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THE RADIOPHYSICS FIELD STATION AT PENRITH, NEW SOUTH WALES, AND THE WORLD'S FIRST SOLAR RADIOSPECTROGRAPH

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Abstract: The Solar Radio Astronomy Group within the Commonwealth Scientific and Industrial Research Organisation's Division of Radiophysics built the world's first radiospectrograph at Penrith (Australia) in 1948. The instrument was used to study radio emission from the active Sun over the continuous frequency range of 70 to 130 MHz. This led to the first spectral classification of solar radio bursts which advanced the scientific study of space research by the real time monitoring of the active corona.

Keywords: radio astronomy, solar radio emission, radiospectrograph, Division of Radiophysics, CSIRO.

1 INTRODUCTION

Although the foundations of radio astronomy date from Karl Jansky's pioneering research in 1931-1932 (Sullivan, 1984), radio emission from the Sun was first detected during World War II when Hey (1946) in England, Reber (1944) and Southworth (1945) in the USA, Alexander in New Zealand (see Orchiston, 2005), Slee in Australia (see Orchiston and Slee, 2002) and German radar operators in Denmark (Schott, 1947) made and reported a succession of independent discoveries at a variety of frequencies.

Figure 1: The 200 MHz radar installation at Dover Heights, circa 1945 (courtesy: ATNF Historic Photographic Archive).

Because of the pivotal role that radar played in the War effort most of these discoveries had to remain 'top secret' until hostilities ended, but in mid-1945 a copy of Reber's paper and reports about Hey's and Alexander's projects were received by staff in the CSIR's Division of Radiophysics in Sydney (Payne-Scott, 1945),[1] and these spawned a local solar radio astronomy program. This became a mainstay of the Division's efforts when it was necessary to redirect attention from wartime radar developments to peacetime research, and Australia quickly established an international reputation in the fledgling discipline of radio astronomy—as it became known (e.g. see Pawsey, 1961; Sullivan 2009).[2] In this paper we review the early solar radio astronomy program that inspired the construction of the world's first solar radiospectrograph in 1948, and the pioneering work on spectra that was then carried out at the Penrith field station.[3]

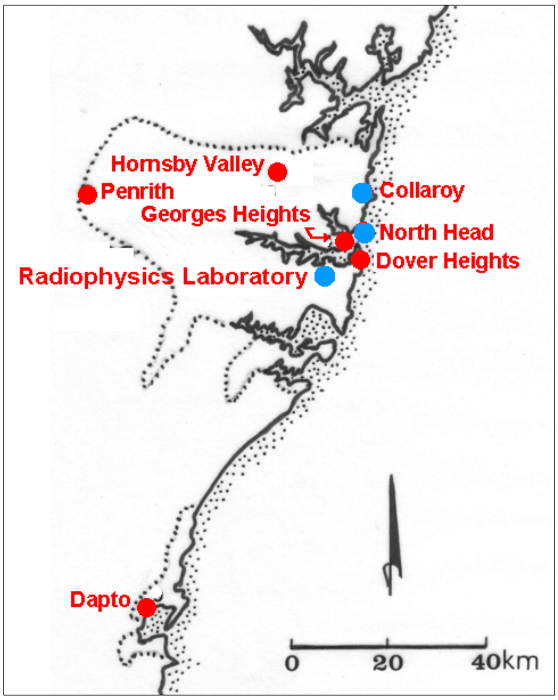

Figure 2: Localities mentioned in the text. The upper dotted outline marks the approximate current boundary of suburban Sydney and the lower dotted outline of suburban Wollongong. Different Radiophysics field stations are indicated by red circles, and other sites by blue circles.

Figures 3a (left) and 3b (right): J.L. Pawsey, 1908-1962, and Ruby Payne-Scott, 1912-1981 (courtesy: ATNF Historic Photographic Archive and Miller Goss, respectively).

2 THE EARLY 200 MHz OBSERVATIONS

Orchiston, Slee and Burman (2006) have recounted how the first observations of the Sun by Radiophysics scientists were conducted during October 1945 using a 200 MHz wartime coastal radar unit at Collaroy and led to the detection of solar emission. This prompted further observations through to March 1946 from Collaroy and the Dover Heights WWII radar stations (see Figure 2 for Sydney localities mentioned in the text), using the 200 MHz broadside radar antennas there, and confirmed the association between solar radio emission and sunspot activity reported previously by Hey and Alexander. This research was led by the inspirational Dr J.L. (Joe) Pawsey (Figure 3a), who headed the Division of Radiophysics' radio astronomy group. The other members of the team were Lindsay McCready and Ruby Payne-Scott (Figure 3b), who has been described by Goss and McGee (2009) as the world's first female radio astronomer.[4]

The limitations of the wartime radars were soon realized, and in March 1946 a 200 MHz Yagi antenna that could track the Sun throughout the day was installed at Dover Heights. At the same time similar Yagi 200 MHz antennas were also placed at the North Head radar station at the entrance to Sydney Harbour,

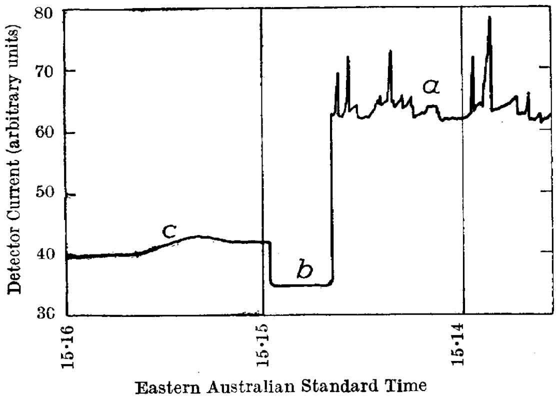

Figure 5: A 200 MHz record showing for the first time that noise storms are circularly polarized. a) = RH polarization, (c) = LH polarization and (b) = background sky level when the antenna was pointed away from the Sun (after Martyn, 1946).

and at the Commonwealth Solar Observatory on Mt Stromlo, about 200 km southwest of Sydney.

These early Sydney-based observations with the radar antennas and the 200 MHz Yagis revealed the existence of two different types of energetic solar emission, dubbed 'isolated bursts' and 'outbursts', and examples of these are shown in Figure 4. At about the same time, during 200 MHz observations made at Mt Stromlo, David F. Martyn (1946) and Cla Allen[5] (1947a) found evidence of a third type of solar activity, which the latter called 'noise storms'. These were characterised by enhanced emission and short bursts. It was Martyn who first noticed that bursts associated with noise storms were highly circularly polarized (see Figure 5).

3 MULTI-FREQUENCY OBSERVATIONS

The challenge then was to learn more about these various types of solar activity, and in 1946 the Division of Radiophysics consolidated its solar program at the Dover Heights field station, where the 200 MHz Yagi

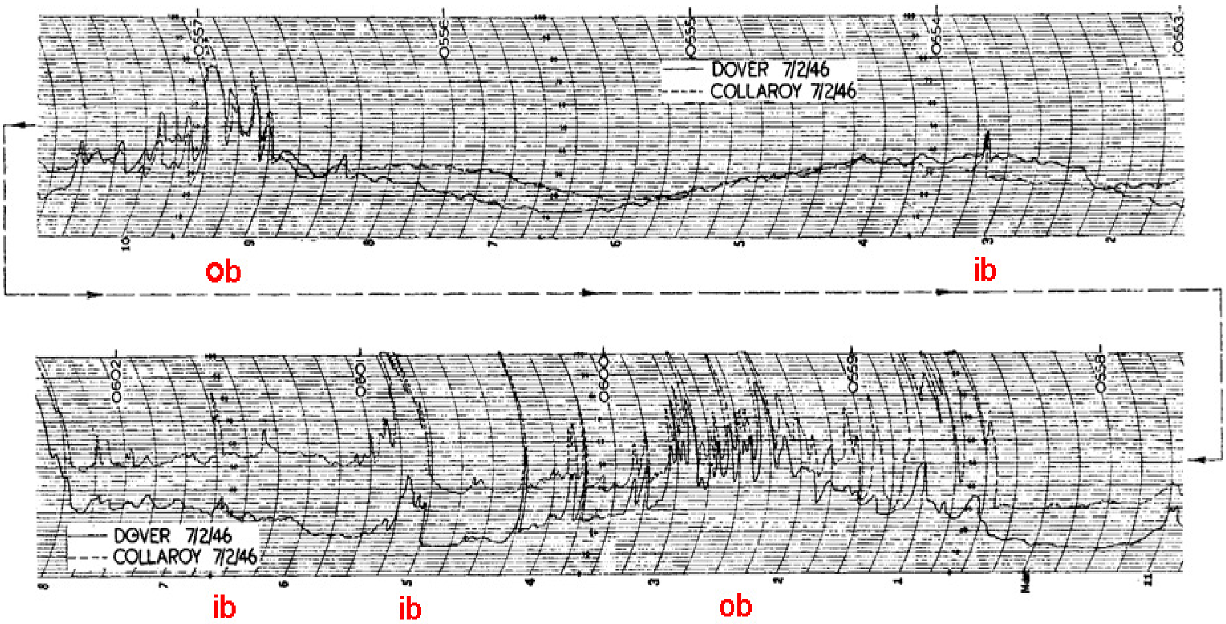

Figure 4: Chart recordings at 200 MHz made on 7 February 1946 at Dover Heights and Collaroy showing isolated bursts (ib) and outbursts (ob), examples of which are marked in red print below the chart recordings (adapted from McCready, Pawsey and Payne-Scott, 1947: 362).

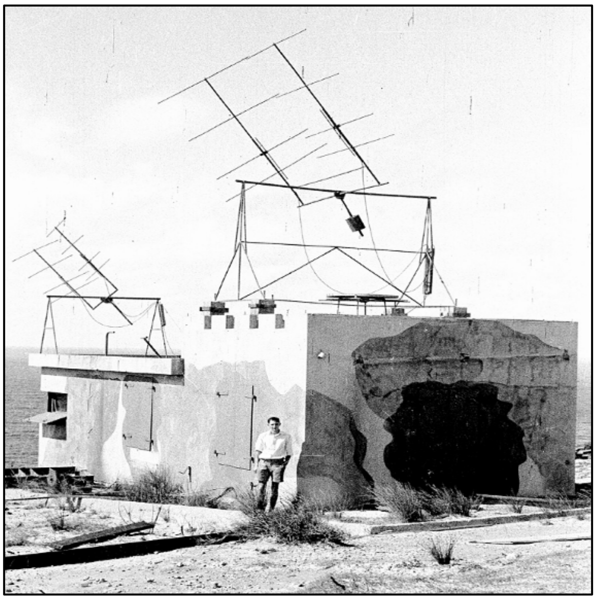

Figure 6: John Bolton standing outside the Dover Heights block house on 1 May 1947. On the roof can be seen the 60 MHz (left) and 100 MHz (right) twin Yagi antennas; the 200 MHz Yagis are hidden from view (courtesy: ATNF Historic Photographic Archive).

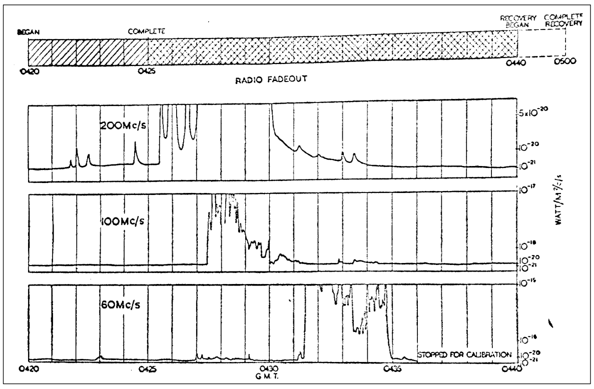

Figure 7: The outburst recorded simultaneously at three frequencies on 8 March 1947, and showing delays between the starting times different frequencies (after Payne-Scott et al., 1947).

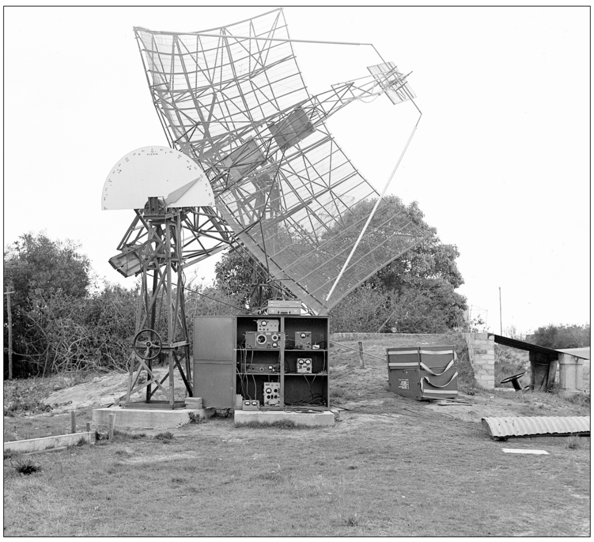

Figure 8: The WWII experimental radar that was used by Lehany and Yabsley at 200, 600 and 1200 MHz to monitor solar emission (courtesy: ATNF Historic Photographic Archive).

was joined by 60 MHz and 75 MHz Yagis (see Goss and McGee, 2009). Judging from later developments, all three antennas were located on the roof of the small concrete building shown near the left hand margin in Figure 1, and Payne-Scott was now in an excellent position to begin a multi-wavelength assault on solar radio emission. In November 1946 she was joined by John Bolton and Bruce Slee (Bolton, 1982), and the 75 MHz antenna was replaced by a 100 MHz Yagi. It was only in early 1947 that the radar antenna on the roof of the concrete block house close to the sea cliff was removed, and the three Yagi aerials were relocated to this new site (see Figure 6).

Isolated bursts continued to be observed in 1946, but their detection at more than one frequency posed some interesting interpretive problems. For instance, on 12 August 1946 McCready (1946b) reported to the Division's Propagation Committee that

> Two large sunspots have been on the sun lately. Almost continuous observations have been made from 22nd July to 12th August, dawn to sunset on 200, 75 and 60 Mc/s … Sometimes there appears to be a lag at lower frequencies in individual bursts.

This possibility of a time delay between burst onset at different frequencies was confirmed in a remarkable fashion on 8 March 1947 when a very large bipolar sunspot appeared on the limb of the sun. Bolton, Payne-Scott and Stanley observed an intense 'outburst' at all three frequencies, which lasted for about 15 minutes. Although the 200 MHz receiver at Dover Heights was not working at the time, a record of the outburst was obtained at the Commonwealth Solar Observatory and was used in their analysis. The outburst showed a systematic delay of several minutes between its commencement at 200, 100 and 60 MHz (Figure 7) suggesting the possibility that the source moved outwards through the corona. Based on their observations of onset times at the different frequencies, Payne-Scott, Yabsley and Bolton (1947) estimated an outward velocity for the outburst of approximately 500 km/s, following Martyn's (1947) suggestion that the radio emission at each frequency escaped from the corona at a height where the refractive index reduced to zero (see Section 7.2, below).

On the evening following this unique event a prominent aurora was observed in Sydney. Payne-Scott et al. (1947) speculated that the outburst might be caused by particles travelling outwards through the corona with sufficient speed to arrive at the Earth a day or two later and initiate the auroral display.

The importance of this outburst was immediately recognized by Pawsey (1949) who later wrote:

> One of the interesting speculations concerning the origin of some of the largest radio disturbances, which are called *outbursts*, is that these may be due to explosions on the Sun which hurl great masses of gas upwards, some with so great a velocity as to escape from the Sun. Incidentally, terrestrial magnetic storms and auroras are supposed to be caused by the arrival at the Earth of such masses of gas. In the Sun, these gases would move upwards and if, as is suspected, a particular wavelength of radiation is associated with each level in the solar atmosphere, we should expect to observe different wavelengths excited in succession. Some of the greatest outbursts have shown just such delays between the onsets at different wavelengths.

Inspired by these successful investigations at Dover Heights, Pawsey (1947a) was keen to expand the solar monitoring program and in mid-1947 he installed Fred Lehany and Don Yabsley at the Division's Georges Heights field station near the entrance to Sydney Harbour (see Figure 2) where they used an experimental WWII radar antenna that operated at 200, 600 and 1200 MHz (Figure 8). Between 18 August and 30 November they detected many bursts at 200 MHz, but energetic emission was only occasionally recorded at the two higher frequencies (see Lehany and Yabsley, 1948; 1949).

Late in 1947 the Yagis at Dover Heights were being used intensively for non-solar work (see Bolton, 1982; Slee, 1994), so Payne-Scott decided to transfer to the Hornsby Valley field station on the northern outskirts of Sydney (Figure 2),[6] where she continued her investigation of solar bursts using 60, 65 and 85 MHz Yagis, an 18.3 MHz broadside array and a 19.8 MHz rhombic aerial. Observations were conducted between January and September 1948 and these revealed two types of variable high-intensity emission which Payne-Scott (1949: 215) termed 'enhanced radiation' and 'unpolarized bursts'. She describes the 'enhanced radiation':

> 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 … Superimposed on it may be bursts … for the great part of its life the enhanced level shows circular polarization of one sense or the other. (Payne-Scott, 1949: 216-217).

The 85 MHz observations were made with crossed Yagis, so that circular polarization could be studied. Examples of enhanced radiation recorded at 60 and 85 MHz on 30 August 1948 are shown in Figure 9.

Apart from the enhanced emission, many 'unpolarised bursts' were recorded, and these showed

> … a very good correspondence on different frequentcies, though their shapes and relative amplitudes may vary considerably ... A characteristic unpolarised burst shows a finite rise time, rounded top, and slow decay … (Payne-Scott, 1949: 219-220).

Unpolarized bursts generally occurred in groups—single bursts were rare—and they often exhibited double peaks, suggesting that the second peak "… may be an echo of the original disturbance." (Payne-Scott, 1949: 222). Payne-Scott was also particularly interested in the starting times of the bursts at different frequencies:

> The occurrence of time delays between the arrival of "corresponding" unpolarized bursts [previously referred to as isolated bursts] on different frequencies is confirmed, the higher frequency commonly arriving earlier, with delays of about 0.7 second between 85 and 60 Mc/s and 9 seconds between 60 and 19 Mc/s.

An example from her paper is shown in Figure 10.

What Payne-Scott was not able to do though was confirm the earlier findings relating to the 8 March 1947 outburst:

> … on the question of longer delays, the present author has never since, in the recording of hundreds of bursts, obtained any evidence for delays of the order of minutes. Either this case reported earlier was very unusual, or the record was misinterpreted; as the relative amplitudes of different portions of a complex burst may be different on different frequencies, such an interpretation of a single case is quite possible. (Payne-Scott, 1949: 223).

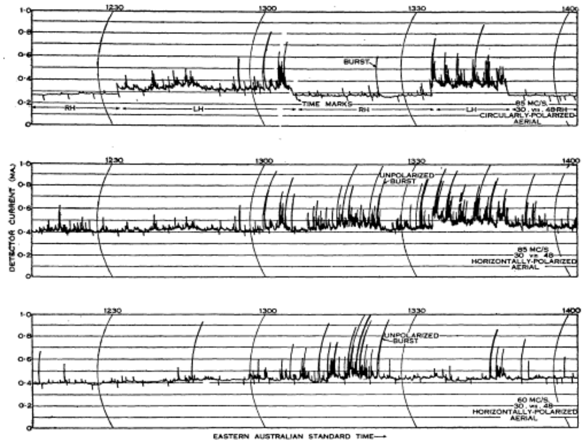

Figure 9: Examples of 'enhanced radiation' with superimposed bursts of short duration at 85 MHz (top and middle) and 60 MHz (bottom), recorded on 30 July 1948. The 85 MHz records indicate that the enhanced radiation shows left-hand circular polarization (after Payne-Scott, 1949: 218).

Long before the end of 1948 a confusing picture had emerged regarding the energetic burst emission received from the Sun at frequencies between 65 and 200 MHz, on the basis of observations made at Collaroy, North Head, Dover Heights, Georges Heights and Hornsby Valley in suburban Sydney, and at the Commonwealth Solar Observatory near Canberra. On record were isolated unpolarised bursts, outbursts, noise storms and enhanced emission (which was sometimes accompanied by polarised bursts). The relationship between these various types of emission, and particularly between noise storms and enhanced emission containing polarised bursts, was obscure. Clearly, what was needed was a radiospectrograph which could provide an instant profile of the emission across a wide frequency band at any one point in time.

In the next section of this paper we follow the development of this instrument by examining early archival material and relevant publications. We were also fortunate to be able to discuss this project with John Murray, who was one of the original members of the team that designed and operated the Penrith radiospectrograph.

4 THE 'SPECTRUM ANALYZER PROJECT'

The first reference to using a radiospectrograph in the Division's solar program is found in the Minutes of the

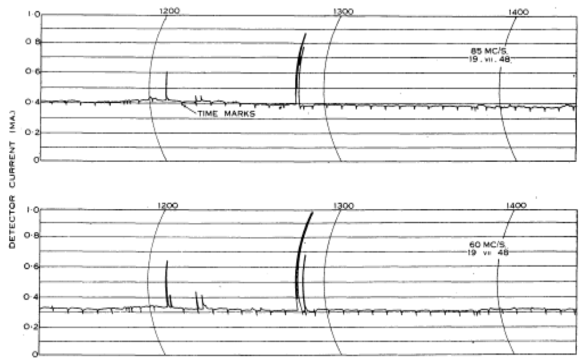

Figure 10: Examples of 'unpolarized bursts' at 85 MHz (upper) and 60 MHz (lower), recorded on 19 July 1948 (after Payne-Scott, 1949: 216).

Figure 11: Aerial photograph taken in 2006 of land near the Penrith Railway Station. The white outline defines the Department of Defence land which was acquired in 1946. The Division of Radiophysics Penrith field station was located about 300m to the north of the railway station in or near the current car park (courtesy: Penrith Municipal Council).

Propagation Committee Meeting held at Radiophysics on 8 July 1946. While discussing the possibility of extending solar observations to 200 MHz at Brisbane, Lindsay McCready (1946a) reported that: "General opinion however favoured a spectrum analyser style of approach, with all frequencies being studied at the same place." But more than a year was to pass before there was progress in this direction.

Thus, on 23 September 1947 McCready (1947a) reported to Pawsey's Radio Noise Group:

> <u>Object.</u>
>
> To investigate in detail the frequency–time distribution of intensity over a range of frequencies of the order of 2/1.
>
> <u>Basic Question.</u>
>
> Normal extent in frequency of disturbances of different types and any systematic delays between disturbances on different frequencies.
>
> <u>Region of interest:</u>
>
> (a) About 100 Mc/s where bursts are very common.
> (b) Between 200 and 600 Mc/s where bursts disappear.
>
> <u>Proposed Techniques:</u>
>
> Spectrum analyser – arrangement with alternative displays.
>
> (1) Similar to Class A with visual observation = cine photography.
> (2) Intensity modulation with f and t as axes.
>
> <u>Plans:</u>
>
> Begin on 100 Mc/s using rhombic aerial.
>
> <u>Personnel:</u>
>
> McCready + Medhurst (part time) until he leaves then <u>new man</u>. (Cf. Pawsey, 1947b).

The 'new man' was Paul Wild who arrived soon afterwards. From the minutes of the Noise Committee given below it appears that surplus war equipment was found to be unsuitable for solar observations and was replaced by an in-house designed 70-130 MHz receiver which used the semi-butterfly tuning condensers from one of the P58 search receivers.

On 16 October McCready (1947b) and Wild reported to the Noise Committee:

> A P58 English search receiver covering the range 200-600 MHz has been borrowed from Electrotech. It is proposed to modify this and to obtain another model if possible.
>
> Wild is looking into the theory of Rhombics for U.H.F. operation.

On 14 November McCready (1947c), Wild and Medhurst reported:

> The P58 search receiver (280-610Mc/s) has been tested. Its noise factor is 20 db. While it may still be useful, it is considered advisable to proceed with another RF unit designed for a noise factor of 10 db, to avoid delays in waiting for large magnitude bursts.
>
> In the meantime a 200 to 600 Mc/s rhombic is being constructed for use with the P58 receiver during periods of intense bursts at 200 Mc/s, when it is hoped to find the region where they disappear.
>
> An additional P58 receiver has now been obtained and it is proposed to modify this to cover the 70-140 Mc/s range pending the completion of a better receiver.

On 6 January 1948 McCready (1948a) and Wild reported:

> The 200-600 Mc/s Rhombic has been completed.
>
> MacAlister has commenced design of polar axis mount for 70-140 Mc/s Rhombic.
>
> P58 search receivers are not sufficiently sensitive for average bursts.
>
> Wild will commence design of a 70-140 Mc/s RF unit shortly.

In an undated letter to Pawsey, who was then in England, McCready (1948b) wrote:

> Rhombic is under construction and the motor tuned R.F. unit (MkI) is almost ready. The remainder of the show is straight forward & the new chap Murray is very useful and appears to be able to handle it, in good engineering fashion at any rate.
>
> Should you come across any suitable butterfly type condensers over there we could use them. Even drawings would save time. Such things will have to be made in our own workshop.
>
> At the moment we are using a semi-butterfly type pinched from some P58 English Search receivers (B.T.H) and only attempting to cover 70-140 Mc/s until we establish & finalise receiver details.

John Murray, who is first referred to in this letter, joined Radiophysics in January 1948 and was given the task of completing the radiospectrograph display and helping Bill Rowe assemble the receiving equipment (Murray, 2007).

On 20 February 1948 McCready (1948c) and Wild reported:

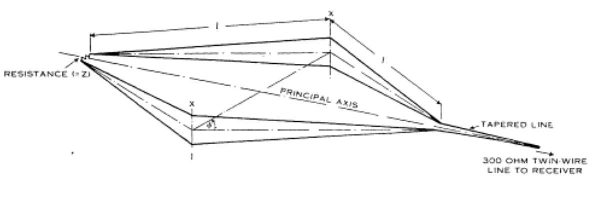

Figure 12: The rhombic aerial (after Wild and McCready, 1950: Figure 1).

> Design of rhombic aerial mount completed and orders placed for timber etc.
>
> Exp. Tuneable RF unit (70-140Mc/s) has been completed. Good sensitivity has been obtained and consideration now being given to the design of a high speed mechanical drive for this unit.
>
> Tentative breadboard models of oscillograph amplifiers, slow speed time bases etc. were completed by Medhurst before he left.

In a letter to McCready dated 5 May 1948 Pawsey wrote from England:

> Spectrum presentation. I would like to see you try this in a simple manner first – e.g. 30 Mc/s spread near 100 would be a first rate initial experiment. The point I wish to clear is the delay question.
>
> I find some people over here do not believe our sequence "high frequency precedes low frequency" is correct.
>
> Surely the move is to push on with what you can make easily.

In a letter from McCready (1948d) to Pawsey dated 25 July 1948:

> I'm having a hectic time trying to get our rhombic installed on a temporary basis at Penrith pending proper tests for site noise etc.
>
> Difficulties are organisational & personal rather than technical (e.g. retaining unofficially good relations with a farmer etc).
>
> Regret the slow progress on the spectrum analyser but it is due to many causes.
>
> Finally I have little time to attend to detail & secondly my staff tend to be a little too thorough & of the perfectionist type.
>
> All very well in due course but as you've already said "Do it simply first to check general features etc & then see if it is worth developing a properly engineered model".
>
> However I think you'll find Wild & Murray a very keen & useful physicist and engineer respectively on your return.

This prediction proved to be true with the events which followed.

5 THE PENRITH FIELD STATION AND THE RADIOSPECTROGRAPH

5.1 Selection of the Penrith Site

The site chosen for a new field station at which to conduct these solar observations was on Department of Defence land which was acquired in 1946 (Penrith Library staff, pers. comm., 2007). It was within easy walking distance (~300 metres north) from the Penrith railway station which, at that time, contained a large shunting yard for steam locomotives travelling over the Blue Mountains (see Figure 11). The site was located on the western outskirts of suburban Sydney (see Figure 2). It was easily accessible by train and was relatively free from radio interference (Murray, 2007).

5.2 Method of Operation

The radiospectrograph operated for about 8 hours per day from February through to July 1949, and burst radiation from the Sun was collected with the broad-

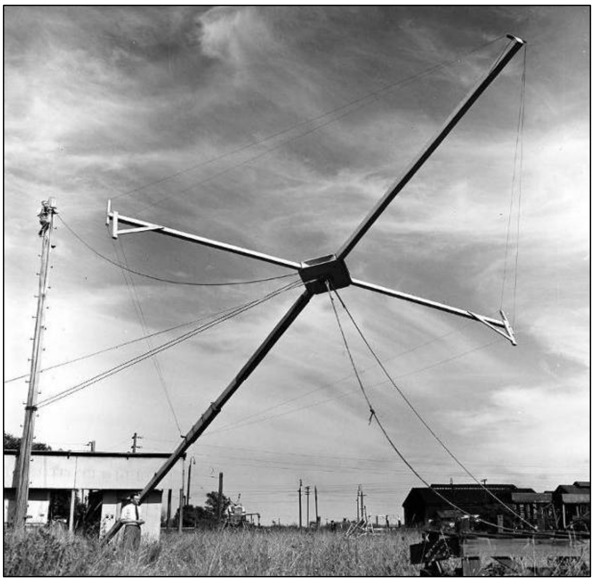

Figure 13: Photograph of the rhombic aerial and pulley system with Bill Rowe standing nearby. In the background to the right are the railway locomotive shunting sheds (courtesy: ATNF Historical Photographic Archive).

band rhombic aerial which was connected to a receiver that was rapidly 'swept' over the 70-130 MHz frequency range. The tuner was mechanically driven so that the frequency sweep occurred in 0.07 second, and repeated about three times per second, giving a time resolution for recording of 4 scans per second. The spectrum was displayed on a cathode-ray tube in the form of a graph of received power (vertical axis) versus frequency (horizontal axis), called in radar terms an A-scan, and was then photographed.

5.3 The Rhombic Aerial

The aerial was of rhombic design (see Figure 12) with sides (l) of 6.4 m (3λ at 100 MHz) and Φ = 56.4º, giving an impedance (resistance) of 670 ohms and an effective area of almost 12 m^2 at the central frequency. A tapered line three metres long transformed this resistance to 300 ohms, which matched into a two-wire line connected to the receiver that was located some distance away.

The antenna was designed by Paul Wild and constructed with a wooden frame under the supervision of the Division's Keith McAlister, a mechanical and electrical engineer who became well known over the years

Figure 14: The rhombic aerial's polar mount, with right ascension and declination scales (courtesy: ATNF Historical Photographic Archive).

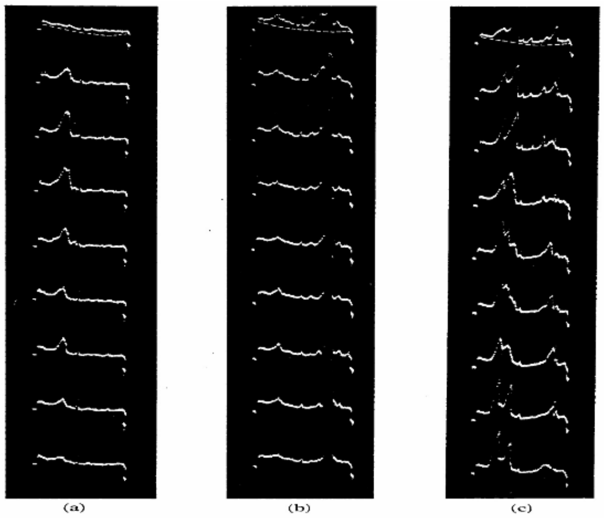

Figure 15: A-scans of three storm bursts, each section of 3 seconds duration. Frequency varies from 70 MHz on the left hand side to 130 MHz on the right. Scans are separated by ⅓ second. The dotted lines show the background level in the absence of storm continuum. (a) shows a typical storm burst from start to finish; (b) part of a large storm burst; and (c) storm bursts during a period of very high activity (after Wild, 1951: Plate 1).

for the design and construction of low-cost antennas at various Radiophysics field stations. Wild derived the theoretical effective receiving area or 'gain' of the aerial from first principles, with some help from Chris Christiansen (Wild and McCready, 1950: Appendix I).

During observations the principal axis of the rhombic aerial was pointed towards the Sun in order to receive maximum signal. This was achieved by moving the aerial by hand every twenty minutes using a rope and pulley system. The aerial and associated ropes can be seen in Figure 13. The aerial rotated about a polar axis which was embedded in a concrete footing, as shown in Figure 14. The principal axis of the

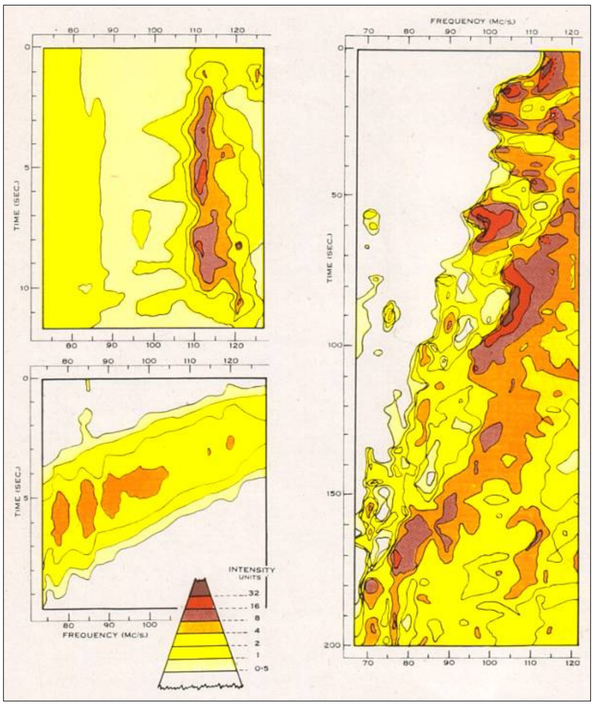

Figure 16: Dynamic spectra of Type I (top left), Type III and Type II (right) bursts (after Wild and McCready, 1950: Plate 2).

rhombic antenna was tilted in declination every few days to keep the Sun in the main lobe of the aerial. At night the aerial was lowered onto the supporting trestle shown near the bottom right-hand corner of Figure 13 (Murray, 2007).

5.4 The Receiving System

According to Wild and McCready (1950),

> The receiver was of conventional superheterodyne design with a single stage of radio-frequency amplification. The local oscillator and the input circuits of the radio-frequency amplifier and the mixer were tuned by 'slit-stator' condensers on a single shaft which was rotated by a motor at about three revolutions per second … By using split-stator condensers, the need for making electrical contacts with rotating shafts was avoided.

The split-stator condenser referred to was probably the semi-butterfly type salvaged from one of the P58 search radar receivers (see the letter from McCready (1948b) to Pawsey, discussed in Section 4).

The intermediate-amplifier operated at 10 MHz with a bandwidth of 300 kHz. The signal was then detected, amplified and fed to the 'y-plate' of the cathode ray tube for display.

5.5 The Display

The display on the screen was a graph of receiver output (vertically) versus frequency (horizontally). This 'A-scan' was photographed with a hand-held Zeiss 16 mm movie camera, which meant that during times of solar activity the equipment hut was kept in darkness (Murray, 2007). Examples of 3 seconds continuous recording during three noise storms are shown in Figure 15.

The photographic records were then converted into time-frequency diagrams for analysis as shown by the examples in Figure 16. Intensity contours were plotted on a logarithmic scale. In a subsequent paper Wild (1950a) referred to these diagrams as 'dynamic spectra' because they showed variations in intensity with time.

6 THE SPECTRAL CLASSIFICATION OF SOLAR BURSTS

By 1950, Wild and McCready had sufficient data to present papers on the first spectral classification of solar radio bursts at metre-wavelengths, which greatly helped remove the confusion introduced by the earlier single frequency records, as Wild (1985) correctly recalled.

The most outstanding result from this groundbreaking investigation was the ability to recognize three distinct types of solar bursts. According to Wild and McCready (1950) the dynamic spectra of the observed bursts were often complicated with widely-different features, but analysis showed that many conformed to one of three specific spectral types which they named Types I, II and III.[7] Typical examples of these Types were shown in Plate 2 of Wild and McCready (1950) and are reproduced here in Figure 16.

6.1 Type I Bursts

Wild and McCready (1950: 393) wrote:

> Plate 2a is typical of bursts which occurred in hundreds during restricted periods, called "noise storms" by Allen [1947]. Such periods usually last for hours, or even days, and were marked by a high, slowly-varying background continuum above which the bursts appeared. Bursts of his type rarely occurred as isolated phenomena. The type is characterized by its narrow spectrum, a few megacycles per second wide … The lifetime of the bursts is sometimes less than one second and sometimes as long as 20 seconds.

These storm bursts were the predominate type of activity observed at Penrith during the operation of the radiospectrograph. Other bursts occurred occasionally either singly or in small groups.

6.2 Type II Bursts

According to Wild and McCready (1950: 393):

> Plate 2b illustrates a type of burst of comparatively rare occurrence. In this type, the spectrum at any instant near the start shows a distinct "cut-off" in frequency, little or no radiation being received at frequencies immediately below a critical frequency. The critical frequency varies with time and, on the average, drifts gradually towards the lower frequencies at a rate of ¾ (Mc/s.) sec.$^{-1}$ The bursts last for several minutes … Of five such bursts observed, three coincided with a large solar flare or sudden short-wave communication fade-out.

6.3 Type III Bursts

Of the other thirty or so sporadic bursts or groups recorded none coincided with a reported flare or fade-out. They were of short duration (about 3 to 30 seconds) and broad bandwidth (≥15 MHz). Less than half conformed to this third distinct spectral type.

Again, according to Wild and McCready (1950: 394):

> In this type, illustrated in plate 2c, the frequency of maximum intensity drifts rapidly (at a rate of the order of 20 (Mc/s.) sec^{-1}) towards the lower frequencies. The bandwidth of these bursts at any instant is not usually less than about 50 Mc/s. They last for a few seconds.

6.4 Relation between Spectral Types and Bursts Recorded at Single Frequencies

Comparing their results with earlier observations made by the Radiophysics group, Wild and McCready (1950) noted that Payne-Scott (1949) had established that metre wavelength solar bursts could be divided into two broad groups according to whether or not the radiation was circularly polarized:

(a) '<u>Enhanced radiation</u>' which occurred during noise storms was closely associated with large sunspot groups and was circularly polarized. It appeared on single-frequency records as a slowly-varying background radiation with superimposed short bursts of similar polarization. The bursts showed little or no correspondence at frequencies differing by a few megahertz and were clearly the storm bursts of spectral Type I mentioned above.

(b) Radiation which was not circularly polarized occurred as sporadic bursts which lasted for several seconds, or in extreme cases, for several minutes. The bursts were often observed almost simultaneously at widely-spaced frequencies.

When larger sporadic bursts occurred at the time of solar flares they were called 'outbursts' (Allen, 1947a). Wild and McCready (1950) were able to establish that at least some of these outbursts could be identified with spectral Type II bursts, especially those that showed onset time delays at widely-spaced frequencies (such as the 8 March 1947 event).

Other sporadic bursts, called 'isolated bursts' by Pawsey (1950) were of shorter duration than outbursts and, according to Wild and McCready showed diverse spectral features but at least some of them conformed to spectral Type III (characterized by a rapid drift from high to low frequencies). The fast frequency drift also explained the time delays of several seconds found at spaced frequencies in 'unpolarized' bursts by Payne-Scott (1949) and mentioned above in Section 3.

The reason Payne-Scott (1949) did not detect more delayed outbursts is probably due to the complex nature of the flare event at metre wavelengths. Often more than one Type III burst preceded the Type II burst, making recognition difficult on single frequency records.

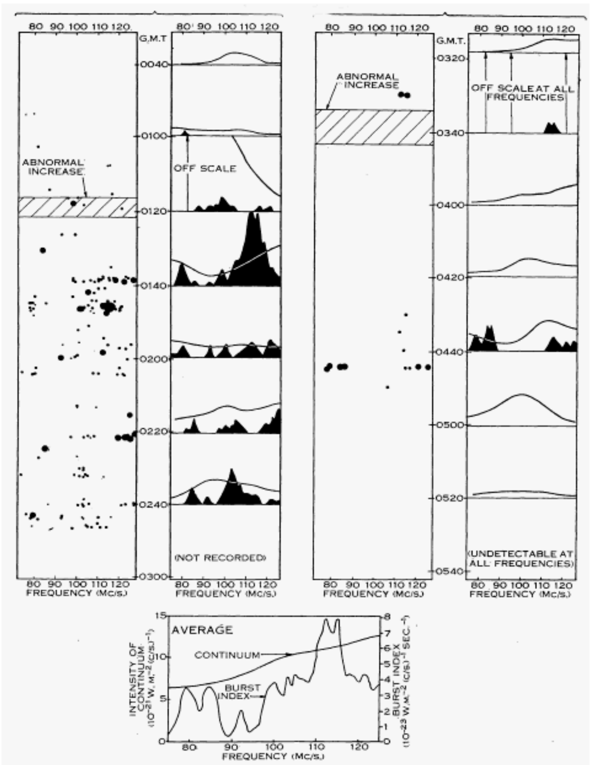

Figure 17: The LH plot shows the distribution of Type I storm bursts recorded on 14 April 1949 and the RH plot shows the continuum spectrum and the 'burst index'. The bottom plot shows the averaged spectra (after Wild, 1951: Figure 2). The burst index gives a fair indication of the mean-intensity distribution of the Type I bursts.

7 DETAILED ANALYSIS

7.1 Type I Bursts

The Penrith dynamic spectrum of Type I bursts (Figure 16 top left) explained why these bursts were not correlated on spaced-frequency records such as those obtained by Payne-Scott (1949). Wild (1951) then investigated the possibility that the enhancements accompanying Type I bursts was merely a composite of many unresolved bursts.

It was suggested earlier by McCready, Pawsey and Payne-Scott (1947) and also by Ryle and Vonberg

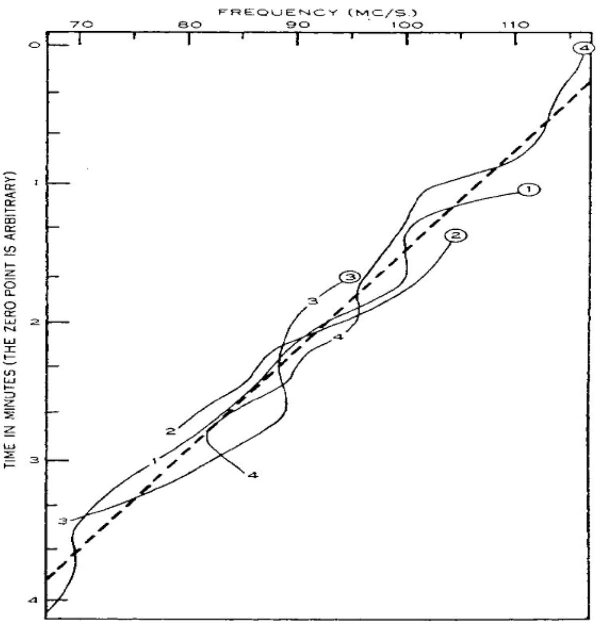

Figure 18: Smoothed curves of the variation with frequency of the low-frequency cut-off of the four type II bursts (after Wild, 1950a: Figure 1).

(1948) that the background continuum may be the result of a large number of storm bursts, with only the larger ones being recognized as distinct phenomena. This hypothesis is supported by (1) the observed circular polarization of both bursts and continuum, and (2) the good general daily correlation of occurrence of the two components.

On the other hand, Wild pointed out that the opposite view—that the two components are fundamenally different—is suggested by (1) the usual small degree of fluctuation in the background continuum; (2) the lack of correspondence between the spectrum of the continuum and the integrated spectrum of the bursts (see Figure 17); and (3) the fact that during some periods a high continuum level is observed without appreciable burst activity and at other times bursts occur without detectable continuum.

Wild (1951) concluded that more observations of noise storms were needed to resolve this question.

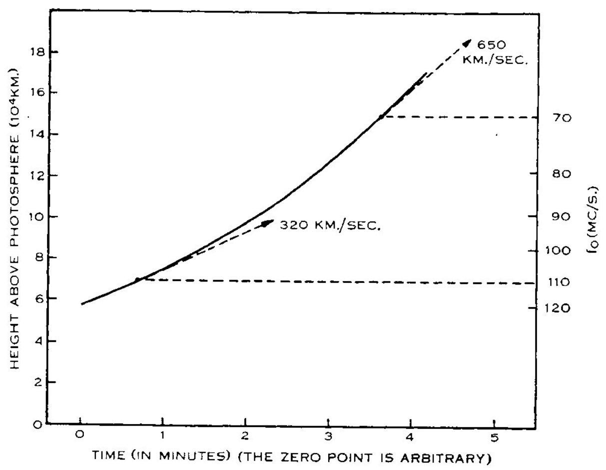

Figure 19: The curve shows the motion of the disturbance moving outwards through the solar corona producing a frequency drift corresponding to the dotted line of Figure 18 (after Wild, 1950a: Figure 2).

7.2 Type II Bursts

Wild (1950a) analysed the frequency drift of four of the five Type II bursts recorded at Penrith, and his results are reproduced in Figure 18. Points on the curves correspond to the position of the low-frequency 'cut-off' edge which he found to be a distinct feature of Type II bursts. The four curves were superimposed by adjusting their starting points. The dotted line represents a constant drift rate of 0.22 MHz per second. The diagram shows that the average drift rate of each of the four bursts was close to this value and that the drift rate was constant with frequency.

Martyn (1947) had suggested that solar bursts were due to plasma oscillations and this suggestion was adopted by Payne-Scott et al. (1947) in their analysis of the outburst shown in Figure 7.

Wild (1950a) also used this 'plasma hypothesis' to interpret the frequency drift rate of the Type II outburst shown in Figure 16. He identified the cut-off frequency of the outburst with the local plasma frequency, f_0, where the refractive index for electromagnetic waves reduces to zero. In the absence of a magnetic field, f_0 is given by:

$$f_0^2 = e^2 N / \pi m \qquad (1)$$

where N is the electron density of the medium, e is the electronic charge (cm^{-3}) and m is the electronic mass. Values of N, obtained from an optically-derived electron density model for a spherically-symmetrical corona by Baumbach and modified by Allen (1947b), were used to produce the height-versus-time plot of Figure 19.

Finally, Wild (1950a) considered two known coronal phenomenon as possible candidates for the outburst disturbance. First he examined 'surge-prominences', but he discarded these because they were observed to rise and then fall back towards the solar surface whereas the outburst showed a tendency to accelerate outwards through the corona. Instead, he was of the opinion that the most likely cause was the fast particles that were known to be emitted from the Sun at the time of flares, and which caused magnetic storms with sudden commencements here at the Earth about one day later. Indeed, two of the four Type II bursts analysed represented in Figure 18 were found to be associated with geomagnetic storm commencements 28-29 hours later. This idea had previously been suggested by Payne-Scott et al. (1947) and Pawsey (1949) to explain the outburst of 8 March 1947. Later it was found that the Type II event was caused by a magneto-hydrodynamic shock wave.

7.3 Type III Bursts

Wild (1950b) considered three possible mechanisms for the rapid frequency drift of maximum intensity towards lower frequencies which is characteristic of Type III bursts (such as shown in Figure 16):

(a) Selective group retardation of the radiation from a localized, instantaneous disturbance in the corona. Jaeger and Westfold (1950) had found that such a disturbance may be capable of producing a radio burst of short duration at the Earth, where the higher frequencies would arrive before the lower ones, due to group retardation effects near the plasma level.

(b) The outward motion, through the corona, of a localized source that excites plasma oscillations of continuously-decreasing frequency (similar to the mechanism discussed above for Type II outbursts).

(c) Some mechanism in which the wave frequency is controlled by an external magnetic field.

Wild dismissed mechanism (c) as a possibility because of the absence of observed circular polarization in Type III bursts. Then to decide between (a) and (b), he analysed the decay rate and frequency drift of the simple Type III bursts observed, and noted that the time profiles of these showed a gradual rise to a maximum value followed by slower decay which appeared to be approximately exponential in form (as found earlier by Payne-Scott 1949, and Williams 1948). Wild showed that the mean value of the normalized decay constant for Type III bursts tended to decrease with decreasing frequency (see Figure 20). This result cannot be easily explained by mechanism (a), above, but it can be explained by mechanism (b) if it is accepted that the decay constant is related to the electron-atom collision frequency (Westfold, 1949), which would decrease as the disturbance moved outwards through the corona (Smerd, 1950).

To test the frequency drift of mechanisms (a) and (b) further Wild constructed the diagram which is reproduced here in Figure 21. Clearly the observations do not fit mechanism (1). On the other hand, mechanism (2) gives much better agreement. Here the line OB shows the prediction for an outward-moving source of constant velocity in a Baumbach-Allen atmosphere, where the numbers on the line refer to velocities in 10^4 km/sec. The other lines, labeled n = 0, 1, 2, and 3, refer to a curvature of the intensity ridge line of the burst if the drift rate is proportional to f^n. The scatter of points on the graph suggests that a small acceleration of the source occurred as it moved outwards through the corona.

However, it should be noted that when more realistic density models for the corona became available further analyses indicated that the outward-velocity of the Type III burst remained more or less constant.

From the above analysis Wild (1950b: 554) concluded that:

> With the assumed electron density distribution, velocities of between about 2×10^4 and 10^5 km./sec would be required to account for the observed drift rates … Corpuscular streams with these velocities have not been observed in the solar atmosphere, but in any case such streams would likely to be highly ionized and may consequently escape optical detection.

8 LATER REMINISCENCES

In his recollections of the early days of Australian radio astronomy, Dr E.G. (Taffy) Bowen (1984), who was the Chief of the Division of Radiophysics at that time, wrote:

> It happened that during the war the Division—as part of a secret within a secret—had been involved in the construction of receivers for surveillance of enemy radio and radar transmissions.
>
> The basic method of carrying this out was to scan rapidly over a 2:1 frequency range and to cover the whole band of usable frequencies in a series of 2:1 steps.
>
> Within the Division there was a substantial store of such receivers. These were ready made for spectral analysis of the noise from the Sun and they were quickly pressed into service.
>
> In the inventive hands of Lindsay McCready and Paul Wild, a "radio spectrometer" evolved which was to dominate the field of solar studies for the next twenty years.

Although it is true that the Penrith radiospectrograph was built on the principles developed earlier for wartime radar, the archival records and publications used in this study reveal that Bowen's claim that wartime equipment was quickly pressed into service was not entirely correct. These spectrum analysers were found to be unsuitable for solar observations. Instead, new equipment—including a broadband rhombic antenna matched to a swept-frequency receiver which was coupled to a photographic display—had to be designed and constructed before being installed at the Penrith field station in 1948.

As we have seen, this took careful planning and experimentation by a number of skilled personnel under the leadership of Joe Pawsey and his deputy Lindsay McCready, who had formed the Solar Noise Group within the Division back on 15 January 1946 (Bowen, 1946).

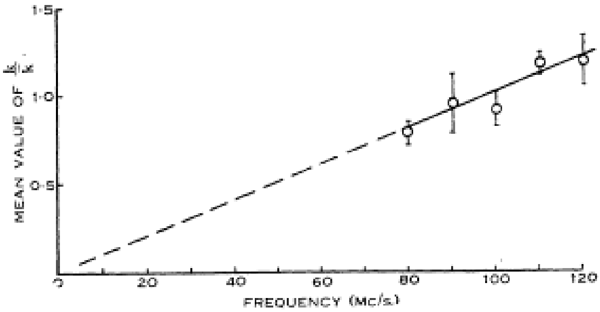

Figure 20: Plot of the average normalized decay constant versus frequency for five Type III bursts (after Wild, 1950b: Figure 4).

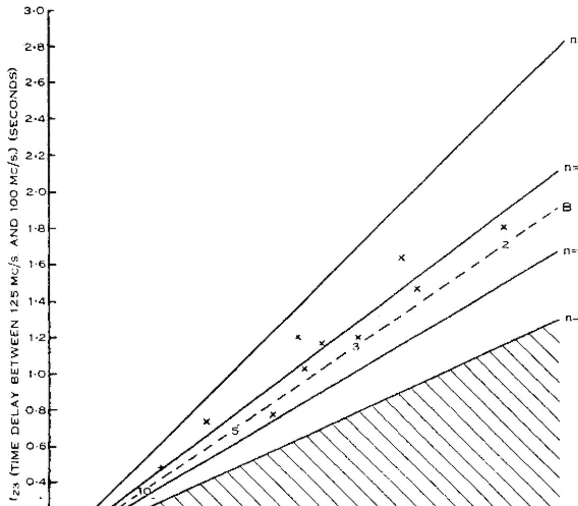

Figure 21: Diagram for studying the frequency drift of Type III bursts. Ten Type III bursts are shown by crosses. The line OA shows the predicted results of selective group retardation in a Baumbach-Allen coronal electron density model. The shaded region shows selected group retardation in any atmosphere (after Wild, 1950b: Figure 6).

Figure 22: View of the receiver hut and three crossed-rhombic antennas at the Dapto field station (courtesy: ATNF Historic Photographic Archive).

Another somewhat contentious issue which drove the development of the Penrith radiospectrograph was the question of whether time delays occurred between the onsets of solar outbursts at different frequencies.

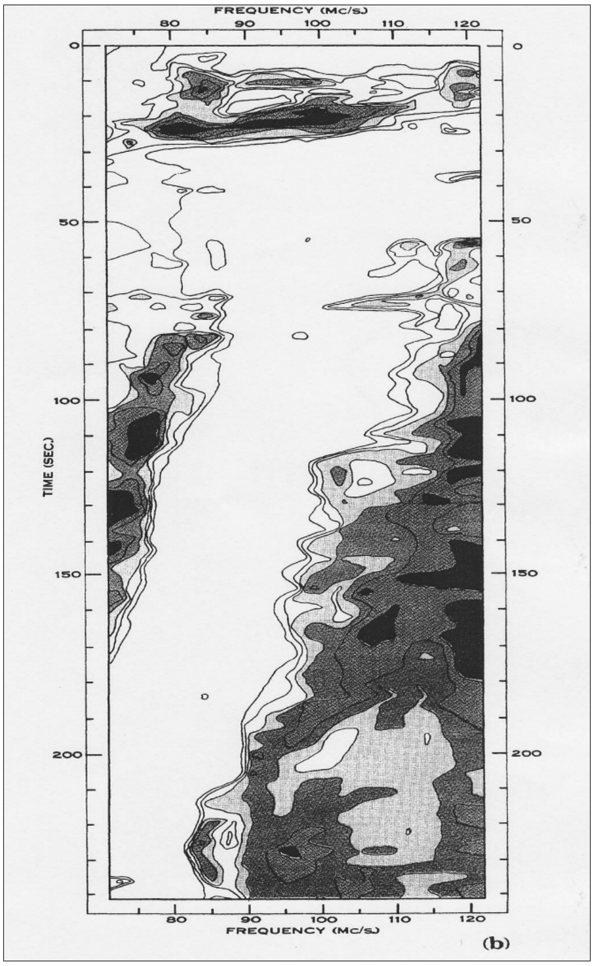

Figure 23: Dynamic spectral record of a type II burst showing probable fundamental and second harmonic structure. Only the trailing edge of the fundamental band and the leading edge of the second harmonic band were recorded. At the top of the record is a type III burst (after Wild, 1950a: Figure 2a).

Years later, when he was the Chief of CSIRO, Paul Wild wrote about his early days at Radiophysics:

> The situation around 1948, when I joined the Sydney group of investigators led by Joe Pawsey, was one characterized by mystery, incredulity and intense interest. A whole new field of research lay ahead with obvious objectives: to disentangle the conglomeration of phenomena; to interpret and understand them; and to put the results to use in the mainstream of research for solar physics, astronomy and physics.
>
> Before the 'origin of species' could be identified there had to be an exercise in taxonomy. Already Pawsey and his colleagues at Sydney had found that, in addition to the polarized storm radiation, there were different kinds of unpolarized bursts: there were large outbursts lasting 10 or 20 min which accompanied large flares, and there were short, sharp 'isolated' bursts lasting a few seconds ...
>
> A new clue was discovered when Payne-Scott et. al (1947) noted systematic time delays in the starting time of bursts, high frequency preceding low. In the case of the isolated bursts these delays were typically a few seconds and were thought to be due to the difference in travel time …
>
> In the case of outbursts, one event was recorded with long delays (a few minutes) between frequencies, and the possibility was suggested that the delay was due to the outward movement of the source. However, in a subsequent extended series of observations Payne-Scott (1949) found no further evidence of similar delays and was inclined to believe that the long delays of that one event was fortuitous. She stressed the difficulty of identifying corresponding features of a complex burst at different frequencies …
>
> An obvious next step, therefore, was to develop a radiospectrograph to record the intensity of the solar emission as a continuous function of frequency and time. (Wild, 1985: 8).

9 PROLOGUE

Following the success at Penrith the radiospectrograph was extended to cover the 40 to 240 MHz frequency range and three different rhombic aerials were installed at a new field station at Dapto (Figure 22), south of Sydney (see Figure 2), in 1952. Fundamental and second harmonic structure was observed in both Type II and Type III bursts, lending support to the 'plasma hypothesis' and Wild's interpretation of the frequency drifts.

It is interesting to note that an example of a Type II burst with harmonic structure was partially recorded by the Penrith radiospectrograph (Figure 23). Although the restricted frequency range does not show the complete burst, it is likely that the trailing edge of the fundamental band and leading edge of the second harmonic were recorded.

The 'plasma hypothesis' was finally confirmed by Wild and Sheridan (1958) when they constructed a swept-frequency interferometer to measure the heights of the sources of solar bursts (Figure 24). The positions agreed with the plasma levels of coronal density models, derived from white-light eclipse observations.

Thus the dynamic spectra, when converted to height -versus-time plots, gave an instant snapshot of coronal activity when other means of observing the corona were not available. Later observations from spacecraft identified the Type III electron streams and the Type II shock waves as they travelled out into interplanetary space. Today, radiospectrographs are still used as part of the global watch on space-weather, because of the disruptive effects massive solar ejections can have on communications and GPS satellites.

10 CONCLUSION

The Penrith radiospectrograph was built to solve the problem of time delays between burst onset at different frequencies. Although the principles involved in building a radiospectrograph were known from war-time radar it took careful planning, experimentation and innovative design to produce a successful instrument.

In 1949 this led to the first spectral classification of solar bursts at metre wavelengths. The discovery of streams of ionised particles travelling outwards through the corona at speeds of 10^4–10^5 km/sec and flare-initiated disturbances moving at speeds of 500 to 1000 km/sec heralded the advent of space research and space weather.

11 NOTES

1. The Division had been set up by the CSIR (Council of Scientific and Industrial Research) in 1939 to develop radar for Australia and the South Pacific. When the war ended the Division experimented with various peace-time research options before deciding to focus primarily on radio astronomy, cloud physics and rain-making. The CSIR also reinvented itself, in 1949 becoming the CSIRO (Commonwealth Scientific and Industrial Research Organisation). For details of these developments see Sullivan, 2005 and 2009.
2. Sullivan (1984) has shown that the term ‘radio astronomy’ only began to gain international visibility in about 1948. Prior to this, terms like ‘solar noise’ and ‘cosmic noise’ were widely used.
3. Penrith was merely one of a large number of radar stations, field stations and remote sites used by Radiophysics staff for solar, galactic and extra-galactic research between 1945 and 1965. For a succinct summary of this work see Orchiston and Slee (2005).
4. In 2005 one of the authors of this paper (WO) published a paper titled “Dr Elizabeth Alexander: first female radio astronomer”, and assigned her the title of the world’s first female radio astronomer on the basis of her New Zealand-based investigation of 200 MHz solar radio emission during 1945. At that time we were aware that Ruby Payne-Scott and Joe Pawsey had made earlier attempts to detect galactic emission (in 1944), but they were unsuccessful, whereas Alexander did carry out successful radio astronomical observations in 1945 and report on her work in reports and in one brief post-war research paper (see Alexander, 1946). Given these differing circumstances we feel that Alexander and Payne-Scott should be assigned equal billing in the ‘first female radio astronomer’ stakes (cf. Goss and McGee, 2009).
5. The Commonwealth Solar Observatory’s foray into radio astronomy is discussed in Orchiston, Slee and Burman (2006: 51-53) and by Frame and Faulkner (2003). Dr David Martyn’s interest in radio astronomy stems from the fact that he was at one time Chief of the Division of Radiophysics, but he was unceremonially removed from the post and seconded to the Commonwealth Solar Observatory. His colleague, Dr Cla Allen, was a solar physicist, but war-time research he carried out into the causes of short-wave radio fadeouts whetted his appetite to investigate solar radio emission.
6. For information about this relocation to Hornsby Valley see Goss and McGee (2009: Chapter 8).
7. Sullivan (2009: 304, footnote 24) has noted that initially, Wild considered using an α, β and γ classification, but he quickly dropped it in favour of I, II and III.

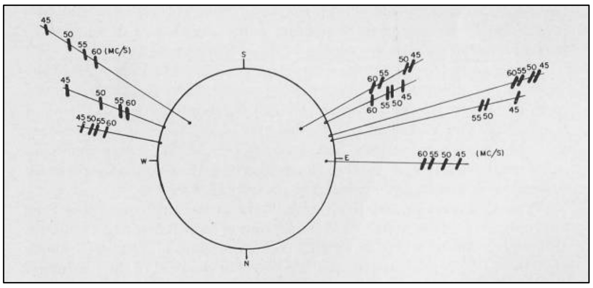

Figure 24: Dapto swept-frequency interferometer observations of the source heights of Type III bursts at different frequencies (after Wild, Sheridan and Neylan, 1959: 382).

12 ACKNOWLEDGEMENTS

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