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THE CONTRIBUTION OF THE AN/TPS-3 RADAR ANTENNA TO AUSTRALIAN RADIO ASTRONOMY

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Abstract: The CSIRO Division of Radiophysics used the WWII surplus AN/TPS-3 radar dishes for their early solar radio astronomy research and eclipse observations. These aerials were also used in a spaced (Michelson) interferometer configuration in the late 1940s to investigate solar limb brightening at 600 MHz. This work paralleled early solar observations at Cambridge. None of the Australian research results using the spaced interferometry technique appeared in publications, and the invention of the solar grating array in 1950 made further use of the method redundant.

Keywords: AN/TPS-3 radar antennas, solar radio astronomy, CSIRO Division of Radiophysics

1 INTRODUCTION

When the IAU Working Group on Historical Radio Astronomy formed in 2003, one of the challenges it set was the identification and research of radio telescopes that made significant contributions to radio astronomy before 1961. The use of the 7.5-m ex-WWII Würzburg radar dishes in England, France, Holland, the Soviet Union, Sweden and the United States in their early radio astronomy research groups immediately after the war is well known (e.g. see Dagkesamanskii, 2007; Edge and Mulcay, 1976; Orchiston et al., 2009; Radhakrishnan, 2006; Smith, 2007; Sullivan, 2009; Van Woerden and Strom, 2006). Less well known is the use of American ex-WWII radar dishes by Australian researchers.

The Australian Council for Scientific and Industrial Research (CSIR)[1] formed the Division of Radiophysics (RP) explicitly to exploit the secrets of radar shared by the British Government in 1939. Together with Australian industry, RP developed unique Australian radar designs as well as reproducing models from the UK and later the USA. A declassified summary of the collective works on radar by RP appeared in a book form in 1948 (Bowen, 1948a).

The first deliberate and successful radio astronomy observations in Australia occurred at sunrise on Wednesday, 3 October 1945 at Collaroy Plateau, to the north of Sydney, using a 200 MHz Chain Overseas Low (COL) Mk.V radar antenna and receiver from Royal Australian Airforce Radar Station No. 101/54 (see Figure 1). The radar operating in receive-only mode was directed toward the Sun at sunrise and sunset by the leader of the RP group, Dr Joseph L. Pawsey (1908–1962, Christiansen and Mills, 1964) and Ruby Payne-Scott (1912–1981, Goss and McGee, 2009) working with the RAAF radar operators. They measured enhanced levels of electromagnetic radiation coming directly from the Sun. These measurements led to two important discoveries. The Sun's corona had a temperature of over 1 million°C, much higher than its surface temperature of 5800° C (Pawsey, 1946). Further, they noted periods of much stronger radiation and that this overall level of enhanced radiation correlated with the number of sunspots visible on the Sun's surface (Pawsey et al., 1946; cf. Orchiston et al., 2006). In further observations, they also were able to detect an enhanced level of electromagnetic radiation coming from the centre of our Galaxy as it rose above the eastern horizon (Payne-Scott, 1947).

Following the initial success at Collaroy, RP moved their observational program to an Army radar station at Dover Heights and a series of other field stations in and near Sydney (Figure 2; see Orchiston and Slee, 2017), where a number of innovative radio telescopes were soon developed or invented. These included grating interferometers, solar radio spectrographs, various cross-type radio telescopes and the Dover Heights 'hole-in-the ground antenna' and, in line with the objectives of the IAU Historic Radio Astronomy Working Group, most of these have been researched and documented (see Orchiston and Mathewson, 2009; Orchiston and Slee, 2002a; 2002b; Orchiston et al., 2015a; 2015b; Stewart et al., 2010; 2011; and Wendt et al., 2008a; 2011).

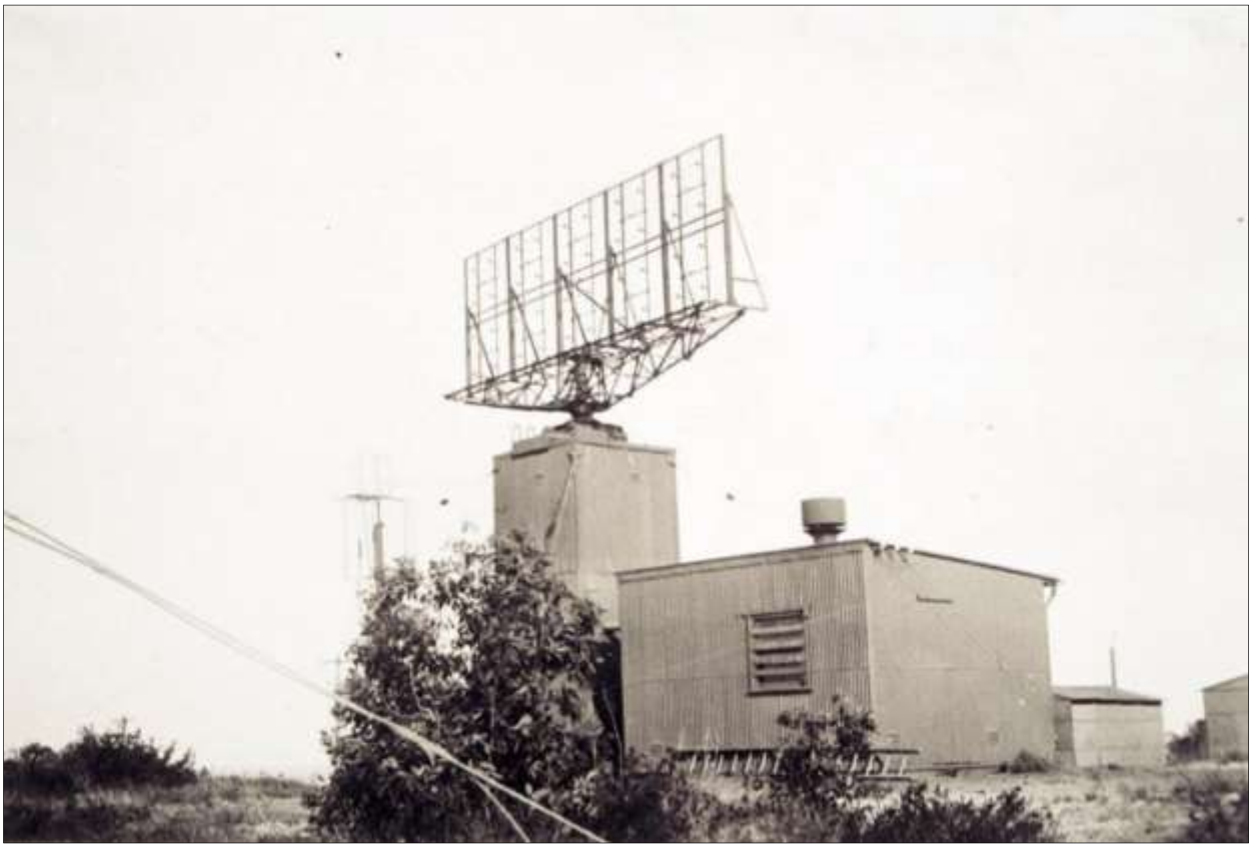

Figure 1: The 200 MHz COL Mk.V radar at Collaroy Plateau in early 1946. The view is looking toward the east with the control room in the foreground. The COL radar was a British design with the tower structure built by the NSW Government Railways (after Dellit, 2000: 48).

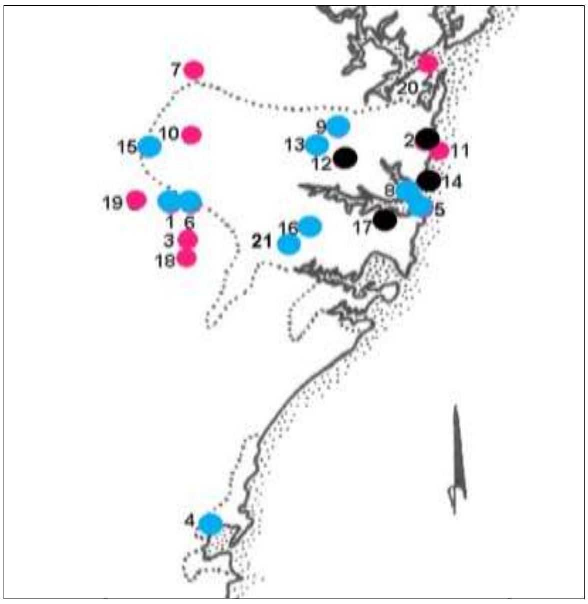

Figure 2: Radio astronomy localities in the Sydney-Wollongong region; the dotted outlines show the current approximate boundaries of Greater Sydney and Greater Wollongong. Key. Field stations: blue; remote sites: red; other sites: black. 1 = Badgerys Creek, 2 = Collaroy, 3 = Cumberland Park, 4 = Dapto, 5 = Dover Heights, 6 = Fleurs, 7 = Freeman's Reach, 8 = Georges Heights, 9 = Hornsby Valley, 10 = Llandilo, 11 = Long Reef, 12 = Marsfield (ATNF Headquarters), 13 = Murraybank, 14 = North Head, 15 = Penrith, 16 = Potts Hill, 17 = Radiophysics Laboratory (Sydney University grounds), 18 = Rossmore, 19 = Wallacia, 20 = West Head, 21 = Bankstown Aerodrome. For scale: from Dapto (site 4) to Dover Heights (site 5), as the crow flies, is 88 km (map: Wayne Orchiston).

One of the RP field stations was at the experimental radar site at Georges Heights (Site 8 in Figure 2) on a headland facing the entrance to Sydney Harbour (Orchiston, 2004). In a previous paper (Orchiston and Wendt, 2017), we discussed a 16 × 18-ft experimental radar located at Georges Heights. In this paper, we discuss the use of AN/TPS-3 radar aerials that initially also were located at Georges Heights.

2 BACKGROUND

The development of the AN/TPS-3 radar began in 1942 in the USA. The main components of the original radar, also designated SCR-602 or British Type 63, were a direct copy of the British Chain Overseas Low (COL) design. There was a range of design variations produced, with the most successful being the SCR-602 T8 which became the AN/TPS-3 and was designed to operate as a lightweight, air transportable unit that could be used to support assault operations as a medium- to long-range air warning radar (see Figure 3). The production models of the radar entered service in time for active use in support of the Normandy D-Day invasion in June 1944, with more than 900 units eventually manufactured during the war (Zhal and Marchetti, 1946).

The radar used the Emiac VT-158 Triode operating at 600 MHz and had both A-scan and Plan Position Indicator (PPI) displays (see Figure

Figure 3: The AN/TPS-3 Radar at Camp Evans, Belmar, New Jersey (USA) on 16 June 1944. In the foreground is the single cylinder gasoline engine used to drive a 400 Hz alternator and a DC generator mounted on the same shaft. Inside the tent are the transmitting and receiving equipment (courtesy: CE LCMS Historial Office Department of the Army, USA).

4). The antenna was a 10-ft (3-m) parabolic reflector made of 8 × 45° aluminium frame sections covered by metal mesh reflector backing with a horizontally polarised dipole radiator at the prime focus. The entire radar, including power supply and spare parts, weighed 545 kg when packed for air transport, although no single component weighed more than 91 kg. A four-man crew could assemble the unit and have it operating within 30 minutes of arrival at a suitable site. The radar had a maximum range of ~190 km against a bomber aircraft. The operating parameters of the radar are in Table 1.

As an interesting aside, the designers of the AN/TPS-3 had noted the potential issue of interference lobes produced between the direct path signal and ground reflections that could potentially hide an approaching bomber in an interference null. They employed a unique triple-head dipole arrangement to allow switching between dipoles (see Figure 5). By switching to the anti-phase outer dipoles, a change in lobe pattern occurred, and hopefully, this resulted in the de-

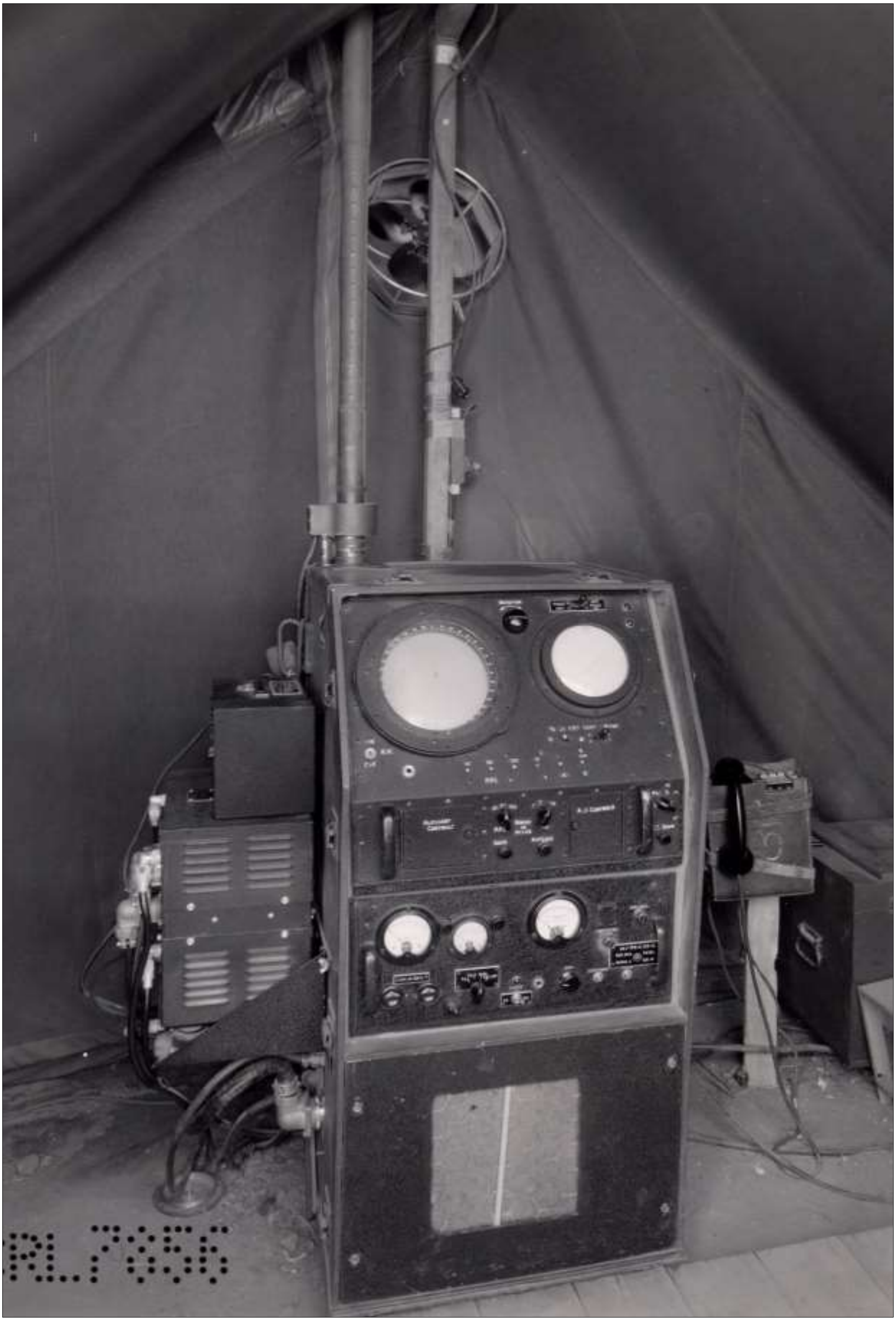

Figure 4: The AN/TPS-3 transmitter and receiver, showing the PPI (left) and A-scan (right) displays (courtesy: CE LCMS Historial Office Department of the Army, USA).

Table 1: Operating parameters of AN/TPS-1 (Source: http://www.history.navy.mil/Library/online/radar-9.htm).

Description	Lightweight, portable medium to long range radar unit designed for early warning against aircraft.
Frequency	590 MHz to 610 MHz
Power Output	200 kilowatts peak
Pulse Width	1.5 µseconds
Pulse Repetition	200 pulses per second
Range	120 miles (193 km), accuracy 2 miles (3.2 km)
Vertical Coverage	Up to 30,000 feet
Horizontal Coverage	360 degrees
Antenna	10-foot (3-m) parabolic reflector
Antenna Speed	5 rpm
Beamwidth	10 degrees at half power points
Display Indicator	7-inch (-m) PPI and 5-inch (13-cm) A-scope

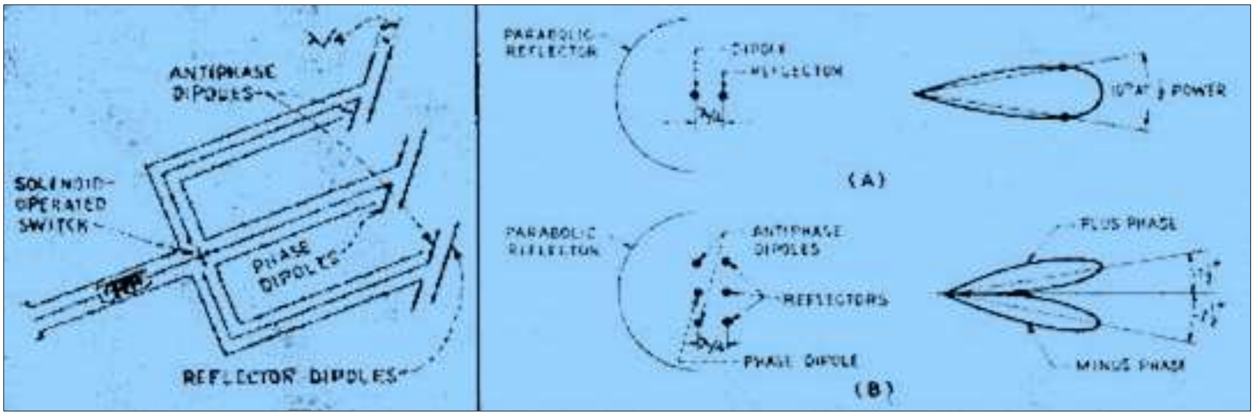

Figure 5: The left diagram shows the triple-head dipole used in the AN/TPS-3. The right diagram shows the beam pattern of the antenna (A) with the primary phase dipole producing a 10° beam and (B) with the anti-phase dipoles used to generate two 7.5° beams (after Zhal and Marchetti, 1946: 102).

Figure 6: A 1948 view from the west of the Georges Heights field station, showing two experimental radars. In the background is North Head at the entrance to Sydney Harbour (courtesy: CSIRO Radio Astronomy Image Archive (henceforth RAIA), B1362).

tection of an approaching bomber that may have been in the null of the main lobe. This same type of interference lobe pattern was later exploited in radio astronomy using the sea-interferometer technique or a spaced (Michelson) interferometer to obtain higher beamwidth resolution (see McCready et al., 1947).

3 GEORGES HEIGHTS

The Georges Heights field station was located on military land near Middle Head, facing the entrance to Sydney Harbour, and functioned as a radar test site (see Figure 6). When it became an RP field station in 1947 it offered a variety of ex-WWII surplus equipment including at least three AN/TPS-3 radar aerials. During 1947–1948, RP used the site for solar radio astronomy (see Orchiston, 2004a).

Of prime interest at this time was obtaining higher resolution observations of the Sun and measurements at a range of different radio frequencies. An eclipse provided an ideal opportunity to acquire high-resolution observations as the terminator of the Moon moved in front of the solar disk obscuring sources of solar radio emission. The experience of preparations for the aborted 1947 eclipse (see Wendt et al., 2008b), indicated the need for more portable equipment. Towards this end, RP decided to re-purpose surplus AN/TPS-3 aerials for use in radio astronomy. The next solar eclipse that would be visible from Australia was the partial eclipse of 1 November 1948.

In preparation for this eclipse, the AN/TPS-3 aerials were modified to use a simple alt-azimuth mounting that could be hand steered (see Figure 7). Testing of the equipment at Georges Heights came under the responsibility of Fred Lehany (1915–1994) and Don Yabsley (1923–2003). The receivers built for these observations operated at 600 MHz and consisted of a quarter-wave transmission-type cavity-resonator, followed by a crystal converter, 30 MHz intermediate frequency amplifier and a diode second detector. After rectification, the signal passed through a DC amplifier which was connected to a recording milli-ammeter. Receiver gain drift was a significant issue for this type of receiver. The receivers were run for several hours before observations to ensure a constant receiver temperature, and measures were taken to ensure input voltage stability.

4 THE SEARCH FOR SOLAR LIMB BRIGHTENING

One of the prime objectives of the proposed eclipse observations was to test the theory proposed by David F. Martyn (1906–1970; Orchiston, 2014a) that limb brightening should occur at radio frequencies due to the higher optical depth of the corona where radio emission occurred as viewed near the edge of the visible solar disk (Martyn, 1946).

Another possible method of obtaining higher resolution observations was to use interferometry which had already been proven using the sea-cliff interferometry technique. The minutes of the RP Solar Noise Group meeting of 23 September 1947 contains the first mention of the

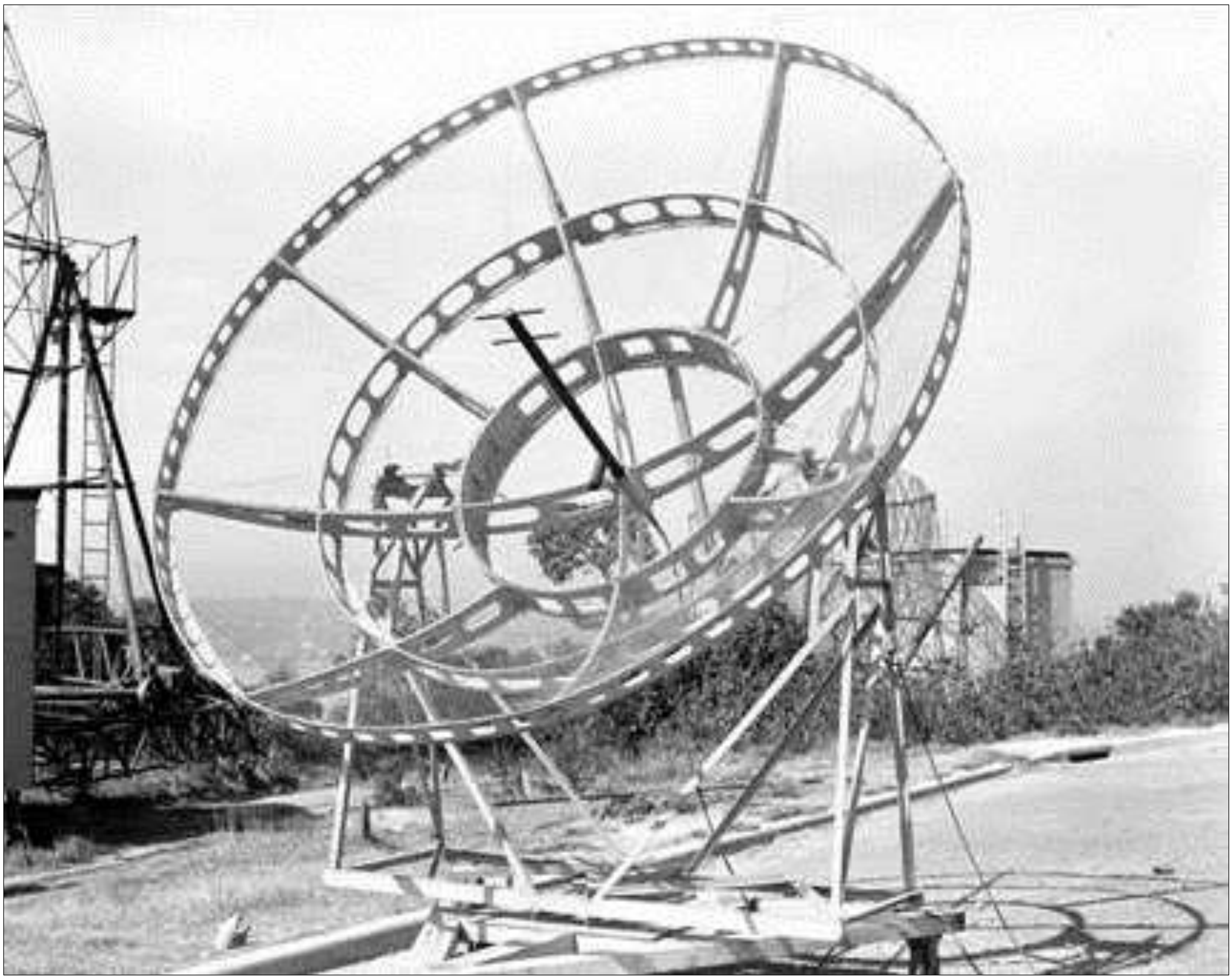

Figure 7: An AN/TPS-3 aerial mounted on a simple hand-steered alt-azimuth mounting and undergoing testing at Georges Heights field station on 13 August 1948. Note only a single horizontally polarised dipole was in use at this stage (courtesy: RAIA, B1511).

idea of using the AN/TPS-3 aerials at Georges Heights to "… experiment to investigate limb brightening …", using a two-element interferometer configuration. The observations were to be conducted by Yabsley and supervised by Lehany as the leader of the Georges Heights team. On the 31 December, they reported that

> The second TPS-3 aerial (600 Mc/s) has been recovered with chicken wire. The first experiments should be made in the next fortnight.

On 20 January 1948 they reported:

> Measurements of the interference pattern have been made with two different aerial separations, using improvised mounts for the TPS-3 aerials. The results indicate a considerable degree of limb brightening at 600-Mc/s, but careful calibrations and polar diagram measurements are necessary before definitive conclusions can be drawn.

In February 1948, Lehany decided to leave the Solar Noise Group, and his position was taken by the newly recruited, W.N. 'Chris' Christiansen (see Frater and Goss, 2011; Wendt et al., 2011a). In his final report, dated 8 February 1948, Lehany wrote:

> Limb brightening at 600 Mc/s – This is entirely a Yabsley effort, and he obtained his first drift interference pattern yesterday. A few weeks observation should definitely result in a paper.

On 12 April 1948 Yabsley gave an update to the Solar Noise Committee:

> An attempt is being made to measure variations in intensity (at 600 Mc/s) across the sun's disc, particularly to check Martyn's theory of limb-brightening and to measure temperatures of areas near sunspots.

On 5 May 1948 the Chief of the Division of Radiophysics, Edward G. 'Taffy' Bowen (1911–1991; Bowen, 1987) wrote to Pawsey, who was then visiting the UK:

> Yablsey's work is going well, and he has obtained preliminary results giving evidence of limb brightening. When he has made some minor improvements to the equipment, he will be in a position to get his final results (Bowen, 1948b).

Pawsey shared this information with the leader of the Cambridge radio astronomy group, Martin Ryle (1918–1984) when they met during his visit to Cambridge.

In June 1948 Lindsay L. McCready (1910–1976), who then was acting leader of the Solar Noise Group in Pawsey's absence, negotiated the use of a new field station on the grounds of the Potts Hill reservoir in the outer western suburbs of Sydney. The site (number 16 in Figure 2) offered a secure patrolled non-military location in a radio-quiet area that appealed given RP's experiences with vandalism at both Dover Heights and Bankstown aerodrome (sites 5 and 21, respectively, in Figure 2). By 1952, Potts Hill would become RP's largest field station (see Wendt, 2008; Wendt et al., 2011b). Around this time, the decision was also made to move the Georges Heights radio astronomy group to Potts Hill, under the leadership of Christiansen. The other team that was experimenting with spaced interferometers at Bankstown aerodrome also relocated to Potts Hill, where Ruby Payne-Scott (1912–1981) and Alec Little (1925–1985; Mills, 1985) set up their swept-lobe interferometer (Little and Payne-Scott, 1951).

The move to Potts Hill caused some disruption for Yabsley. In the July 1948 minutes of the Solar Noise Group, he reported that

> Limb-brightening and intensity distribution across the sun on 600 Mc/s:- Aerials are calibrated, and observations will begin soon. It is intended to work on 1200 Mc/s, also and a 1200 Mc/s feed for the AN/TPS-3 aerial has been tested. A paper has been written describing last year's work by Lehany and Yabsley on 1200, 600 and 200 Mc/s. The equipment is now sufficiently stable but is waiting on mounts for aerials. Preliminary results give evidence of limb-brightening and show that areas around sunspots have a temperature about 10^6 °K in contrast to the average solar temperature at 600 Mc/s of 0.5 x 10^6 °K.

In an updated report, likely late August 1948, that appeared in the internal proposed publications report for the radio astronomy group, Yabsley gave an update on his limb-brightening experiments:

> Observations of solar radiation received at 600 and 1200 Mc/s using spaced interferometers are described. It is shown that the form of distribution of the intensity of radiation from different parts of the sun can be deduced from the degree of interference between the rays received at the two aerials as the sun moves relative to them. It is concluded that a pronounced limb brightening effect is present at these frequencies, the bulk of the energy originating from the rim of the solar disc. It is also shown that there is a change in the depth of the interference pattern when sunspot groups are present on the face of the sun, and it is concluded that this is due to enhanced thermal radiation from the region of the sunspots.

Yabsley went on to conclude:

> Confirmatory measurements could be made during the eclipse on November 1st [1948], but it is considered desirable at this stage to push ahead with present techniques.

Yabsley's recommendations to place the primary focus on his spaced interferometer technique were not followed through. Instead, the primary focus moved to conducting the eclipse experiments from three widely separated sites, and at a range of frequencies. The two AN/TPS-3 aerials were used for observations of the eclipse at Rockbank in Victoria and Strahan in Tasmania. Their feeds were modified to allow switching between horizontal and vertical polarisation (see Figure 8). The results of the eclipse observations were highly successful in identifying the source of enhanced radiation with sunspot groups but did not provide definitive evidence of limb brightening (Christiansen et al., 1949a; 1949b).

The last report on Yabsley's limb-brightening experiments appeared in the minutes of the Solar Noise Group on 17 November 1949. The minutes noted that following the establishment of routine solar continuous recording on 1200, 600 and 200 MHz at Potts Hill, "… the first job is to complete Yabsley's work on limb-brightening." In practice, this never occurred. Soon after Yabsley decided to transfer to a separate group in Radiophysics that was investigating air navigation aids. He worked on the development of Distance Measuring Equipment (DME) that became widely adopted in Australia. He later returned to radio astronomy working on the 64-m Parkes radio telescope and the Australia Telescope.

At around this same time, Christiansen who was leading the solar group at Potts Hill had the inspiration for the design of a grating array (see

Figure 8: An AN/TPS-3 Aerial at Potts Hill field station in 1949. The horizontal and vertically polarised dipoles at the prime focus are visible (courtesy: RAIA, B1511).

Wendt et al., 2008a). He first presented this new plan to a meeting of the RP Radio Astronomy Group on 14 March 1950, initially calling it a 'multi-beam interferometer' before changing the name to 'grating array interferometer'. The invention of the grating array marked the end of solar observations by RP using simple spaced interferometers. In 1953 Christiansen found conclusive evidence of limb brightening at 1420 MHz using the grating array (Christiansen and Warburton, 1953), and later, in 1954–1955, the solar grating array was modified to operate at 500 MHz and again provided definitive evidence of limb brightening (see Swarup and Parthasarathy, 1955).

In 1946 Ryle at Cambridge had published results of solar observations using for the first time a spaced (or Michelson) interferometer (Ryle and Vonberg, 1946). It is interesting to note that under Ryle's leadership, Stanier (1950), Machin (1951) and O'Brien (1953) would all complete Ph.D.s based on using the same spaced interferometer technique to investigate the distribution of radio emission across the solar disk. Throughout 1949, Stanier monitored the Sun with two 3-m Würzburg dishes and found no evidence of limb brightening at 500 MHz, in fact, he found evidence of limb darkening. Checking this result was the primary motivation for the modification of Christiansen's solar grating array to operate at 500 MHz. It turned out that Stanier had used a simplifying assumption of circular symmetry in the Fourier transformations of his brightness distributions and hence missed the limb brightening. The use of the spaced interferometers by Ryle's group marked the beginning of his development of the principle of assembling a radio image from interferometric data (Sullivan, 2009: 292) and partly for which he was to receive the Nobel Prize for Physics.

Ryle was well aware of the observations being carried out by Yabsley as Pawsey had provided him with details during his visit in 1948. Ryle had also likely discussed this with Ron Bracewell (1921–2007; Thompson and Frater, 2010) who had taken on the unofficial role of promoting RP's research with UK researchers after completing his Ph.D. at Cambridge in 1949. On 18 February 1950, he wrote to Ron Bracewell asking for more information:

> I was very interested to hear of the solar spaced-aerial work on 600 and 1200 Mc/s and the application to the study of limb-brightening. I do not know if this is also a "Fourier analysis" method, but as you know, Stanier has now completed a measurement of the distribution across the quiet sun on 600 Mc/s. His results showed no limb-brightening, though there was appreciable radiation from the corona off the limb (in agreement with the suggestions made by Christiansen, Yabsley and Mills).

We have found no data in the archives that provide any insight into the data reduction techniques used by Yabsley to obtain his brightness distributions. The first paper to appear suggesting the use of the Fourier transform method to achieve a brightness distribution from interferometric data in radio astronomy came from the RP group (McCready et al., 1947), so presumably, Yabsley was familiar with the technique from the outset. The McCready et al. paper very clearly noted that measurement of sufficient interference fringe amplitudes and phases at different baselines would provide all of the Fourier components of the brightness distribution within the primary beam of the aerial. Christiansen's invention of the grating array, however, provided a direct means of obtaining a high-resolution beamwidth which negated the need for interferometer measurement at different spacings and the use of a Fourier transform to reconstruct the brightness distribution. This invention was perhaps the primary reason why Yabsley abandoned the technique. Christiansen later used the method to restore a two-dimensional brightness distribution across the Sun based on the use of the Earth rotational synthesis technique (Christiansen and Warburton, 1955). These observations marked the first application of Earth rotational synthesis in radio astronomy, almost a decade before it appeared elsewhere. This is often overlooked in historical reviews (Christiansen, 1989). However, further use of the technique was abandoned by RP as the data reduction, in the days before digital computers became more common, required months of manual effort to produce a single image. Instead, Christiansen again turned to a direct means of obtaining a high-resolution image of the Sun in two-dimensions with the invention of the crossed-grating array that he built at the Fleurs field station (see Orchiston, 2004; Orchiston and Mathewson, 2009).

5 ECLIPSE OBSERVATIONS

As discussed earlier, the 1 November 1948 partial solar eclipse was observed using a variety of instruments at three separate sites in Australia (for details see Orchiston et al., 2006). The results were published in both *Nature* and the *Australian Journal of Scientific Research* (Christiansen et al., 1949a; 1949b; Piddington and Hindman, 1949; Minnett and Labrum, 1950). The AN/TPS-3 aerials were used for observations at the remote sites of Rockbank in Victoria (Orchiston, 2004c) and Strahan in Tasmania (see Figure 9) for the 600 MHz observations, with other observations performed at Potts Hill. By observing from the three widely separated locations, it was possible to triangulate the location of emission by timing the decrease in emission as the Moon's disk obscured the source when viewed from each site. Figure 10 shows the locations of sources of enhanced emission on the solar disc with intersecting timing arcs from each of the sites.

The eclipse observations provided vital data relating to the quiet Sun and the slowly varying component at radio frequencies. While optical emission comes from the lowest layer of the solar atmosphere, the photosphere, the observational evidence showed that the radio component of the radiation had its origin above the chromosphere. The observations also revealed that much higher temperatures than the 5800 K photosphere temperature were present and these ranged from 10^3 K in the chromosphere to 10^6 K in the corona. At the time of the observations, the general hypothesis for the origin of the radiation was thermal, although a non-thermal origin had not been ruled out. From the observations, it was also clear that at 600 MHz emission extended well beyond the visible disk of the Sun, correlating with an origin in the corona. The extended source was not as apparent at the higher frequencies, nor was the predicted limb brightening effect definitively observed. Correlation of the variable component with sunspot areas appeared clear at all frequencies and the position measurements at 600 MHz associated emission with existing and old sunspot groups. Circular polarisation also was detected relating to the discrete sources and ultimately to some sunspot groups. Early research had proposed the existence of a general solar magnetic field (Hale et al., 1918), although the radio observations found no evidence of this. RP's Stefan Smerd (1916–1978; Orchiston, 2014d; Robertson, 2002) used these observations to establish a lower limit for the strength of the field, if, in fact, it existed at all (see Smerd, 1950).

The next eclipse to occur in Australia was another partial eclipse due on 22 October 1949. RP again mounted observing expeditions to remote sites using the AN/TPS-3 aerials. One of the new places was the aerodrome in Bairnsdale in south-eastern Victoria. The other was at Eaglehawk Neck near Hobart in Tasmania. The mountings of the aerial were improved by using a motor-driven polar mount in place of the hand-steered alt-azimuth mounts to allow automated tracking of the Sun. Also, the 600 MHz receivers were replaced to allow observations at the higher frequency of 1200 MHz. Figure 11 shows the aerial being set up at the Tasmanian site.

Although the 1949 eclipse observations were successful at all sites, the results were inconclusive and were never published (see Wendt et al., 2008b).

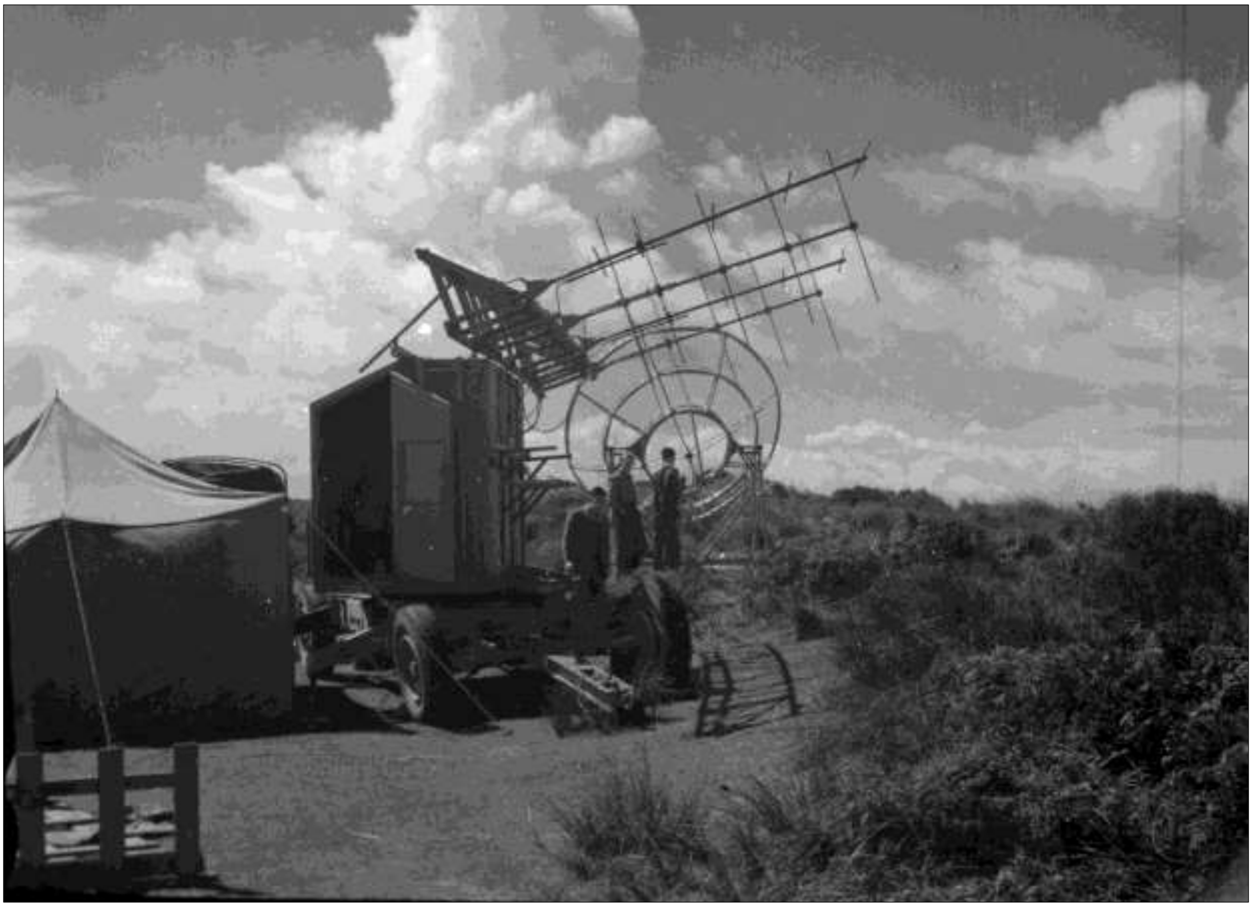

Figure 9: The equipment taken to Strahan by RP included the AN/TPS-3 antena and the mobile sea interferometer that earlier in the year had been used in New Zealand to observe discrete radio sources (courtesy: Stanley Family).

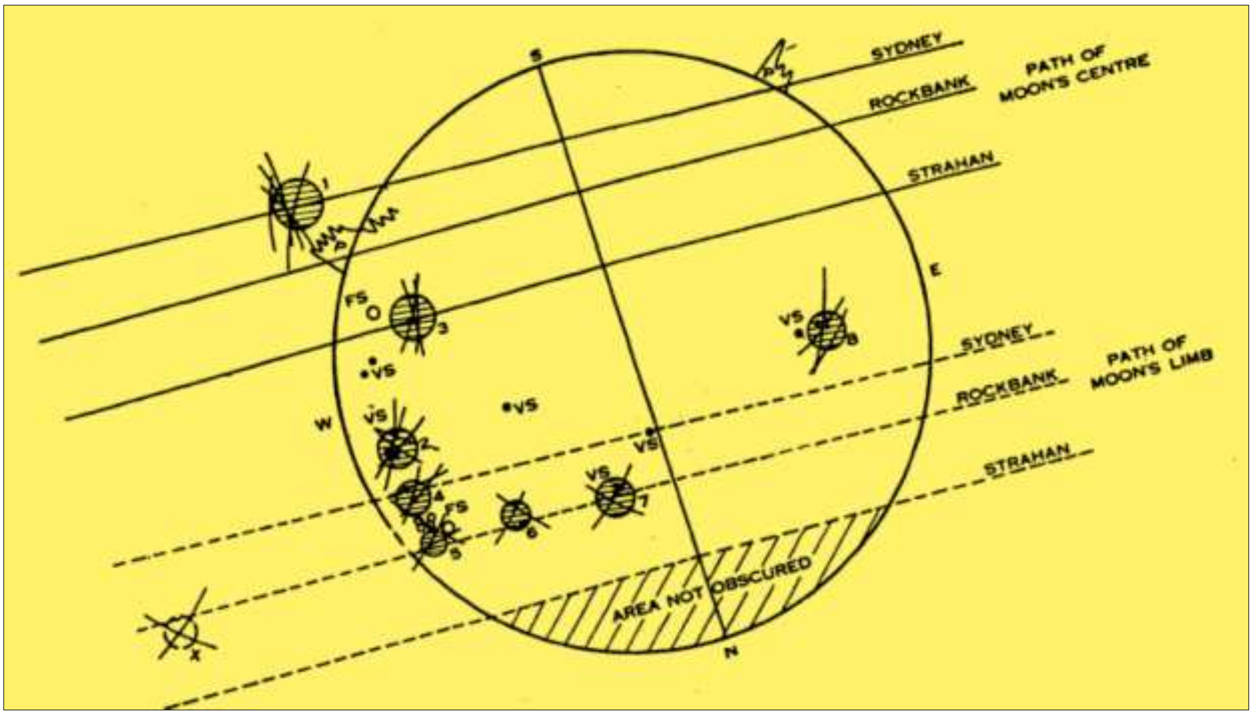

Figure 10: The location of radio sources at 600 MHz on the solar disk. VS = visible sunspot, FS = position of a visible 27 days earlier sunspot, P = solar prominence (after Christiansen et al., 1949b: 513).

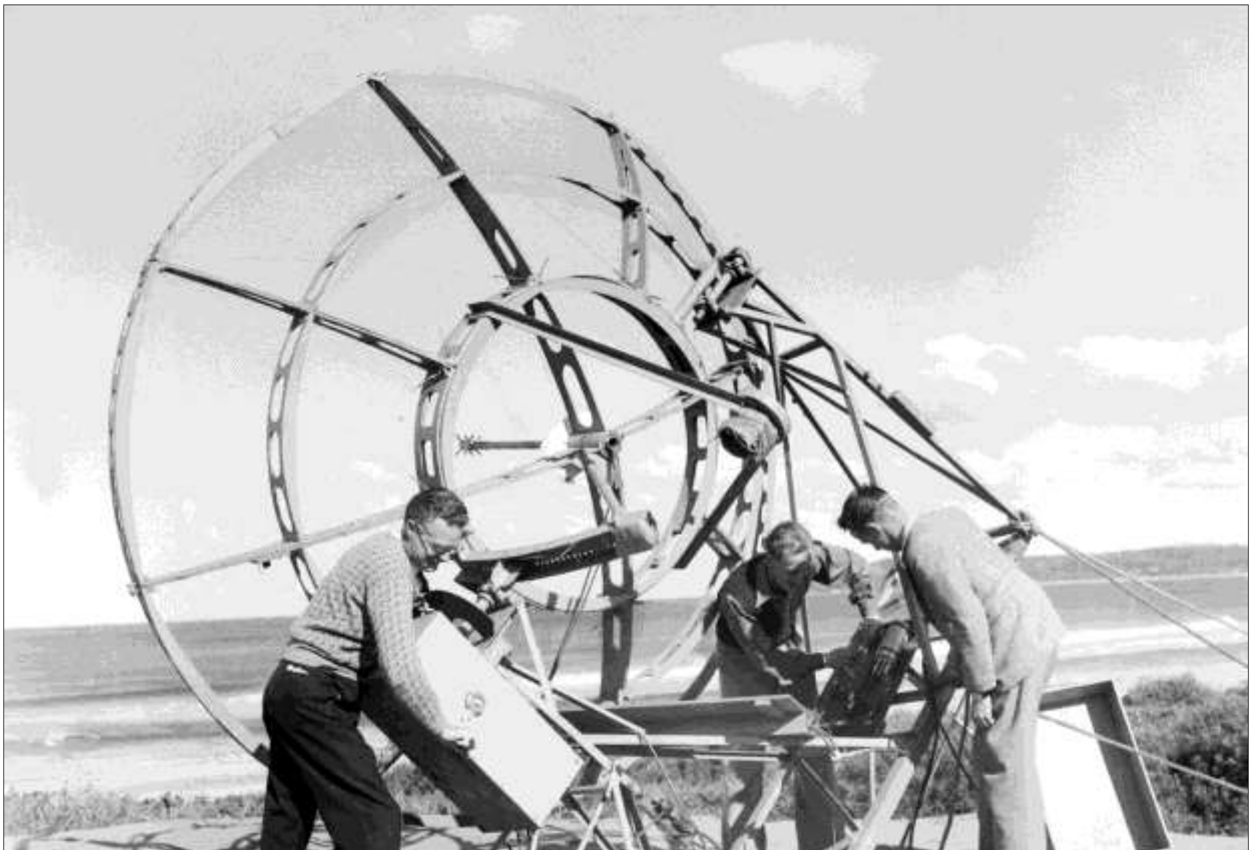

Figure 11: An AN/TPS-3 aerial being set up at Eaglehawk Neck in Tasmania for the 1949 eclipse observations. From left to right are Jack Harragon, John Murray and Don Yabsley (courtesy: *The Mercury* newspaper).

6 GALACTIC RADIO SOURCES

The instruments at Potts Hill field station that were used for the early solar observations also often were used for cosmic source investigations. Bernard Mills (1920–2011; Frater et al., 2013) used Ruby Payne-Scott's swept-lobe interferometer to investigate discrete sources when it was not being used for solar observations.

Similarly, Jack Piddington (1910–1997; Orchiston, 2014c) and Harry Minnett (1917–2003; Orchiston, 2014b) used the AN/TPS-3 aerials for their initial exploration of cosmic sources at 1210 MHz in 1948. When the larger and more sensitive ex-Georges Heights 16 × 18-ft aerial became available during 1949, the AN/TPS-3 aerial became the backup for when the 16 × 18-ft antenna was unavailable (Piddington and Minnett, 1951). Piddington and Minnett's investigations led them to the discovery of the discrete radio source at the centre of our Galaxy (Goss and McGee, 1996).[2] The preliminary observations of the Galactic Centre source (Sagittarius A) were made using the AN/TPS-3 antenna.

Following Piddington and Minnett's investigations, the AN/TPS-3 aerials fell into disuse. Over time their condition deteriorated (e.g. see Figure 12), and although there is no definitive record of the ultimate fate of the aerials, it is likely that they were scrapped as their condition deteriorated in the mid-1950s.

Figure 12: One of the AN/TPS-3 aerials at Potts Hill in November 1951 showing damage to one of the aluminium segments (adapted from RAIA, B2639).

7 DISCUSSION

There is a remarkable parallel between the use of 3-m class ex-WWII radar dishes between the Cambridge and Radiophysics (RP) groups. Cambridge used the 3-m Würzburg radar dishes, while Radiophysics used the 3-m AN/TPS-3 antennas. Over almost the same period in the late 1940s, both groups used the dishes in spaced interferometer configurations to explore the distribution of solar radio emission. Despite having earlier proposed the use of different interferometer spacings to obtain the Fourier components of a source distribution, RP quickly abandoned any development of the technique for solar observations in favour of using solar grating arrays. On the other hand, the Cambridge group led by Martin Ryle persisted with the technique, and they ultimately developed it into the aperture synthesis imaging method when digital computers became more readily available. It was partly for this work on aperture synthesis that Ryle received the Nobel Prize. In both cases, the availability of surplus WWII equipment supported the rapid development of the new science of radio astronomy. While the Cambridge story is well known, the RP experiments are almost unknown as few results or descriptions—outside of internal laboratory records—appeared in publications.

8 CONCLUDING REMARKS

Instead of relying on German ex-WWII Würzburg radar dishes, the Australian Radiophysics Group used American AN/TPS-3 dishes for some of their early radio astronomy research.[3] These antennas formed a central part of the 1948 eclipse observations that helped establish RP's reputation as an early leader in solar radio astronomy. The dishes also were used for galactic observations and contributed to the discovery of the discrete radio source (Sagittarius A) at the Galactic Centre. This paper provides a record of the contribution made by AN/TPS-3 radar dishes to early radio astronomy, consistent with the objectives of the IAU Working Group on Historical Radio Astronomy.

9 NOTES

1. The CSIR became the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in 1949.
2. In fact, Piddington and Minnett (1951) only claimed that their newly-discovered discrete source was *near* the Galactic Centre, not *at* the Galactic Centre (Orchiston and Wendt, 2017). It was Bolton and McGee (1954) and McGee et al. (1955), reporting on observations made later with the Dover Heights 'hole-in-the-ground antenna' (Orchiston and Robertson, 2017), who claimed a direct association of Sagittarius A with the Galactic Centre (Bland-Hawthorn and Robertson, 2014).
3. Even though the RP group never acquired any Würzburg antennas, in 1945 they did consider using them. Thus, on 6 November 1945 the Chief of the Division of Radiophysics, John Briton, wrote to Guy Gresford in London:

> We understand that there is a good possibility of sidetracking one of the German Wurzburg equipments from the RAF. We would be very glad indeed to acquire one of these. We would set it up at our new field testing site at George's Heights, Sydney, where it would be very useful for a number of purposes … (Briton, 1945).

Unfortunately, nothing came of this idea.

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