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THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 12: REBER, HIGGINS AND THE MOOTED ALL-SKY SURVEY WITH THE SHAIN CROSS

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Abstract: During the 1950s and 1960s, Australia was a world leader in the specialised field of low frequency radio astronomy, with two geographically distinct areas of activity. One was in the Sydney region run by the CSIRO Division of Radiophysics (RP), and the other was on the island of Tasmania to the south of the Australian mainland, undertaken by the radio astronomy pioneer Grote Reber, and researchers for the University of Tasmania.

This paper deals with Reber's interactions with RP and his unpublished research based on observations taken by Charlie Higgins using the 19.7 MHz Shain Cross in August 1960. It also details Reber's unsuccessful efforts to lobby for RP to complete a southern sky survey using the Shain Cross.

Keywords: Australian low frequency radio astronomy, Grote Reber, Charlie Higgins, CSIRO Division of Radiophysics, Shain Cross, Fleurs field station.

1 INTRODUCTION

As described in earlier papers in this series (George et al., 2015a; 2015b; 2015c; 2016; 2017a; 2017b; 2018; 2020; Orchiston et al., 2015a; 2015b; 2021a; Wendt and Orchiston, 2024) Australia was an early international leader in low frequency[1] radio astronomy, with two centres of excellence: one near Sydney and the other in the island state of Tasmania, south of the Australian mainland (for localities mentioned in the text see Figure 1).

The Sydney initiatives were under the auspices of the CSIRO's Division of Radiophysics (henceforth RP), which, from 1946 through into the early 1960s, maintained a large number of field stations and remote sites, mainly in and around Sydney (Orchiston et al., 2021b). Two of these field stations, Hornsby Valley (Orchiston and Slee, 2005) and Fleurs (Orchiston and Slee, 2002), were involved in low frequency radio astronomy (Figure 1). However, Fleurs was home to three different cross-type radio telescopes (see Figure 2), but only one of these, the Shain Cross, was a low-frequency radio telescope.

This paper details some interactions between RP and the pioneering US radio astronomer Grote Reber with his unpublished research based on observations made by Charles S. (Charlie) Higgins (Figure 3)[2] using the 19.7 MHz Shain Cross at Fleurs after the untimely death of Charles Alexander (Alex) Shain (1923–1961).[3] It also details Reber's subsequent unsuccessful lobbying to have RP complete a southern sky 19.7 MHz survey. But first, a little about Reber.

2 GROTE REBER: A BRIEF BIOGRAPHICAL SKETCH

Grote Reber (1911–2002; Figure 4; George, 2023; Kellermann, 2005) was born in Chicago on 22 December 1911. He took a great interest in radio, and installed receiving equipment in the family home in Wheaton, Illinois, 60 kilometres west of Chicago. He obtained his first radio licence at the age of 16 with the call sign W9GFZ. His passion for radio continued right through his life, and it included collecting antique radios, many of which he still had in his possession in Tasmania at the time of his death.

In 1933 Reber obtained a degree in electrical engineering from the Armour Institute of Technology, following which he worked with several organisations including the Research Foundation of the Armour Institute of Technology.

In the early 1930s, Karl Guthe Jansky (1905–1950) was seeking the source of interference

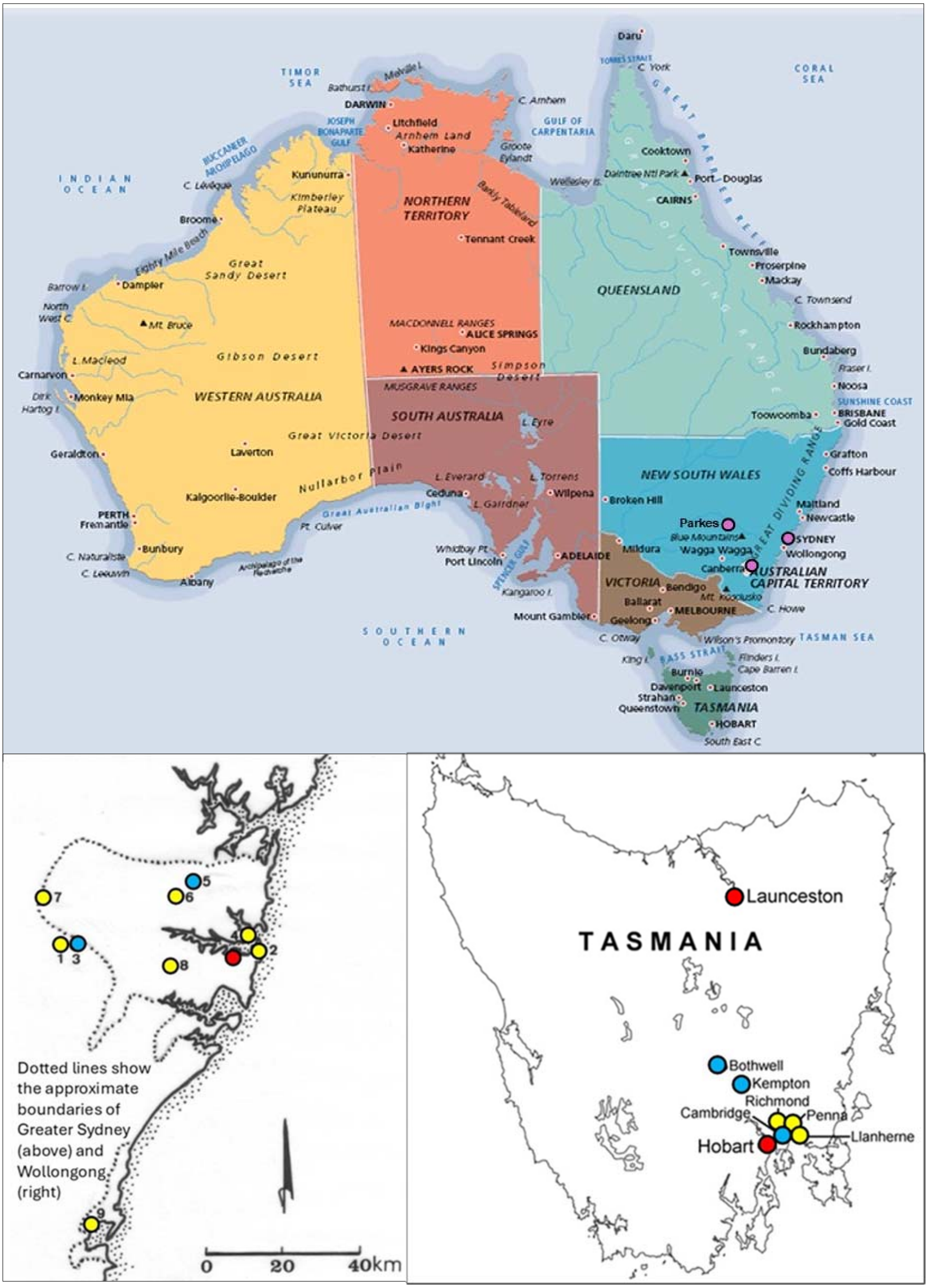


Figure 1 (top): Australia, showing Sydney, Canberra and Parkes; Bottom Left: The Radiophysics Laboratory (red circle) and RP field stations, 1 = Badgerys Creek; 2 = Dover Heights; 3 = Fleurs; 4 = Georges Heights; 5 = Hornsby Valley; 6 = Murraybank; 7 = Penrith; 8 = Potts Hill; 9 = Dapto, with the two low frequency field stations in blue; Bottom Right: The island State of Tasmania showing the two main cities (red), Reber's sites (blue) and other radio astronomy sites discussed in the research papers by George et al. (maps and modifications: Wayne Orchiston).

in radio transmissions when he discovered that there were radio emissions from the Milky Way. Reber took a great interest in this, as little was being done to pursue what Reber saw as a new field of research. Accordingly, in 1937 he constructed the world's first purpose-built radio telescope on a vacant plot of land adjacent to the family home in Wheaton (Figure 5). It had a reflecting 'dish' 9.6 metres in diameter, which focused radio waves in the same way as an optical reflecting telescope, and had a receiver at the focus. Wheaton residents had never before seen such a device, and many were suspicious of it, some of them walking home using alternative streets to avoid being too close to it (Wheaton informants, pers. comm., 2008).

Using this instrument, Reber observed and mapped the radio sky at a frequency of 160 MHz (Reber, 1940a; 1940b; 1944). However, he init--ially had trouble establishing what was only later called radio astronomy as an important topic, commenting negatively on the reluctance of Otto Struve, who was editor of the *Astrophysical Journal*, to publish his work (Kellermann, 2004).

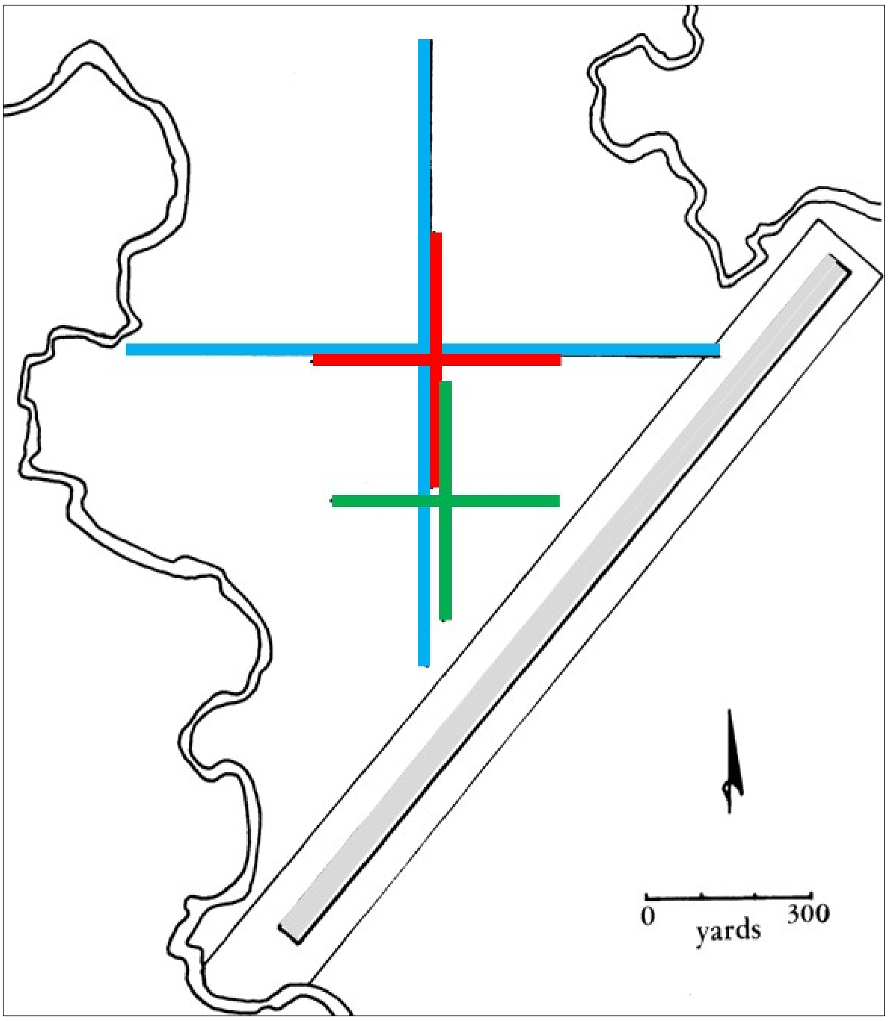
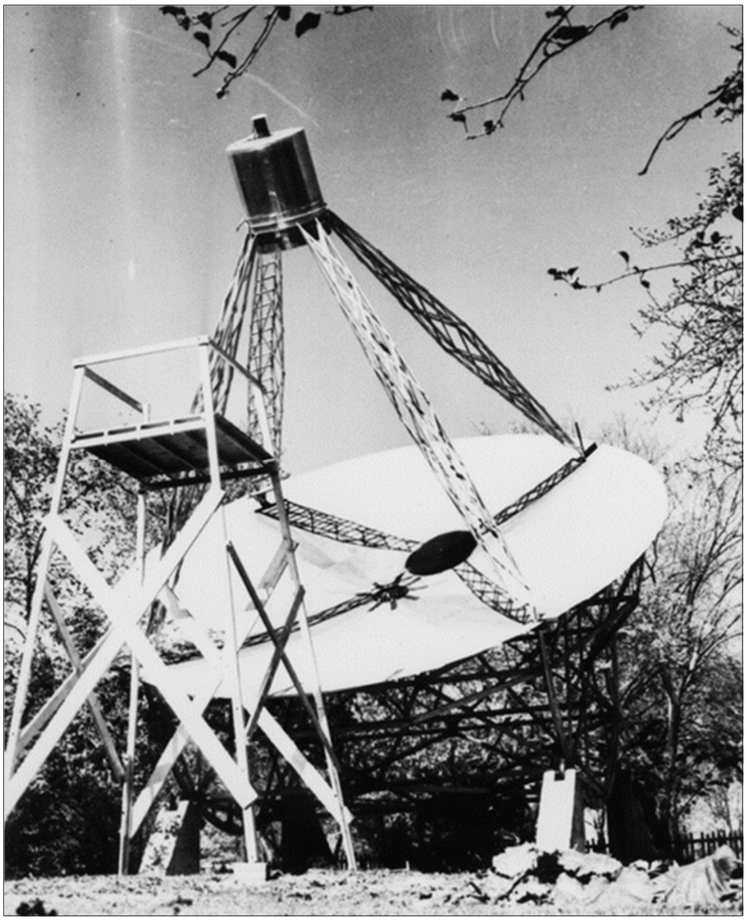


Figure 2: Fleurs field station showing the ex-WWII air strip (grey) and the three cross-type radio telescopes constructed there between 1953 and 1957; red = Mills Cross; blue = Shain Cross; green = Chris Cross (map: Wayne Orchiston).

Reber's continued interest in celestial radio emissions included the detection of emissions from the quiet Sun (Reber, 1944). He also successfully observed radio emissions from the region around the Sun's disc during a total solar eclipse from the Aleutian Islands on 12 September 1950, as part of a solar eclipse expedition by the Naval Research Laboratories (Reber and Beck, 1951).

After his early groundbreaking solo research efforts Reber struggled to find a role in the broader US research community that suited his unique personality, and ultimately he moved to Hawaii (Kellermann et al., 2020). He was intrigued by the sea interferometry technique that had been developed in Australia to determine the positions of discrete sources. He decided that the best way to exploit the method would be to observe from a 3000-m mountaintop in

Figure 3 (left): Charlie Higgins in 1972 (courtesy: CSIRO RAIA SH019-9Feb1972A).
Figure 4 (right): Grote Reber in 1962 (courtesy: NRAO/AUI/NSF https://www.nrao.edu/archives/items/show/30539).



Hawaii so he could measure both rising and setting times from a single location. From 1951 to 1954, he conducted a series of observations at 20 to 100 MHz (Reber, 1955b; 1959). He was plagued by ionospheric effects and terrestrial interference and concluded that the mountaintops were not a good place for a low frequency radio telescope.

Reber took a great interest in low frequency radio astronomy, which, especially for frequencies below about 10 MHz, is severely hampered by the failure of the ionosphere to transmit at increasingly low frequencies. Accordingly, he obtained ionospheric data from many locations around the world to select a suitable site for his work. His communications with Graeme Ellis (1921–2011) (Figure 6) in Tasmania, who was employed by the Ionospheric Prediction Service at that time, were highly encouraging. Ellis had been working near Hobart Airport and some

Figure 5: Grote Reber's original radio telescope, at Wheaton (courtesy: National Science Foundation/Associated Universities Inc.).

equipment remained at the site (see, e.g., Ellis, 1954a; 1954b). Reber travelled to Australia, arriving in November 1954, and carried out observations with Ellis at the Tasmanian site during 1955, claiming the detection of celestial radio emissions as low as 1.435 MHz and possible results at 0.9 MHz and 0.52 MHz (George et al., 2015b; Reber and Ellis, 1956).

Subsequently, Reber constructed a four-dipole antenna array across a valley at Kempton, about 50 kilometres by road north of Hobart (Figure 7). Encouraged by the work with Ellis,

Figure 6: Graeme ('Bill') Ellis in about 1970 (courtesy: University of Tasmania).

he attempted observations at 520 KHz. He initially believed that he had detected celestial emissions at that frequency, but later expressed doubt about whether these were actually from celestial sources (George et al, 2015c).

Reber's most ambitious project in Tasmania was the construction of his 2.085-MHz dipole

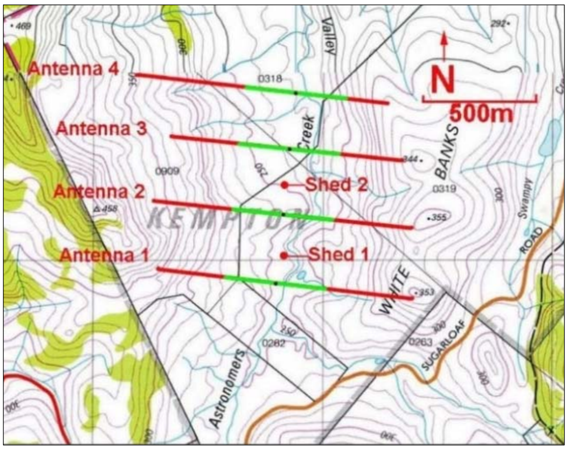


Figure 7: The locations of the four antennas across Irish Valley, near Kempton. The dipole sections are shown in green and the supporting wires in red. Rear anchoring wires extending beyond the poles and stay wires are not included. Shown, also, are the two equipment sheds which at different times housed the receivers (after George et al., 2015c: 315).

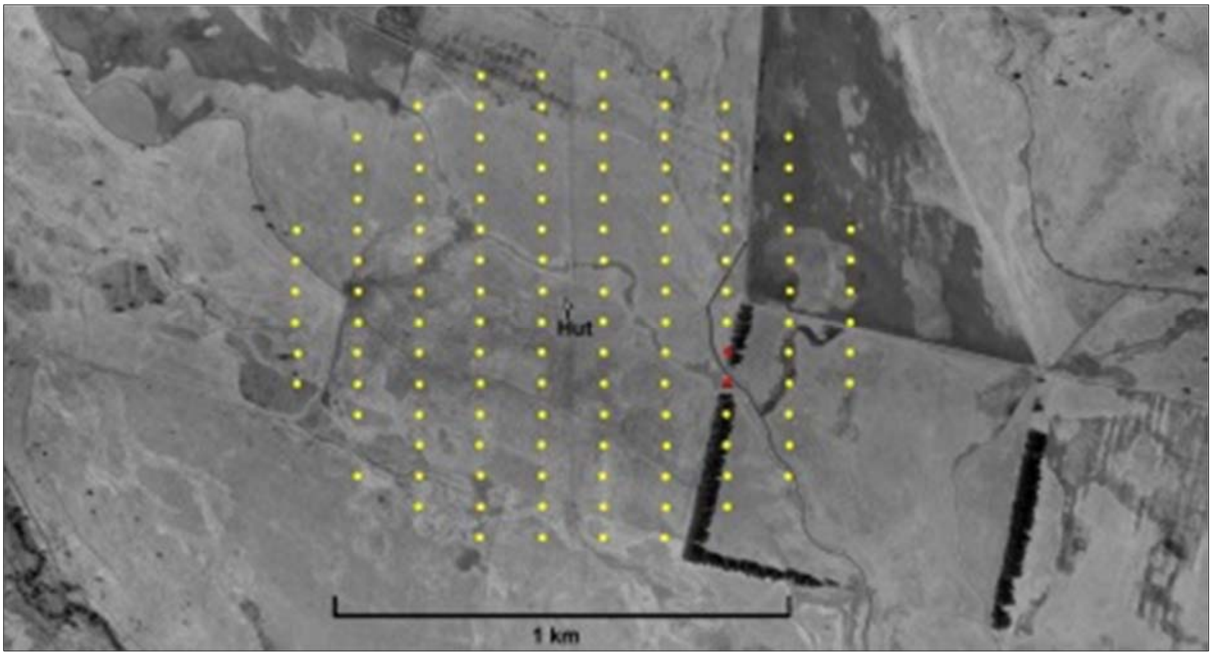


Figure 8: The locations of poles that can be identified on an aerial photograph taken on 15 February 1968. Yellow dots mark the positions of the 'pole' end of identified shadows; red dots are extrapolated from incomplete shadows. One pole, in the southwestern part, may have fallen (after George et al., 2017: 198).

Figure 9: An aerial photograph of most of Reber's Bothwell array taken in 1965, showing the 20.4-m high poles that supported the dipoles, and the small white central receiver hut (courtesy: Estate of Grote Reber).

array near Bothwell (Figures 8 and 9), about 80 km north of Hobart, on a flat area of land owned by local farmer Geoffrey Edgell. The elliptically-shaped array "… covered an area of 0.97 square kilometre … [making] this the world's first 'Square Kilometre Array'." (George et al., 2017: 197, 199). It was completed in 1963, and was used to successfully map 2.085 MHz emission from the southern sky (Figure 10) during the mid-1960s solar minimum when the ionosphere was more transparent due to the lower level of ionisation (Reber, 1968).

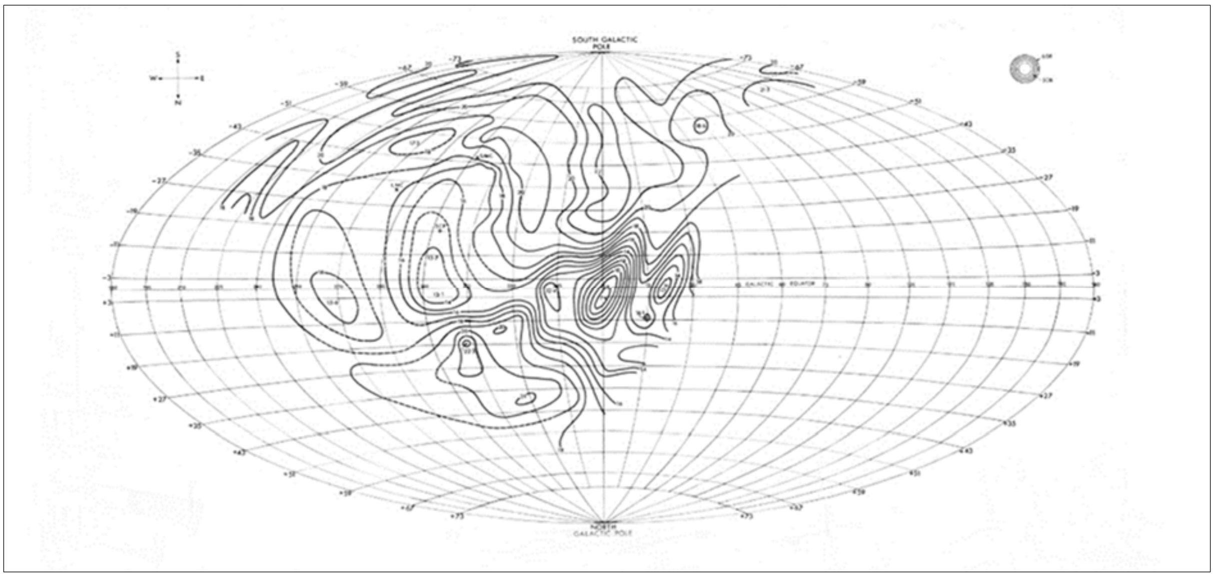


Figure 10: Reber's isophote plot of 2.085 MHz emission, presented in galactic coordinates with the Galactic Equator running horizontally through the centre of the diagram, and the South and North Galactic Poles at the top and bottom (after Reber, 1968).

Buoyed by his success, Reber then restrung the array so that it could operate at 1.155 MHz for the next solar minimum in the mid-1970s. This attempt failed, although he did note the presence of many Australian radio stations (Reber, 1974)!

Subsequently, Reber attempted observations at 2.055 MHz at Ashton, near Ottawa in Canada. He regarded this generally as a failure, although he did claim that he obtained some results, showing the expected absorption dip along the Galactic Plane (Reber, 1988).

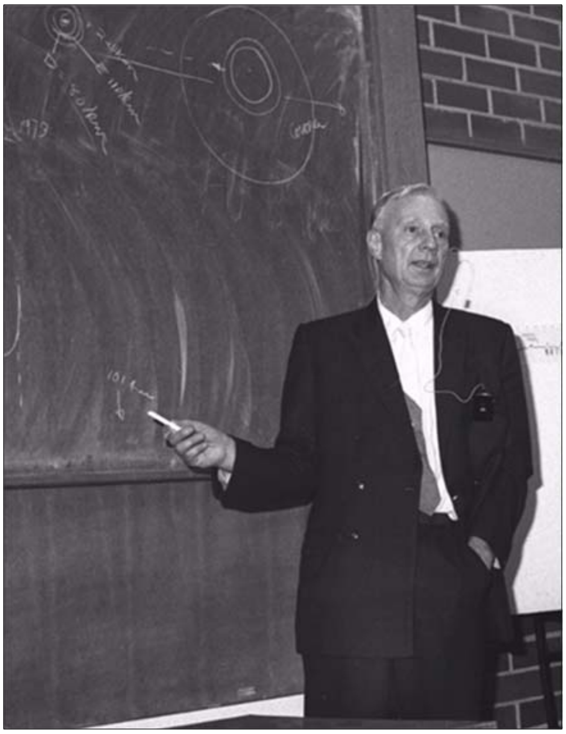


Figure 11. Grote Reber speaking to the Astronomical Society of Tasmania in 1972 about his response to the Big Bang Theory (photograph: Martin George).

His passion for low frequency radio astronomy led Reber to plan the modification of the ionosphere on a temporary basis by 'blowing a hole' in it in order to allow observations at much lower frequencies. This was achieved in 1985 by a firing of the engines of the Space Shuttle *Challenger* over Tasmania, which allowed observations as low as 1.7 MHz. Reber was a co-author of the resulting paper (Mendillo et al., 1987).

Reber's studies were supported financially throughout by the Research Corporation in the USA, and by Reber personally; indeed, the construction of his original radio telescope in Wheaton was achieved using his own funds (Kellermann, 2004).

We need to mention that Reber was not a mainstream astronomer. Thus, he did not accept the Big Bang Theory and felt that redshift was due to 'tired light' as it crossed the Universe. He often spoke on this subject (e.g. see Figure 11), and eventually published his views through the University of Tasmania (Reber, 1977).

Grote Reber had many other interests, including cosmic rays, but also several that were not related to astronomy. He was keen to investigate efficient methods of transport, even building an electric car he called Pixie (Figure 12), which was a well-known sight in the town of Bothwell. He theorised that beans yielded a higher bean-to-shuck ratio if they were forced to

Figure 12: Grote Reber with his electric car Pixie (courtesy: Estate of Grote Reber).

twist in the opposite direction to the natural one as they grew, and he carbon-dated a number of Tasmanian Aboriginal sites (Reber, 1960b). A special project for him in Bothwell, for which he won an award, was to build an energy-efficient home in Michael Street, which used solar energy collected from material mounted on the northern wall of the house, with the resulting warm air circulating through ducts running around the building.

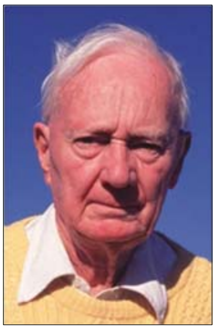
Over the years Reber was awarded a number of prizes, including the 1962 Bruce Medal from the Astronomical Society of the Pacific and an honorary Doctor of Science Degree from Ohio State University.

Reber never lost his interest in low frequency radio astronomy, even into his 80s (Figure 13). He passed away on 20 December 2002 at the hospital in Ouse, Tasmania, just two days short of his 91st birthday. He had continued observations through his hospital window, commenting to his lifelong friend Dale Blanchard about the position of the Sun and the times of sunset (Dale Blanchard, pers. comm, 2003).

3 GROTE REBER'S RELATIONSHIP WITH JOE PAWSEY

In early 1948, Joseph Lade (Joe) Pawsey (1908–1962; Figure 14), the scientific leader of the RP radio astronomy group, visited the US as part of his efforts to further his international network. As part of his trip, he met Reber, who alerted him to the possibility of detecting the 21-cm hydrogen emission line (Wendt et al., 2008). Thus began Pawsey's relationship with Reber, which continued until Pawsey's untimely death in 1962 (for details on Pawsey's career see Goss et al., 2023).

In May 1954 Reber wrote Pawsey from Hawaii, saying he planned to leave shortly for Tasmania to obtain atmospheric data to explore the possibility of carrying out very low frequency observations there (Reber, 1954). He noted that Graeme Reade Anthony ('Bill') Ellis (Figure 6;



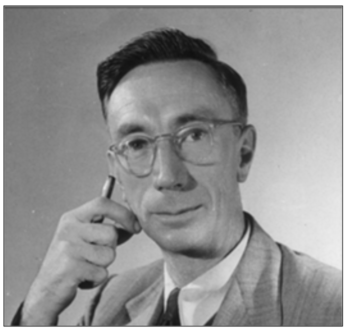


Figure 13 (left): Grote Reber at his home in Bothwell, Tasmania, in 1995 (photograph: Martin George).
Figure 14 (right): Joe Pawsey at RP in about 1952 (courtesy: CSIRO RAIA, 7454-2 cropped).

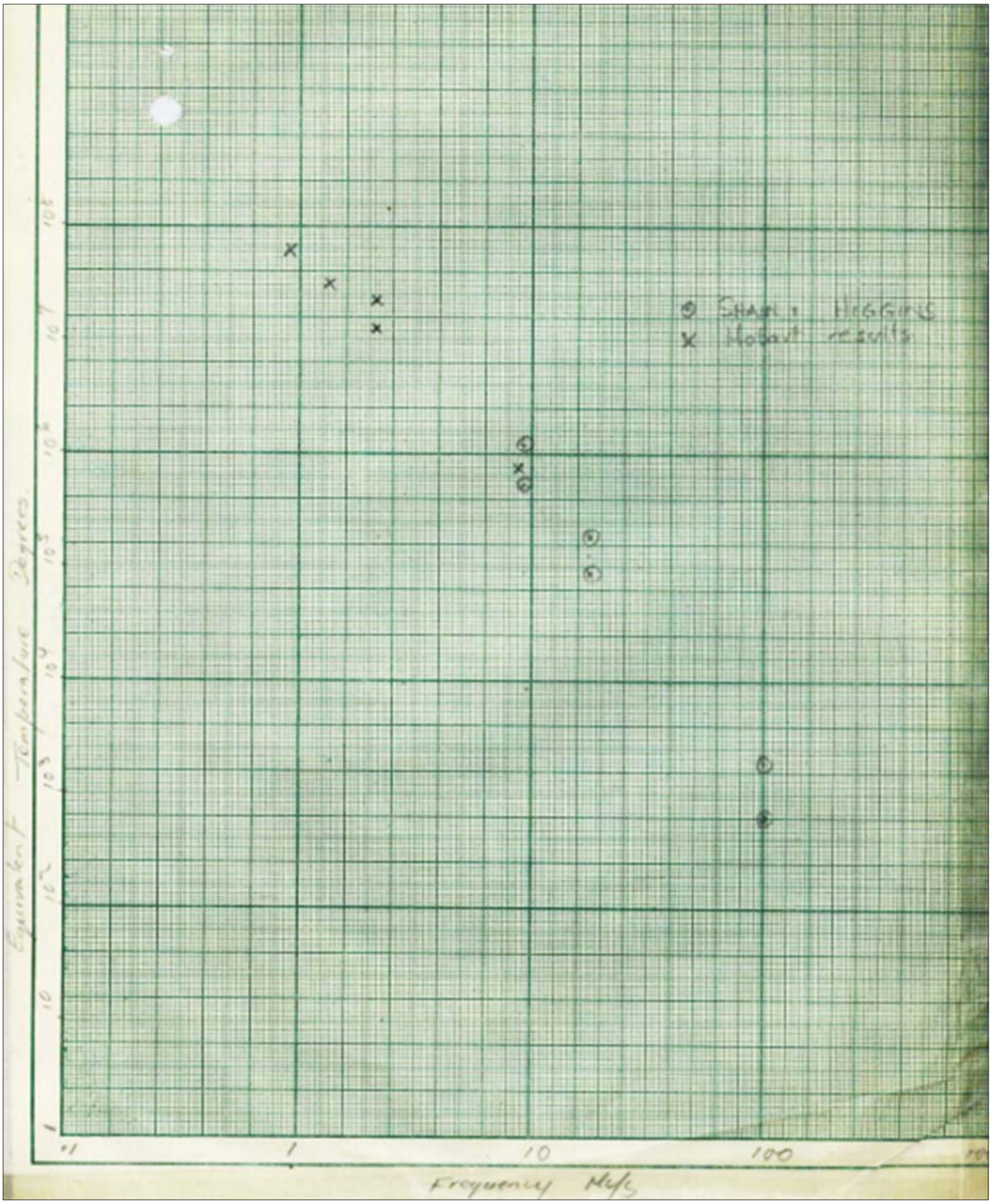


Figure 15: Ellis' equipment temperature vs frequency plot shows data points from Hobart (x) and Shain and Higgins (o). Note that the Shain and Higgins results show the maximum and minimum temperature observed for each frequency, as published in Higgins and Shain, 1954: Figure 7a. The chart was an attachment to Ellis' letter to Pawsey of 5 October 1955 (Ellis, 1955).

Delbourgo and McCulloch, 2013) of the Ionospheric Prediction Service (IPS) had offered to provide a field station and some assistance. Pawsey was also interested in exploring the low frequency domain and shared Shain and Higgins' earlier 9.15 MHz observations at Hornsby Valley (Higgins and Shain, 1954).

Ellis (1955) wrote to Pawsey describing the preliminary low frequency work underway in Tasmania in cooperation with Reber. He included a spectrum plot (see Figure 15) with data points using half-wave dipoles from the Hobart work and that from RP's Hornsby Valley observations (Higgins and Shain, 1954). The Hobart data show the aerial temperature (intensity) from 9.15 MHz down to 900 KHz increaseing linearly on the log plot, consistent with the slope from the 18.3 MHz to 100 MHz data points from Shain and Higgins. Pawsey (1955) noted that "The interesting point is that the intensity is still very high and will probably still be going up. This will give the theorists something to chew on". Although the observations were consistent with a non-thermal origin, the synchrotron emission mechanism was not considered despite Reber's earlier discussions with Kiepenheuer.[4]

Reber wrote to Pawsey on 6 June 1955, discussing his preliminary results of low frequency measurements. He found "… a hole opened [in the ionosphere] in the early evening and that stayed open most every night and closes with the snap of sunrise." (Reber, 1955a). During his visit to Sydney, Reber (*ibid.*) also noted that

> Shain was building phase reversing coils for use at 20 Mc. It would be of assistance to me if he could supply information on the best ratios of coil length to diameter, wire centre spacing to diameter, and self-resonant frequency to operating frequency.

A pencil note on the letter shows that Pawsey asked Shain to respond, and subsequently he sent details to Reber.

4 REBER AND THE SHAIN CROSS

4.1 An Opportunity to Observe Using the Shain Cross

With the passing of the solar minimum and the onset of solar Cycle 19, Reber concentrated on planning his next set of observations during the following solar minimum expected in the mid-1960s. He was particularly interested in extending low frequency survey work using a new design of radio telescopes inspired by the Shain Cross.

Alec Shain was the RP radio astronomer behind the Shain Cross, which comprised

> … two long arrays, oriented North–South and East–West … connected to a receiver through a phase-switching system. The output of the phase switch is a modulated signal at the switching frequency, which effectively produces a pencil beam response from the area of the sky common to the two arrays … The N–S array consisted of half-wave-length dipoles suspended parallel between insulators connected to cables running between wooden posts. In the E–W array, the dipoles were suspended end-to-end. The N–S array was 1108 m long, while the E–W array was 1036 m long. Along each array ran a coaxial feeder cable to which the dipoles in each array were lightly coupled. Because of the low frequency used, unlike the Mills Cross, the Shain Cross used the ground as a reflector rather than a suspended mesh. (Wendt and Orchiston, 2024: 639–641).

Technical design features of the Shain Cross are contained in Shain (1958), while Figures 16, 17, and 18 shows several different views of the N–S arm of the Shain Cross, which—as Figure 2 indicates—was located beside the much shorter 85.5 MHz Mills Cross (see Mills et al., 1958; Orchiston and Slee, 2017: 548–555).

Shain's untimely death in February 1960 cut short his research with the Shain Cross, which culminated in a survey of the Galactic Plane (Shain et al., 1961). Following Shain's death, RP's Bernard Yarnton (Bernie) Mills (1920–2011; Frater et al., 2013; Mills, 2006)—inventor of the cross-type of radio telescope (Mills, 1963)—wrote to Reber on 5 April 1960 outlining what he saw as the significant limitations of using the 19.7 MHz Shain Cross for further survey work (Mills, 1960). He compared the earlier 19.7 MHz records taken at high latitudes with his 85.5 MHz Fleurs Mills Cross survey. Mills concluded that the sensitivity of the 19.7 MHz Cross was too low for useful survey work, stating, "My own impression is that he [Alex Shain] has got about as much as can be got from the instrument." (*ibid.*).

The other major issue Mills noted was that it would be very difficult to calibrate the instrument successfully due to ionospheric transparency across the broad response range of the Cross' N–S fan beam. However, despite these limitations, he saw benefit in Reber coming to Fleurs to gain experience using a cross-type radio telescope before attempting to build his own one.

Reber replied to Mills in a letter dated 22 April 1960, thanking him for his informative letter (Reber, 1960a). While he understood the significant challenges, he was not perturbed. Reber was keen to take advantage of the upcoming solar minimum and would push on with designing his own 2 MHz Tasmanian Shain Cross. He also agreed it would make sense for him to gain some experience with the 19.7 MHz Cross in order to help generate new ideas.

In a letter dated 28 April 1960, Pawsey offered Reber the opportunity to observe with the 19.7 MHz Cross (Pawsey, 1960). At the time, Reber was in the US visiting Green Bank. Pawsey stated:

Figure 16: A view looking north along the N–S arm of the Shain Cross, showing the central line of poles that carried the coaxial feeder cable, and the adjacent poles that supported the dipoles (courtesy: CSIRO RAIA 5753-4 cropped).

Figure 17: A view looking south along the N–S arm of the Shain Cross, showing part of the adjacent N–S arm of the 85.5 MHz Mills Cross and parabolas in the N–S arm and part of the E–W arm of the 1400 MHz Chris Cross solar grating array (courtesy: CSIRO, RAIA 5192-9).

Figure 18: A view looking south along the N–S arm of the Shain Cross, showing part of the adjacent N–S arm of the 85.5 MHz Mills Cross. Beyond it, to the left, is a broadside antenna that was used with a similar antenna at nearby Badgerys Creek field station to investigate Hydra-A and the sizes of some of the Mills Cross discrete sources (courtesy: CSIRO, RAIA B3868-19).

> They will keep the array in working order, and Charlie Higgins will try to get started on some records of the southern galactic polar region. (*ibid*.).

Reber planned to visit RP in July 1960, which he eventually did in December 1960. He spent time with Higgins at Fleurs and visited Parkes. During his visit to Fleurs, he took detailed notes on the phase and amplitude system used in the Shain Cross N–S array and received a copy of the raw survey data collected by Higgins in August 1960 (Reber, 1960c). He also sketched out notes from a discussion with Higgins on the antenna configurations used at Hornsby Valley for 18.3 and 9.15 MHz observations (see Orchiston et al., 2015b).

4.2 Reber's 'Rough Map'

On 25 January 1961, Reber wrote to Pawsey, having analysed data collected by Higgins in August 1960 (Reber, 1961). After "… considerable arithmetic …" Reber assembled a "… rough map …" showing some unusual features in the region surveyed (see Figure 19). He believed that "… a lot more good data could be extracted from Shain's antenna." However, he also felt a number of changes to the observing technique could be made to improve the speed of observations without compromising sensitivity. Reber was greatly encouraged, having seen what could be done at 19.7 MHz, and was more enthused than ever to pursue his own research at 2.14 MHz.

Reber's map produced using Shain Cross data covered an area bounded by Dec –22° to –32° and RA 22:00 to 02:02. The most prominent features are two areas of absorption at Dec –31°, one ~2° × 4° centred on RA 01:20 and the other ~3° × 3° centred on RA 22:30. He believeed that since the HII regions were at high latitudes, they were presumed to be quite close. He wrote to Professor Bart Bok (1906–1983),

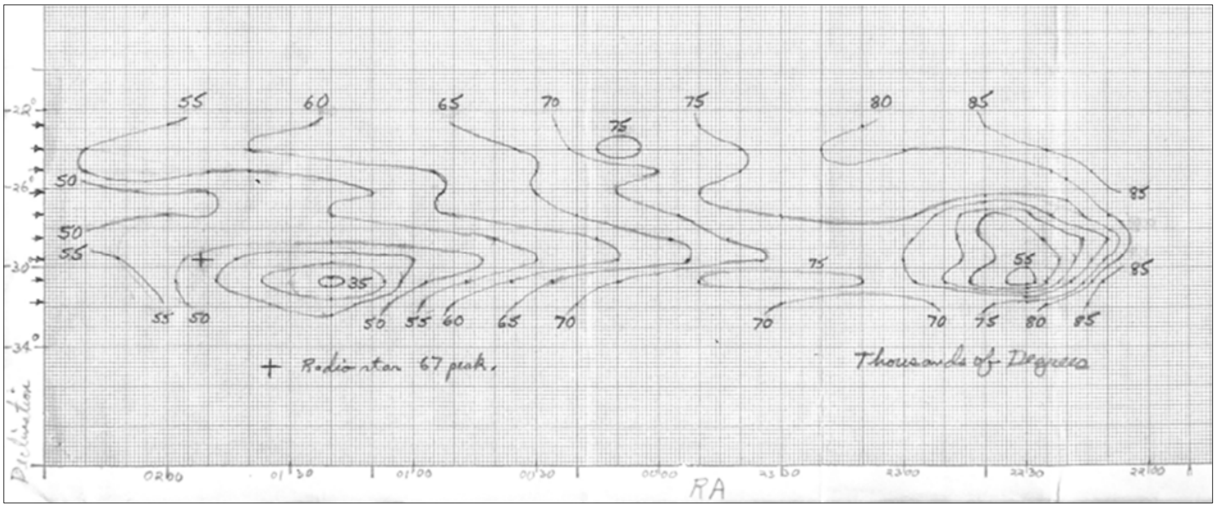


Figure 19: A 'rough map' of a high-latitude region produced by Grote Reber based on data taken by Higgins using the 19.7 MHz Shain Cross in August 1960. Reber performed the data reduction. The map shows two extended sources in absorption assumed to be from HII regions. Reber also marked a strong discrete source with a '+' on the chart, although no contours were drawn (Papers of Grote Reber, "Correspondence from Grote Reber to Joseph L. Pawsey," NRAO/AUI Archives, https://www.nrao.edu/archives/items/show/13127; accessed 3 August 2024).

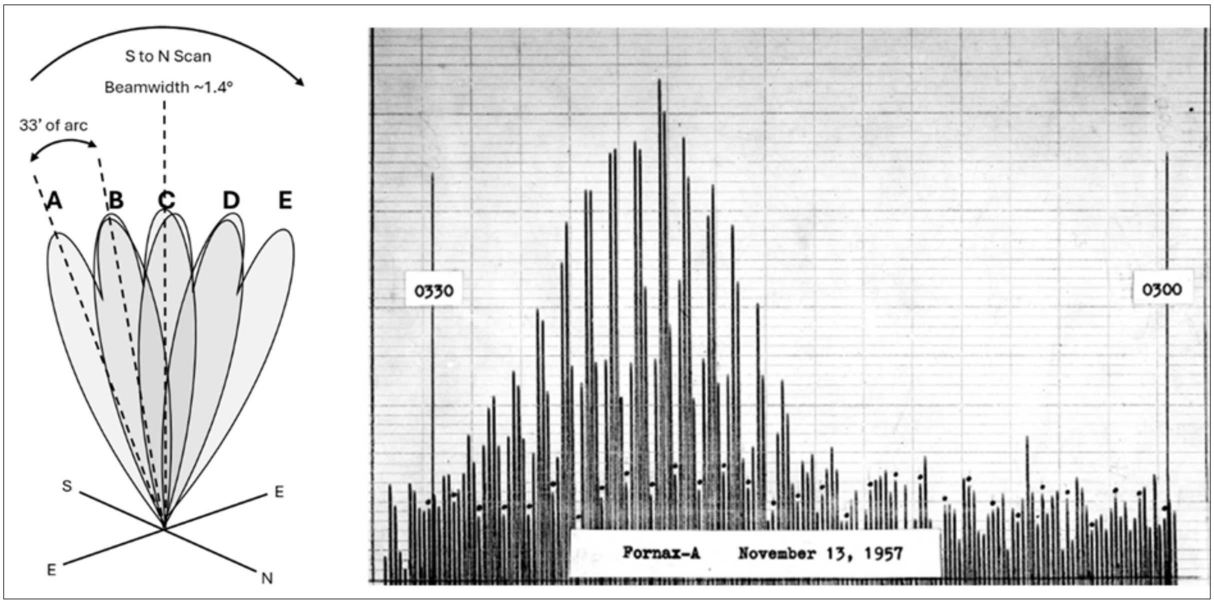


Figure 20: On the left is a schematic representation of the five-beam (A to E) automated scanning system used by the 19.7 MHz Shain Cross. The chart on the right shows an example of a recording of the source Fornax-A. A dot marks the south-most beam position in each group of five vertical bars. The length of each vertical bar is the 12-second integration of energy received at that declination. The array scans from south to north (A → E), separating each beam by 33 minutes of arc. It reads right to left on the chart, repeating the pattern every 60 seconds (i.e. 5 beams × 12 second integration) (chart record courtesy: CSIRO RAIA B5819 cropped).

the Director of the Australian National University's Mount Stromlo Observatory near the Australian capital, Canberra, asking if they had any information on these potential HII regions (Reber, 1962c). Bok passed Reber's letter to the Uppsala Schmidt Observer at Mount Stromlo, Bengt Westerlund (1921–2008), who responded that he would endeavour to take field photographs with the 8-inch f/1 Schmidt camera, but no further response appears in Reber's archive (Reber, 1962b).

Reber produced his 'rough map' through his own laborious manual data reduction process based on the observations taken by Charlie Higgins over eleven days in August 1960. The Shain Cross used a scanning system in which the 1.4° pencil beam (the intersection of the two array fan beams) was automatically scanned across five positions (A to E) 33′ of arc apart from south to north, with a 12-second integration period for each observation (see Figure 20). The separate output of the N–S array fan beam was recorded periodically to provide a base calibration level. In this case, Miss W. Wolfe from RP manually recorded the data on reduction worksheets, providing Reber with averages of each of four successive readings to give one point for every four minutes of time.

Reber wanted to increase the integration time of the records further to improve sensitivity and reduce scintillation and random noise effects. He assembled the data from the same areas over three days to calculate a further set of averages. This gave four-minute data points for roughly every 34′ of declination. He then averaged together the three centre beams (B+C+D) and then averaged together the duplicate scans of the outer two beams (A+E) on adjacent beam phase settings (see Figure 21). This produced data points for every four minutes of time, every 1.1° of declination. The overall effect was to increase integration time to 432 seconds per data point. No attempt was made to correct for ionospheric refraction.

Pawsey shared Reber's analysis of the August 1960 19.7 MHz observations with Mills and RP colleague Eric R. Hill (1927–2016), asking for their opinions. Hill, who worked with Mills and Slee on the Fleurs 85.5 MHz MSH Catalogue, noted that the radio source Reber had marked with an '+' on his map was almost certainly MSH 01-217 from the MSH survey. However, its position was likely offset due to ionospheric refraction at 19.7 MHz. As for the rest of Reber's map, there was little correlation with the 85.5 MHz survey, but he did note that there did not appear to be any apparent side-lobe effects that could account for this. For his part, Mills believed the proposed changes to the observing technique that Reber suggested would undoubtedly reduce the observation and data reduction time but would sacrifice the data quality. He also felt the influence of ionospheric refraction would be a much more severe issue than anticipated. To reduce this, he suggested it would be necessary to considerably shorten the length of the N–S arm of the Shain Cross. Pawsey (1961a) suggested to Reber that further experimentation would be needed to proceed with a survey, his main concern being the array's possible low amplitude side lobes.

On 6 March 1962 Bowen (the Chief of RP) wrote to Reber advising the CSIRO Executive had approved his appointment as an Honorary Research Fellow in Radio Astronomy (Bowen, 1962). This appointment was intended to formalise the working relationship established by Pawsey. Figure 3 shows Reber's 'official photograph' that was taken by the CSIRO in 1962.

4.3 Lobbying for a 19.7 MHz Southern Sky Survey

On 20 April 1961 Pawsey again wrote to Reber, letting him know that Higgins was currently using the 19.7 MHz equipment for Jupiter observations and that it would be possible to accommodate a visit by Reber to conduct observations using the Shain Cross (Pawsey, 1961b). Ultimately, Reber did not take up Pawsey's offer to come and observe with the Cross. Instead, he focused on designing and building his equipment for future observations near Bothwell while lobbying for the separate continuation of RP's low frequency survey work.

On 13 June 1962, Reber wrote to Bowen (in the absence of Pawsey, who was in the US having accepted the NRAO Directorship) urging him to maintain the operation of the Shain Cross (Reber, 1962a). He noted that the next few years of low solar activity would provide good observing conditions and an ideal opportunity to complete a full-sky survey. Reber also stated that

> … about two years ago, Higgins took a number of observations for me covering the region near the south galactic pole. Reduction of the data shows various complex features, including two prominent dark patches.

He urged RP to complete a 19.7 MHz survey of the southern sky as he felt it would be

> … an important complement to the surveys being undertaken here [Tasmania] by Professor Ellis at 4.7 mc and me at 2.1 mc.

There is no response on file from Bowen to Reber's letter. While he was visiting the US as a precursor to taking up the Directorship of the NRAO, Pawsey suffered a stroke and was subsequently diagnosed with an aggressive brain tumour. He returned to Australia and passed away on 30 November 1962 (see Goss et al., 2023). With both Shain and Pawsey gone and given Mills' earlier conclusions on the limitations of using the 19.7 MHz Cross for broader survey work, it was likely concluded that this was not a worthwhile endeavour, particularly with the shift of resources and focus to the 64-m Parkes Radio Telescope (now known as *Murriyang*). Furthermore, there is an undated handwritten note on file from John Bolton, the first Director of the Parkes Radio Telescope, discussing how the 19.7 MHz equipment might be used for Jupiter observations, but after that he wished to see the integration of Fleur's researchers into the Parkes group.[5]

Reber continued to maintain a relationship with RP, visiting Parkes and Culgoora and re-

+31A + 24E
Point Averages

+31A					+24E				Average Points		
8th	23rd	24th	25th	26th	23rd	30th	31st	Av.	+31A	+24E	Av.
16			-4	4				5	5		5
-7			-18	11				-5	-5		-5
8			-17	11				(2220) 1	1		(2220) 1
-8		.	5	11				3	3		3
(-4)		-11	-21	30				-2	-2		-2
(0)		-7	-29	21		(-34)		-10	-4	(-34)	-19
8	13	-1	-36	11		-2		-1	-1	-2	-2
13	-26	-1	-30	41		-20		(2240) [illegible]	-1	-20	(2240) -11
16	13	-6	-24	31		0		5	6	0	3
17	-12	2	-11	46		-14		5	8	-14	-3
–	2	-14	(-12)	27		3		1	1	3	2
(4)	-16	-5	-25	44		1		1	0	1	1
4	5	-4	-21	46		–		(2300) 6	6	–	(2300) 6
39	4	-11	-10	25		-7	11	4	9	2	6
6	3	-19	-15	26		-3	-4	-1	0	-4	-2
13	15	-13	-13	48		(3)	-7	7	17	-2	8
(13)	-23	1	-10	42		-38	-6	-3	5	-22	-9
17	-19	5	-16	33		-8	4	(2320) 2	5	-2	(2320) 2
11	-6	-16	3	25		11	20	7	3	16	10
18	-8	-1	-17	37		9	8	7	6	9	8
24	-2	18	-8	38		-23	6	8	14	-9	3
3	-22	-5	-7	37		-8	-15	-2	1	-12	6
6	-20	10	-8	52	-24	-16	4	(2340) 1	8	-12	(2340) 2
14	10	-15	-21	21	-16	13	3	-1	2	0	1
5	-8	(-28)	-21	44	-9	-4	-3	-3	-2	-5	-4
4	8	-4	-22	26	-33	-2	-3	-4	2	-13	-6
-2	-23	7	-10	29	(-29)	-6	-13	-6	0	-16	-8
4	(-5)	-26	-15	44	-25	-3	-16	(0000) -5	0	-15	(0000) -8
-10	-19	-28	-9	39	2	(6)	-13	-4	-5	-2	-4
(0)	4	-24	-3	24	-1	-5	-12	-2	0	-6	-3
-7	-16	7	-6	32	-9	-8	1	-1	3	-5	-1
-3	2	0	-13	32	-15	8	8	2	4	0	2

Figure 21: An example page of Grote Reber's data reduction of Higgins' 19.7 MHz Shain Cross observations. The example shows an averaging of the A and E beam readings across observations from 8 to 31 August 1960 from 22:20 to midnight. Units are mA prior to calibration (Papers of Grote Reber, "(+31A + 24E) Dec. –25.1", NRAO/AUI Archives, https://www.nrao.edu/archives/items/show/19249; accessed 3 August 2024).

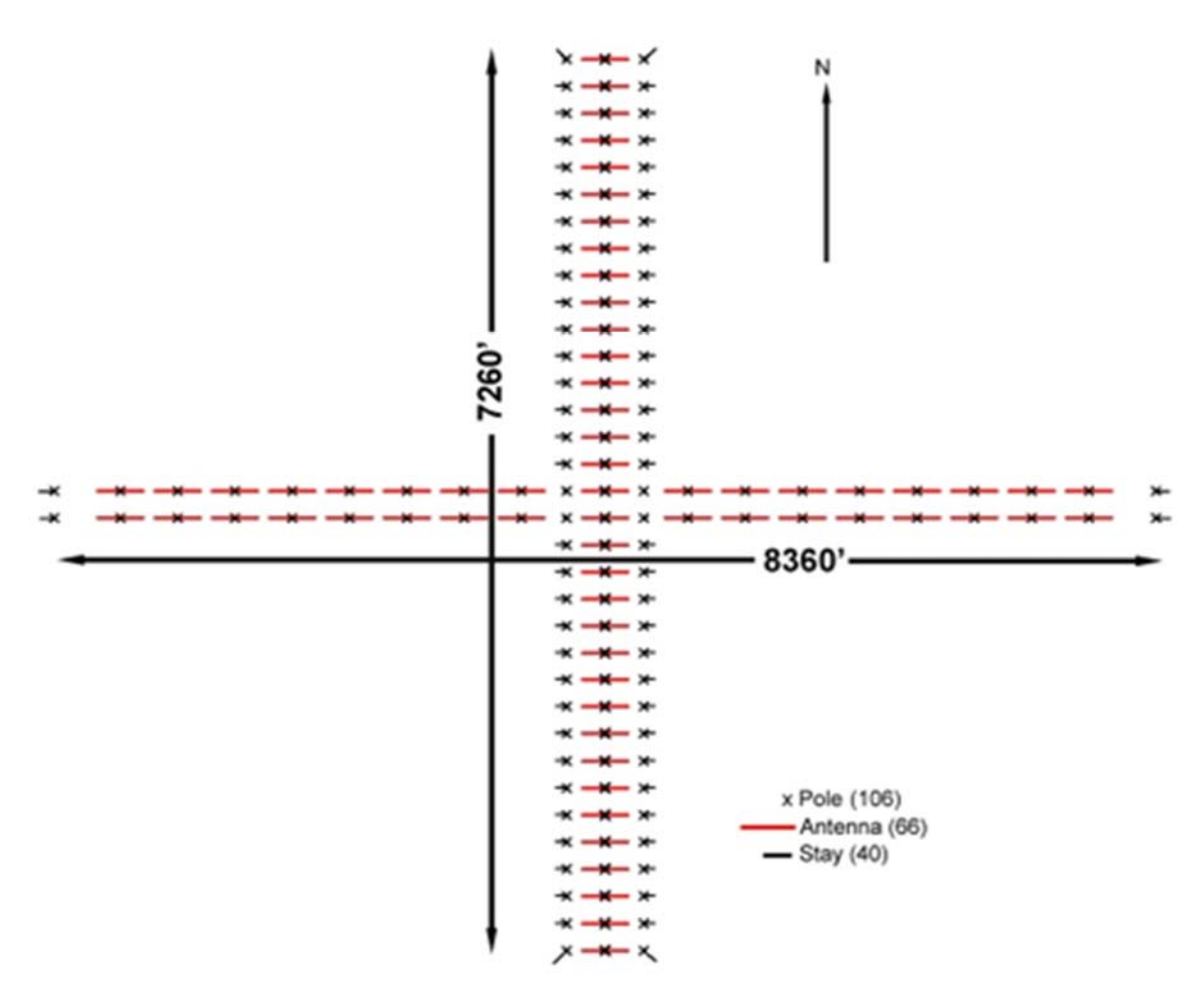


Figure 22: Reber's original Bothwell 2 MHz Tasmanian Shain Cross concept, adapted from his original diagram drawn on 18 April 1960 (courtesy: Henry Edgell).

ceiving technical advice and assistance importing equipment into Australia. Bowen later reported to the CSIRO Executive that "He is a delightful fellow to have around, adds some lustre to C.S.I.R.O., *and does not cost us anything."* (Bowen, 1970; our italics).

After Shain's death, Higgins began working with Bruce Slee (see Orchiston, 2005), and this relationship continued until his retirement. In the process, he carried out further observations of Jupiter, surveyed dMe flare stars for radio emission, and conducted an 80 MHz survey of discrete sources using the Culgoora radioheliograph solar array, rebadged, of an evening, as the 'Culgoora Circular Array' (Orchiston 2004).

5 CONCLUDING REMARKS

Joe Pawsey maintained an active working relationship with Grote Reber from their first meeting in 1948 through to his death in 1962, providing advice and technical assistance. The unfortunate death of Alex Shain in February 1960, just before completing his 19.7 MHz Galactic Plane survey, provided an opportunity for Reber to gain experience in observing with a cross-type radio telescope. At that time, Reber was thinking about designing new equipment for his next foray into low frequency astronomy in Tasmania.

Reber was greatly encouraged after producing a 'rough map' based on data collected by RP's C.S. Higgins using the 19.7 MHz Shain Cross. This spurred him to consider building his own 2 MHz Tasmanian Shain Cross, and he even went ahead and prepared plans for this (see Figure 22). Meanwhile, Pawsey offered Reber the opportunity to conduct observations with the Shain Cross in order to gain experience using this type of radio telescope.

As we saw in Section 2, Reber eventually abandoned plans to build his own Shain Cross, and instead he built a filled-aperture 'square kilometre array' at Bothwell (Figure 9). This was more akin to the array design that Shain and Higgins had used earlier at Hornsby Valley (Orchiston et al., 2015b), which Higgins discussed in detail with Reber during his December 1960 visit to Fleurs. We suspect that the scepticism that Mills displayed towards successful completion of a 2 MHz Shain Cross all-sky survey and support by Higgins for filled-aperture arrays prompted Reber to abandon the cross design.

Meanwhile, Reber continued to lobby for RP to complete a southern sky survey using the Shain Cross. However, with the deaths of both Shain and Pawsey and the shift in focus to the newly built 64-m Parkes Radio Telescope, this never occurred.

6 NOTES

1. In the context of this paper, we refer to low frequency being <100 MHz, i.e. decametric to metre wavelengths, although low frequency radio astronomy is often used to refer to any frequency below 1 GHz.
2. As noted by Wendt and Orchiston (2024: 651), "Charles S. ('Charlie') Higgins came to Radiophysics in the late 1940s from a radio company. He had a certificate in radio engineering, and an interest in astronomy (Orchiston et al., 2015b). He was employed as a Technical Assistant, and initially he worked with Shain at Hornsby Valley and Fleurs field stations, and later, after Shain's death, with Bruce Slee (Orchiston, 2004[a]) at Fleurs. Higgins developed a passion for radio astronomy, and on various occasions he lectured to Sydney-based amateur astronomical societies." Before he transferred to the Chris Cross (see Orchiston and Mathewson, 2009) at Fleurs, the third author of this paper (WO) worked with Slee and Higgins using the Shain Cross.
3. As noted by Wendt and Orchiston (2024: 651), "Shain was born in Melbourne on 6 February 1922. He attended the University of Melbourne, where he studied Physics. After graduating with a BSc Honours in 1942 he immediately signed up for service with the Second Australian Imperial Force but was discharged on medical grounds in early 1943. Seeking another way to contribute to the war effort, he joined the CSIR's Division of Radiophysics, where he was engaged in the development of radar countermeasures until the end of the war in 1945. With the shift to peacetime research, Shain spent the rest of his career focused on decametric radio astronomy. He remained at Radiophysics until his untimely death from lung cancer on 11 February 1960, just after his 38th birthday (Orchiston et al., 2021b: 58; Pawsey, 1960)."
4. Kiepenheuer Kiepenheuer (1950) acknowledges Grote Reber in his paper, "Cosmic rays as the source of general galactic radio emission", for his "… helpful discussions."
5. In fact, this suggestion was taken up by Slee and Higgins (see Slee and Higgins, 1963; Slee, 2005).

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Harry has since published a series of papers based on his thesis and subsequent research. He co-authored the book *Four Pillars of Radio Astronomy: Mills, Christiansen, Wild, Bracewell* (2017, Springer) with Bob Frater and Miller Goss and is a member of the IAU Working Group on Historical Radio Astronomy.

Harry retired from full-time work in 2017 after a 28-year career in banking, including time as Chief Technology Officer and General Manager of Digital for Westpac Banking Corporation in Australia. Before this, he worked in the computer industry and spent eight years as an aircrew officer in the Royal Australian Navy Fleet Air Arm. It was

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Dr Martin George is Principal Astronomer at the Ulverstone Planetarium at Hive, in Ulverstone. Tasmania. He completed an undergraduate degree in Physics at the University of Tasmania and a PhD in Astronomy from the University of Southern Queensland. His thesis was on the history of low frequency radio astronomy in Tasmania, supervised by Professors Wayne Orchiston and Richard Wielebinski (and originally also by Professor Bruce Slee). Prior to moving to Ulverstone Martin was the Collections and Research Manager at the Queen Victoria Museum and Art Gallery in Launceston, where he also was responsible for the Museum's planetarium and astronomy collections.

Apart from the history of early radio astronomy, Martin has research interests in the history of astronomy in Tasmania and in mainland SE Asia, and in the role of planetariums in astronomy education and outreach. He is a former President of the International Planetarium Society and continues to promote the Society and planetariums worldwide as the Chair of International Development.

Over the years Martin has published a succession of research papers on early Tasmanian radio astronomy, and on the role of the Jesuits of developing 'Western astronomy' in Siam (present-day Thailand) during the seventeenth century. He is also passionate about astronomy education and outreach.

Martin is a member of the IAU/URSI Working Group on Historical Radio Astronomy, and was the Administrator of the Grote Reber Medal.

Professor Wayne Orchiston was born in Auckland (New Zealand) in 1943 and has BA First Class Honours and PhD degrees from the University of Sydney. Currently, he is employed by the University of Science and Technology of China in Hefei as the Co-editor of the *Journal of Astronomical History and Heritage*. He is also an Adjunct Professor of Astronomy in the Centre for Astrophysics at the University of Southern Queensland (USQ) in Toowoomba, Australia. Formerly, Wayne worked at observatories, research institutes and universities in Australia, New Zealand and Thailand. Over the past two decades he has supervised more than 35 Master of Astronomy and PhD history of astronomy research projects through three different Australian universities.

Wayne has wide-ranging research interests and more than 500 publications, mainly about historic transits of Venus; historic solar eclipses; historic telescopes and observatories; the emergence of astrophysics; the history of cometary and meteor astronomy; the astronomy of James Cook's three voyages to the Pacific; amateur astronomy and the amateur–professional interface; the history of meteoritics; Indian, Southeast Asian and Māori ethnoastronomy; and the history of radio astronomy in Australia, France, India, Japan, New Zealand and the USA.

Recent books by Wayne include *Exploring the History of New Zealand Astronomy …* (2016, Springer); *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy* (2017, Springer); *The Emergence of Astrophysics in Asia …* (2017, Springer, co-edited by Tsuko Nakamura); *Exploring the History of Southeast Asian Astronomy …* (2021, Springer, co-edited by Mayank Vahia) and *Golden Years of Australian Radio Astronomy: An Illustrated History* (2021, Springer, co-authored by Peter Robertson and Woody Sullivan). He has also edited or co-edited a succession of conference proceedings.

Since 1985 Wayne has been a member of the IAU, and he is a former President of Commission C3 (History of Astronomy). In 2003 he founded the IAU's Historical Radio Astronomy Working Group, and is the current Radio Astronomy Subject Editor for the Third Edition of Springer's *Biographical Encyclopedia of Astronomers*. He also founded the IAU Working Group on Historic Transits of Venus, is the Founding Chair of the History & Heritage Working Group of the SE Asian Astronomy Network, and is the founding Director of the Historical Section of the Royal Astronomical Society of New Zealand.

In 1998 Wayne co-founded the *Journal of Astronomical History and Heritage,* and was the Managing Editor until 31 July 2022 when he passed ownership of the journal to the University of Science and Technology of China. In 2013 the IAU named minor planet 48471 'Orchiston', and in 2019 he and Dr Stella Cottam were co-recipients of the American Astronomical Society's Donald E. Osterbrock Book Prize for their 2015 Springer book, *Eclipses, Transits and Comets of the Nineteenth Century: How America's Perception of the Skies Change*d. In 2023 Wayne was elected an Honorary Member of the Royal Astronomical Society of New Zealand, and Springer published the following Festschrift: Gullberg, S., and Robertson, P. (eds), *Essays in Astronomical History and Heritage: A Tribute to Wayne Orchiston on His 80th Birthday*. In January 2024 Wayne and Darunee Lingling Orchiston attended the Winter Meeting of the American Astronomical Society in New Orleans, where he was presented with the 2024 Le Roy E. Doggett Prize for History of Astronomy.