8. INTRODUCTION TO THESIS

This thesis examines the contribution to radio astronomy of work carried out at the Potts Hill and Murraybank field stations operated by the Division of Radiophysics, Commonwealth Scientific and Industrial Research Organization, Australia. While a number of histories of the early years of radio astronomy in Australia have been published (e.g. Orchiston and Slee, 2005, Robertson, 1992, Sullivan, 2005), there has not been a comprehensive review of the specific contribution made by the Potts Hill and Murraybank field stations. Twenty field stations and remote sites (Figure 1) operated during the first 16 years (1945-1961) of Australian radio astronomy, or the 'pre-Parkes' era (Orchiston and Slee, 2005a). Potts Hill and the better historically-documented Dover Heights field station (e.g. see Bolton, 1982; Kellermann et al., 2005; Orchiston and Slee, 2002; Slee, 1994; Stanley, 1994; Westfold, 1994) were the two major field stations operating during this period, although by 1952 Potts Hill had become the largest field station of the Division (Pawsey, 1952f).

The Potts Hill field station was located on vacant land adjacent to a water supply reservoir on the outskirts of suburban Sydney, some 16 km to the southwest of the central business district. A wide variety of instruments was used at Potts Hill and a number of the scientists who worked there emerged as leading researchers in Australian radio astronomy. For a period it was the focal site for Australian solar radio observations, and it was where the Australian confirmation of the 21-cm Hydrogen emission spectral-line took place. The Hydrogen line emission observations would become central to our early understanding galactic structure and this was the catalyst for establishing the Murraybank field station so as to further the receiver development and survey work that had commenced at Potts Hill.

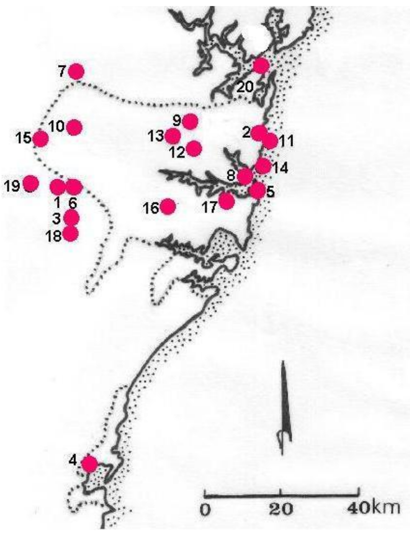

Figure 1: The twenty different sites in the Greater Sydney-Wollongong regions associated with radio astronomy. These were Badgerys Creek (1), Collaroy (2), Cumberland Park (3), Dapto (4), Dover Heights (5), Fleurs (6), Freeman's Reach (7), Georges Heights (8), Hornsby Valley (9), Llandilo (10), Long Reef (11), Marsfield (12), Murraybank (13), North Head (14), Penrith (15), Potts Hill (16), the Radiophysics Laboratory in the grounds of the University of Sydney (17), Rossmore (18), Wallacia (19), West Head (20).

The dotted outline shows the current approximate boundaries of Greater Sydney and Greater Wollongong (after Orchiston and Slee, 2005a: 121).

Potts Hill was also the site of the discovery of the discrete source known as Sagittarius A at the centre of our Galaxy, although many histories incorrectly credit this to work carried out at Dover Heights (e.g. Kerr, 1983: 297; cf. Orchiston and Slee, 2002: 30). The first use of Earth-rotational synthesis occurred at Potts Hill, but because it was not further developed, credit is now largely given to Cambridge for initiation of this technique (Christiansen, 1989b).

To understand the contribution made at Potts Hill and Murraybank it is necessary to understand the context within which this work was carried out. There have been a number of publications examining why Australia was able to make such major contributions to early radio astronomy (e.g. Bowen, 1984, 1988; Christiansen, 1984; Mills, 1988; Pawsey, 1956, 1961a; Roberts, 1954; Sullivan, 2005; Wild, 1972). Many of the histories that have been published are based on the direct recollections of the people involved and in many cases by the researchers themselves. In this context there has been much focus on achievement, and perhaps rightly so given the period of rapid development in a pioneering field by a nation still finding its feet on the global scientific and economic stage after World War II. While it is understandable that there is a sense of pride in the achievements, this thesis attempts to stand back and examine these in a broader context. Without doubt, Australia made a very significant contribution to international radio astronomy, achieved a number of world-first discoveries and developed new techniques (Sullivan, 2005: 11). However, some of the truly fundamental discoveries eluded Australian researchers (Christiansen, 1989a: 96). In some cases, where the Australian researchers did achieve world-first developments they were slow to capitalise on them (e.g. earth rotational synthesis imaging in Christiansen and Warburton, 1955a), yet in other cases they were quick to take advantage of the discoveries of others (e.g. H-line confirmation in Pawsey, 1951b). Australia's isolation is often quoted as a factor that researchers faced in the 1940-1950s (e.g. Sullivan, 2005: 23), yet some of the first collaborations with optical astronomers, and early cooperative international research projects originated in Australia (e.g. Allen, 1947; Christiansen et al., 1951). The work carried out at Potts Hill and Murraybank contains many of these examples and as such provides a rich illustration of these contrasts in the early development of Australian radio astronomy.

People shape history and Potts Hill and Murraybank involved, either directly or indirectly, nearly all of the leading scientists in first 10 years of Australian radio astronomy. Some 64 research papers were published during 1949-1962 based on work carried at Potts Hill (refer to Appendix A for a full listing of these) and a further 12 papers were produced from Murraybank in the period 1958-1964 (refer to Appendix B for a full listing of these). Many of these appeared in the *Australian Journal of Scientific Research* which was later to become the *Australian Journal of Physics.* Although these two journals were not widely read outside Australia, many of the findings also appeared in *Nature*, the *Astrophysical Journal*, *Monthly Notices of the Royal Astronomical Society* and *The Observatory*.

During the International Astronomy Union (I.A.U.) General Assembly held in Sydney in 2003, Commission 41 (History of Astronomy) and Commission 40 (Radio Astronomy) formed a joint working group on Historic Radio Astronomy under Divisions X and XII. One of the objectives of this Working Group is to document the technical specifications and scientific achievements of historically-significant radio telescopes and associated instruments worldwide (Orchiston, 2006). This Thesis covers the contribution to international radio astronomy of work carried out at the Potts Hill and Murraybank field stations and as such provides a detailed record consistent with the objectives of the Working Group.

9. RADIO ASTRONOMY IN AUSTRALIA

Jansky's original identification of radio emission of galactic origin was published in 1933 (Jansky, 1933). Initially there was little follow up in exploring the potential of this new discovery in the wider scientific and astronomical organizations of the time. This was not for a lack of publicity, as the discovery made the front page of the *New York Times* on 5 May (1933) and was widely followed up in other press and in radio news broadcasts. In the 1930s only one scientific paper appeared in response to Jansky's discovery. This was a theoretical paper published by Whipple and Greenstein (1937) that examined the mechanism that might have produced the detected radiation. Some tentative observations were made: for example, Caltech's Potapenko and Folland were able to confirm Jansky's detection working with a simple dipole aerial in the Mojave Desert (Reber, 1983). However, they were unable to obtain funding to build a more substantial instrument and no results were published. Apart from the solo efforts of Grote Reber who followed up Jansky's discovery as a self-funded hobby and produced a number of seminal papers (Reber, 1940a,b, 1944), the wider scientific community largely overlooked the potential of radio astronomy for the next ten years. Today it is difficult to comprehend why there was so little initial interest. However, the simplest explanation is that at this time astronomers were not familiar with any portion of the electromagnetic spectrum outside of the optical range and certainly did not have a background or training in radio physics or radio engineering. As Reber observed:

> "The astronomers were afraid of it because they didn't know anything about radio. The radio people weren't interested because it was so faint it didn't even constitute an interference. Nobody was going to do anything. So, alright, if nobody was going to do anything, maybe I should do something. So I consulted with myself and decided to build a dish." (Kellermann, 2005: 49).

As more than one historian of radio astronomy has already remarked, Australian radio astronomy, like its counterpart in the U.K., truly was a case of "...swords into ploughshares." (e.g. Hanbury-Brown, 1991; Haynes et al., 1996).

Australia's involvement in World War II and the Australian Government's commitment to develop radar technology for the war effort were the events that would ultimately lead to the development of radio astronomy in Australia. In 1939 the Australian High Commissioner to England, Stanley Melbourne Bruce, cabled the Australian Government with a request to send a 'physicist of discretion' to collect top-secret information regarding a new Allied development (Haynes et al., 1996). The person selected for this mission was David Forbes Martyn, who was a Research Officer with the Radio Research Board of the Australian Council for Scientific and Industrial Research - CSIR (the precursor to the Commonwealth Scientific and Industrial Research Organization – CSIRO). Martyn visited the UK to collect this information and returned it to Australia along with a special report to the Prime Minister. This report led directly to the formation of the Radiophysics Division of the CSIR with Martyn appointed as the first Chief of the Division on 2 September 1939, one day prior to the commencement of World War II. The purpose of this new Division was to specifically focus on the development of radar for the war effort, and the Division ended up making very significant contributions to the introduction of radar in the Southwest Pacific.

Meanwhile, in the U.K. James Hey, who had been drafted into the Army Operational Research Group (AORG) to examine the performance of British Army radar, was investigating jamming by the German Forces. On 27 and 28 of February 1942 severe jamming noise was reported across many radar sites, but no enemy attack was evident. Hey recognised that the maximum levels of interference appeared to follow the direction of the Sun as it rose in the east and tracked westward, coincidentally in the same direction from which a German jamming attack would commence. As Hey recalled:

> "I immediately telephoned the Royal Observatory at Greenwich to inquire whether there was any unusual solar activity, and was informed that although we were within two years of the minimum of the sunspot cycle, an exceptionally active sunspot was in transit across the solar disk and situated on the central meridian on 28 February. It was clear to me that the Sun must be radiating electromagnetic waves directly – for how else could the coincidence in direction be explained – and that the active sunspot region was the likely source. I knew that magnetron valves generated centimetric radio waves from the motion of electrons in kilogauss magnetic fields, and I thought why should it not be possible for a sunspot region, with its vast reservoir of energy and known emission of corpuscular streams of ions and electrons in magnetic fields of the order of 100 gauss, to generate metre wave radiation." (Hey, 1973).

Hey (1942) wrote a paper on his findings, but this research was classified under the wartime Secrecy Act and so its publication in scientific journals would have to wait until the end of hostilities in 1945.

Independently, also in 1942, George Southworth was conducting work on developing more sensitive centimetric receivers at Bell Telephone Laboratories in the U.S. He also detected radiation from the Sun and concluded that this was the natural blackbody radiation spectrum extending down into radio frequency for a blackbody of 6,000 K, which was the photospheric temperature of the Sun (unfortunately Southworth made an error in the calculation of the temperature conversion and so he failed to recognise that the temperature was actually 18,000 K (Pawsey and Bracewell, 1955:150)). Like Hey's report, Southworth's initial report was also classified (Southworth, 1942), so it was actually Grote Reber who became the first person to publish in a scientific journal on the radio frequency detection of the Sun (Reber, 1944).

Although both Hey and Southworth's papers of these discoveries were restricted, their findings were discussed with colleagues working in radio, ionosphere and radio communications research. Their findings were however often met with a degree of disbelief, or more often just ignored. As Bolton noted:

> "Those of us who were associated with low frequency radar during the war regarded it [extraterrestrial radio noise] as a nuisance which could limit the detection range of enemy aircraft" (Bolton, 1990: 381).

Pawsey (1961a) has noted that in 1944, F.J. Kerr made, "a preliminary attempt to observe cosmic radio waves but was frustrated by claims of military work".

In early 1945, New Zealand Air Force radar stations operating at 200 MHz observed similar radiation from the Sun as had been detected by Hey. This work was carried out by Elizabeth Alexander and was shared with Australian researchers, but apart from a brief report (Alexander, 1945), remained unpublished (see Orchiston, 2005; Orchiston et al., 2006).

At the end of World War II, the role of the Radiophysics Division was altered to focus solely on peace-time activities. This was a pivotal moment in the birth of radio astronomy in Australia. The decision was made by the then Chairman of the CSIR, Sir David Rivett. It meant that a highly-developed laboratory with a trained and experienced staff became available for a wide range of research and practical developments. Edward George 'Taffy' Bowen (1911-1991: Hanbury-Brown et al., 1992) replaced Fredrick White as the Chief of Radiophysics and oversaw this transformation. White had replaced Martyn in late 1940, initially on an interim basis, however in 1942 this became permanent when Martyn was transferred to the post of Director of the Army Operational Research Group. Martyn harboured an ongoing institutional and personal resentment against what he saw as a demotion (Robertson, 1992: 26).

Bowen had been heavily involved in the development of airborne radar in the U.K. as part of the war effort. At the time the Division had approximately 200 staff who were highly skilled in electronic research and development. Bowen prepared a draft report on the "Future Programme for the Division of

Radiophysics" which was presented for consideration to the 35th Session of the Council of the CSIR. The report was 26 pages in length and contained a short paragraph, titled "Study of Extra-thunderstorm sources of Noise (Thermal and Cosmic)":

> "Little is known of this noise and a comparatively simple series of observations on radar and short wavelengths might lead to the discovery of new phenomena or to the introduction of new techniques. For example it is practicable to measure the sensitivity of a radar receiver by the change in output observed when the aerial is pointed in turn at the sky and at a body at ambient temperature. The aerial receives correspondingly different amounts of radiant energy (very far infra red) in the two cases. Similarly, the absorption of transmitted energy in a cloud can be estimated in terms of the energy radiated to the receiver by the cloud. None of these techniques is at present in use." (Bowen, 1945: Section 1.2).

On the basis of this report, a number of independent research groups were formed focusing on air navigation, cloud physics, electronic computers, transistors, and as described above, investigation of radio noise sources. The radio noise investigation group was headed by Joseph Lade Pawsey (1908-1962: Kerr, 1963), and would later become known as the Radio Astronomy Group. Almost from the beginning of the solar and cosmic research by Pawsey's Group there was a close collaboration with the Commonwealth Solar Observatory at Mount Stromlo, as noted in the first official Programme of the Division of Radiophysics (Bowen, 1946: Section 1.2 Solar and Cosmic Noise at Radio Frequencies).

Pawsey had joined the Radiophysics Division in 1940 and had been a team leader of a research team producing radar systems. He had worked at the Cavendish Laboratory at Cambridge under J.A. Ratcliffe and had very early exposure to radio astronomy from his visit during the war to the Bell Telephone Laboratory, where he became aware of George Southworth's work on solar radio emission. Pawsey also had access to the then still secret work of James Hey, and to the New Zealand solar detections on equipment that was similar to the radars being used in Australia. With this background Pawsey, together with fellow researchers Lindsay McCready and Ruby Payne-Scott, set out to conduct the first serious project in radio astronomy in Australia in the later part of 1945. In October 1945, at Collaroy, about 20 kilometres north of Sydney, they used a Royal Australian Air Force (RAAF) 200 MHz coastal defence radar antenna operating in its passive receive mode to conduct solar observations. They noted that the radio emission that was detected indicated a temperature of up to one million Kelvin for some regions of the Sun. At this time conventional optical measurement suggested a surface temperature of 6,000 K. Their results -- the first Australian paper on Radio Astronomy -- were published in *Nature* in 1946, and the paper was titled, "Radio-frequency energy from the Sun" (Pawsey et al., 1946). A separate paper by Pawsey (1946) was later published in *Nature* alongside a theoretical paper by David Martyn (1946b) that predicted a temperature of 1 million K for the corona. David Martyn was at this time working as an ionospheric physicist at the Commonwealth Solar Observatory at Mount Stromlo near Canberra in

Australia. There has been some minor controversy as to whether Pawsey's determination of the 1 million K temperature preceded Martyn's theoretical prediction or was conducted in confirmation of the predication. Hey (1973: 42) has argued that it was clearly Pawsey's experimental results that triggered Martyn's paper. It is interesting to note that Pawsey's paper acknowledged Martyn's work, but not vice versa, even though there had been a number of discussions between the parties prior to publication. As mentioned earlier, Martyn had previously been Chief of the Radiophysics Division, but because of a combination of issues associated with his management approach and security concerns he had been seconded to the Commonwealth Solar Observatory and replaced by Bowen as the head of the Division. For this reason he retained bitterness, particularly towards Bowen, and a keen sense of rivalry towards his former colleagues. In a detailed analysis of events, Sullivan (2005: 19) has concluded that it was indeed Martyn who brought attention to the earlier astronomical evidence indicating the possibility of the million degree temperature in the corona, and that it was also likely that Martyn pointed out that the 'apparent' temperature measured by the Radiophysics team could actually be equated to thermal emission from the corona.

In March, 1946 a young Leading Aircraftsman stationed with the Royal Australian Air Force in Darwin wrote to Radiophysics about his own experiments in detection of solar radio noise using a C.O.L. Mk. 5 Radar operating at 200 MHz (Slee, 1946). This was Bruce Slee, who would go on to become a very distinguished Australian Radio Astronomer. He received a very encouraging reply from J.N. Briton (1946) who was then Head of the Division with details of Radiophysics' own research as well as an offer to visit the Radiophysics Laboratory if he were ever in Sydney.

Although the Collaroy work had been successful, one of the problems confronting the group was the low resolution of the 200 MHz radar antenna with a beamwidth of ~10°. This limited their ability to determine where on the Sun's disk the emission they detected had occurred, as the Sun's disk is only thirty arc minutes in diameter when observed from Earth. In a breakthrough, Pawsey's team established that interferometry could be used to improve resolution. The first interference fringes were observed on Australia Day (26 January) 1946. A landmark paper was eventually published in 1947 (McCready et al., 1947) after a lengthy and controversial delay by the British journal, *Proceedings of the Royal Society* (Orchiston et al., 2006: Note (2)). This paper laid the foundations for interferometry and the use of Fourier techniques in radio astronomy. A dedicated Radiophysics field station was established at Dover Heights to further the sea-interferometry research in place of relying on shared access to the RAAF site at Collaroy (see Bolton, 1982; Slee, 1994).

The Dover Heights site consisted of a concrete blockhouse on the edge of a 278-ft sea cliff, with the receiving aerials located nearby (McCready et al., 1947: 359). The configuration thus acted as an interferometer. Radio signals from the Sun as it rose over the eastern horizon were detected via the direct path, but also from the reflected path from the ocean's surface. Because the path lengths were different the arriving wavefronts constructively and destructively interfered in a Lloyd's mirror effect. Shortly after the receiving equipment was first set up at Dover Heights, a very compact sunspot group appeared. The combination of these observations together with the earlier observations at Collaroy, and a description of the interferometry approach, was published in the initial paper in *Nature*. The early-morning interference patterns recorded at Dover Heights established beyond doubt that the strong increase in radio emission observed as a vertical strip from the interferometer measurement correlated directly with sunspot regions on the solar disk. This paper also suggested the application of Fourier synthesis as an analytical technique although it was not until the advent of the digital computer that this technique could be fully exploited.

At approximately the same time a group of astronomers led by Martin Ryle at Cambridge University had independently developed interferometry and had also correlated radio emission with sunspots. In this case they used a two-element interferometer rather than the sea-interferometer technique. Although, strictly speaking, their observations occurred later, they succeeded in getting their work published ahead of Pawsey's group (Ryle and Vonberg, 1946).

During 1946 Pawsey had also attempted to confirm Hey's newly-reported discovery of a fluctuating cosmic source in the constellation of Cygnus. There is some disagreement in the historical record as to the success of these initial attempts to detect the Cygnus source. Robertson notes:

> "Within days he [Pawsey] had confirmed the existence of signals from Cygnus and also noted how fluctuations were not unlike the type of 'bursts' observed in solar noise." (Robertson, 1992: 44).

Bolton (1982) recalled that Pawsey was unable to repeat Hey's result, and this may be supported by the fact that no paper was published on the subject at that stage.

At this same time Pawsey was actively seeking to expand the emergent group and recruited two young physicists who were to become prominent figures in radio astronomy – John Paul Wild and John Gatenby Bolton (Wild and Radhakrishnan, 1995). Wild was not actively involved in the observational work at Dover Heights and was initially assigned to work in the Laboratory's Test Room. Bolton however went on to provide the foundations for research at Dover Heights.

It was David Martyn who suggested to Bolton that he investigate the polarization properties of sunspot radiation (Bolton, 1982). Martyn (1946a), working at Mount Stromlo using a 4-element Yagi array that had been installed by Radiophysics, had observed that the radiation was circularly polarized and reversed sense with passage of the central meridian. Bolton set out to test this observation, but unfortunately the Sun at this stage had returned to an almost dormant state. Despite this set back he and his assistant, Bruce Slee, set out to see if they could detect any other astronomical bodies using the two Yagi arrays in a parallel configuration looking out over the sea. Bolton's knowledge of astronomy at the time was at best very rudimentary. Their reference library consisted of only two astronomy books, *Astronomy* by Russell, Dugan and Stewart and *Norton's Star Atlas* (Bolton, 1982). With these they attempted their initial survey work. According to Bolton (1982: 349), this lasted for only about two weeks when Pawsey arrived to inspect their progress on the solar radiation work and found that the Yagi arrays were not pointing at the Sun! Their observations were cut short and both men were re-assigned to work back at the Laboratory, curtailing any further research at Dover Heights in 1946. Wild (1987: 99) has suggested that Bolton's recollection of the circumstance leading to his re-assignment to the Laboratory seemed out of character for Pawsey.

1946 had proved a defining year for radio astronomy in Australia. Pawsey's group had pioneered the technique of radio interferometry to improve resolution. This technique would become of central importance to the development of radio astronomy throughout the world, although Australia's contribution would be clouded by the rivalry from the Cambridge group (Mills, 1984). The group had also done much of the work to clarify the nature of radio emission from the Sun and had also identified sunspots as a source of radio outbursts through the use of interferometry.

In late February 1947 fortunes turned for Bolton. After his banishment from Dover Heights, he had been working in the Laboratory building equipment for a solar eclipse expedition that was to have been conducted in Brazil (see Wendt et al., 2008). The expedition was, however, cancelled and Pawsey told Bolton, "If you can think of anything to do with all this equipment – you can have it" (Bolton, 1982). He also allowed Bolton to have Gordon Stanley assist him. Bolton quickly gathered the equipment and relocated to Dover Heights. Their first task was to construct receiving equipment that would allow them to listen to the Cricket Test Match between England and Australia, which they completed by 11am on their first day.

Soon after they had set up their equipment a large bipolar sunspot appeared on the limb of the Sun. After about a week of monitoring this spot, a very large solar outburst was detected on 200 MHz, 100 MHz and 60 MHz receivers which lasted for approximately 15 minutes in total. This was the first outburst of its kind to be observed and would later be classified by Paul Wild as a Type II outburst. Based on their observations of detection time at the different frequencies they estimated an outward velocity for the outburst in the solar corona of approximately 1,000km/s, which gave a time of travel to the Earth of approximately 26 hours. On the following evening a prominent aurora was observed in Sydney, an extremely rare event given the city's latitude of 34° S. These observations were published in *Nature* in a paper titled "Relative times of arrival of bursts of solar noise on different radio frequencies" (Payne-Scott et al., 1947). The paper appeared together with data by Ruby Payne-Scott and Don Yabsley recording delays of the order of 1 second between short solar bursts observed at two frequencies. These observations showed that solar flares were associated with streams of charged particles, electrons and ions, which travelled at very high velocities through the solar atmosphere. As the charged particles reached the more rarefied corona, radio emission occurred at progressively longer wavelengths, accounting for the delays observed between the different wavelengths. The following day as the solar storm continued Payne-Scott et al. finally managed to detect the circular polarization that they had set out to find in late 1946 and which Martyn had predicted.

In August 1947 a smaller field station was operating at Georges Heights overlooking the entrance to Sydney Harbour (Orchiston, 2004b). Like Dover Heights and Collaroy, this site had been a radar station during the war. An ex-experimental 16-ft × 18-ft alt-azimuth mounted radar antenna had been converted to observe solar radiation at 200, 600 and 1,200 MHz. These observations were conducted by Fred Lehany and Don Yabsley (1949) and contributed to a better understanding of emission from solar flares and correlations to sunspots at higher frequencies (600 & 1,200 MHz) and were complementary to the solar observations being conducted at Dover Heights at the same time.

In June 1947, Bolton and Stanley switched their attention to non-solar sources of radio emission and set out to conduct an empirical search using sea interferometers at 100 MHz and 200 MHz. They quickly detected the Cygnus A source that had been previously been reported by Hey and which Pawsey had earlier unsuccessfully tried to detect. Of key importance was the nature of the interference patterns they detected, which indicated that the angular size of the source could be no more than eight arc minutes in diameter, which was a significant improvement on the early angular size estimate of being less than or equal to two degrees (Hey et al., 1946). They monitored this source for some months while attempting to improve their techniques and eventually wrote up their findings in November 1947 (Bolton and Stanley, 1948b). While Hey had inferred that Cygnus A was point-like, Bolton and Stanley's work now provided proof.

On 6 November 1947, Bolton and Stanley – who had been joined by Slee – detected a second source, Taurus A, which would later be identified with the Crab Nebula which is the remnant of a supernova reported by Chinese astronomers in A.D. 1054 (Mitton, 1978: 15). Shortly after this they detected two other sources, Virgo A and Centaurus A, and at least two other possible sources.

Thus, 1947 heralded the genesis of non-solar radio astronomy in Australia. This work was of fundamental significance in radio astronomy because it raised a number of key questions: What was the origin of these discrete sources? How many other sources were there, and how were they distributed? What was the cause of the variability in the Cygnus source? Was it possible that most of the 'cosmic static' originated from discrete sources rather than large clouds of ionized interstellar gas as Jansky and Reber had proposed?

While the majority of observational work was being conducted at the field stations, in 1948 some important high frequency solar observations were conducted by Norman Labrum, Harry Minnett and Jack Piddington using a converted WWII search light antenna (mirror) located in the 'Eagle's Nest' on top of the Radiophysics Laboratory in the grounds of Sydney University. They found the day-to-day variation in radiation at the higher frequency of 24,000 MHz was only a few percent and that the emission was consistent with 84% of the radiation coming from a uniform disk and 16% from a narrow ring around the circumference which they concluded was consistent with Martyn's prediction of limb-brightening (Piddington and Minnett, 1949b). This instrument was also used to observe the Moon at 24,000 MHz (Piddington and Minnett, 1949a). From these observations they concluded that the radio thermal emission was consistent with the Moon having a solid surface covered by a thin layer of dust about 40 cm in depth.

It was also at this time that the need for a new field station arose. At a site at Bankstown aerodrome, R.F. Treharne and A. Little were engaged in an program to develop a 100 MHz solar interferometry instrument that would become the swept-lobe interferometer described in Section 10.4.5. In the September 1947 monthly report to the Solar Noise Research Group, Treharne and Little noted:

> "Our building at Bankstown has been "sold". Eagles and Burgman are attending to the acquisition of another building." (Pawsey, 1947f).

In November 1947, they reported that:

> "The gear is now installed at Bankstown and that drift interference patterns have been obtained. The motor phase shifter is still under construction." (Pawsey, 1947c).

By April 1948, Payne-Scott was assigned to supervise the swept-lobe interferometry project, replacing Treharne. Payne-Scott was also still working with M. Clark at the Hornsby Valley field station, recording solar observations with a circularly-polarised 85 MHz aerial. In their monthly report Payne-Scott and Little noted:

> "A search for a site to replace Bankstown has resulted in the choice of Potts Hill reservoir (which should also provide a suitable stretch of water for K-band interferometry); negotiations with the Waterboard have begun. Meanwhile equipment is being made to replace that stolen, and some obvious faults in the system are being remediated" (Pawsey, 1948c).

The report also noted that Christiansen had assumed responsibility for the 200, 600 & 1,200 MHz solar observations at Georges Heights. In his report he noted that it was not possible to perform measurements due to problems with the alt-azimuth mount of the 16-ft × 18-ft Paraboloid.

In a letter to Pawsey, McCready reported:

> "We've found a good site on a large area of fenced in and reasonably guarded land at the Potts Hill reservoir between Lidcombe and Bankstown. Takes only 5 minutes longer to reach there by car than Georges Heights and large areas of water offer some possibilities for Harry Minnett and K-Band interference patterns. By a fortunate coincidence the Water Board Engineer with whom arrangements have to date been conducted visited a RP party sometime ago and quoting him "knew all about Solar Noise". He is most anxious to help us." (McCready, 1948a).

The Water Board employee referred to by McCready, was H. A. Stowe who was the Chief of Electrical Engineering. Stowe had been one of the early Australian Amateur Radio Operators and he maintained a keen interest in the activities of the Radiophysics Division that continued even following his retirement from the Water Board in 1957 (Stowe, 1962).

By August 1948, Payne-Scott and Little had installed the Swept-Lobe Interferometer at Potts Hill and obtained their first lobe patterns (McCready, 1948c).

The new site at Potts Hill provided an opportunity to consolidate the solar program, and the 1 November 1948 partial solar eclipse that would be visible throughout south-eastern Australia provided the catalyst for action. The eclipse observations presented the rare chance to more accurately determine the locations of localised radio emission on the solar disk by observing the timing of their occultation by the Moon's disk during the eclipse. In the later part of 1948 therefore, the Radiophysics Division established Potts Hill as its main solar radio astronomy field station and over the first half of the next decade it would become the Division's major field station, before ultimately succumbing to the urban growth of Sydney's western suburbs.

9.1. The Division of Radiophysics

Immediately after World War II the focus of the Radiophysics Division had shifted to peacetime research. Pawsey (Figure 2) headed the overall research group of the Division, under Bowen. Sullivan (2005) has extensively discussed the beginnings of radio astronomy in Australia, including the key role that both Bowen and Pawsey played in leading and fostering the development of a group that by the late 1950s had produced more research papers in radio astronomy than any other group in the world.

Immediately following the war, the research group comprised four main subgroups: Propagation, Radar Meteorology, Mathematical Physics, Standards and Vacuum Physics. The Propagation group was soon renamed the Solar Noise Group and following that became known as the Radio Astronomy Group in April 1949 (Christiansen, 1949a).

Figure 2: Dr. J.L. Pawsey (Courtesy of ATNF Historical Photographic Archive: B7454-1).

The June 1947 structural chart of the Radiophysics Division shows that the Propagation Group was organised into four subgroups (1947):

a)	Piddington:	Minnett
		Hindman
b)	McCready:	Payne-Scott
		Yabsley
		Smerd
		Bolton
		Stanley
		Slee
		Medhurst
c)	Kerr:	Shain
		Higgins
d)	Munro:	Treharne

Piddington was the senior member of the Group as a Principal Research Officer. The next most senior member was McCready as a Senior Research Officer. Of this group, Piddington, Minnett, Hindman, Payne-

Scott, Yabsley and Smerd would all go on to conduct research at the newly-established Potts Hill field station.

It is interesting to note when the term 'radio astronomy' was first adopted at the Radiophysics Division. During a visit to the U.S. in 1947-1948, Pawsey was invited to attend a meeting that was being organised by C.R. Burrows of Cornell University. It was intended that this meeting be held immediately preceding the March 1948 I.R.E. Convention. The title of the meeting was *Microwave Astronomy*. In reply to a letter from Pawsey on the topic Bowen stated:

> "I don't think much of Burrows' invention of the title "Microwave Astronomy". A lot of it is certainly not microwave and I am not at all sure whether it is astronomy." (Bowen, 1948c).

Pawsey did not attend this meeting, but while in the U.K. received another invitation to submit material for a session during the May 1948 U.S.R.I. Conference, titled *Radio Astronomy*. This session of the conference was chaired by J.P. Hagen. This time in response to Pawsey's advice, Bowen wrote:

> "Incidentally, I like the term "Radio Astronomy" much better than Burrows' effort and we might very well consider adopting it generally." (Bowen, 1948d).

Just over a year later the term 'radio astronomy' was formally adopted by Radiophysics with the change of name of the *Propagation Committee* to the *Radio Astronomy Committee*, as noted in the minutes of the meeting of the 11 April 1949 (Christiansen, 1949a).

The headquarters for the Radiophysics Division was located on the grounds of Sydney University. This acted as the hub of activity for the Division. From its beginnings in radar research the Division had operated a number of remote field stations. Originally these were generally at military sites. However, with the shift to peace-time activities new sites were being sought out. For a discussion of operations at the various field stations see Orchiston and Slee (2005a).

Pawsey coordinated the activities of the field stations and the overall research programme through a series of regular meetings at headquarters, but also by regularly visiting the field stations. Although he had increasingly less time for his own research, he had a major influence and his contribution was acknowledged in nearly all of the published works emanating from the Radio Astronomy Group.

J.D. Murray's recollection (2007) of the early meetings (1948-1951) of the Solar Noise Group was that it always seemed simple to get support to justify solar research within the group, but much harder to justify looking at cosmic sources. He felt this was left over from experiences during World War II. The passage of two German warships through the English Channel undetected by radar (presumably due to solar noise) meant that any research that could shed light on solar noise was always well supported. This would change substantially in later years with the success in identifying discrete cosmic sources (Bolton et al., 1949).

Pawsey promoted a strong relationship between theoretical and observational work. On 18 May 1948 he wrote a three page memo to the group outlining his views on the relationship between pursuing research on 'theoretical lines' and 'exploratory lines'. He concluded his memo as follows:

> "And finally may I remark that a research group is not healthy unless the theoreticians indulge in forceful criticisms of the practical people and vice versa. Out of the clash of personalities come ideas, but it is equally essential that the criticism should be open and friendly and accompanied by a generous measure of admiration for the other man's speciality even though it happens to be a lowly or useless branch of human achievement in comparison with one's own." (Pawsey, 1948b).

In 1948 Christiansen had joined the Division as a Senior Research Officer, which was of the same level as McCready and second only in seniority to Piddington. After initially working at the Georges Heights field station, Christiansen joined Payne-Scott and Little at the newly-established Potts Hill field station to observe the partial solar eclipse of 1 November 1948. He was joined by two other teams, Piddington and Hindman, and Minnett and Labrum, who conducted their own observations of the eclipse at different frequencies. Potts Hill became the centre of the Division's solar program, with the exception of the solar spectroscopy work which had been initiated at Penrith by Paul Wild and then relocated to Dapto.

In 1951, Kerr returned from a fellowship in the U.S. and took over from Christiansen the work program on the newly-discovered H-line. Christiansen returned to his solar research, which he maintained for the remainder of his time at Potts Hill.

As the activities of the field stations expanded, coordination became more difficult and at times their activities could also be in competition. The minutes of the meeting of senior officers of the Radio Astronomy Group held on 21 August 1951 detailed the demarcation of research and some of the protocols to be applied within the group (Mills, 1951a). In attendance at this meeting were Pawsey, Mills, Bolton, Piddington, Bracewell, Shain, Gardner, Smerd, McCready and Wild. The allocations, listed in Table 1, were agreed:

Table 1 - Research Topic Allocations

Area	Research Focus	Principle Researcher
Observational Research:		
Ionosphere	D-region temperature and echoes	Gardner
Ionosphere	Long waves	Bracewell
Sun	Metre waves – Interferometry and Spectrometry	Wild

Sun	Decimetre waves – Examining and continuing records	Piddington
Sun	Decimetre waves – Interferometry	Christiansen
Cosmic	18 mc/s & 19 mc/s	Shain
Cosmic	Metre waves – Cliff Interferometry	Bolton
Cosmic	Metre waves – Michelson Interferometry	Mills
Cosmic	1420 mc/s – Preliminary experiments	Christiansen (Kerr)
Cosmic	1420 mc/s – Development of gear	McCready
Cosmic	1420 mc/s – Subsequent work	Kerr (tentative)
Non-Observational Research:		
Hydrogen	Theory of spectrum emission	Wild
Sun & Cosmic	Review of emission mechanism	Piddington
Sun & Cosmic	Review of quiet Sun	Piddington
Sun	Burst theory	Smerd
Sun	Editing of QBSA in place of Allen	Smerd
Sun	Terrestrial (meteorological) relations and exploratory investigations	Piddington

At this time, Piddington, Christiansen and Kerr were the research leaders at Potts Hill. It was agreed at this meeting, that although there was a formal demarcation of research areas, the general goal was still to promote informal collaboration and cooperation. It was also agreed that no new fields of research would be undertaken without first discussing the research with Pawsey, and that all new research papers would be first presented in draft to the Radio Astronomy Group for review.

At times there were also disputes as to priorities on research within a field station. A good example of this was a dispute between Payne-Scott and Bolton at the Dover Heights field station. As Pawsey noted in a letter to Bowen dated 8 December 1947:

> "I had a letter from Lindsay [McCready] in which he mentioned that there had been some sort of showdown between Ruby [Payne-Scott] and John Bolton. This is not unexpected to me as Ruby seemed to me to be getting in the way at Dover [Heights]. As I understand it, Lindsay has the situation well under control, at any rate when he wrote the letter, having arranged a transfer of Ruby's work to Hornsby. I don't think Lindsay had mentioned this to you, and I am only doing so because there might be some future complications in which Lindsay might require your backing. My feeling on the matter is that Lindsay's actions are likely to be above reproach. I also think that Bolton has, through his hard work and effective results, earned the right to take control of Dover, so that anyone working there, shall be doing so at his invitation." (Pawsey, 1947e).

This example shows that Pawsey supported a hierarchy of operations at the field stations with clear lead researchers.

Under Pawsey's leadership the Group took a very open and active approach to research within the Group, but also with external groups, often sharing research results prior to publication. From the very beginning the Group had a very strong relationship with the Commonwealth Observatory at Mount Stromlo. Pawsey also maintained strong relationships with overseas groups, particularly in the U.S., U.K, Canada, France and the Netherlands. Regular visits were conducted and Visiting Fellowships were supported.

As a product of World War II the Group had access to a vast store of surplus military equipment on which to draw for the construction of their original instruments (Sullivan, 2005:12). As time progressed the Group grew and the size and complexity of instruments and projects outstripped the resources of the ex-military stores. Funding of projects was always an issue, requiring a great deal of resourcefulness and creativity in constructing new instruments. However, ultimately the early success of the Group led to increased tension and competition over which projects would receive funding.

By the mid-1950s research at the Potts Hill field station had reached its peak. Insufficient space at the field station and radio interference from the growing suburbs of Sydney had begun to take their toll. Mills was the first to relocate his discrete source research, initially to Badgerys Creek and then to the Fleurs field station. He was later followed by Christiansen who needed a large area to construct his cross array. The solar monitoring work continued at Potts Hill for a period in support of both Dapto and Fleurs. Finally, the H-line survey work at Potts Hill was transferred to Murraybank and then to Parkes. The Potts Hill 36-ft aerial continued to be used as a test bed for receiver trials until the 64-m Parkes telescope was commissioned in late 1961.