The Contribution of the CSIRO Division of Radiophysics Penrith and Dapto Field Stations to International Radio Astronomy

Thesis submitted by

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I certify that this thesis is entirely my own work apart from assistance offered by Harry Wendt in obtaining archival material from the National Archives of Australia, discussions with John Murray and Jim Roberts about the early days at Penrith and Dapto Field Stations, and email correspondence with Kevin Sheridan and Donald Mclean. I also made use of the library services provided by the Australian Telescope National Facility (ATNF) , the Anglo Australian Telescope (AAT), the University of Sydney and Macquarie University.

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I would also like to thank Dr. Harry Wendt for assistance in digging into the National Archives of Australia for relevant letters and minutes of meetings before my arrival at the CSIRO Division of Radiophysics, as well as help on other IT matters.

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Finally I would like to thank my family for their encouragement and wish to dedicate this thesis to the memory of three giants in the history of Australian solar radio astronomy, Paul Wild, Steve Smerd and Kevin Sheridan who were my mentors and a continuing source of inspiration throughout my career.

ABSTRACT

This thesis presents a detailed study of the research activities of the CSIRO Division of Radiophysics Penrith and Dapto Solar Group, who, it will be demonstrated, achieved an international reputation in solar radiophysics during the period 1949 to 1964, by innovative design of observing equipment and by ground breaking investigations into the nature of metre wavelength solar radio bursts and the disturbances which give rise to them.

An account of the planning, development and implementation of the world's first radiospectrograph at the Penrith field station in 1949 and its extensions to increasingly lower frequencies at the Dapto field station from 1952 to 1963, as well as the first swept-frequency interferometer, is presented using archival material, personal reminiscences and published literature.

The Penrith observations led to the first classification of Spectral Type I, II and III bursts. The observed frequencies of the leading edges of the slowly drifting Type II bursts and the rapidly drifting Type III bursts were converted to radial heights by using a standard coronal density model and by assuming that the radio emission occurs at the fundamental plasma frequency. This was referred as the *plasma hypothesis*.

The resulting height-time plots suggested that the disturbances exciting the radio emissions moved outwards through the corona with velocities of the order of 1000 km/sec for Type II bursts and 100,000 km/sec for Type III bursts. This was the first evidence for the ejection of corpuscular material to such great heights in the corona and it was suggested that the Type II disturbance upon reaching the Earth might be responsible for initiating geomagnetic storms which disrupt radio communication. Likewise the fast moving Type III disturbance was considered to be a possible candidate for solar cosmic rays, although the exact nature of the particles involved in the emission of Type II and III bursts was not known at that time.

The development of an improved radiospectrograph at Dapto led to the discovery in 1954 of fundamental and second harmonic components in both Type II and III bursts. This discovery gave support to the plasma hypothesis and allowed the height-time plots to be extended to greater heights in the corona. Further low frequency extensions to the spectrograph from 1956 to 1961

pushed the investigations to even greater coronal heights until it was established that the fast moving electron streams responsible for the Type III burst moved virtually unimpeded out to heights of at least 3 solar radii above the photosphere. This height was the limit that could be observed by ground based radio observations because of absorption effects in the Earth's ionosphere at frequencies below 7 MHz. Also, the Type II disturbance was traced to similar heights indicating that the shock wave responsible also escaped into interplanetary space.

Final confirmation of the *plasma hypothesis* was obtained with the development of the swept-frequency interferometer at Dapto in 1957. The radial heights found subsequently for Type II and III sources were in good agreement with coronal density models assuming, as before, that the emission occurs at the fundamental and second harmonic plasma level. An earlier experimental model of the interferometer, the first of its kind, had been installed at Dapto in 1954 for the study of radio scintillations from the source Cygnus A.

Later, spacecraft observations confirmed that the Type III bursts were associated with electron streams travelling outwards towards the earth along Archimedes spiral paths, at speeds of the order of c/3 in agreement with the earlier Dapto results. Similarly, the Type II burst was found sometimes to be associated with interplanetary shock waves and ejected plasma clouds known as coronal mass ejections (CME's). The latter are considered now to be the initiating cause of the Geomagnetic disturbance. The close association of Type II-IV bursts with CME's is why ground based radiospectrographs are still used today to monitor space weather.

The Dapto observations also led to the classification of a new type of burst called the Type V which sometimes followed Type III bursts. A model was proposed for this event in which some of the Type III electrons became trapped in coronal magnetic fields to produce the longer duration and broader bandwidth Type V burst. Other phenomena discovered at Dapto included the reverse drift pairs (RDPs) which were closely associated with Type I storms and the split-band and *herring-bone* structure in Type II bursts. The RDPs were thought to be evidence for radio echoes in the corona while several magnetic theories were proposed for the split-band structure in Type II bursts. The *herringbone* features were found to be highly polarized suggesting that the Type II shock wave excited streams of fast electrons as it moved across magnetic field lines in the corona.

The only metre wavelength burst not discovered by the Australian group was the Type IV, first classified by the French in 1957, who attributed the emission to synchrotron radiation from electrons spiralling along magnetic field lines in the corona. Dapto interferometer observations revealed that the Type IV had two components, an early moving source, called the *moving Type IV burst*, followed by a stationary source called the *stationary Type IV burst*. A model was proposed to account for the observed characteristics of the moving Type IV burst, which involved an ejected plasmoid, containing relativistic electrons generating synchrotron radiation, behind a Type II shock wave. The second stationary component lasted several hours before degenerating into a Type I storm. It was assumed that the fast electrons generating plasma emission in these stationary sources were trapped in magnetic fields above the flare region. Spectral observations of slowly drifting chains of Type I bursts were taken as evidence that the emitting electrons were excited by Alfven waves in the corona.

Although the Solar Group concentrated mainly on the collection and interpretation of the observed properties of solar radio bursts at metre wavelengths, several important contributions of a theoretical nature also were produced and theories reviewed. These concerned the propagation of electron streams and shock waves in the corona, as well as the conditions required for coherent plasma wave emission which occurs in Type II and Type III bursts. Also a two phase acceleration process for flare particles was propose based mainly on metre wavelength observations of solar bursts.

By the early 1960s the Division of Radiophysics had been granted funding to build a radioheliograph at Culgoora, NSW. As a result the Dapto Field Station was closed down in 1964. Solar radio observations continued at Culgoora from 1967 until 1984.

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