astronomy*. Green Bank, National Radio Astronomy Observatory.
Kellermann, K., 2005. Grote Reber (1911–2002): a radio astronomy pioneer. In Orchiston, 2005a, 43–70.
Kellermann, K.I., Orchiston, W., and Slee, O.B., 2005. Gordon James Stanley and the early development of radio astronomy in Australia and the United States. *Publications of the Astronomical Society of Australia*, 22, 13–23.
McCulloch, P.M., and Delbourgo, R., 2013. Graeme Reade Anthony ('Bill') Ellis 1921–2011: a pioneer in the area of low-frequency radio observations. *Historical Records of Australian Science,* 24, 96–108.
Meeus, J., 1983. *Astronomical Tables of the Sun, Moon and Planets*. Richmond, Willman-Bell.
Orchiston, W., 2004. From the solar corona to clusters of galaxies: the radio astronomy of Bruce Slee. *Publications of the Astronomical Society of Australia*, 21, 23–71.
Orchiston, W. (ed.), 2005a. *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth. A Meeting to Honor Woody Sullivan on His 60th Birthday.* Dordrecht, Springer.
Orchiston, W., 2005b. Sixty years in radio astronomy: a tribute to Owen Bruce Slee. *Journal of Astronomical History and Heritage*, 8, 3–10.
Orchiston, W., and Slee, B., 2005. The Radiophysics field stations and the early development of radio astronomy. In Orchiston, 2005a, 119–168.
Orchiston, W., Slee, B., and Burman, R., 2006. The genesis of solar radio astronomy in Australia. *Journal of Astronomical History and Heritage*, 9, 35–56.
Orchiston, W., George, M., Slee, B., and Wielebinski, R., 2015. The history of early low frequency radio astronomy in Australia. 1: The CSIRO Division of Radiophysics. *Journal of Astronomical History and Heritage*, 18, 3–13.
Reber, G., 1940. Cosmic Static. *Astrophysical Journal*, 91, 621–624.
Reber, G., 1944. Cosmic static. *Astrophysical Journal*, 100, 279–287.
Reber, G., 1949. Radio Astronomy. *Scientific American*, 181 (3), 34–41.
Reber, G., 1954a. Letter to Graeme Ellis, dated 22 January. In Archives, National Radio Astronomy Observatory/Associated Universities Inc., Green Bank.
Reber, G., 1954b. Letter to Graeme Ellis, dated 12 March. In Archives, National Radio Astronomy Observatory/Associated Universities Inc., Green Bank.
Reber, G., 1954c. Letter to Graeme Ellis, dated 23 June. In Archives, National Radio Astronomy Observatory/Associated Universiites Inc., Green Bank.
Reber, G., 1955. Letter to University of Tasmania Vice-Chancellor Professor T Hytten, dated 8 November. In Archives, National Radio Astronomy Observatory/Associated Universities Inc., Green Bank.
Reber, G., and Ellis, G.R.A., 1956. Cosmic radio-frequency radiation near one megacycle. *Journal of Geophysical Research*, 61, 1–10.
Reber, G., 1959. Radio interferometry at three kilometers altitude above the Pacific Ocean. *Journal of Geophysical Research*, 64, 3, 287–303.
Reber, G., 1977. *Endless, Boundless, Stable Universe*. Hobart, University of Tasmania (Occasional Paper 9).
Reber, G., 1982. My adventures in Tasmania. *Tasmanian Tramp* 24, 148–151.
Reber, G., 1983. Radio astronomy between Jansky and Reber. In Kellermann and Sheets, 71–78.
Reber, G., 1984. Early radio astronomy at Wheaton, Illinois. In Sullivan, 1984a, 43–66.
Robertson, P., 1992. *Beyond Southern Skies. Radio Astronomy and the Parkes Telescope*. Cambridge, Cambridge University Press.
Robertson, P., Orchiston, W., and Slee, B., 2014. John Bolton and the discovery of discrete radio sources. *Journal of Astronomical History and Heritage*, 17, 283–306.
Robertson, P., 2015. John Bolton and the Nature of Discrete Radio Sources. Unpublished Ph.D. Thesis, University of Southern Queensland.
Shain, C.A., 1957. Galactic absorption of 19.7 Mc/s radiation. *Australian Journal of Physics*, 10, 195–203.
Sullivan III, W.T., 1983. Karl Jansky and the beginnings of radio astronomy. In Kellermann, K., and Sheets, 39–56.
Sullivan III, W.T., 1984a. *The Early Years of Radio Astronomy*. Cambridge, Cambridge University Press.
Sullivan III, W.T., 1984b. Karl Jansky and the discovery of extraterrestrial radio waves. In Sullivan, 1984a, 3–42.
Sullivan III, W.T, 2009. *Cosmic Noise. A History of Early Radio Astronomy*. Cambridge, Cambridge University Press.
The Mercury, 15 November, 1954. Radio Programmes (page 19).
Wendt, H., Orchiston, W., and Slee, B., 2008. The Australian solar eclipse expedtions of 1947 and 1949. *Journal of Astronomical History and Heritage*, 11, 71–78.

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 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.

Professor Wayne Orchiston was born in New Zealand in 1943 and works as a Senior Researcher at the National Astronomical Research Institute of Thailand and is an Adjunct Professor of Astronomy at the University of Southern Queensland in Toowoomba, Australia. In the 1960s Wayne worked as a Technical Assistant in the CSIRO's Division of Radiophysics in Sydney, and forty years later joined its successor, the Australia Telescope National Facility, as its Archivist and Historian. He has a special interest in the history of radio astronomy, and in 2003 was founding Chairman of the IAU Working Group on Historic Radio Astronomy. He has supervised six Ph.D. or Masters theses on historic radio astronomy, and has published papers on early radio astronomy in Australia, England, France, Japan, New Zealand and the USA. He also has published extensively on the history of meteoritics, historic transits of Venus and solar eclipses, historic telescopes and observatories, and the history of cometary and asteroidal astronomy. He is a co-founder and the current Editor of the *Journal of Astronomical History and Heritage*, and in 2013 the IAU named minor planet 48471 Orchiston after him.



Dr Bruce Slee was born in Adelaide, Australia, in 1924 and is one of the pioneers of Australian radio astronomy. Since he independently detected solar radio emission during WWII he has carried out wide-ranging research, first as a member of the CSIRO's Division of Radiophysics, and then through its successor, the Australia Telescope National Facility. After working with Bolton and Stanley on the first discrete sources at Dover Heights, he moved to the Fleurs field station and researched discrete sources with Mills using the Mills Cross, and radio emission from flare stars with the Shain Cross and the 64-m Parkes Radio Telescope. He also used the Shain Cross and a number of antennas at remote sites to investigate Jovian decametric emission. With the commissioning of the Parkes Radio Telescope he began a wide-ranging program that focussed on discrete sources, and radio emission from various types of active stars. He also used the Culgoora Circular Array (*aka* Culgoora Radioheliograph) for non-solar research, with emphasis on pulsars, source surveys and clusters of galaxies, and continued some of these projects using the Australia Telescope Compact Array. Over the past two decades, he also has written many papers on the history of Australian radio astronomy, and has supervised a number of Ph.D. students who were researching the history of radio astronomy. .

Professor Richard Wielebinski was 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 für Radioastronomie in Bonn, where he was responsible for the instrumentation of the 100m 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 millimeter-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.