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THE GENESIS OF SOLAR RADIO ASTRONOMY IN AUSTRALIA

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Abstract: In late 1945, O.B. Slee at RAAF Radar Station 59 near Darwin and staff from the CSIRO's Division of Radiophysics in Sydney were involved in Australia's first investigation of radio emission from the Sun. After WWII, the Sydney radio astronomers were joined by small independent groups based at the Commonwealth Observatory, Mt Stromlo, and in the Physics Department at the University of Western Australia, in Perth. Between 1946 and 1948, these young scientists made an important contribution to international astronomy, heightening our understanding of solar physics and the relationship between sunspots and solar radio emission.

Keywords: Australia, solar radio astronomy, O.B. Slee, CSIRO Division of Radiophysics, Commonwealth Observatory, University of Western Australia, W.N. Christiansen, L.L. McCready, J.L. Pawsey, R. Payne-Scott

1 INTRODUCTION

Radio astronomy enjoys a history that extends back a little over seventy years, but it only blossomed following WWII, largely as a result of technological advances made during the war years. These years of turmoil also marked the independent detection of solar emission in the U.S.A., Denmark, England, Australia and New Zealand (see Orchiston and Slee, 2002a; Sullivan, 1984), and it was the British and New Zealand discoveries that precipitated the solar radio astronomy program at the CSIRO's Division of Radiophysics (RP) in Sydney. In the immediate post-war years the RP group quickly gained world supremacy in this field of radio astronomy (Sullivan, 1988), a status that they were able to maintain with distinction through into the mid-1980s when the closing of the Culgoora Radioheliograph and staff promotions and retirements saw the demise of the Solar Group.

In this paper we describe the independent discovery of solar radio emission at Darwin in 1945, and document the solar radio astronomy research programs pursued by RP, the Commonwealth Observatory and the University of Western Australia during the formative years, 1945-1948.

2 THE DIVISION OF RADIOPHYSICS

According to Payne-Scott (1945: 1), the initial solar observations carried out by the RP group "... were inspired by the almost simultaneous arrival of three reports in the laboratory ..." in mid-1945. One was Reber's (1944) paper in the *Astrophysical Journal*, and the other two were 'secret' war-time accounts of the independent detection of solar radio emission by New Zealand and British radar operators (Alexander, 1945; Army Operational Research Group, 1945).

Of most significance were the New Zealand results, which were coordinated by Dr Elizabeth Alexander (Figure 1), a British-born Cambridge geology graduate who unwittingly became the world's first female radio astronomer (see Orchiston, 2005a). The observations were made with five British-built 200 MHz COL units (Figure 2) sited at Royal New Zealand Air Force radar stations on the northern part of the North Island of New Zealand and on Norfolk Island (Figure 3).

Figure 1: Dr Alexander (1908–1958) the world's first female radio astronomer (courtesy Mary Harris).

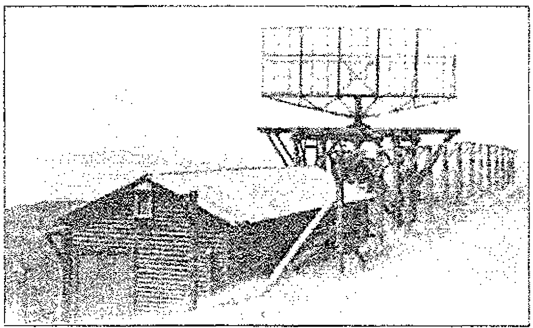

Figure 2: The RNZAF Whangaroa Radar Station (courtesy Gordon Burns).

Figure 3: Locations of the five Royal New Zealand Air Force radar stations where solar observations were made during March-April 1945. Key: 1 = Norfolk Island, 2 = North Cape, 3 = Whangaroa, 4 = Maunganui Bluff, and 5 = Piha (adapted from Orchiston and Slee, 2002a).

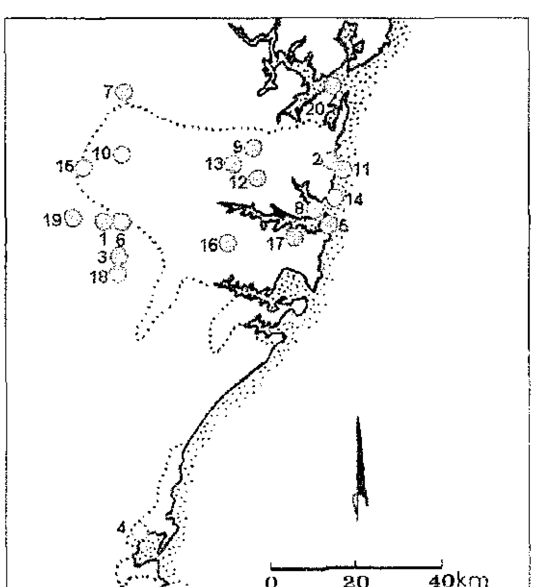

Figure 4: The twenty different sites in the Greater Sydney-Wollongong regions associated with radio astronomy, 1945-1963. Those mentioned in this paper are Collaroy (2), Dapto (4), Dover Heights (5), Fleurs (6), Georges Heights (8), Hornsby Valley (9), North Head (14), Penrith (15), Potts Hill (16) and the Radiophysics Laboratory in the grounds of the University of Sydney (17). (after Orchiston and Slee, 2005a).

2.1 The Initial Observations at Collaroy

Since similar COL radar units were deployed in Australia at Royal Australian Air Force radar stations the RP radio astronomy group leader, Dr Joe Pawsey (1908-1960; see Figure 3 on page 22), commandeered the antenna at Collaroy, a coastal suburb of Sydney (location 2 in Figure 4), in an attempt to replicate the New Zealand results. Radar 54 at Collaroy was situated ~107 m above sea level, and comprised a vertical "... broadside array of four horizontal rows each of ten half-wave dipoles with a reflector, having a gain of 80 relative to a half-wave dipole (i.e. g = 130) and a horizontal beamwidth (to the half power points) of 10°." (Payne-Scott, 1945: 6-7). The antenna was mounted so as to rotate in azimuth only. In this configuration it functioned as a sea interferometer (see Bolton and Slee, 1953), and because of the location of the site could only observe the rising and setting Sun.

Despite this shortcoming, from 3 October 1945 RAAF personnel at Station 54 carried out regular solar monitoring on behalf of RP for about an hour after sunrise and before sunset. At these times,

> The aerial (whose elevation remains zero) is swept from a bearing of about 15° south of the position of the sun at rising (or setting) to a position 25° on the other side of the bearing of rising (or setting); it is stopped at intervals of about 2° and a reading taken of the meter. The zero and general noise level are checked at the beginning and end of each sweep. (Payne-Scott, 1945: 7).

From the very first observations there were promising results:

> The first readings were taken on the morning of October 3rd of this year [1945]. The time of sunrise was 0530 hours and the bearing 95°. A few sweeps were taken before sunrise and showed only a slight random variation, due probably to a combination of changes in aerial impedance with bearing, man-made noise on certain bearings and changes in the receiver itself. At 0531 an increase in noise power of about 27% over the general level was observed at a bearing of about 94°. In successive sweeps this increase in noise became more marked, until at 0540 the noise power on a bearing of 93° was 4½ times the normal noise power. Over the next twenty minutes it declined, rose again to a smaller peak at 0610 and then declined again, the effect being just detectable at 0730.
>
> Since this date a fairly continuous series of observations have been made each sunrise and sunset, and on each occasion radiation has been observed ... One feature not shown [in Figure 5, overleaf] ... is the short period fluctuations; the noise from the sun causes a fairly steady meter deflection on which are superimposed at intervals of perhaps a few seconds kicks which may be of the same order as the steady deflection; the relative magnitude and frequency of occurrence of these kicks seems to be independent of the elevation of the sun over the hour or so during which it is observed. (Payne-Scott, 1945: 7-8)

The accumulated evidence from October 1945 left no doubt that the anomalous 'noise' was of solar origin. It was there at sunrise and sunset and came from ±3° of the bearing of the Sun; the rate of change of peak intensity reflected that of the Sun; the 'noise' was only detectable when the Sun was in the aerial beam (i.e. for about an hour after sunrise and before sunset); and the horizontal field pattern was similar to the aerial field pattern, "... indicating radiation from a source of small angular width." (Payne-Scott, 1945: 8).

However, a major limitation of the Collaroy COL radar system was that the antennae could only monitor solar emission at sunrise and sunset. To determine the level of solar noise between sunrise and sunset it was necessary to employ a different antenna system, one that could track the Sun throughout the day. Accordingly,

> ... some observations were made with an Army S.L.C. radar at North Head [location 14 in Figure 4] having 4 Yagi aerials with a total gain of about 24 and a receiver of worse noise factor than that used at Collaroy. The radiation from the sun produced a change in meter reading of only a few percent on this set. On 31st October the radiation from the sun was observed from 1400 hours till sunset, during which time there was no observable change in its value except for a gradual increase towards sunset to about twice the original level, probably due to reinforcement from ground reflections. The radiation ceased within a few minutes of sunset. (Payne-Scott, 1945: 11).

One of the features of the solar emission, the short-period fluctuations (or 'kicks') mentioned above by Payne-Scott, provided an intriguing challenge:

> The meter deflections observed over a period of a few seconds ... may be due either to absorption or scattering of the radiation in the earth's atmosphere or to genuine fluctuations in the solar radiation. There is so far little evidence one way or the other, but *this will be one of the first points to be investigated in future work, as it is critical in deciding the origin of the radiation.* (Payne-Scott, 1945: 9; our italics).

Payne-Scott's (1945: 10) detailed unpublished report reveals that on 4 and 5 October solar observations also were made at sunrise "... on two other laboratory systems, one operating on 600 Mc/s. and the other on 1200 Mc/s."[1] While no solar emission was noted at 600 MHz, detections were recorded on both days at 1,200 MHz.

In their war-time 'secret' reports, Alexander and Hey both commented on the association between sunspots and solar emission, and this was immediately apparent when the mean daily 200 MHz Collaroy noise levels between 3 and 23 October 1945 were compared with total sunspot area (see Figure 5).

On 23 October 1945, Ruby Payne-Scott (Figure 6) joined with Joe Pawsey and Lindsay McCready in penning a brief report on their work for *Nature*, and after unexpected and totally unacceptable delays[2] this was published in the 9 February 1946 issue of the journal—shortly after Hey's (1946) belated announcement of his war-time observations.[3] In their paper, "Radio-frequency Energy from the Sun", Pawsey et al. (1946: 158) announced that they had

> ... observed, from the direction of the sun, a considerable amount of radiation having the apparent characteristics of fluctuation 'noise' when observed on a cathode-ray oscillograph or head-phones. However, the output meter reading fluctuated considerably, a characteristic which is not typical of normal thermal agitation 'noise'. The variation of apparent azimuth of arrival and of intensity with horizontal rotation of the aerial and the sun's elevation was qualitatively consistent with the assumption of radiation from the body of the sun modified by the known directional characteristics of the aerial.

In commenting on the Figure 5 data, Pawsey et al. (ibid.) stated that:

> It is apparent that the peaks of 1.5-metre radiation coincide with the peaks of the sunspot area curve and with the passage of large sunspot groups across the meridian. This strongly indicates a physical relationship between the two phenomena ...

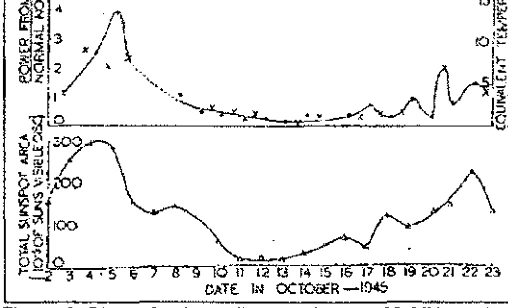

Figure 5: Plots of solar radio emission at 200 MHz and total sunspot area, in 1945 October (after Pawsey et al., 1946).

These initial RP excursions into solar 'noise' produced promising results but they also raised many interesting questions. They also served to justify the continuation of radio astronomy (as it would later become known) as a valid field of investigation in RP's quest to identify a viable post-war research portfolio.

Figure 6: Ruby Payne-Scott (1912–1981), Australia's first female radio astronomer (courtesy Miller Goss).

2.2 Parallel Observations at Dover Heights

Following the successes of October 1945, solar monitoring at Collaroy continued through to March 1946, and it was soon arranged for parallel observations to be made with the SHD antenna at the Dover Heights radar station (Figure 7). This was situated in the eastern suburbs of Sydney, and ~17 km to the south of Collaroy (location 5 in Figure 4). In order to obtain a visual record of solar radio emission, chart recorders were included in the receiving systems, and in February 1946 (when a massive sunspot group dominated the photosphere) these provided a clear permanent record of the Sun's passage through the sea interferometer fringes, not only revealing temporal variations in the background level of solar radiation but also intense bursts of short duration (see Figure 8). Obviously these bursts were the 'kicks' that Payne-Scott had earlier alluded to.

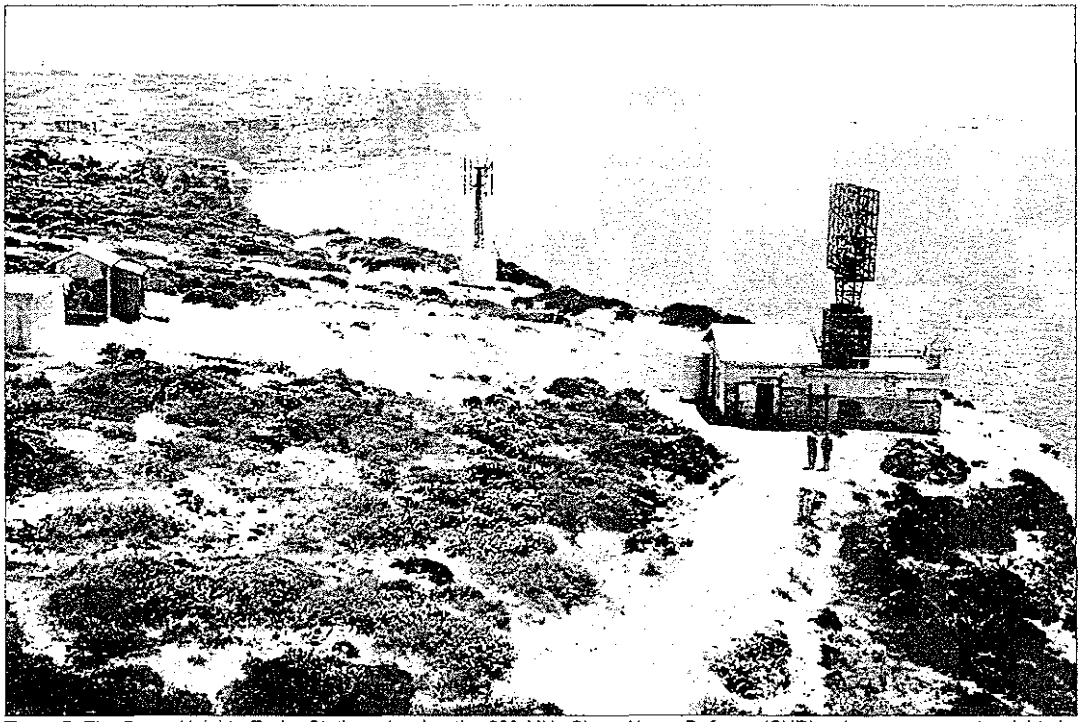

Figure 7: The Dover Heights Radar Station, showing the 200 MHz Shore Home Defence (SHD) radar antenna centre right. An identical unit was sited at the Collaroy Radar Station (ATNF Historic Photographic Archive: B81-1).

In addition to this burst emission, Pawsey was interested in the quiescent level of solar radiation at 200 MHz, and by isolating and quantifying the non-burst component he was able to demonstrate the existence of a 'hot corona' that far exceeded the temperature of the photosphere, something that had been hinted at previously by optical astronomers (see Sullivan, 1982: 208). Pawsey's (1946b) announcement in *Nature* of a temperature of 10^6 K immediately followed a theoretical paper by D.F. Martyn (1946b) predicting a coronal temperature of that order. Originally an RP employee, Martyn was at that time based at the Commonwealth Observatory, Mt Stromlo, and had good working relations with some of his former colleagues at RP. Notwithstanding the order in which the two *Nature* papers were published and Martyn's inclusion in Pawsey's acknowledgements (but not *vice versa*), there has been considerable debate about who first came up with the million degree coronal temperature. Did Pawsey discover this through his Collaroy observations and pass on this result to Martyn (who subsequently developed the appropriate theoretical framework), or was it Martyn's theoretical work that prompted Pawsey to look at the radio data? Sullivan (2005: 19) recently reviewed this interesting issue and although he assigns Pawsey chronological priority, he concludes that

> ... Martyn was indeed the one who brought in the previous astronomical evidence of a million-degree corona and who pointed out that that the million-degree 'effective' or 'apparent' temperatures cited by the RP group could actually represent *thermal* emission from the solar atmosphere. Pawsey and his colleagues had calculated these temperatures, but thought of them only in a formal sense. In fact, to them these incredibly high values were at first prima facie evidence of *non*-thermal phenomena.

One of the major problems with the Collaroy and Dover Heights radar antennas was that they could not track the Sun for extended periods, so in early 1946 this prompted the RP staff to install simple 200 MHz 4-Yagi arrays on the roof of the blockhouse at Dover Heights (Figure 9), and at the North Head radar station. A third Yagi array was also set up at the Commonwealth Solar Observatory, Mt Stromlo, but more on this later.

Parallel daily monitoring with these steerable antennas quickly revealed almost identical patterns of solar emission, with a changing level of background radiation upon which were superimposed bursts of varying duration and intensity. The precise correspondence in the case of bursts, and the fact that burst activity did not vary systematically as the Sun rose from the horizon towards the zenith, proved conclusively that the emission was of solar origin and not caused by ionospheric scintillations

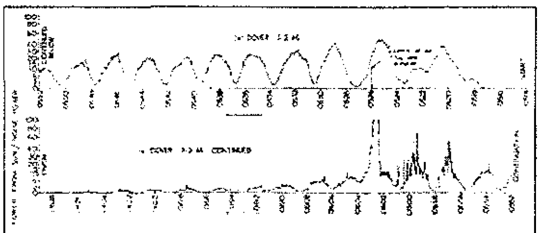

Figure 8: Chart record of the Sun passing through the sea interferometer fringes on 7 February 1946 at Dover Heights. Time, in minutes, runs from left to right, and the chronological sequence is continued in the lower strip where intense burst emission is apparent immediately before the Sun rises above the beam of the antenna (after McCready et al., 1947: 366).

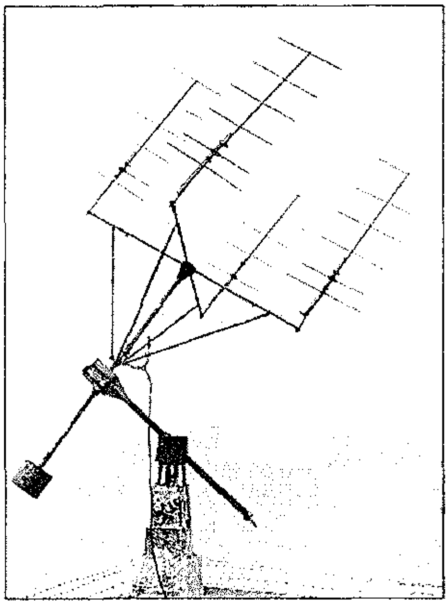

Figure 9: 200 MHz 4-Yagi antenna on the roof of the blockhouse at Dover Heights. Similar antennas were also installed at North Head and Mt Stromlo in early 1946 (ATNF Historic Photographic Archive: B1165-2).

By plotting the general background level of solar emission during October 1945-February 1946 against sunspot number and sunspot areas, the correlation noted earlier for October 1945 was confirmed, but in this instance McCready et al. (1947: 363) observed that "... the correlation with areas is somewhat closer than with sunspot number but neither is exact." The Sun was particularly active during this period, and as Sullivan (1982: 183) has pointed out, "... these novice astronomers were somewhat lucky in being able to observe the great sunspot group of February, 1946, one whose main sunspot is amongst the largest ever photographed." This group is shown in Figure 10.

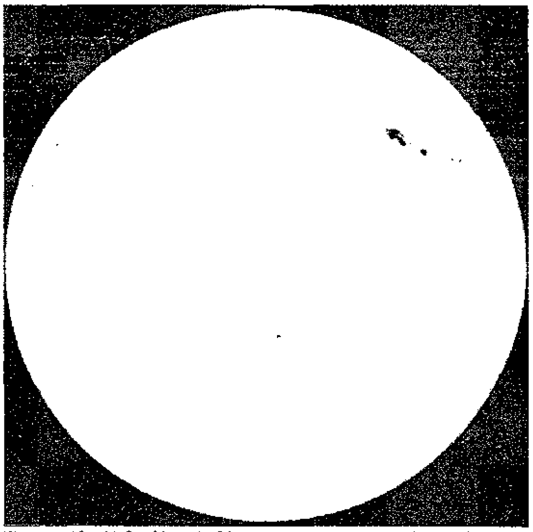

Figure 10: U.S. Naval Observatory photograph of the Sun taken on 8 February 1946, showing what at that time was the largest sunspot group on record (after Stetson, 1947: Plate I).

McCready et al. also investigated the location of the source of emission on the Sun by analyzing the interference fringes, as shown in Figure 8, and during the presence of the great sunspot group of February 1946 they were able to demonstrate conclusively that the solar radiation originated from a strip that in each case included this sunspot group. Examples deriving from Collaroy and Dover Heights are shown in Figure 11, and

> In each case the radiating strip has a width considerably less than that of the sun's disk, being of the order of the size of the sunspot group, and passes through the group. It moves across the sun with the spots as the sun rotates ... There seems no reasonable doubt that the source was localized in a small region in the vicinity of the spots. [However] The observations do not provide any information as to the detailed structure of the source within this region. (McCready et al., 1947: 368).

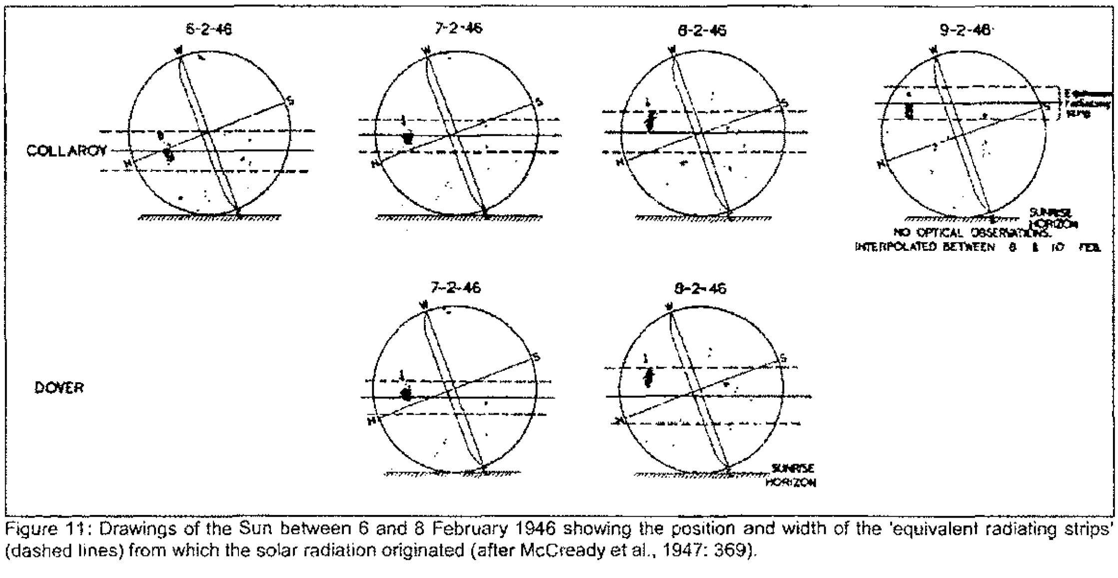

Figure 11: Drawings of the Sun between 6 and 8 February 1946 showing the position and width of the 'equivalent radiating strips' (dashed lines) from which the solar radiation originated (after McCready et al., 1947: 369).

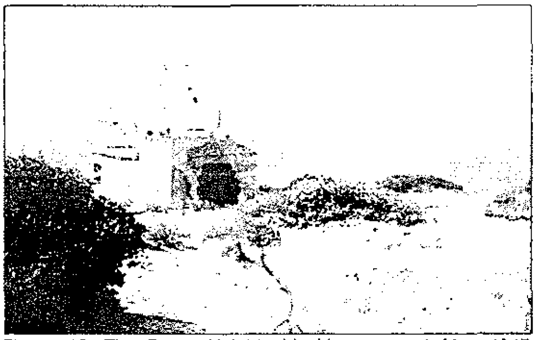

Figure 12: The Dover Heights blockhouse on 1 May 1947, showing the 60 MHz (left) and 100 MHz twin Yagis (right) (ATNF Historic Photographic Archive: B1031-3).

Although McCready et al. (1947) conducted most of these pioneering investigations at 200 MHz, they also made a few observations at 75 and 3,000 MHz. At the higher frequency they detected a low level of solar radiation, consistent with Southworth's (1945) published results, whereas at 75 MHz the solar emission was comparable to that recorded at 200 MHz. They concluded that the intensity of the 200 MHz was at times too great to be accounted for in terms of thermal radiation, and suggested the solar noise derived from "... gross electrical disturbances analogous to our thunderstorms." (McCready et al., 1947).

The next challenge was to expand these multifrequency observations, with particular emphasis on burst emission, and in mid-1946 a simple 60 MHz twin Yagi was constructed and joined the 75 MHz twin Yagi and 200 MHz 4-Yagi array already on the roof of the block-house at Dover Heights. At the time, Pawsey was pleased with progress, and in a letter to the British radio physicist Jack Ratcliffe, dated 2 August 1946, he wrote:

> I have been principally interested over the last six months in the problem of radio frequency noise from the sun ... At the moment we are doing a bit of exploring, taking measurements of intensities at a number of different frequencies, some during the day and others at dawn. We have found that the variation of solar noise on different frequencies is dissimilar and that the dawn effect on 60 Mcs. is much more complicated than it is on 200 Mcs. (Pawsey, 1946a).

In November 1946, Payne-Scott and her colleagues were able to improve the range of observations made at Dover Heights when a 100 MHz twin Yagi (Bolton, 1982) replaced the 75 MHz antenna on the roof of the blockhouse. The general appearance of the blockhouse in mid-1947 is shown in Figure 12, although the 200 MHz antenna is hidden from view.

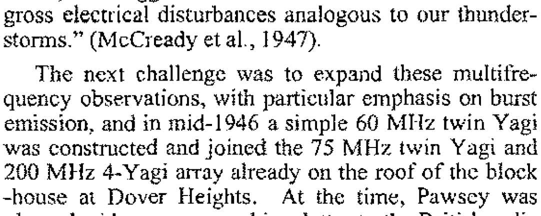

Figure 13: Large outburst on 8 March 1947 (after Payne-Scott et al., 1947).

From July 1946 the relative arrival times of bursts recorded at three frequencies were noted, and on 21 May 1947 Payne-Scott, Don Yabsley and John Bolton (1947) completed a paper reporting the results of this research. They found that small bursts often were not correlated at the three frequencies. In contrast, many of the larger bursts detected during July-August 1946 were present at all three frequencies, but did not occur simultaneously. They arrived in the sequence 200, 75 and 60 MHz, with a typical delay of ~2 seconds between bursts at 200 and 75 MHz, and a similar interval between bursts at 75 and 60 MHz. A few observations were also made at 30 MHz, and the delay in arrival times of bursts at 60 and 30 MHz was also a few seconds. When it came to outbursts, the delays in the respective arrival times at the different frequencies were of at the order of several minutes, and an excellent example, recorded at 200, 100 and 60 MHz on 8 March 1947, is shown in Figure 13 (see, also, Bolton, 1982: 350 for a dramatic account of this event). This outburst was associated with a solar flare and short-wave radio fadeout, and an aurora was visible from some areas of Australia on the evening of 9 March.

In interpreting their observations, Payne-Scott et al. (ibid.) concluded that "The successive delays between the onset of the outburst on 200, 100 and 60 Mc/s. suggest that the outburst was related to some physical agency passing from high-frequency to lower-frequency levels [in the solar corona]." Later this 8 March 1947 event would be classified as a Type II outburst in Paul Wild's spectral classification of solar bursts, while those bursts with short inter-frequency time delays referred to above are examples of Type III and the isolated non-correlated bursts belong to Type I.

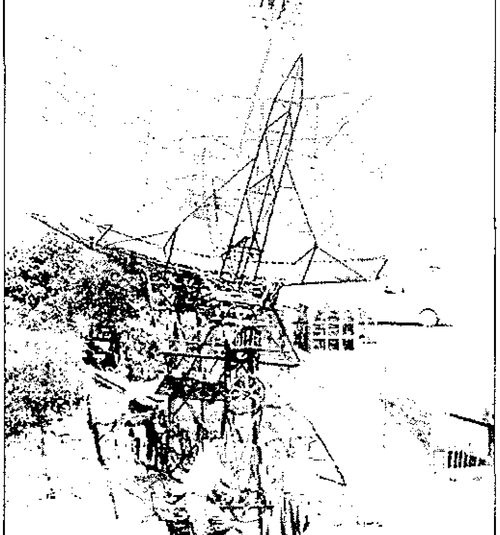

Figure 14: The radar antenna that was used for solar radio astronomy at Georges Heights and later at the Potts Hill field station. Joe Pawsey is on the left and Don Yabsley on the right (ATNF Historical Photographic Archive: B1031-1).

2.3 Expanding the Frequency Coverage

Pawsey was keen to expand the range of frequencies used in the RP solar monitoring program, and in 1947 and 1948 the work at Dover Heights was complemented by data supplied from two new observing sites, Georges Heights and the 'Eagles Nest'.

The WWII Georges Height radar station (Orchiston, 2004b; Orchiston and Slee, 2005a) occupied an attractive site at Middle Head over-looking the entrance to Sydney Harbour (location 8 in Figure 4), and Pawsey wanted to take advantage of a novel experimental radar antenna comprising a 14 × 18 ft (i.e. 4.3 × 4.8 metre) section of a parabola (Figure 14) which was located there. In June 1947 Fred Lehany and Don Yabsley were assigned to this instrument, and many years later Lehany (1978) recalled that their involvement "... came about in a typical 'Pawseyian way', before I knew what was happening ... there was an observing program and ... Yabsley and I were a suitable pair to share not only the week days but also the weekend duty ..." Between June and August 1947 Bruce Slee assisted Lehany and Yabsley in developing the receivers and feed systems and operational testing of the antenna, before returning to Dover Heights.

Yabsley (1978) built a triple-feed system that allowed the ex-radar antenna to operate simultaneously at 200, 600 and 1200 MHz (see Figure 15), but a problem was the cumbersome altazimuth mounting that was never designed for radio astronomy. The fledgling radio astronomers found that the only way the antenna could be used effectively was to position it ahead of the Sun, let the Sun drift through the beam, hand-crank it ahead of the Sun again, and repeat the process throughout the day. This procedure produced a distinctive 'picket fence' chart record (see Figure 16).

By August 1947 the equipment was fully operational, and solar monitoring was carried out for about two hours daily, from 18 August until 30 November, resulting in the detection of many bursts at 200 MHz. In contrast, bursts were rare at 600 and 1200 MHz (see Figure 16), where the general flux variations with time were correlated with sunspot area (Figure 17). This distinctive pattern was discussed by Lehany and Yabsley in papers published in *Nature* and the *Australian Journal of Scientific Research* in 1948 and 1949 respectively. The 600 and 1,200 MHz emission was "... compatible with the thermal radiation expected from the solar atmosphere at these frequencies. It is considered that the variations in intensity ... are at least partly due to the magnetic fields of the sunspots raising parts of the effective radiating shells into the corona ..." (Lehany and Yabsley, 1949: 60).

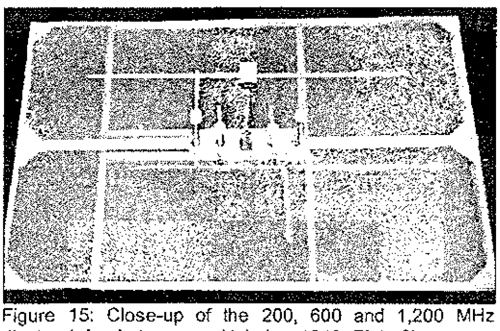

Figure 15: Close-up of the 200, 600 and 1,200 MHz dipoles (after Lehany and Yabsley, 1949: Plate 2).

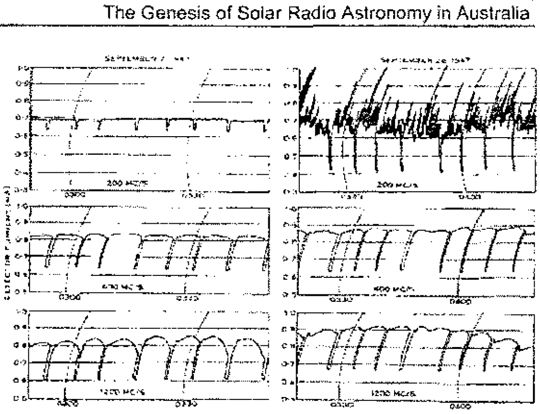

Figure 16: Chart records for 200, 600 and 1,200 MHz obtained at Georges Heights on 7 and 26 September 1947. Note the extensive 200 MHz burst emission on 26 September. The distinctive 'picket fence' nature of the chart record is clearly illustrated in the 600 and 1,200 MHz plots (after Lehany and Yabsley, 1949: 55).

Although burst emission at 600 and 1,200 MHz was rare, Lehany and Yabsley occasionally recorded

> Isolated disturbances ... mainly of low intensity and fairly short duration. In some instances they were definitely associated with chromospheric flares and sudden daylight radio fadeouts ...
>
> The largest 600 Mc/s. and 1200 Mc/s. disturbance in the series occurred on October 4, when the intensity levels at both frequencies increased to thirty times their normal value and remained high for approximately ten minutes ... (Lehany and Yabsley, 1949: 58; cf. Lehany and Yabsley, 1948).

The most conspicuous 'disturbances'—or outbursts—mirrrored the event recorded at Dover Heights on 8 March 1947 (cf. Figure 13).

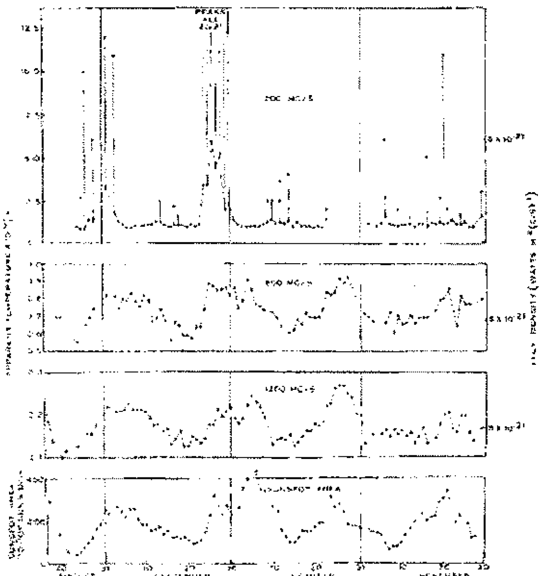

Figure 17: Georges Heights 200, 600 and 1,200 MHz observations during August-November 1947. At the two higher frequencies the correlation with variations in sunspot numbers is obvious. The sunspot data were provided by the Commonwealth Solar Observatory at Mt Stromlo (after Lehany and Yabsley, 1949: 56).

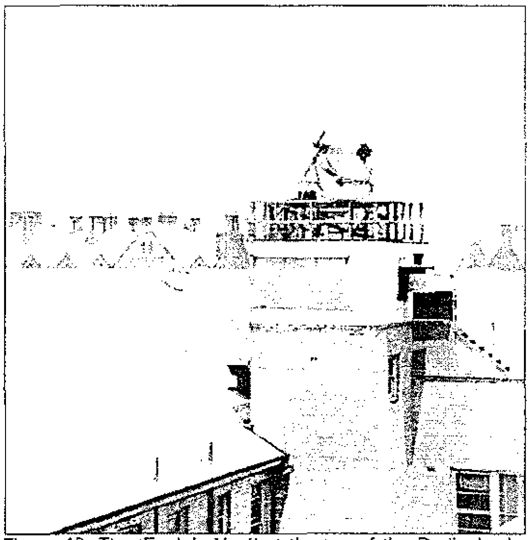

Figure 18: The 'Eagle's Nest' at the top of the Radiophysics Laboratory, showing the small antenna used Piddington and Minnett (ATNF Historic Photographic Archive: B1641).

These promising results from Georges Heights inspired Pawsey to expand the solar program far beyond 1,200 MHz, and in early 1948 he arranged for a 1.1 metre (44-inch) equatorially-mounted dish to be installed on the roof of the 'Eagle's Nest' (Figure 18), a small room located at the very top of the Radiophysics Laboratory (location 17 in Figure 4). Between April and October 1948, Jack Piddington (Figure 19) and Harry Minnett used this recycled WWII searchlight mirror to observe the Sun at 24,000 MHz. At this frequency the radiation originates from the chromosphere, and from 5 April to 30 August it was found

> "... to vary from day to day by amounts of up to about ± 8 per cent. These variations are smaller among the latter results, being less than ± 3 per cent. for the period July 14 to August 30 (with one exception on August 4). The variations were principally due to instrumental errors and decreased as the measuring technique was improved ... It is evident that solar radiation at a wavelength of 1.25 cm. remains fairly constant for long periods. There is little or no sign of correlation with sunspot areas or relative sunspot numbers (Piddington and Minnett, 1949: 543-544).

This pattern is in marked contrast to that obtained by Lehany and Yabsley at 600 and 1,200 MHz.

Figure 19: Jack H. Piddington, 1910–1997 (ATNF Historic Photo-graphic Archive).

On rare occasions between July and October 1948 Piddington and Minnett (1949: 545-546) recorded intervals of several hours when there were fluctuations of about ±5% in the solar radiation level. In at least one instance, on 6 August, the variations in 24,000 MHz emission mimicked those recorded at 200 MHz, but most major changes in 200 MHz noise levels were not accompanied by observable variations in solar emission at 24,000 MHz.

By the end of October 1948 the little radio telescope atop the Eagle's Nest had served its purpose and revealed the basic pattern of solar emission at 24,000 MHz. This modest aerial and the Georges Heights radar antenna were then transferred to the Potts Hill field station in anticipation of the November 1948 solar eclipse (see Section 2.4, below).

Before examining the key role played by this solar eclipse, let us return briefly to Dover Heights—the site of many of RP's most important solar discoveries in 1945-1946. By the end of 1947, the various Yagi antennas there were being used very effectively by John Bolton, Gordon Stanley and Bruce Slee in their search for new 'radio stars' (Bolton, 1982; Kellermann et al., 2005; Orchiston, 2004a; Slee, 1994), so Payne-Scott decided to transfer her solar program to Hornsby Valley.

The Hornsby Valley field station (Figure 20) occupied a radio-quiet valley on the isolated northern fringes of suburban Sydney (location 9 in Figure 4), and initially was used by Frank Kerr and Alex Shain to bounce radar signals off the Moon in a quest to investigate the Earth's ionosphere and the nature of the lunar surface (see Orchiston and Slee, 2005a, 2005b). At the end of 1947 Payne-Scott set up single 60, 65 and 85 MHz Yagi antennas at Hornsby Valley, and from January through to September 1948 she used these, plus an 18.3 MHz broadside array and Kerr and Shain's 19.8 MHz Moon-bounce rhombic antenna, to study the characteristics of solar burst emission. Most of the observations were made at 60 and 85 MHz; a pair of crossed Yagis was used at 85 MHz so that circular polarization could be studied. While all of the Yagi antennas could track the Sun during the day, the 18.3 MHz and 19.8 MHz aerials were fixed and could not be directed exactly at the Sun so measurements made with them were subject to correction factors.

The accumulated observations revealed the existence of two distinct types of variable high-intensity radiation which Payne-Scott (1949: 215) termed 'enhanced radiation' and 'unpolarized bursts'. She describes the first of these phenomena:

> The intensity reaches a high level and remains there for hours or days on end; there are continual fluctuations in intensity, both long-term and short-term. The short-term increases are somewhat similar to [isolated] bursts ... but usually have a lower ratio of maximum to background radiation. This type of radiation will be called "enhanced radiation" ... Superimposed on it may be bursts ... There may be short periods during which the polarization is indefinite, either because two sources of opposite polarization are superimposed or because the radiation is linearly or randomly polarized, but for the great part of its life the enhanced level shows circular polarization of one sense or the other. (Payne-Scott, 1949: 216-217).

Enhanced radiation normally occurred during the passage of large sunspot groups, and the presence of circular polarization suggested "... that the magnetic field of the spot group plays a part in its production." (Payne-Scott, 1949: 225). Figure 21 shows examples of enhanced radiation recorded at 60 and 85 MHz on 30 August 1948. Payne-Scott (1949: 219) noted that at the two lowest frequencies surveyed (18.3 and 19.8 MHz) enhanced radiation was rare.

The second type of solar radiation Payne-Scott investigated at Hornsby Valley was the 'unpolarized bursts', which showed

> ... a very good correspondence on different frequencies, though their shapes and relative amplitudes may vary considerably ... the closer the frequencies and the larger the bursts, the closer their relationship. Corresponding bursts do not appear to skip frequencies. Thus, if a burst appears on 95 and 19 Mc/s., there will be a corresponding burst on 60 Mc/s. ... A characteristic unpolarized burst shows a finite rise time, rounded top, and slow decay, reminiscent of the transient response of a medium with a natural resonant frequency ... There is no marked connexion between the rate of decay and the intensity of the burst ... [but bursts recorded at 18.3 and 19.8 MHz] have a markedly slower decay rate ... (Payne-Scott, 1949: 219-221).

Payne-Scott noted that single unpolarized bursts were rare (they generally occurred in complex groups), and double-peaked bursts were particularly common, suggesting that "... the second peak may be an echo of the original disturbance." (Payne-Scott, 1949: 222).

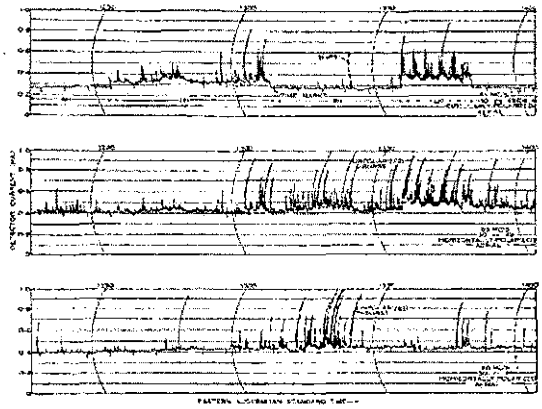

Figure 21: Examples of enhanced radiation with superimposed bursts of short duration. The enhanced radiation shows left-hand circular polarization (after Payne-Scott, 1949: 218).

Payne-Scott concluded that the generation of unpolarized bursts was not associated with sunspot magnetic fields—even though bursts were most common when sunspot groups were visible on the solar disk. Rather, they originated well out in the solar corona.

Figure 20: The picturesque Hornsby Valley field station showing one of the low frequency arrays used by Shain and Higgins for Galactic research. Unfortunately, no clear images exist of the Yagi antennas that Payne-Scott used for her Hornsby Valley solar radio astronomy program (ATNF Historic Photographic Archive: B2802-10).

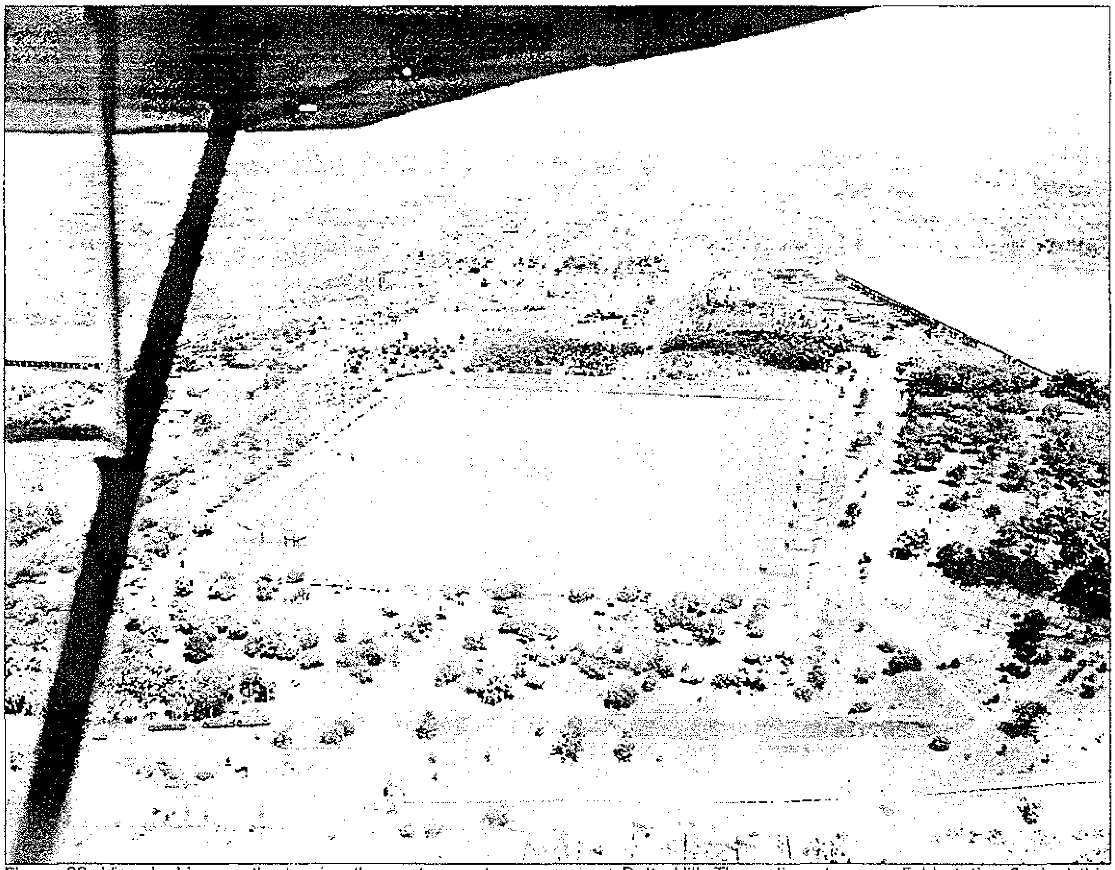

Figure 22: View looking south showing the eastern water reservoir at Potts Hill. The radio astronomy field station flanked this reservoir, and the radio telescopes used to observe the November 1948 solar eclipse were located on the flat sparsely-wooded area in the foreground, immediately to the north of the reservoir (ATNF Historic Photographic Archive: B3253-1).

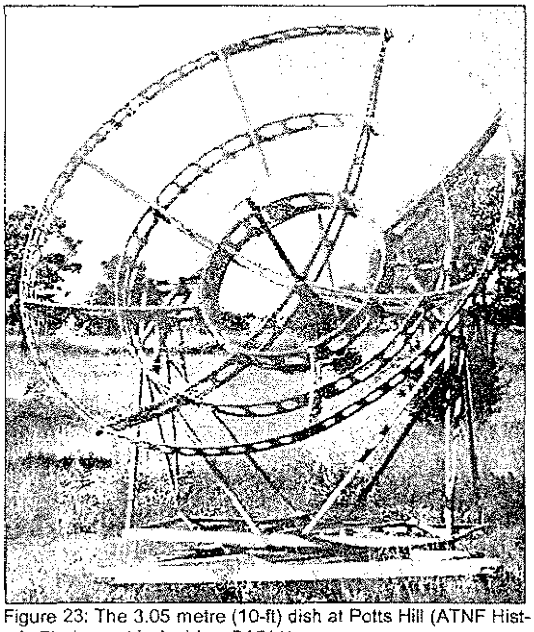

Figure 23: The 3.05 metre (10-ft) dish at Potts Hill (ATNF Historic Photographic Archive: B1511).

Payne-Scott (1949) also investigated the relative arrival times of associated unpolarized bursts at different frequencies, and found that 60 MHz bursts arrived on average 0.7 seconds later than their 85 MHz counterparts; 60 MHz bursts 0.3 seconds later than their 65 MHz counterparts; and 18.3 and 19.8 MHz bursts about 9 seconds later than their 60 MHz counterparts. However, considerably variations were encountered in all three studies. Nonetheless, these delays differed markedly from those shown in Figure 13, and indicate that Payne-Scott's relatively common 'unpolarized bursts' represented a very different type of solar event.

Upon completing her Hornsby Valley solar studies, Payne-Scott transferred to the Potts Hill field station (see Orchiston and Slee, 2005a), which then became the home base for most of the Division's burgeoning Solar Group.

2.4 The Source of the Solar Emission and the 1948 Solar Eclipse

The Potts Hill field station (Figure 22) in suburban Sydney (location 16 in Figure 4) was located beside Sydney's main water reservoir and apart from the relocated Georges Heights and Eagle's Nest radio telescopes, by November 1948 boasted a single Yagi antenna that was used by Alec Little to observe the Sun at 62 MHz and a simple 3.05 metre (10-ft) altazimuth-mounted wire-mesh dish (Figure 23) that would later be employed by Piddington and Minnett for solar and Galactic research at 1,210 MHz.

The principal incentive for the consolidation of solar astronomy at Potts Hill was the 1 November 1948 partial eclipse of the Sun. In the late 1940s the angular resolution of radio telescopes was poor, and observations of total and partial solar eclipses offered an elegant way of pinpointing the positions of localised regions responsible for solar radio emission and also of determining the distribution of radio brightness across the disk of the Sun. The reasoning was that as the Moon's limb moved across the Sun's disk and masked different radio-emitting regions there would be obvious dips in the chart record (Hey, 1955). Covington (1947) was the first to pioneer this technique, in 1946, and the RP radio astronomers were keen to take advantage of the 1948 eclipse which was visible from Australia.

If there was only one observing site, then any dip in the chart record would simply indicate that the source region was located *somewhere* along the arc subtended by the lunar limb *at that particular moment*, but by using several widely-spaced observing sites the intersections of the different limb profiles allowed the precise positions of the radio-active regions to be determined. For the 1948 eclipse, the refurbished ex-Georges Heights radar antenna—complete with a new equatorial mounting (Figure 24)—was used at Potts Hill, while 3.05 metre wire mesh dishes (identical to the antenna shown in Figure 23) were installed at temporary observing stations at Rockbank, near Melbourne, and Strahan, on the west coast of Tasmania (see Figure 25 for non-Sydney locations). For the States of Victoria and Tasmania, this eclipse represented their very first forays into the exciting new world of radio astronomy (e.g. see Orchiston, 2004d). All three radio telescopes operated at 600 MHz, a frequency where the radio emission was known to be associated with sunspot activity. Meanwhile, photographs taken at the Sydney Technical College's observatory (Figure 26) provided optical coverage of the event (Millett and Nester, 1948).

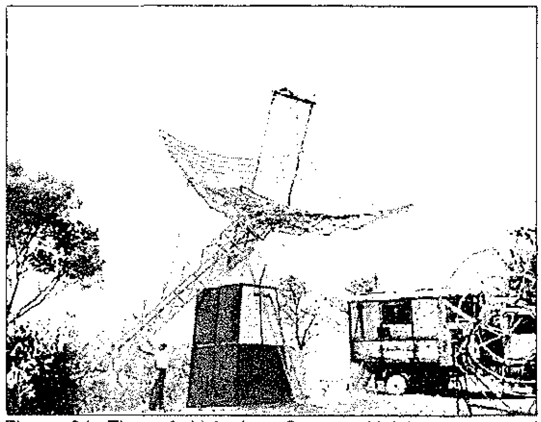

Figure 24: The refurbished ex-Georges Heights antenna at Potts Hill. In the background is one of the WWII mobile equipment huts (ATNF Historic Photographic Archive: B2649-3).

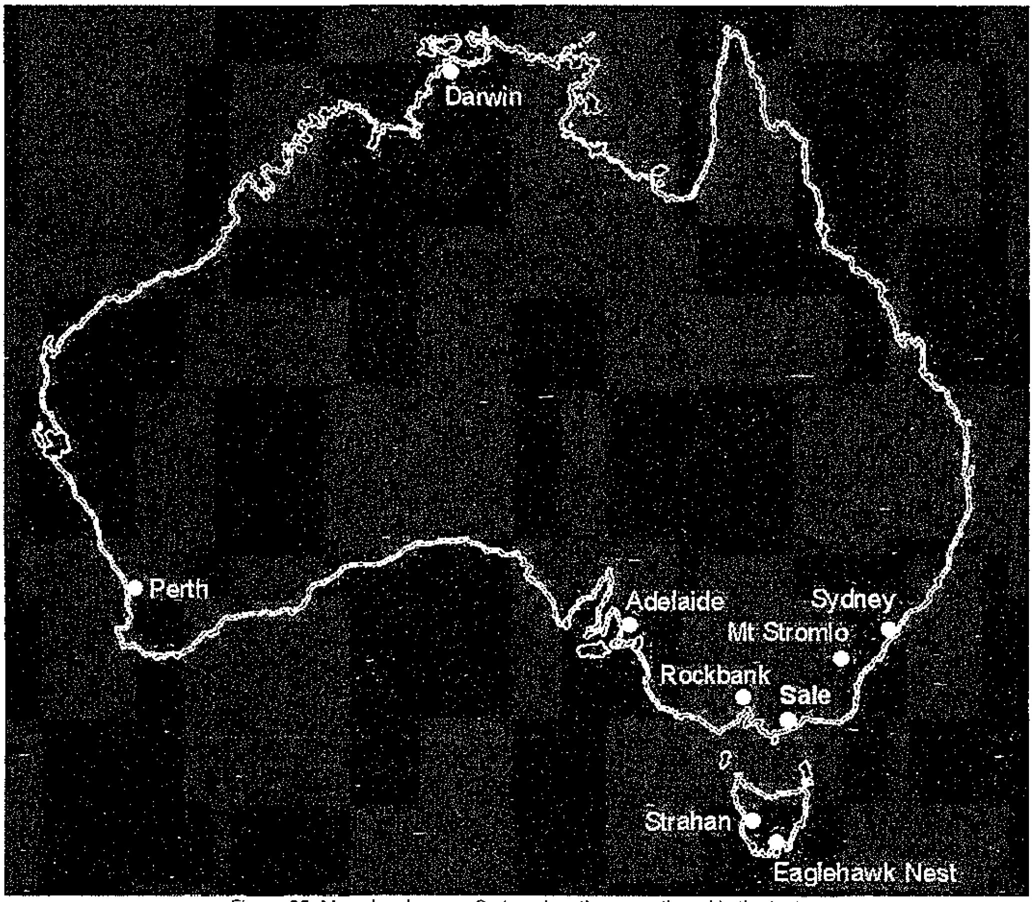

Figure 25: Map showing non-Sydney locations mentioned in the text.

Figure 26: Photographs of the Sun during the eclipse were taken through the 15 cm (6-in) guide-scope attached to the 46 cm (18-in) reflector at the Sydney Technical College (ATNF Historic Photographic Archive: B1899-7).

The observations at the three sites were co-ordinated by Chris Christiansen, Bernie Mills and Don Yabsley. This was the first solar research project conducted by Christiansen (see Figure 9 on page 25), who would go on to establish an international reputation in this field with innovative new radio telescopes and associated research programs at Potts Hill, and later at the Fleurs field station (location 6 in Figure 4).

Successful observations were made at all three sites, and small, but obvious, variations in the levels of solar emission were noted during the eclipse (see Figure 27). Meanwhile, photographs taken in Sydney revealed the presence of six groups of sunspots, but their total area was small, amounting to only ~0.085% of the total area of the visible disk of the Sun.

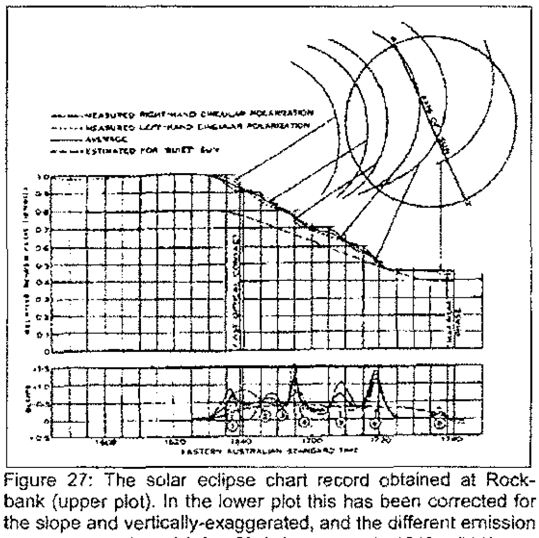

Figure 27: The solar eclipse chart record obtained at Rockbank (upper plot). In the lower plot this has been corrected for the slope and vertically-exaggerated, and the different emission peaks are numbered (after Christiansen et al., 1949a: 511).

The radio observations made at Potts Hill, Rockbank and Strahan showed that radio emission from the Sun began to decrease ~10 minutes before the commencement of the optical event (consistent with the idea that 600 MHz radio emission originates in the corona). As the eclipse progressed, the troughs in the declining emission curve indicated that several different localized regions of enhanced solar emission were present, and their precise positions—projected onto the solar disk—are shown in Figure 28.

Calculations indicated that the eight localized regions of enhanced emission shown in this figure contributed ~20% of the total solar radiation received on 1 November 1948. These emitting regions were assumed to be approximately circular, and their areas varied by little more than a factor of two, with a mean of ~0.4% of the total area of the visible disk of the Sun. Their effective temperatures varied by more than 10:1, and if we assume a quiet Sun temperature of ~0.5×10^6 K at 600 MHz, then the brightest localized regions in Figure 28 (numbers 4 and 6) would have had effective temperatures of ~10^7 K.

Figure 28 shows that peak number 1 was located ~1.7×10^5 km beyond the solar limb, and above a magnetically-active region in the chromosphere marked by a conspicuous prominence. All other emission peaks were on the solar disk, and in the case of numbers 2, 7 and 8 coincided with sunspot groups. However, peaks 3–6 did not appear to be associated with any obvious photospheric features, although three of these were close to the positions occupied by sunspot groups exactly one solar rotation earlier. Meanwhile, two small sunspots groups and one large group (near the western limb) were not associated with measurable levels of solar radio emission.

In addition to determining the positions of radio-active regions, the RP radio astronomers also wanted to use the 1948 eclipse to determine whether limb-brightening existed at a frequency of 600 MHz (as postulated by Martyn in 1946) and see whether radio-emitting regions in the northern and southern hemispheres of the Sun exhibited opposite senses of circular polarization—as also predicted by Martyn.

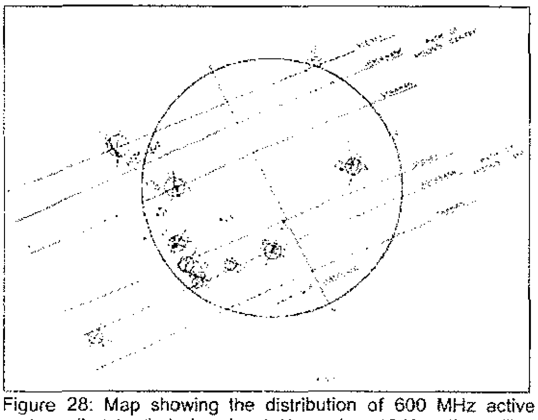

Figure 28: Map showing the distribution of 600 MHz active regions (hatched) during the 1 November 1948 eclipse. The small black dots indicate visible sunspots (VS), P indicates a prominence, and FS marks the position of a sunspot group that was prominent 27 days earlier (after Christiansen et al., 1949a: 513).

Unfortunately, the limb brightening investigation produced inconclusive results:

> ... roughly half the (presumed) thermal component of the radiation originated close to, and predominantly outside, the edge of the visible disk of the sun. The details of the brightness distribution could not be derived from the records. The latter were shown to

be consistent with two tentative distributions, the first a theoretical one, involving limb brightening ... and the second a uniform one over a disk having 1.3 times the diameter of the optical disk of the sun. The existence of limb brightening, therefore, was not proved. (Christiansen *et al.*, 1949b: 570).

The polarization analysis proved interesting in that Rockbank was the only site to provide relevant data. Before the eclipse the two modes of circular polarization differed in amplitude by less than 2%, but on 1 November 1948, "The eclipsing of the active areas produced changes that sometimes were confined to one or other circularly-polarized component, or in some cases involved both components." (Christiansen et al., 1949a: 521). The changes were of short duration, and the two components quickly returned to equality. This is illustrated in Figure 27, where the most significant variations in the relative levels of left-hand and right-hand circular polarization are associated with active regions 1, 4 and 5. Since the difference in the two polarizations curves was <3% at the maximum phase of the eclipse, this indicated that the general magnetic field strength of the Sun at the poles was <8 gauss. We should note that this is in line with current thinking, but that in 1948 a value of ~50 gauss was assumed. Christiansen, Yabsley and Mills summarized their three-station observations in a letter to *Nature* (1949b) and provided a full account in a paper published in the *Australian Journal of Scientific Research* (1949a).

Two other small RP teams at Potts Hill carried out observations of the 1 November 1948 eclipse in conjunction with Christiansen's group. Jack Piddington and Jim Hindman used a 1.7 metre (68-in) dish to secure observations at 3,000 (Figure 29), while Harry Minnett and Norman Labrum observed at 9,428 MHz with the relocated 1.1 metre (44-inch) Eagle's Nest antenna (see Figure 30).

Pre-eclipse observations made by Piddington and Hindman at 3,000 MHz and Covington at 2,600 MHz showed that variations in solar emission were correlated with sunspot area, as at 600 and 1,200 MHz. During the eclipse, the emphasis therefore was on explaining variations in the intensity of the emission, and investigating its polarization. Piddington and Hindman (1949: 525) examined the latter "... at intervals during the eclipse, a method of excluding either right- or left-hand circularly polarized component being employed. It was hoped to associate certain polarization with given sunspots and also to measure the general magnetic field of the sun." They also examined the distribution of background radiation over the solar disk.

Unlike the 600 MHz observations, the 3,000 MHz Potts Hill curve showed few obvious variations during the eclipse, the only one of consequence being associated with active region #3 in Figure 28. The polarization results were even less impressive:

Owing to the apparent random variations of polarization of the order of one per cent, and the rather long intervals between measurements, it is impossible to attribute any definite degree of polarization to any particular area of the solar disk ... [However,] continuous measurement of polarization was in progress between 1743 and 1747 hours and the change of polarization by 2 per cent. took place within one minute. This change took the form of an increase in LH polarization while the RH component remained unchanged thus indicating that the change was probably due to the uncovering of an area with predominantly LH polarized radiation. (Piddington and Hindman, 1949: 531).

Piddington and Hindman were unable to identify a possible spot group or target region.

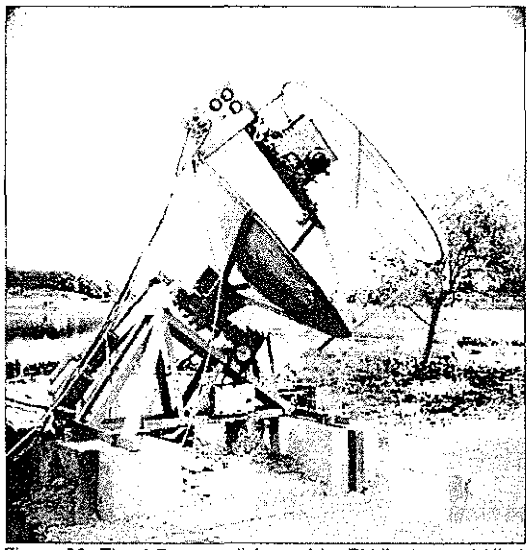

Figure 29: The 1.7 metre dish used by Piddington and Hindman to observe the 1948 solar eclipse. Particularly conspicuous is the full-aperture screen used to study polarization (ATNF Historic Photographic Archive: B1624-7).

After allowing for a single radio 'hotspot', Piddington and Hindman (1949: 532) investigated the distribution of 3,000 MHz emission over the solar disk, and concluded that "The distribution of radiation consisting of 32 per cent. from a thin disk around the solar limb and 68 per cent. from a uniform disk will, therefore, provide an eclipse curve very similar to that observed." This is illustrated in Figure 31).

The final aspect of 3,000 MHz eclipse program was an investigation of the magnetic field of the Sun, and "... although the results were not definite, they suggest that if a general magnetic field exists at all it is considerably smaller than the usually accepted value of 50 gauss at the poles." (Piddington and Hindman, 1949: 534).

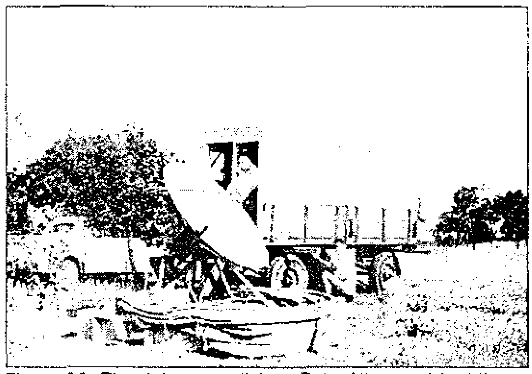

Figure 30: The 1.1 metre dish at Potts Hill, used by Minnett and Labrum for solar observations at 9,428 MHz. Norman Labrum is crouching beside the old mobile instrument trailer (ATNF Historic Photographic Archive: B1581-2).

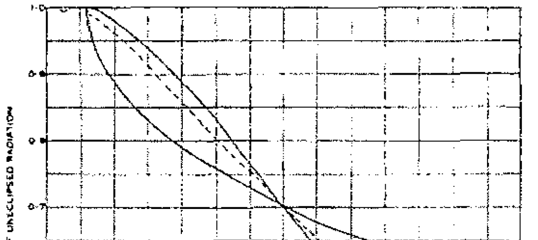

Figure 31: Alternative 3,000 MHz eclipse curves. (a) is the curve obtained during the eclipse; (b) is the theoretical curve for a uniform disk; and (c) is the theoretical curve for a circumferential ring (after Piddington and Hindman, 1949: 533).

Let us now examine Minnett and Labrum's 9,428 MHz solar research program carried out before, during and after the 1 November 1948 eclipse with the modest antenna shown in Figure 30. Ongoing measurements of mean daily radiation levels revealed a clear correlation with variations in sunspot area, as illustrated in Figure 32. During the eclipse, the declining radiation curve included minor variations, but "Any changes due to the covering and uncovering of the spots [present at that time] are too small to be distinguished from instrumental variations." (Minnett and Labrum, 1950: 69). However, the authors did note that the radio event began seven minutes before first optical contact, which "... could possibly have been caused by a localized emitting region extending from the sun's limb." (ibid.).

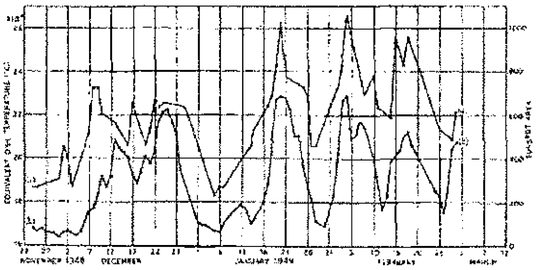

Figure 32: Correlated daily variations in solar emission at 9,428 MHz (a) and sunspot area (b) between November 1948 and March 1949 (after Minnett and Labrum, 1950: 65).

Despite the inherent instrumental limitations, Minnett and Labrum were able to investigate the brightness distribution of 9,428 MHz radiation across the disk of the Sun, and they found that the smoothed eclipse result was best represented by curve (d) in Figure 33, which requires 74% of the radiation to originate in a source of type (a) and the remaining 26% in a source of type (b).

Flushed with the success of their 1948 eclipse program, the RP radio astronomers looked with anticipation at another partial solar eclipse that would be visible from Australia in October 1949. Once again a multi-frequency campaign was planned, and the two portable 3.08 metre dishes were readied for further service interstate. One was sited in Sale, in eastern Victoria, and the other was transported to Eaglehawk Neck on the east coast of Tasmania, near Hobart. Once again successful observations were made but, strangely, no papers reporting this second eclipse program were ever published.

So from an international perspective, the Sydney, Rockbank and Strahan observations of 1948 marked a watershed in solar radio astronomy. They not only signalled the end of an era, but they were also the trigger that inspired Chris Christiansen (1984: 117) "... to devise some method of viewing the Sun [at high resolution] more frequently than was possible with eclipse observations. This of course meant devising some antenna system of very great directivity." The result was the first solar grating array, an innovative 32-element solar grating array operating at 21 cm that was constructed at Potts Hill in 1951 (see Christiansen and Warburton, 1953).

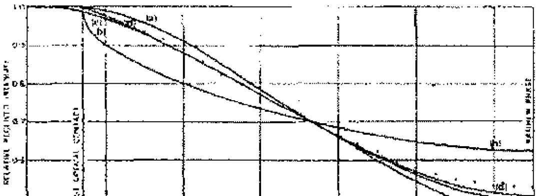

Figure 33: Comparison of the eclipse measures (dots) with various theoretical results for brightness distributions over the solar disk at 9,428 MHz. (a) is the theoretical curve for uniform distribution over the disk; (b) is the theoretical curve for a circumferential ring; (c) is the theoretical curve for a radius 1.1 times that of the optical disk; and (d) is the theoretical curve for a disk with 74% of the radiation from a type (a) source and 26% from a type (b) source (after Minnett and Labrum, 1950: 70).

2.5 The Pawsey Review Papers

The initial appearance of review papers in a new research field typically herald its 'coming of age', as the landslide of discoveries and technological developments demands an initial stock-take. This was certainly so of 'solar noise' studies after the hectic years of post-war achievement, and by 1948 optical astronomers were beginning to recognize the value of this avalanche of new data derived from the distant 'long' end of the electromagnetic spectrum. Only then did the term 'radio astronomy' begin to slip into common usage.

Given RP's international supremacy in solar radio astronomy is it little wonder that the first two major reviews of this new research field were penned by Sydney's Joe Pawsey? One of these, titled "Solar radio-frequency radiation", was completed in September 1948, revised through to early February 1949, and then submitted to The Institution of Electrical Engineers in London (reflecting radio astronomy's early affinity with radio engineering rather than astronomy). This 21-page paper was read before the Radio Section of the Institution on 7 December 1949, and appeared in the *Proceedings* exactly nine months later (Pawsey, 1950). The initial introductory section is followed by sections on "Observed Characteristics", "High-Frequency Characteristics of the Solar Atmosphere" and "Discussion and Hypothesis", before a succinct Conclusion introduces a very useful Bibliography featuring sixty-six different entries. The final two and a half pages record the discussion that followed the presentation of the paper, and Pawsey's rejoinder. The paper is profusely illustrated, and includes a number of previously-unpublished diagrams, mainly deriving from the Bolton's investigation of polarized bursts in 1947.

Pawsey's second review paper was titled "Solar radio-frequency radiation of thermal origin". It was co-authored by Don Yabsley, received by the Editor of the *Australian Journal of Scientific Research* on 17 January 1949, and published in the journal later that same year. Although it does discuss the RP achievements, this 16-page paper includes many results from overseas workers. Pawsey and Yabsley (1949: 198) found that

> ... a relatively constant component can be identified throughout the whole of this wavelength range [from 1cm to 4m] despite the complication introduced on the longer wavelengths by the presence of highly variable components. This steady component has the properties expected of thermal radiation and it is concluded that it is, in fact, thermal radiation from the ionized gases of the outer atmosphere of the sun.
>
> The intensity of radiation is found to increase fairly uniformly from that corresponding to black-body radiation at about 10^4 °K. at 1.25 cm. to about 10^6 °K. at 1.5 m.
>
> The results yield direct confirmation of the hypothesis that the corona has a kinetic temperature of about a million degrees.

3 BRUCE SLEE AND RADAR 59 NEAR DARWIN

While the RP group was carrying out its first solar observations at Collaroy in October 1945, Owen Bruce Slee (Figure 34) was making independent observations at RAAF radar station 59 near Darwin (Figure 25) that would constitute an independent discovery of solar radio emission. Station 59 at Lea Point featured a British 200 MHz COL Mk5 radar unit situated ~0.5 km from the coast and ~70 m above sea level (Figure 35).

Slee was trained as a radar mechanic, but he also served as a radar operator in order to monitor the stability and sensitivity of the equipment. Between October 1945 and March 1946 he noticed from time to time that in the hour leading up to sunset

> ... the 'grass' on the range display increased its height by up to a factor of ten when the antenna was pointing towards the setting Sun. By slowly scanning backwards and forwards through the Sun, he was able to establish that the source of the signal lay at the solar azimuth to within the errors of measurement. Furthermore, when he stopped the antenna while pointing at the Sun, he noticed that the amplitude of the 'grass' varied regularly by a large factor with a period of about 3 minutes. He concluded that this behaviour was consistent with the setting Sun passing through the sea interference fringes formed by the antenna and its image in the sea. (Orchiston and Slee, 2002a: 27).

In early March 1946 Slee read in a newspaper that the CSIRO Division of Radiophysics had been carrying out solar radio observations, and on 4 March he wrote them a letter describing his own work. In this letter he comments that "Tonight for example the interference first made itself evident on a bearing of 264 degrees at 1830 hrs. gradually becoming stronger until at 1845 hrs the Sig/noise ratio was 2:1. Then it faded out gradually and was gone by 1900 hrs. The sensitivity of the receiver at present is 91 d.b. below .1 volt for a signal equal to noise, and this may give you some idea of the signal strength of the interference." (Slee, 1946a). Elsewhere in this letter Slee (ibid.) states that he is "... convinced that the interference is solar radiation ...", and he asks the Sydney scientists to confirm these latter suspicions. He also offers to make further observations and to submit these to the Division of Radiophysics.

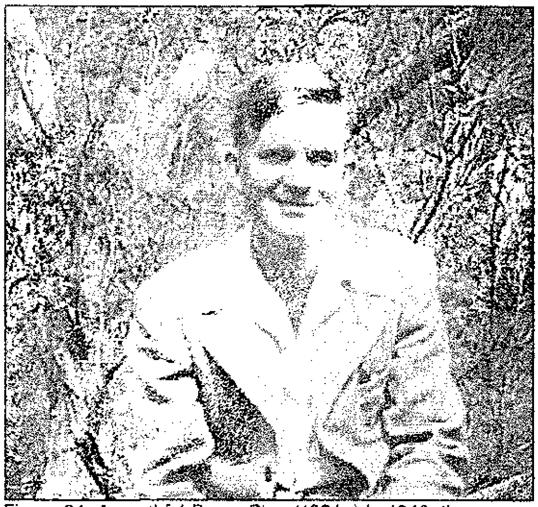

Figure 34: A youthful Bruce Slee (1924–) in 1948, three years after his Darwin solar observations.

Figure 35: The 200 MHz COL Mk 5 radar antenna at Station 59, Lee Point (after Fenton and Simmonds, 1993: 27).

As might be expected, Slee's letter caused considerable excitement when it reached Sydney and was circulated among senior RP staff. Pawsey wrote "Good Stuff" above his signature, while Burgmann recommended that they "Tell this chap a lot". The reply letter came from J.N. Briton, Chief of the Division, and began very positively:

> We were very interested in your observations made at No.59 Radar Station. In particular the information regarding bearing, receiver sensitivity, height of the array etc. was important, and such data is [sic] often omitted by observers reporting abnormal phenomena. There is very little doubt that the noise you observe originates in the sun. (Briton, 1946b).

This 5-page letter contains an account of the Division's solar observations, including the relation between emission levels and sunspots, four different diagrams, and an accompanying booklet with (amongst other information) charts that could be used to calculate the position of the Sun on cloudy days. Briton made it clear that he and his colleagues were eager to receive observations from Slee towards the time of sunset:

> We would be interested in obtaining maximum readings (e.g. 3/2 [sic], 2, 3, 4 ... 10 times noise level) during periods of high sunspot activity ... [These] would be valuable data to supplement readings taken in Sydney ... In the event of any abnormal radiation being recorded in Sydney we may send you a signal ..." (ibid.).

Unfortunately, this planned collaboration between Sydney and Darwin never eventuated, for soon after Slee sent his letter of 4 March the radar station was unexpectedly closed down and all of the equipment was removed. Obviously disappointed with this development, Slee (1946b) wrote apologetically from his home in Adelaide following his discharge: "As a result, I shall not be able to make the required readings, as much as I would like to do so." He also enquired about possible vacancies at RP, noting that "I am intensely interested in your experimental work, and plan to do Radio Engineering, as soon as possible. Having had three years experience in the radar game on various types of gear, I thought that perhaps you may have some use for me." These were indeed prophetic words, for later in the year he was appointed a Technical Assistant in the Division, and went on to build an international reputation in radio astronomy (see Orchiston, 2004a; 2005b).

Figure 36: Dr S.E. Williams (1910–1979) (courtesy of the University of Western Australia).

4 UNIVERSITY OF WESTERN AUSTRALIA

It is not widely known that a small group at the University of Western Australia in Perth (see Figure 25) was active in solar radio astronomy in 1946–1948, even though attention was drawn to the group's work in papers published by Burman (1991) and Burman and Jeffery (1992), and this research is mentioned in Robertson's (1992) history of the Parkes radio telescope and in the Haynes et al. (1996) history of Australian astronomy.

The project was set up by Dr Sydney E. Williams (Figure 36), a Lecturer in Physics with a background in optical astronomy at the Commonwealth Observatory, following a seminar on radar held at the Radiophysics Laboratory, Sydney, in January 1946. At the end of April 1946 Williams installed a 75 MHz Yagi and receiver on the flat roof of one of the buildings on campus in suburban Perth. In a letter to Pawsey, Williams (1946a) describes how

> We made a Yagi (dismountable for portability) on a wooden polar axis with synchronous motor drive. Matching aerial to coaxial and receiver has so far been done simply by fiddling with the dipole and director lengths till we got the best polar diagram and sensitivity. We are using simply milliameter but soon will have a film camera recorder on the oscillograph.

For two years, Williams, assisted by three Honours (fourth-year) students, P. Hands, E. Denton and P.M. Jeffery, carried out studies of solar bursts and enhanced levels of solar emission using this Yagi, and an example of one of their chart records is reproduced here as Figure 37 (after Williams, 1946b). The focus was on temporal variations in the intensity of solar radio emission, correlations with sunspots, solar flares and ionospheric radio fadeouts, and the shapes of short pulses of radiation.

This research resulted in an editorial note (Williams and Hands, 1946) and two letters in *Nature* (Williams, 1947, 1948b), and a full-length paper in the *Journal of the Royal Society of Western Australia* (Williams, 1948a), which was based on a lecture presented to that Society. There were also unpublished papers given by Williams at the 1946 and 1947 ANZAAS Congresses (Burman and Jeffery, 1992). Of particular note, in the context of the present study, is the fact that the four papers by the Perth group comprise 33% of all observation-based papers on Australian solar radio astronomy published during the interval 1946-1948 (see Burman, 1991, for a relevant bibliography).

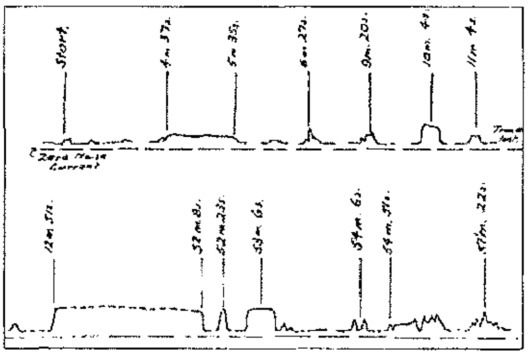

Figure 37: Annotated chart record showing 75 MHz bursts and enhanced emission recorded at Perth on 25 September 1946.

Williams ended these radio astronomical investigations in 1948, and later returned to optical astronomy. Burman and Jeffery (1992: 168) conclude that "Although the work was noticed internationally, its influence on the course of radio astronomy seems to have been slight ..." They also note (page 169) that "Probably the main innovation introduced by the Perth group was the analysis and interpretation of the time decay of the pulses ..." We shall look more closely here at that aspect of the work (Williams 1948b; also 1948a: Section 6).

The third of the *Nature* papers, a brief letter by Williams entitled "Shape of Pulses of Radio-frequency Radiation from the Sun", seems to have been the only one of the four Perth papers to have had any direct influence on contemporaneous radio astronomers. The paper, based on some 400 hours of observations, was aimed at examining the tails of pulses for exponential decay, as an indication of the decay of the source when it is no longer subject to the influence of an exciting agency, or of the decrease in influence of that agency. Filmed records of a vibration galvanometer output of detected radio bursts were used. There were 99 single pulses, lasting a few seconds each, that were considered to be sufficiently clear of others to indicate a faithful record of the variation of the power from the source: 78 of the 99 had a peak at least 25% above background and a sufficient length of falling slope for significant measurements to be made. Of these, 58 were found to be very probably exponential, 11 less probably so, 4 probably not so and 5 definitely not (see Figure 38).

Williams' table binning the half-lives (time for the power to reduce to half) of the 58 exponential tails shows them to range over 0.4–2.2 seconds, with a distribution peaking in 0.8–1.2 s. A second table lists the half-lives of 30 of these 58 pulses that occurred either consecutively or within a short interval. (The intervals listed are mostly 30 s, but 5 minutes for one sequence of 6 pulses.) From this table, Williams (1948b) noted that "Although it might be assumed that pulses closely connected in time come from the same region and should therefore show similar half-value times, the results given above do not offer firm support for such a hypothesis." The paper concludes with the remark that no success had been obtained in attempts to interpret the rising portions of the pulses in terms of exponential functions.

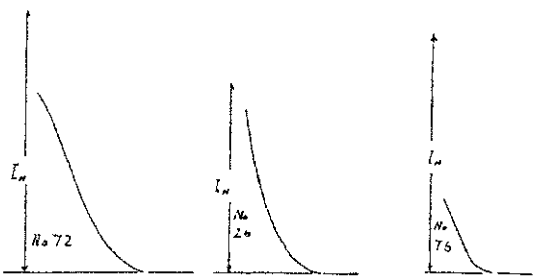

Figure 38: The tails of three pulses illustrating three of four categories; left = exponential, centre = doubtfully exponential, right = not exponential (after Williams, 1948a: 28).

5 COMMONWEALTH OBSERVATORY

The Commonwealth Observatory (CO) was located at Mt Stromlo, near the national capital, Canberra, and under the guidance of its talented Director, Dr Richard Woolley, it sought to reinvent itself in the immediate post-war years by moving from solar to Galactic and extragalactic studies (see Frame and Faulkner, 2003). However, before this quantum shift was able to take place, the CO enjoyed one serious foray in radio astronomy. This had its origin in a letter that Radiophysics Chief, Taffy Bowen sent Richard Woolley on 13 February 1946. Almost certainly drafted by Joe Pawsey, it reads:

> During the recent intense solar activity we have been taking extended observations on radio frequency noise originating in the sun. The level shows a large variation with a high maximum in the middle of last week.
>
> We wish to examine this data [sic] together with visual and ionospheric data, which you will have, in order to search for possible relations between them. I consider it essential that this be done with personal discussion between members of this Laboratory and your Observatory as each are expert in their different fields.
>
> As we have about four officers who have been concerned in the recent observations, it is difficult for us to go to Canberra, and I should appreciate it if you could arrange to send one of your officers to Sydney to bring the relevant data and discuss it with us. I anticipate the discussion should occupy a few days ... (Bowen, 1946a).

Dr Cla W. Allen (Figure 39) was dispatched to Sydney, and the planned meeting took place on 20 and 21 February 1946 (Hogg, 1946). Although Allen specialized in solar spectroscopy and the terrestrial effects of solar flares (McNally, 1990), war-time research into the causes of short-wave radio fadeouts whetted his appetite to investigate solar radio emission.

Figure 39: Cla Allen (1904–1987) with the coelostat of the CO solar telescope (courtesy Mt Stromlo and Siding Spring Observatories).

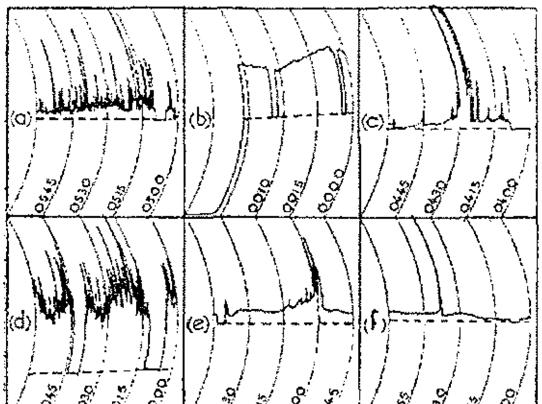

Figure 40: Six examples of solar radio emission recorded at Mt Stromlo between 14 September 1946 and 18 March 1947. (a) frequent bursts and a low noise level; (b) no bursts but a high noise level; (c) a large outburst; (d) frequent bursts and a high noise level; (e) a small outburst; and (f) an isolated burst and a low noise level (after Allen 1947: 388).

A direct outcome of this meeting was the decision to install a 200 MHz steerable 4-Yagi array at Mt Stromlo. This was a replica of an identical antenna then in service at Dover Heights (see Figure 9), and it was loaned by the Division of Radiophysics. Two of the RP radio astronomers, Lindsay McCready and Gordon Stanley, arrived at Mt Stromlo with the antenna and receiving equipment on 1 March, and it was installed the following day (Briton, 1946a). On 2 April, soon after the equipment became operational, Allen (1946) sent Pawsey the first of what was to become an on-going series of reports. In this instance, his telegram read:

> WE ARE RECORDING 9 TO 5 ON WEEK DAYS AT THREE INCHES AN HOUR STOP BURSTS ON FRIDAY WERE AT 1431 AND 1435 STOP SUN ACTIVITY ON SATURDAY MORNING BUT NOTHING MONDAY NOR TODAY TUESDAY STOP NO RECORD SUNDAY.

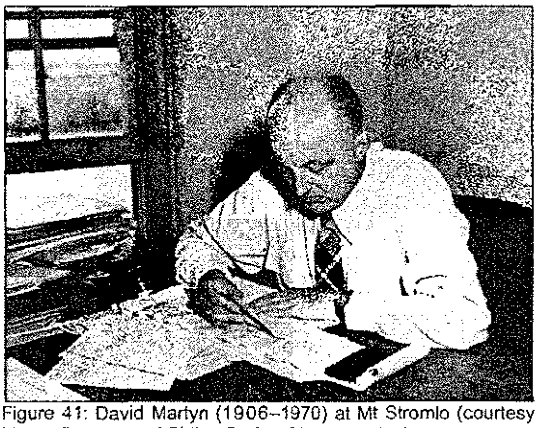

Figure 41: David Martyn (1906–1970) at Mt Stromlo (courtesy Mount Stromlo and Siding Spring Observatories).

Between April 1946 and March 1947 Allen carried out regular solar monitoring at the CO, and upon analyzing the accumulated observations found that even on radio-quiet days

> ... there has always been a detectable amount of radiation which appears to be quite variable ... [In addition] there are occasional sudden "bursts" of solar radio-noise which last for periods of the order of 1 sec ... [and] rather rarely, sudden outbursts of radio noise, which last for a few minutes, fluctuating violently, and then disappear. (Allen, 1947: 387).

Examples of generally-enhanced emission levels, bursts and outbursts are shown in Figure 40.

Allen confirmed that solar emission was closely related to the central meridian passage of sunspots, just as Pawsey et al. (1946) had reported, although not all sunspots produced solar noise. Meanwhile, his analysis failed to show a general correlation between solar noise and H features or geomagnetic storms, although some solar flares were associated with outbursts.

While Allen was conducting these investigations, his CO colleague, David F. Martyn (Figure 41),[4] was using data obtained with the 200 MHz array to research the polarization of solar radio emission. He reasoned that since solar bursts were associated in some way with sunspots and in their turn sunspots were associated with strong magnetic fields,

> ... we should expect to find evidence of the magnetic field in the production of gyratory effects at the source of the [radio] emissions, and/or in differential absorption of right-handed and left-handed components of polarization during transmission through the corona. (Martyn, 1946a).

The passage of the large sunspot group of July 1946 provided an ideal opportunity for Martyn to test this hypothesis, by turning two of the Yagis in the array at right-angles to the other two Yagis. Observations made on 26 July revealed

> ... that the right-handed circularly polarized power received was some seven times greater than that received when the system accepted only left-handed circularly polarized radiation ... Three days later, when this group had crossed the meridian, these conditions were reversed, five times more power being then received on the left-handed than on the right-handed system. (ibid.).

Part of the 26 July chart record is shown in Figure 42. This overall result, incidentally, was confirmed at 60 and 100 MHz by RP's John Bolton during observations made at Dover Heights in March and April 1947 (see Pawsey, 1950: Figures 17 and 18). Nonetheless, Martyn's polarization studies drew high praise from the Astronomer Royal:

> SIR HAROLD SPENCER JONES said that he considered the discovery of circular polarization of solar noise to be an important piece of work. Solar noise promised to be a very fruitful field of investigation and the Commonwealth Observatory was taking a place second to none in this particular branch. (Commonwealth Observatory ..., 1947: 3).

Martyn followed up this important paper with the theoretical contribution on the 10^6 K coronal temperature referred to earlier (Martyn, 1946b) and two other theoretical papers on solar radio emission. In the first of these (Martyn, 1947), he invokes plasma oscillations to account for the energetic burst emission seen at low frequencies (cf. Solar radio noise, 1948). Martyn's next paper, "Solar radiation in the radio spectrum. I. Radiation from the quiet Sun", related solely to thermal emission, and was published in the prestigious *Proceedings of the Royal Society* in 1948. Undoubtedly, the most important predictive aspect of this seminal paper was Martyn's calculation of the distribution of thermal emission across the face of the Sun at wavelengths ranging from 20 cm to 30 m. As Figure 43 shows, between 20 and 60 cm there should be conspicuous 'limb brightening'. Despite the title of this paper—and the promise of a further paper, or papers, in this series—this was to be Martyn's final publication in solar radio astronomy, and he turned to other research interests (see Piddington and Oliphant, 1972). Allen, meanwhile, used the 200 MHz equipment at the CO to research Galactic radio emission (Allen and Gum, 1950), but his appointment to a Chair at University College, London, in 1951 brought Mt Stromlo's escapade in radio astronomy to an end. It had been a brief but profitable research diversion.

In addition to the research outcome of these radio astronomy initiatives at Mt Stromlo, there were direct benefits for RP during these nascent years of solar radio astronomy, as Robertson (1992: 109) points out:

> Despite some tension this early collaboration with the Commonwealth Observatory undoubtedly benefited the Radiophysics group. The radio scientists, turned radio astronomers, came into contact with Australia's leading astronomers at a time when the Sydney group was only learning the basics of the science. Clay Allen in particular provided a steady flow of information to Radiophysics on solar phenomena and astronomical objects. The association between Mt Stromlo and Radiophysics was the first major collaboration between optical and radio astronomers anywhere in the world.

6 CONCLUDING REMARKS

The birth of solar radio astronomy in Australia occurred towards the end of WWII, soon after news of secret war-time detections by radar units in England and New Zealand reached Sydney, and between October 1945 and December 1948 major advances were made in the study of 'solar noise'. Initially these involved wartime radar antennas and receivers, but Yagis and other types of antennas specifically dedicated to solar (and non-solar) radio astronomy soon emerged. This instrumentation was used at wide-ranging frequencies to investigate emission from the quiet and the 'radio-active' Sun. Of special interest were flux levels at different frequencies; the various types of burst emission; locations of the emitting regions and their association with photospheric features and magnetic fields; and emission mechanisms.

While much of this research was accomplished by staff in the CSIRO's Division of Radiophysics, it is important to remember that initially two other small research groups, at the Commonwealth Observatory (Mt Stromlo) and the University of Western Australia (Perth), were active in solar radio astronomy. To illustrate their contribution, we should note that of the twelve Australian research papers reporting observations of solar radio emission made in 1945-1947, the RP scientists contributed exactly half, the Mt Stromlo group two and those from the University of Western Australia, four. In addition Martyn (from Mt Stromlo) published three theoretical papers. However, Williams' research on solar radio emission ceased in 1948 and Mt Stromlo's involvement ended just three years later, leaving the growing RP group as the sole Australian participants. December 1948 therefore is an appropriate chronological point at which to end this paper.

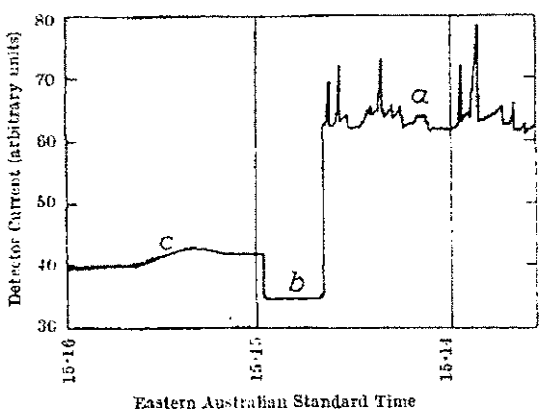

Figure 42: Circular left-handed (a) and right-handed (c) polarized solar emission recorded at 200 MHz on 26 July 1946. The background sky level, when the array was directed away from the Sun, is indicated by (b) (after Martyn 1946a).

Over the next three years, major RP initiatives would lead to a new perspective on energetic solar radio emission. Wild's first solar radio spectrograph at the short-lived Penrith field station would provide the basis for a new classification of low frequency burst emission, while the position interferometer developed by Payne-Scott and Little at Potts Hill would offer precise positions and polarization signatures for the various types of bursts (and outbursts). Meanwhile, Christiansen (Figure 43) would use the first of his innovative solar grating arrays at Potts Hill to track the on-going pattern of 1,420 MHz emission and the evolution of the enigmatic 'radio plages' (see Christiansen, 1984).

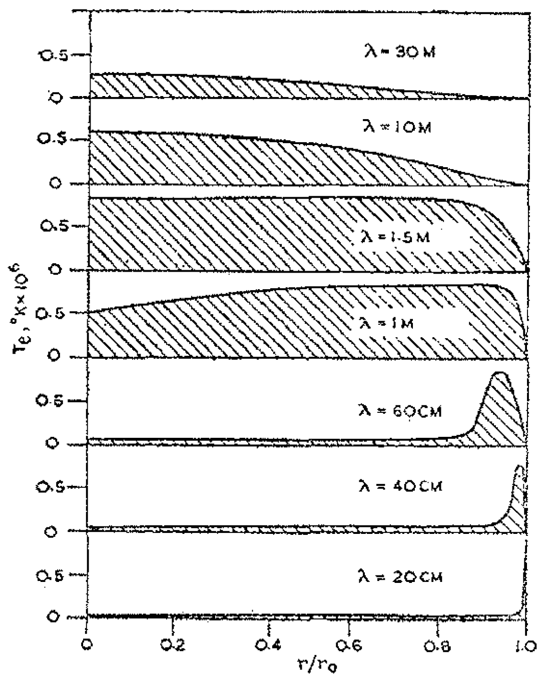

Figure 43: The calculated distribution of effective temperature (T_e) across the solar disk at various wavelengths (after Martyn, 1948: 54).

By 1952, the RP solar radio astronomy program was entrenched at the Dapto and Potts Hill field stations, and five years later Fleurs became a major solar research centre (Orchiston and Slee, 2002b) with the opening of the Chris Cross, the 'next generation' solar radio telescope (see Orchiston, 2004c). By this time, RP was widely regarded as the leading solar radio astronomy research group in the world (Sullivan, 2005).

From the mid-1950s, the journal *Vistas in Astronomy* acquired a reputation for publishing major review papers (see Duerbeck and Beer, 2006). In a paper that appeared in the inaugural issue, Wild (1955: 573-574) wrote:

> The characteristics of the radio-frequency radiation ("noise") from the Sun are complex. In the absence of disturbed conditions on the Sun, the intensity of the noise remains at a steady level corresponding to the thermal radiation emitted by the solar atmosphere. But when sunspots are visible on the Sun's disk the level may become enhanced and show rapid fluctuations above the basic thermal level. At times sudden increases ("bursts"), lasting some seconds or minutes, may increase the level a thousandfold.

It was largely through the pioneering research efforts of the young men and women from the CSIRO's Division of Radiophysics, the Commonwealth Observatory (Mt Stromlo) and the Physics Department at the University of Western Australia (Perth) that the basis of solar radio emission between 60 MHz and 24,000 MHz was unraveled during 1945-1948. These were the formative years of solar radio astronomy.

Figure 44: Sir Edward Appleton (extreme right), discussing Christiansen's first Potts Hill solar grating array in 1952. Chris Christiansen is on the far left, beside one of the antennas (adapted from ATNF Historic Photographic Archive: B2842-66).

7 NOTES

1. The location of these 600 and 1,200 MHz observations is not mentioned, but Payne-Scott (1945: 10) does mention that at the latter frequency "... a large aerial was available having a gain of about 5,000, and a receiver with a noise factor of about 20." This 'large aerial' was possibly the large experimental radar antenna at the Georges Heights radar station (location 8 in Figure 4), which was subsequently used by RP for solar monitoring at 200, 600 and 1,200 MHz (see Section 2.3 above).

2. Orchiston (2005a) and Sullivan (2005) have both discussed the practice that persisted from that time through into the early 1950s for some Australian radio astronomy papers submitted to British journals to be inexplicably held up for many months while British researchers wrote up their own papers and rushed these into print. Sir Edward Appleton and Jack Ratcliffe were identified as two of the main 'offenders'. It would seem that the Collaroy paper met this fate. Although submitted to *Nature* on 23 October 1945, it was only published in the issue of 9 February 1946. In the interim, two other solar radio astronomy papers (by Appleton, and Hey) were published.

3. An interesting case of protocol also relates to this paper in that it referred to the confidential British and New Zealand wartime reports by Hey and Alexander. Subsequently, Sir Edward Appleton sent letters to Frederick White (Chairman of the CSIR, as it then was), Taffy Bowen (Deputy Chief of RP) and Professor A.V. Hill (British Committee of Post-War Publications) pointing out that in the RP paper, "... reference was improperly made to two confidential reports." (Bowen, 1946b). White was forced to write Appleton an apologetic reply, but a letter penned to Bowen on the same day reveals that he was far from amused:

> There is nothing much that can be done about it as far as I can see beyond what I have done in my letter. No doubt we ought to have taken the correct steps to get the acknowledgement of confidential reports cleared by the Committee in England. *Personally I do not think it matters a great deal – it is only a focal point.* (White, 1946; our italics).

It is interesting that these letters from Appleton came after he had been quizzed by the Australians about the delay in publishing their *Nature* paper and was forced to defend the *status quo* (see Orchiston, 2005a: 82-83 for further details). We should note that more amiable relations existed between Appleton and RP by 1952, when Sir Edward led a sizeable overseas contingent to Sydney for the first URSI Congress held in the Southern Hemisphere. Figure 44 shows Appleton on a visit to Potts Hill field station at this time.

4. Martyn was at one time Chief of the Division of Radiophysics. No administrator, he was edged out of the post and seconded to the Commonwealth Observatory, a situation which caused him great bitterness (see Sullivan, 2005). He welcomed the chance to get involved in solar radio astronomy, not just because of the obvious research potential of this promising new field, but—one suspects—because it would give him a chance to compete with his former colleagues at RP.

8 ACKNOWLEDGEMENTS

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