12. CONCLUSION

The seminal period of radio astronomy prior to 1960 was arguably the most exciting and innovative era in Australian Radio Astronomy (i.e. see Robertson, 1992: 202). It marked the era before 'big science' projects emerged, a period when small scale projects dominated and radio engineers first entered the domain of the astronomers. For Australia this was a unique period in which it achieved a research leadership position in the new field of radio astronomy. As Hanbury-Brown (1993) remarked, "golden ages in science are rare and should be recorded". This thesis documents the activities at the Potts Hill field station, which operated for 12 years during this 'golden age' of radio astronomy, a period in which rich contributions to the emergent science of radio astronomy were made, both in terms of new instrumentation development and scientific research. Although the Murraybank field station operated for a much shorter period it also provided a significant contribution. The work at both of these field stations has previously not been documented in detail and as such this thesis provides a detailed record of the scientific contributions made.

Ten different types of radio telescope were operated at Potts Hill. Amongst these there were several examples of world-first instrumental developments:

- The Swept-Lobe Interferometer developed by Payne-Scott and Little used a continuously-variable path length between the two Yagi antennae to change the phase of the signal and hence sweep the aerial beam. This innovation removed the restriction of having to wait for the Earth's rotation to move the source through the aerial beam to produce an interference pattern and was hence ideal for locating the position of short duration sources. At the time of its invention interferometry was being conducted either using the sea-interferometry technique (McCready et al., 1947), or using the Michelson interferometry technique that was first used by the Cambridge group (Ryle and Vonberg, 1946). Not only could the Swept-Lobe Interferometer determine a position accurate to 2 arc minutes at 97 MHz, it could also measure the polarisation of the source. The swept or rotating lobe technique was later adapted by the Jodrell Bank group (Hanbury-Brown et al., 1955) and proved useful in their work on determining source sizes for high declination sources.

- The E-W Solar Grating Array was a unique instrument that provided the first regular one dimensional images of the Sun at radio frequency. Earlier, Stanier (1950) working at Cambridge with a two element Michelson interferometer to obtain a brightness distribution across the solar disk, had failed to detect limb-brightening. The E-W Solar Grating Array provided clear evidence of limb-brightening and was able to produce a large data set of one-dimensional brightness distributions across the solar disk at 1,410 MHz. The Cambridge group went on to develop the aperture synthesis mapping technique, producing the first two-dimensional map of the Sun

(O'Brien, 1953; O'Brien and Tandberg-Hassen, 1955). Meanwhile, with the construction of the N-S Solar Grating Array Christiansen and Warburton were also able to produce a two-dimensional distribution. However, in this instance they used the first application of earth-rotational synthesis in radio astronomy to produce their image. The use of the Earth's rotation to provide a variety of scanning angles proved a much simpler method than relocating the elements of an interferometer as had been employed by O'Brien at Cambridge to obtain the wide variety of base-lines necessary to reconstruct a two dimensional image. The grating-style array proved very useful for solar observations; it was quickly adopted by a number of research groups throughout the world, such as the Carnegie Institute in the U.S., the Research Institute of Atmospherics in Nagoya, Japan and the Meudon Observatory in France.

- The development of the Mills Cross was a major instrumental breakthrough and proved especially useful for extra-solar source surveys. The use of a phase-switched interferometer was first introduced at Cambridge (Ryle, 1952) and was one of the contributing factors for which Sir Martin Ryle was awarded the 1974 Nobel Prize in Physics. After gaining experience using a phase-switched interferometer at the Badgerys Creek field station, Mills struck on the idea of constructing a phase-switched crossed-array. This instrument produced a pencil beam response equivalent to the filled aperture of a parabola of the same diameter as the length of the cross arms. Unlike aperture synthesis techniques, it was not necessary to use a complex Fourier analysis to reconstruct the brightness distribution of the filled aperture. The prototype for the Mills Cross was constructed at Potts Hill and not only was the trial successful, but Mills and Little also achieved the first detection of the Large Magellanic Cloud at radio frequency. The 'Mills-Cross' design proved a very economical way to produce a high resolution pencil beam instrument and its design was subsequently adopted by a number of other countries. It is interesting to note that at almost the same time the Jodrell Bank group had considered a similar cross design, but in view of their existing commitment to the construction of the 250-ft dish they did not develop the idea further (Hanbury-Brown, 1953). The cross design also inspired Christiansen to build a new crossed-grating array at the Fleurs field station which became known as the 'Chris-Cross'.

- The Potts Hill 4-channel H-line receiver was the first proposed design of a multi-channel receiver for H-line observations and the idea of using the multi-channel design was quickly adopted by other radio astronomy groups engaged in H-line research. By 1954 multi-channel receivers were under development at the Carnegie Institute in Washington and at R.R.E Malvern in the U.K. The multi-channel receiver development was extended at Murraybank to produce a 48-channel receiver. Murraybank was also the site of the first deployment of digital recording and computer based reduction of observational data in Australia. The Murraybank 48-channel receiver and the digital recording system became one of the first operational instruments on the newly constructed Parkes 64-m telescope when it was commissioned in late 1961.

Although research at Potts Hill initially focused on the Sun, in later years important contributions were also made to cosmic research and in particular the investigation of the distribution of neutral hydrogen in our Galaxy.

The solar research program provided an important contribution to knowledge of the quiet Sun and the slowly varying component. Although certainly not the first eclipse observations in radio astronomy, the 1948 partial solar eclipse observations provided an important confirmation of the association of enhanced sources of radiation with sunspot groups and the slowly varying component. The development of the grating arrays allowed regular daily determinations of brightness distributions across the solar disk, something which was not practical with any other instrument at the time. The grating array observations provided the most comprehensive dataset during the 1950s on the structure of the solar atmosphere at 1,410 MHz and later also at 500 MHz. The data provided confirmation that the quiet Sun component remained constant over prolonged periods and were used to show that the slowly varying component appeared to correspond with chromospheric plage, something that had first been suggested by Dodson (1954) working in the U.S. In a fitting end to the solar research program the final published work from Potts Hill was the observation of the 8 April 1959 partial solar eclipse. Thus 11 years of solar radio astronomy at Potts Hill began and ended with eclipse observations.

Payne-Scott and Little's observations using the swept-lobe interferometer provided the first accurate positional information on solar bursts and evidence of the outward motion through the solar atmosphere of a number of sources. Unfortunately these investigations were cut short by Payne-Scott's resignation. Had this work continued in conjunction with the work being conducted by Wild's group at Dapto to include a spectral analysis, it seems likely that they would have discovered the type IV sources later discovered by Boischot (1958) using the Nançay interferometer in France (Stewart, 2007).

The initial neutral hydrogen survey conducted at Potts Hill by Christiansen and Hindman provided the first radio frequency indications of the spiral arm structure of our Galaxy. This was a remarkable achievement given that both the U.S. group at Harvard and the Dutch group at Leiden had been working in the field for a much longer period. The H-line program marked the beginning of a major international cooperative program. The Dutch group led by Oort soon overtook the Australians with their galactic mapping of the northern sky and they would have to wait some time for the Australians to complete the southern sky survey so their results could be combined to produce the famous 'Leiden-Sydney' H-line map (Oort et al., 1958). This combined work, together with the 600 MHz continuum survey conducted at Potts Hill, were key components in the redefinition of co-ordinates of the Galactic Plane. Australia's southern location provided access to the Magellanic Clouds something that was not possible for the northern hemisphere groups. It is natural therefore that the Australians dominated the early studies with the first neutral hydrogen maps of the clouds produced at Potts Hill. A later Murraybank survey detected the bridge of neutral hydrogen connecting the two clouds as well as finding the first evidence for ‘splitting’ of the Small Magellanic Cloud, suggesting an earlier interaction between the galaxies. Besides missing the opportunity to be the first to detect the 21-cm hydrogen line emission, the other aspect that escaped the Australian’s early work was the discovery by Williams and Davies (1954) at Jodrell Bank that the hydrogen emission could also be studied in absorption. Hagen, Lilley and McClain (1955) working in the U.S. were also able to exploit this discovery to examine the properties of the interstellar medium and to determine the distance to galactic radio sources. This illustrates that while the Australians had made remarkable progress, there were also missed opportunities.

The most notable of the discrete sources discoveries at Potts Hill were made by Piddington and Minnett. Up to this time, work on discrete sources in Australia had been dominated by Bolton’s group working at Dover Heights and later by Mills working first at Badgerys Creek and then at the Fleurs field station. There was intense competition and some disagreement during this period with the Cambridge group, although relationships with the Jodrell Bank group were more cordial. The two major discrete source discoveries at Potts Hill were Sagittarius A, which was associated with the Galactic Centre, and Cygnus X associated with a large Galactic HII region. While Piddington and Minnett attempted to detect M31 at radio frequencies they were unsuccessful and were soon scooped by the Jodrell Bank group who used a much more sensitive 218-ft transit telescope. Also of note during the early period of Potts Hill investigations was Mills’ determination of the position of Cygnus A. Although discounted at the time, Mills had suggested an optical association of the Cygnus A source with an extra-galactic nebula. However, Smith (1951) working Cambridge obtained a more accurate position that ultimately led to the optical identification of Cygnus-A with the faint extra-galactic nebula, first suggested by Mills (Baade and Minkowski, 1954).

As discussed above, British, Dutch and U.S. scientists were prominent in both solar and galactic research during the Potts Hill-Murraybank period. However, many other international groups also made contributions during this period. For example, Covington (1947), working in Canada, showed that strong solar emission was associated with a sunspot group that was occulted during the 23 November 1946 solar eclipse and went on to develop a slotted waveguide array capable of producing strip scans of the Sun at 10.7-cm wavelength. Khalikin and Chikhachev (1947) from the former Soviet Union observed the 20 May 1947 total solar eclipse from a ship near the Brazilian shore and demonstrated that the radio emission at 200 MHz came from the solar corona. The theoretical contribution of the Soviet astronomers, particularly Ginzberg and Shklovsky, was of great importance and included the independent explanation of the million degree temperature of the solar corona, synchrotron emission and predictions of a number of radio frequency spectral lines. The French were also particularly active in solar research conducting a number of eclipse observations and constructing the 169 MHz Le Grande Interferometer de Nançay, which consisted of 32 × 5-m antennas on a 1,600-m east-west baseline and to which a north-south arm was added in 1959. This instrument was used by Boischot (1958) to discover the Type IV solar bursts. The Japanese had recognised solar radio emission as early as 1938 (Tanaka, 1984). In 1949 they began regular solar monitoring and later constructed their own Solar Grating Array. Yet, despite all of these developments, and others, Australia and Britain were widely regarded as the forefront radio astronomical nations at this time (Sullivan, 2004), and Potts Hill and Murraybank played no small part in establishing and maintaining this reputation.

Many of the Australian pioneers of radio astronomy spent time at Potts Hill and by 1952 it was the major field station of the Division of Radiophysics. Ultimately the lack of space and the encroachment of the suburbs of Sydney (with a consequential increase in radio interference) meant that research was shifted to other field stations. In late 1961 the last of the solar monitoring was transferred to Fleurs field station and Potts Hill was decommissioned in 1962. By this time work at Murraybank had also been completed and the field station was no longer used for radio astronomy after 1961. These events signalled the end of an era in Australian Radio Astronomy. With the construction of the Parkes 64-m telescope and later the Culgoora Radio Heliograph, Australian Radio Astronomy had begun a new ear of 'big science' projects.