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THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 5: REBER AND THE KEMPTON FIELD STATION IN TASMANIA

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Abstract: After initially making low frequency observations with Graeme Ellis near Hobart, Tasmania, in 1955, Grote Reber returned to Tasmania to carry out further observations in 1956–1957 near Kempton, to the north of Hobart. He chose to investigate at 520 kHz, and used four dipoles, each about 670m long, about 300m apart and approximately 100m above a valley floor. Reber deduced that there was a celestial component which appeared to have a maximum, with an intensity he stated to be 4×10^{-20} $Wm^{-2}Hz^{-1}sr^{-1}$, around right ascension 22 hours, declination -6^{o}. By 1960, he had re-interpreted the results and concluded that the maximum emission actually came from a declination of about $+42^{o}$, in the constellation of Cygnus. However, two decades later, he expressed doubt that he had actually observed cosmic emissions at all. In 1957, Reber briefly also made observations from Kempton at 143 kHz. One of us (MG) has visited the Kempton site on several occasions in recent years and has located artefacts that have remained relatively undisturbed for nearly 60 years.

Keywords: Low frequency radio astronomy, Tasmania, Kempton, Reber

1 INTRODUCTION

Grote Reber (1940; 1944) had made the first radio maps of the sky in the early to mid-1940s and continued his interest in this new field. He made observations of radio emission from the quiet Sun (Reber, 1946), and between 1951 and 1954 he worked atop Mount Haleakala on the island of Maui in Hawaii, constructing and using a sea interferometer at frequencies between 20 MHz and 100 MHz (Reber 1955).

The results from Hawaii were unsatisfactory, and Reber then turned his attention to observing the sky at lower frequencies. The problem was ionospheric transparency, which places a lower, but variable, limit on the frequency of cosmic radiation that can reach the Earth's surface—typically just a few MHz. Reber (1982: 148) had gathered "... vast amounts ..." of ionospheric data from many parts of the world, and he discovered that the best conditions for low frequency radio astronomy occurred in winter at or near sunspot minimum, and around 40°–50° latitude. He chose Tasmania as an ideal location,[1] because of its more favourable climate (than Canada—especially in winter) and access to the southern sky, aspects of which he had earlier expressed an interest (Reber, 1949).

Reber arrived in Tasmania in November 1954. During 1955 he worked with Graeme Ellis from the Ionospheric Prediction Service at Cambridge, near Hobart airport (see George et al., 2015b). Together they made many recordings between about 0.5 MHz and 2 MHz, in an effort to detect celestial emissions at much lower frequencies than 9.15 MHz, which at the time was the lowest frequency at which successful observations had been carried out (see Higgins and Shain, 1954). This Cambridge research resulted in the paper "Cosmic radio-frequency radiation near one megacycle" (Reber and Ellis, 1956), in which the authors concluded that the recordings at the higher end of their frequency range were certainly of extraterrestrial origin, but that there was less certainty that the same could be said of the lower-frequency results. This Cambridge work would later inspire Ellis to establish University of Tasmania low frequency radio astronomy at nearby Llanherne (Hobart Airport), Penna and Richmond (for Tasmanian locations see Figure 1).

Encouraged by this preliminary work, Reber made a decision to carry out further low frequency observations, and after a brief period overseas he returned to the State in early 1956 (Reber, 1956a; 1982). Realising that it was essential to minimise artificial interference and that antennas would need to be strung high above the ground, Reber sought a location with a sufficiently deep north-south valley that was distant from Hobart, Tasmania's capital city.

The site chosen was about three kilometres west of the town of Kempton, ~50 kilometres by road north of Hobart. It was a valley at longitude 147° 10′ east, latitude 42° 33′ south, running approximately north-south and with hills on the western and eastern sides that Reber decided offered adequate height for suspension of dipoles across the valley. It is officially known as Irish Valley, but Reber occasionally referred to it as Johnson Valley. At the bottom of the valley there was a creek, which still exists today and became known as Astronomers Creek, presumably because of Reber's presence there. This name has clearly been adopted by the Nomenclature Board of Tasmania: it appears on topographic maps of the region and is listed as 'official' in the Geoscience Australia database of place names.

The valley and its surroundings were spread over two properties that at the time were owned by Cecil Johnson (western section) and Neil Johnson (eastern section).

This paper describes Reber's research that was carried out at Kempton between April 1956 and August 1957.[2]

2 BIOGRAPHICAL NOTE

Grote Reber (Figure 2) was born in Chicago, USA, on 22 December 1911. At an early age he developed a passion for radio. Then he took a great interest in the work of Karl Jansky (1905–1950), who in the early 1930s was the first to detect radio emission from our Galaxy.

In order to investigate this phenomenon further, in 1937 Reber constructed the world's first purpose-built radio telescope and mapped the sky at a frequency of 160 MHz (Reber, 1940; 1944). This was the first detailed radio map of the sky.

Reber maintained his interest in radio waves from celestial sources and eventually decided to make a study of low frequency emission. His first results in Tasmania were in collaboration with Graeme Ellis. Then, after his work at Kempton, he constructed a 2.085-MHz array at Bothwell (and this will be discussed in a later paper in this series).

Although he often travelled back to the USA and to other countries, Reber effectively made Tasmania his home for the second half of his life.

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

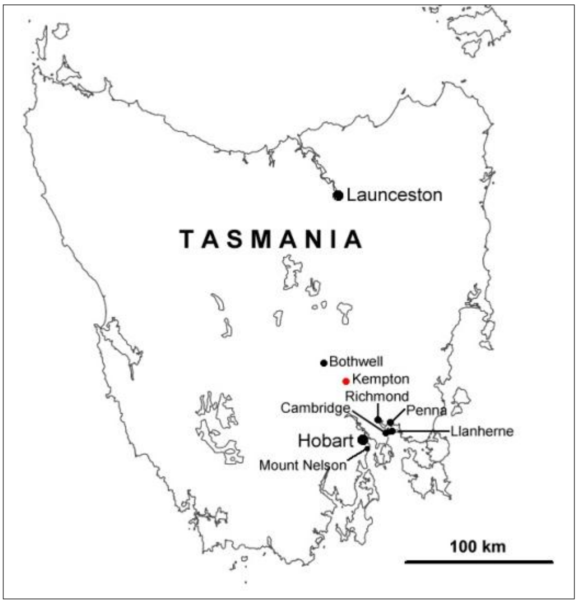

Figure 1: Key radio astronomy sites in Tasmania. This paper discusses Grote Reber's research at Kempton, to the north of Hobart (map: Martin George).

Grote Reber died in Tasmania on 20 December 2002, two days before his 91st birthday. For further biographical information about him, see George et al. (2015b) and Kellermann (2004).

3 INSTRUMENTATION

3.1 General Layout

Grote Reber's Kempton antenna array consisted of four dipoles stretched across Irish Valley. They were spaced about 300 metres apart and

Figure 2: Grote Reber in 1957, during the period when he was conducting research at Kempton (courtesy: George Swenson).

100 metres above the valley floor, and were intended primarily for use at 520 kHz. Reber kept detailed handwritten diary notes of the layout, and mentions that the valley floor was 0.20λ below the dipoles (Reber, 1956b).

In each case the 'wire', as Reber called it, consisted of two 1100-ft lengths in the centre, forming the dipole itself, and extra wire(s) at each end which were connected to anchor points on the hills on each side of the valley. Typically, each wire was therefore ~3,500 feet long and the dipoles were insulated from the supporting sections of wire at each end.

The anchor points were (a) trees, in the case of the eastern end of Antenna 3 and the western ends of Antennas 1 and 2; (b) short posts embedded into the ground, in the case of the eastern ends of Antennas 1 and 2; and (c) tall poles for the eastern end of Antenna 4 and the western end of Antenna 3. Five of these sites—all four anchor points on the eastern side and the anchor point for Antenna 3 on the western side —have been identified and contain artefacts. The exact locations of the other western ends have not been determined, although there are surviving photographs taken by Reber of the western anchor points (trees) for Antennas 1 and 2. No record or image of the western anchoring method of Antenna 4 has yet been found. The positions of all western anchor points other than that of Antenna 3 have been calculated from Reber's notes on the antenna lengths and bearings (see, e.g., Reber, 1956c; 1956d).

A feeder cable from the centre of each dipole led down to a post with a tuner box on the valley floor. Another coaxial lead—buried, to avoid being affected by animals—connected that box to the hut that contained the receiving equipment.

Phasing of the array, allowing for observations at different declinations, was accomplished by inserting extra lengths of cable between the down cable and the receiving equipment, so as to increase the path length by an appropriate amount.

Initially only two dipoles were used, which Reber called the *South Antenna* (Antenna 1) and the *North Antenna* (Antenna 2). A shed (Figure 3) was placed approximately midway between the two. Later, Reber erected two more dipoles farther north, calling these the *Centre North Antenna* (Antenna 3) and the *Far North Antenna* (Antenna 4). Because of this increase in the number of antennas, Reber erected a second shed between Antennas 2 and 3, so that once again the receiving equipment would be near the middle of the array.

The array was effectively a transit instrument, although the perpendicular line through the system was directed toward an azimuth of about 6° (i.e. 6° east of true north). The array could be directed toward different declinations by introducing extra lengths of cable between selected dipoles and the receiver.

Figure 4 shows the positions of the four wires and the two sheds in Irish Valley.

3.2 The Establishment of the Array and Sheds

By April 1956 Reber had obtained permission from the two landowners, Neil Johnson and Cecil Johnson, to use the site for his research.

Figure 3: The first shed, on the valley floor near Kempton (courtesy: Archives, National Radio Astronomy Observatory/Associated Universities, Inc., hereafter ANRAO).

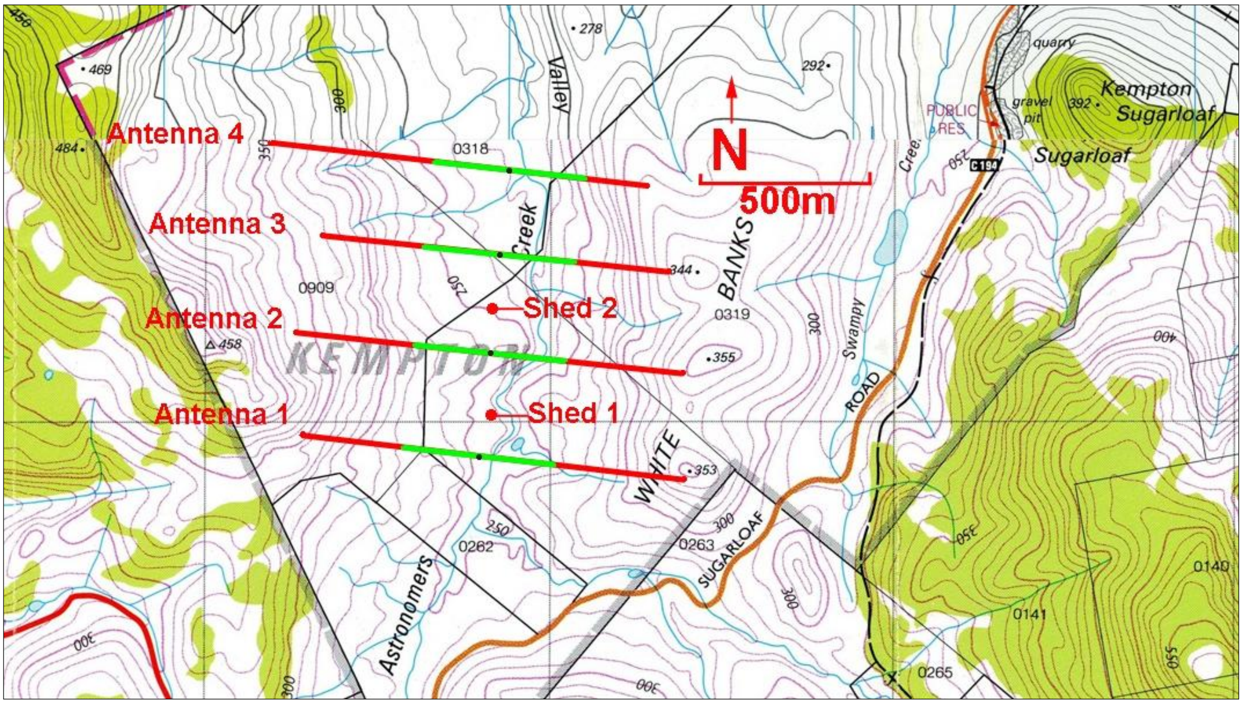

Figure 4: The locations of the four wires over Irish Valley, near Kempton. The dipole sections are shown in green and the supporting wires in red. Rear anchoring wires extending beyond the poles, etc., and stay wires, are not included. The positions of the two sheds are shown (adapted from 1:25000 topographic map, reproduced courtesy of the Department of Primary Industries, Water, Parks and Environment, Tasmania).

Figure 5: A photograph taken by Reber on 28 April 1956 during his initial survey of the area. This shows surveying equipment, and looks west across the valley, from near the future site of the eastern end of Antenna 1 (courtesy: ANRAO).

First he conducted a survey of the site (see Figure 5) and planned where to place the anchor points for Antennas 1 and 2 on each side of Irish Valley.

The first two antennas—the *South Antenna* (Antenna 1) and the *North Antenna* (Antenna 2)—were erected on 23 June and 30 June 1956 respectively (Reber, 1956d; 1956e), near the southern end of the useful part of the valley (Figure 6).

On 3 July 1956 Reber laid foundations for the first shed that was to contain his equipment, and the building was erected two days later (Reber, 1956f; 1956g). This was on the valley

Figure 6: The eastern end of Antenna 1 looking west across the valley, photographed about 28 September 1956 (courtesy: ANRAO).

floor approximately midway between the two antennas (Figure 3). A work bench was inside. The shed was used to house receivers and other equipment (see Section 3.3).

An amusing example of Reber's extensive note-keeping is his diary entry for 5 July 1956:

> Put up building on foundations and spent an hour looking for empty cable spool which was lost on 23/6/56 southwest of post A down slope. No success. Probably in clump [of] grass which will have to be burned off before spool can be seen. (Reber, 1956g).

By September 1956, Reber was planning the installation of the other two antennas. On 24 September he began marking out their positions:

> Made two rock cairns about 900 ft and 1800 ft to north of north red post along top of east ridge. These mark possible sites for east ends of two additional spans across valley ... All very speculative at present state of affairs. (Reber, 1956h).

Figure 7: The second shed erected by Reber. This was placed midway between Antennas 2 and 3 (courtesy: ANRAO).

Antenna 3 was erected on 1 December (Reber, 1956i) and Antenna 4 on 31 December (Reber, 1956j). Now that there were four antennas, it was clearly necessary to house the receiving equipment close to the centre of the array, as the original building had been erected when only the first two antennas were in use. Therefore, on 3 December 1956 a new shed (Figure 7) on the valley floor was erected between Antennas 2 and 3 (Reber, 1956k) and this was in use by 11 January 1957, on which date Reber moved everything from the first shed to this new building (Reber, 1957a).

Reber engaged the assistance of several people in establishing the Kempton site.

At the time, one of the authors of this paper (RW) was an engineering student at the University of Tasmania. He and at least two other fellow students were employed by Reber on weekends to assist with the erection of the Kempton antennas. Wielebinski recalls:

> He [Grote] was given a corner of the downstairs power laboratory of the Electrical Engineering School [in Hobart] to work in. This was partly because he was on good terms with Gordon Newstead.[3] I was then doing electrical engineering and this is how I got involved. He [Reber] went around asking which students were prepared to come on weekends to help him with some work. This is how I got involved.

The work done by the students did not involve actually making observations, but he called on them to assist with many tasks. Wielebinski further remembers:

> We did all the digging, and we put these nails [footholds] into the 'tree' to go up; that was done by students ... He had these nails from somewhere for free. We once had a confrontation with him saying it's easy to fall down.

Geoff Webb, a local radio enthusiast, was asked by Reber for his assistance in providing the tall poles for the eastern end of Antenna 4 and the western end of Antenna 3 (see Figure 8). He confirms (Webb, pers. comm., 2009) that these two were the only tall poles used for the antennas, suggesting that the western end of Antenna 4 was anchored by a tree or a short post. Webb (ibid.) selected "... trees from the forest ..." for these two poles, and gave them to Reber free of charge. Their regular appearances led to locals calling them "... those couple of crazy blokes." (ibid.)

Each of the tall poles was made stable by stay wires attached to short posts on the ground (Figure 8), and each had a pulley on top; the antenna-supporting wire, which led across the valley from the top of each pole, had a rear section running some 300 metres behind the pole before being anchored at ground level (see Figure 9).

With such a long cable run across the valley and the need for an adequate stay wire system of the two tall poles, it was important to have insulators of sufficient strength. Insulators that were considered for use at first often failed, which led Reber to source a different manufacturer to obtain a supply of insulators that were sufficiently strong for the job.[4] Reber had them tested in Hobart, either at the University of Tasmania or at the Mines Department. Similar considerations were important for the wires themselves (ibid.).

Wielebinski recalls that the entire length of each wire, with the supporting wires and dipole, was laid out across the valley floor and that a winch, or winches, were used to raise the wire into position. This is confirmed by Figure 10, which shows Reber operating a winch. We have identified this as almost certainly being the eastern end of Antenna 4.

The feeder lead from the centre of each dipole was an RG213 coaxial cable (ibid.). Webb expressed surprise at this, because of the weight of up to about 100 metres of cable being suspended from the dipole; this was an additional reason why the support mechanism, including the insulators, had to be sufficiently strong.

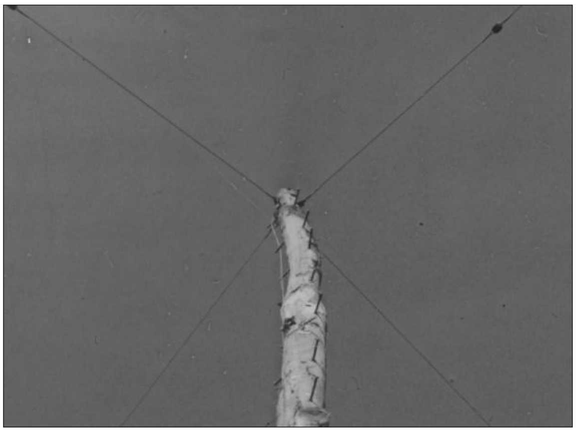

Figure 8: The upper part of the 20m-tall western pole of Antenna 3, one of only two tall poles used to support the wires (courtesy: ANRAO).

3.3 Receiving and Other Equipment

Each shed contained a receiver or receivers (see Figure 11), batteries, a chart recorder, a clock, and extensive rolls of coaxial cable that were used for the delay lines, with the length of each clearly marked (ibid.).

Reber made use of valve-operated radio receivers, at least partly based on equipment that he had brought with him from overseas in 1954 in advance of his initial work with Graeme Ellis (see, e.g., George et al., 2015b). Students assisted with the preparation of this equipment, and as always, Reber was keen to economise as much as possible. Wielebinski recalls that

> Regarding the 'junk' equipment Grote brought with him [from overseas]—the equipment that the wharf strike held up—we had it laid out in this electrical engineering laboratory, and we

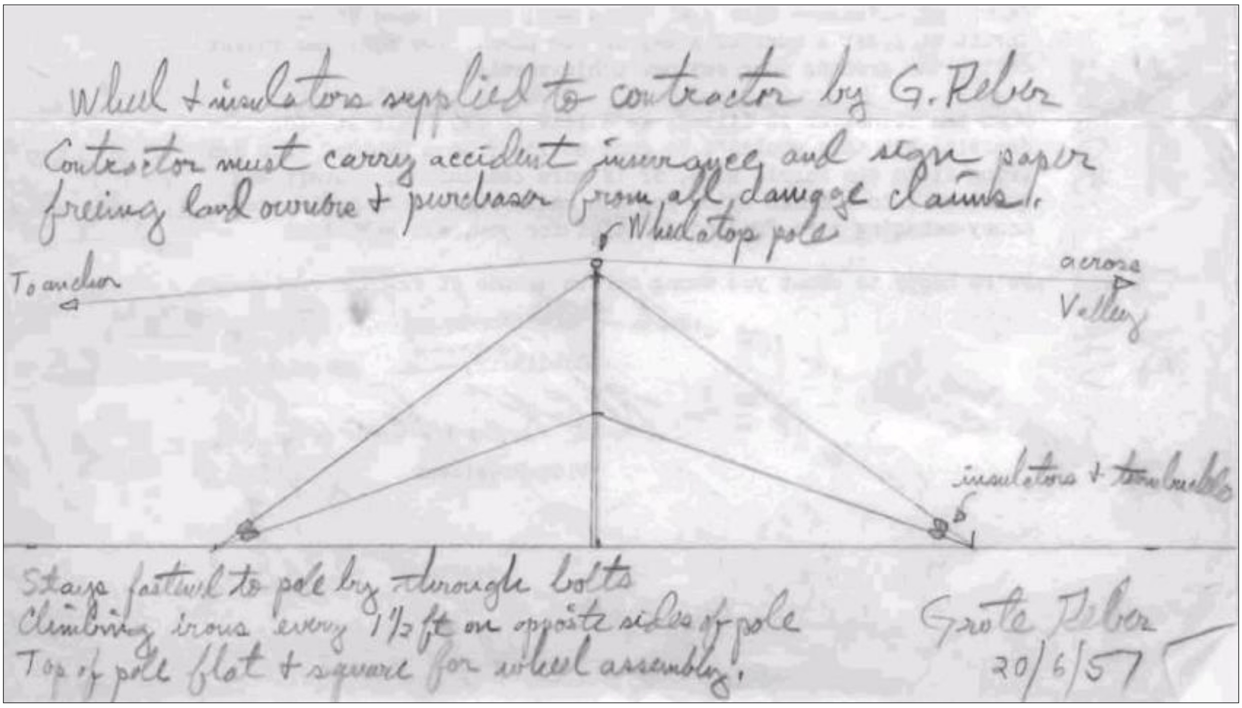

Figure 9: A June 1957 diagram by Reber illustrating the setup, including an anchor, stay wires and a pulley, when a tall pole was in use (courtesy: ANRAO).

Figure 10: Reber with a winch. This is almost certainly at the eastern end of Antenna 4 (courtesy: ANRAO).

> students had to unsolder the resistors and measure them, because he wouldn't use new resistors. He always insisted on stripping these old US navy receivers to reuse everything.

Reber used a set of batteries to provide energy to run the equipment. He made no use of the mains electricity supply, for not only was the site far from the nearest mains but the voltage and frequency of the supply were both unreliable.

In addition to retrieving the observations recorded on the chart rolls, Reber performed other tasks on each of his visits.

Of necessity, Reber regularly checked the condition of the batteries, which he always recorded in his diary notes. He needed to carefully maintain the pen recorder to ensure that the ink level was appropriate and that it was flowing properly. Another important activity was to check his clock against a radio time signal. A fine example of this attention to detail in his diaries is his regular entry of information about clock-winding: he recorded whether the clock was fast or slow, by how much, and even the number of turns of the key required to completely wind it up.[5]

3.4 Equipment Problems

Throughout the period of observations (see Section 4), Reber encountered many problems with the equipment. This included the occasional contact between animals and the tuner boxes located beneath the antennas.

Figure 11: An example of receiving equipment inside one of Reber's sheds on the floor of Irish Valley (courtesy: ANRAO).

The receiving equipment occasionally needed parts to be replaced, but generally it seems to have performed well, apart from occasional troubles with the pen recorder, as evidenced, for example, by the following diary entry made on 25 January 1957:

> 3:45 pm. Put in to use a new large square ink well. Put 1/8" into it. Seems a bit shallow. Also cleaned tip of pen which had a blob of ink on it. Removed blob. This made pen run smoother and vibrate uniformly. (Reber, 1957b).

The high winds in late February 1957 were a significant setback. After being absent from the area for several days and returning on 1 March, Reber discovered that Antennas 1, 3 and 4 had all been blown down, most likely on 28 February which Reber (1957c) learned was the windiest day. Antennas 1 and 3 were re-erected on 4 March and 16 March respectively. No record has yet been found of the date for re-erection of Antenna 4, but it is likely to have been between 5 and 25 April.

After commencing work with the University of Illinois in the USA to construct a large radio telescope, George Swenson (pers. comm., 2008) visited the Kempton site with Reber in 1957. Although he did not record the date, Swenson recalls that it was very hot, and it was therefore likely to have been summer or very early autumn —during the first few months of the year. At that time, one of the antennas was down, and this is likely to have been Antenna 4 for the aforementioned reasons. Reber engaged Swenson's help in trying to determine the cause of the failure.

4 THE OBSERVATIONS

The main frequency at which Reber observed was 520 kHz, despite the fact that the dipole, with an overall length of 2,200 feet (670m), would have operated as a 'full wave' dipole at 450 kHz. Subsequently, observations at 143 kHz were made from June to August 1957.

It is apparent from Reber's notes that the equipment was operating for as great a proportion of time as possible. He ran the chart recorder at a rate of 2.375 inches per hour, and the equipment was used to produce a wealth of data, both during the day and in the evening. Typically, Reber would arrive at the site in the morning, and determine whether the equipment had operated correctly overnight. At the end of each day that he visited the site, he took away the chart records for analysis.

Reber would often insert delay lines—most commonly 64, 96, 128 and 192 feet in length—in order to 'aim' the array at different declinations, and record these changes in his diary notes.

Reber was aware of 'atmospherics', which generally were emissions caused by lightning, hence the title of his 1958 paper ("Between the Atmospherics"). During mid-1957 he obtained data on storm activity over Tasmania (see, e.g., Bureau of Meteorology, 1957). He also was aware of 'precipitation static', in which water droplets cause a build-up of charge on antennas. On several occasions he noted the rainy conditions, including 'rain squalls' and other weather-related phenomena. For example, on 21 December 1956, he noted

> Arrive 950am. Everything going. On way across from Kempton there was a sharp cold front and rain squall. This lasted only a few minutes and sun came out again. The strong precipitation static was recorded just before my arrival. (Reber, 1956l).

His aim at Kempton, therefore, was to study the background intensity when these sources of interference were minimised.

Reber (1958) obtained "... nearly continuous records ..." at 520kHz between August 1956 and May 1957. The observations were conducted by Reber himself; he visited the site every few days and retrieved chart recorder rolls. However, Geoff Webb occasionally tended to necessary work at the site during Reber's absence (Reber, 1958).

From his observations, Reber deduced that there was a celestial component which appeared to have a maximum, with an intensity he stated to be 3.9×10^{-20} Jy/sr, at around R.A. 22h, Dec. –6°. Indeed, Reber's plot of his 520 kHz observations shows this maximum (Figure 12). However, his calculation of the intensity was *actually* 3.9×10^{-20} $Wm^{-2}Hz^{-1}sr^{-1}$; at the time, Reber was defining the Jansky to be the same as this unit (but note that it is now defined as 10^{-26} $Wm^{-2}Hz^{-1}sr^{-1}$). He also comments on a minor maximum near R.A. 4h. However, this does not appear to be a 'maximum'. Rather, it is a slight, yet noticeable, change in the rate of drop of intensity with increasing right ascension.

There is no clear celestial reason for such a peak to exist at the coordinates Reber found, which are located a few degrees south of the star Alpha Aquarii and some 40° from the plane of our Galaxy. Indeed, in his 1958 paper Reber did not offer any clear explanation for this as a source direction, other than suggesting that the source of the radio emission was in a region relatively close to the Sun, thereby removing the connection between the pattern of emission and the galactic plane.

This celestial interpretation has been disputed by others. Apart from the 'atmospherics', of which Reber was well aware, a component of the received radiation that Reber observed may well have been due to auroral emissions (see, e.g. Dowden, 1959; Ellis, 1957).

Reber also was clearly interested in learning of any connection between his results and any auroral activity, but concluded that there was little or no such connection other than suggesting that some intense auroral displays caused abnormal *D*-region absorption at night and that some emissions may be caused by low-energy particles not capable of producing an aurora (Reber, 1958). In his handwritten notes (Reber, 1957d) there is one mention of a visit, in order to enquire about auroral activity, to the 'Bisdee Observatory', presumably the one in Niree Heights, Sandy Bay (Hobart), which was the residence of Colin Bisdee, a well-known member of the Astronomical Society of Tasmania.

Reber (1960) later reinterpreted his 520 kHz Kempton observations. In explaining the lack of coincidence between his deduced position of maximum intensity and an obvious astronomical feature, he commented that

> The measurements had been repeated several times with good consistency. Apparently the trouble was not in the observations but in the interpretation.

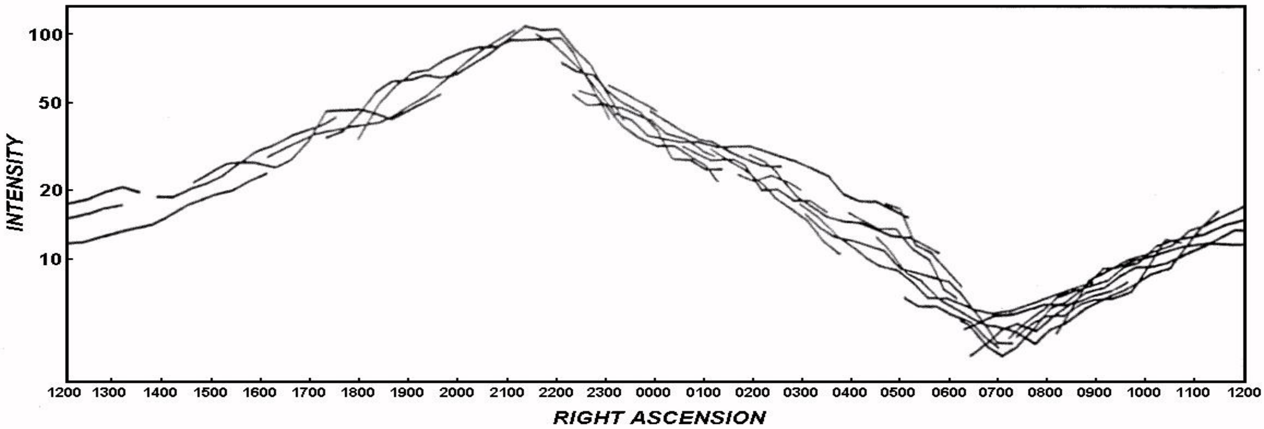

Figure 12: Reber's plot of received intensity against right ascension at declination –6° (adapted from Reber, 1958).

Reber's new interpretation was based on the 520 kHz gyro level intersecting the magnetic line of declination at an angle of 42°, and that the radiation was coming not from declination –6° but from declination +42°, in the constellation of Cygnus. It was Reber's view that the coupling at this point of intersection, between the ordinary and extraordinary longitudinal propagation modes O and X, could lead to radiation from this specific declination passing through to the Earth's surface.

The question of incoming wave direction is also connected with ionospheric variations, because changes in the f_0F2 values would be responsible for changes in the modes and hence in the direction of reception.

During June, July and August 1957, just before the array was dismantled, Reber carried out a series of observations at 143 kHz. Surprisingly, Reber (1958) commented that the 143 kHz results "... confirm the above in a general way ...", indicating that they supported the 520 kHz results. This would not be the case, even if Reber was indeed correct about the celestial nature of some of the 520 kHz results. It appears that the basis for his comments (ibid.) was that he observed that the changes in intensity of the 520 kHz signal were occasionally paralleled at 143 kHz.

However, Reber (1982: 150) later wrote

> ... it was doubtful that any of the results were really of celestial origin. Most seemed to be natural phenomena generated in the Earth's upper atmosphere and the probable cause was charged particles from interplanetary space. Clearly these frequencies were too low, so the observations were discontinued and the results published.

It is likely that these comments, made more than two decades after Reber's time at Kempton, were retrospective, rather than simply being an explanation of his feelings in the 1950s. Supporting this possibility was a letter written from Hawaii on 21 May 1958 to the Astronomical Society of Tasmania in which Reber commented that

> I expect to find my way back to the land of the Southern Cross in the autumn of 1960 and string up my wires again at Johnson Valley. (Bisdee, 1958).

There is no indication as to exactly what he intended to do if he did return to that site, but as it turned out, no further observations were made at Kempton.

Another type of 'observation' made by Reber was the effect of the local electricity supply on his readings. To achieve this aim, he organised to have the power disconnected from the entire area on one Saturday afternoon, having placed a notice in Hobart's *Mercury* newspaper to warn residents. He observed that there was a considerable reduction in the interference, and he concluded that all of the interference was generated within 15km of Kempton.

5 HERITAGE AT THE SITE

Once the series of observations was complete, the four antennas were dismantled. This took place in July and August 1957.

The original 1956 shed was moved to the Lauriston property, and used as a playhouse by Neil Johnson's children. It was later used as a storage shed, but sadly, it fell into disrepair and was demolished in the late 1990s (Tim Johnson, pers. comm., 2007). No record has yet been found of the eventual fate of the second shed.

The eastern pole for Antenna 4 was eventually cut up by Tim Johnson (the current owner of the property) and used as firewood.

However, several artefacts remained at the site. The western pole for Antenna 3 fell in about 2002 (Figure 13). It remains on the ground where it fell, with many of the original footholds still in place, and is just resolvable on Google Earth images. Some stay wires also have been found. The uppermost two-metre section of the pole, including the pulley, was removed by the Queen Victoria Museum (Launceston) in 2008. This was treated by conservation staff, and is now on display to the public at the Museum.[6]

Other artefacts that have been found on the ground include stay wires, insulators, loose footholds, and some remains of all four eastern antenna supports (e.g., see Figure 14).

It is unlikely that any western artefacts, apart from the abovementioned pole, will ever be found. Two extensive but unsuccessful searches were made by one of the authors (MG) in 2009 and 2015. A likely explanation for this is that the devastating bushfires of 7 February 1967 caused considerable destruction west of Astronomers Creek (Tim Johnson, pers. comm. 2015). In view of this, it is remarkable that the abovementioned pole has survived.

6 DISCUSSION

Reber's decision to perform his Kempton work below 1 MHz was clearly influenced by his success with Ellis at Cambridge in 1955, even though there was some doubt about the celestial nature of the lower-frequency Cambridge results. Looking back at Reber's work at Kempton, however, it would seem that rather than being an effort of major scientific importance, the project was an example of Reber accepting a challenge and pushing the boundaries of what could be achieved to their limits.

Figure 13: The western pole for Antenna 3, in 2015. It stood until about 2002, when it finally fell (photograph: Martin George).

It is surprising, however, that Reber saw fit to initially relate his 143 kHz observations to those at 520 kHz, as he would certainly have understood that the former frequency, at least, was clearly too low to allow the detection of emission of cosmic origin from the Earth's surface.

In his notes and research papers Reber does not elaborate on the specific reason(s) for choosing to erect four antennas at Kempton, each spaced half a wavelength apart, rather than selecting flat land and erecting a cross-type array modelled on the 1954 Mills Cross at Fleurs, near Sydney (see Mills and Little, 1953; Mills et al., 1958), which would have provided a circular beam and greatly-improved resolution. However, in his first paper, Reber (1958) does include a diagram showing his calculations of the various nulls in the antenna pattern that were obtainable using his configuration.

It is notable that Reber did not orientate his Kempton dipoles in an exact east-west direction; instead, they were directed toward azimuths 96° and 276°. Although he did not offer an explanation, this may have been because, in 1956–1957, the perpendicular through such a line was half way between geographic north and magnetic north. Later he made it clear, however, that the orientation of the valley was important: "After a brief stay in the States, I returned to Tasmania in 1956 to look for a deep north-south valley." (Reber, 1982: 150). We should note that Reber certainly had adequate resources—trees, posts and poles—to install the antennas where ever he wished.

At 520 KHz, it is interesting that Reber's value for the peak intensity (allowing for his 1957 use of the suggested Jansky unit) was consistent with results obtained in the 1960s (e.g., see Novaco and Brown, 1978).

It is a matter of conjecture as to when Reber came to accept that Kempton produced little or nothing in terms of useful results. His 1958 letter to the Astronomical Society of Tasmania, in which he foreshadows a return to Kempton within two years, suggests that at that stage he felt positive about a continuation at such low frequencies. However, by 1961 he was erecting his 2.085-MHz array near Bothwell, northwest of Kempton, and it is likely that his thoughts were already focussed on this new project.[7]

Figure 14: The post at the eastern end of Antenna 1 looking west, on 7 June 2009 (photograph: Martin George).

Nonetheless, Reber continued to reflect on the possibilities of making detailed studies of the sky at frequencies at or below those used at Kempton. Later (Grote Reber, pers. comm. 1995) he mentioned to one of us (MG) that much could be gained from such an effort, even suggesting that at times of sufficiently low solar activity it may be possible.

7 CONCLUDING REMARKS

Although at the time Reber considered that he had detected evidence of celestial radiation at 520 kHz, this remains highly doubtful, despite later space-based research that does indeed suggest that there is at least one preferred direction—although not corresponding with Reber's—for cosmic radiation at such a frequency (e.g., see Brown, 1973). Reber (1982) later took a quite different view of his research, commenting that most of his results seemed to be atmospheric phenomena and that the frequencies at which he was observing were too low for the detection of celestial emissions. The Kempton project was Reber's last attempt to observe at such low frequencies.

Reber's presence in Kempton had an impact, which apparently was generally positive, on the local community, and presented a fine and inspiring example of practical science.

8 NOTES

1. Tasmania is an island to the south of the Australian mainland and is one of the States of Australia. The latitude of Hobart, the capital city of Tasmania, is –42.9°, well within Reber's preferred latitudinal range. Peter Robertson (pers. comm. 2015) has suggested that Reber's decision to move to Tasmania may partly have been motivated by the problems he encountered in Hawaii.
2. This is the fifth paper in this series. The first two papers overviewed the early low frequency radio astronomy research carried out by staff from the CSIRO's Division of Radiophysics near Sydney (Orchiston et al., 2015a) and research by Ellis, Reber and their collaborators in Tasmania (George et al; 2015a). Papers 3 and 4 were detailed case studies of Ellis and Reber's work at the Cambridge field station near Hobart Airport (George et al., 2015b) and research mainly by Shain and Higgins at Hornsby Valley on the northern outskirts of suburban Sydney (Orchiston et al., 2015b).
3. Gordon Newstead (1917–1987) was then a Senior Lecturer in Electrical Engineering at the University of Tasmania, and he collaborated with Graeme Ellis over a long period.
4. Wielebinski noted that in order to economise, Reber initially sourced insulators that previously had been used by the Post Office, and sometimes were in poor condition.
5. As a somewhat amusing *finalé* to this, on 31 August 1957, after the observations had ended and the equipment was finally being removed, Reber noted in his diary: "Did not wind clock."
6. Observations by one of us (MG) in 2015 indicated that there has since been notable degradation of the section of the pole that remains on the ground at the site.
7. The Bothwell array will be the subject of a future paper in this series.

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10 REFERENCES

The following abbreviation is used:

ANRAO = Archives in the National Radio Astronomy Observatory/Associated Universities Inc., Charlottesvile, VA.

Bisdee, C.E. (ed.), 1958. *Bulletin of the Astronomical Society of Tasmania*, No. 179, June.

Brown, L.W., 1973. The galactic radio spectrum between 130 and 2600 KHz. *Astrophysical Journal*, 180, 359–370.

Bureau of Meteorology, Hobart, 1957. Letter to Grote Reber, dated 13 June. In ANRAO.

Dowden, R.L., 1959. Low frequency (100 kc./s.) radio noise from the aurora. *Nature*, 184, 803.

Ellis, G.R.A., 1957. Low-frequency radio emission from aurorae. *Journal of Atmospheric and Terrestrial Physics*, 10, 302–306.

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

George, M., Orchiston, W., Slee, B., and Wielebinski, R., 2015b. The history of early low frequency radio astronomy in Australia. 3: Ellis, Reber and the Cambridge field station near Hobart. *Journal of Astronomical History and Heritage*, 18, 177–189.

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., 2004. Grote Reber 1911–2002. *Publications of the Astronomical Society of the Pacific*, 116, 703–711.

Mills, B.Y., and Little, A.G., 1953. A high-resolution aerial system of a new type. *Australian Journal of*

Physics, 6, 272–278.
Mills, B.Y., Little, A.G., Slee, O.B., and Sheridan, K.V., 1958. A high resolution radio telescope for use at 3.5m. *Proceedings of the Institute of Radio Engineers*, 46, 67–84.
Novaco, J.C., and Brown, L.W., 1978. Nonthermal galactic emission below 10 megahertz. *Astrophysical Journal*, 221, 114–123.
Orchiston, W., Slee, B., George, M., and Wielebinski, R., 2015a. 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.
Orchiston, W., Slee, B., George, M., and Wielebinski, R., 2015b. The history of early low frequency radio astronomy in Australia. 4: Kerr, Shain, Higgins and the Hornsby Valley field station near Sydney. *Journal of Astronomical History and Heritage*, 18, 285–311.
Reber, G., 1940. Cosmic static. *Astrophysical Journal*, 91, 621–624
Reber, G., 1944. Cosmic static. *Astrophysical Journal*, 100, 279–287.
Reber, G., 1946. Solar radiation at 480 Mc./sec. *Nature,* 158, 945.
Reber, G., 1949. Radio astronomy. *Scientific American*, 181(3), 34–41.
Reber, G., 1955. Radio Astronomy in Hawaii. *Nature*, 175, 78.
Reber, G., 1956a. Letter to Graeme Ellis from Ottawa, Canada, dated 29 January. In ANRAO.
Reber, G., 1956b. Diary entry for 19 March. In ANRAO.
Reber, G., 1956c. Diary entry for 2 May. In ANRAO.
Reber, G., 1956d. Diary entry for 23 June. In ANRAO.
Reber, G., 1956e. Diary entry for 30 June. In ANRAO.
Reber, G., 1956f. Diary entry for 3 July. In ANRAO.
Reber, G., 1956g. Diary entry for 5 July. In ANRAO.
Reber, G., 1956h. Diary entry for 24 September. In ANRAO.
Reber, G., 1956i. Diary entry for 1 December. In ANRAO.
Reber, G., 1956j. Notes attached to a series of photographs by Reber. In ANRAO.
Reber, G., 1956k. Diary entry for 3 December. In ANRAO.
Reber, G., 1956l. Diary entry for 21 December. In ANRAO.
Reber, G., and Ellis, G.R.A., 1956. Cosmic radio-frequency radiation near one megacycle. *Journal of Geophysical Research*, 61, 1–10.
Reber, G., 1957a. Diary entry for 11 January. In ANRAO.
Reber, G., 1957b. Diary entry for 25 January. In ANRAO.
Reber, G., 1957c. Diary entry for 1 March. In ANRAO.
Reber, G., 1957d. Diary entry for 25 March. In ANRAO.
Reber, G., 1958. Between the atmospherics. *Journal of Geophysical Research*, 63, 109–123.
Reber, G., 1960. Cosmic static at kilometer wavelengths. *Symposium on Sun-Earth Environment*, July 1959, Ottawa. DTRE Publ. 1025, 243–248.
Reber, G.**,** 1982. My adventures in Tasmania*. Tasmanian Tramp*, 24, 148–151.

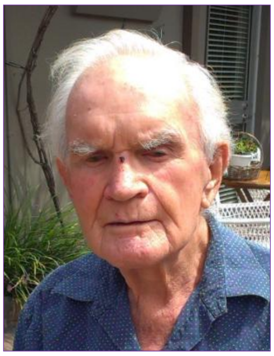
Martin George is the Collections and Research Manager at the Queen Victoria Museum and Art Gallery in Launceston, Tasmania, and also is responsible for the Museum's astronomy collections and the planetarium. He is a former President of the International Planetarium Society. Martin has a special research interest in the history of radio astronomy, and is completing a Ph.D. part-time 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, 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 Toowooma, 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 currently is the Vice-President of IAU Commission C3 (History of Astronomy). In 2013 he was honoured when the IAU named minor planet 48471 Orchiston after him.

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 Martin 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 Engineer-

ing 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-Institut für Radioastronomie 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 cooperation 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.

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 John Bolton and Gordon Stanley at Dover Heights on the first discrete sources, he moved to the Fleurs field station and researched discrete sources with Bernie Mills using the Mills Cross, and radio emission from flare stars with the Mills and Shain Crosses. 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.