# THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 10: SHAIN, GARDNER, AND JOVIAN OBSERVATIONS MADE AT FLEURS AND POTTS HILL FIELD STATIONS IN SYDNEY DURING 1955–1956

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**Abstract:** In 1955–1956, soon after the announcement by Burke and Franklin of the existence of decametric bursts from Jupiter and Shain's report on pre-discovery observations carried out in Australia in 1950–1951, Alex Shain and Frank Gardner carried out observations of this emission at 19.6 MHz from the CSIRO's Division of Radiophysics Fleurs and Potts Hill field stations in Sydney. Some Fleurs observations also were conducted at 14 and 27 MHz. This paper[1] reports on these observations, made prior to Shain's untimely death in 1960.

**Keywords:** low frequency radio astronomy, Jupiter, Fleurs, Potts Hill, Shain, Gardner

## 1 INTRODUCTION

Radio emission from Jupiter was first detected by Bernard Flood Burke (1928–2018; Figure 1a) and Kenneth Linn Franklin (1923–2007; Figure 1b)[2] using the Carnegie Institution of Washington's 22.3 MHz 'Mills Cross' at Seneca (Maryland) in 1955 and was first announced in a paper published in the *Journal of Geophysical Research* (Burke and Franklin, 1955), titled "Observations of a variable radio source associated with the planet Jupiter."[3] As has been pointed out else-where,

> This was not a journal that habitually was read by radio astronomers, but the magnitude of this discovery—the first detection of radio emission from a planet in our Solar System other than the Earth—guaranteed that it found its way into *Nature* (Radio emission from Jupiter, 1955), and this gave it a very wide audience … (Orchiston et al., 2015b: 299).

The 'discovery paper' was followed soon after by others (Franklin and Burke, 1956a; 1956b), and then long after the event Franklin (1983) reminisced on these halcyon days in his short-lived research career. By 1983 he was well-established as an astronomy educator at the Hayden Planetarium in New York.

As might be imagined, the unexpected discovery of radio emission from another body in our Solar System other than our Sun created an international sensation, and prompted C.A. Shain (1922–1960; Figure 2a; Pawsey, 1960)[4] from the CSIRO's Division of Radiophysics in Sydney to reflect on the study of galactic emission at 18.3 MHz that he and his Technical Assistant Charlie Higgins (Figure 2b) had carried out at Hornsby Valley field station on the north-


Figure 1a (left): Bernard Burke at an IAU meeting late in life (courtesy: IAU on-line membership directory); Figure 1b (right): Kenneth Franklin (https://en.wikipedia.org/wiki/Kenneth_Franklin#/media/File:Kenneth_L._Franklin.jpg).

Figure 2a (left): Alex Shain (cropped close-up taken from CSIRO Radio Astronomy Image Archive—henceforth CRAIA—B2842-133); Figure 2b (right): Charlie Higgins (cropped close-up taken from CRAIA, B2842-132).

ern outskirts of suburban Sydney (Figure 3) between June 1950 and June 1951 (Shain, 1951; see, also, Orchiston et al., 2015b).[5]

During their observations Shain and Higgins had noticed that

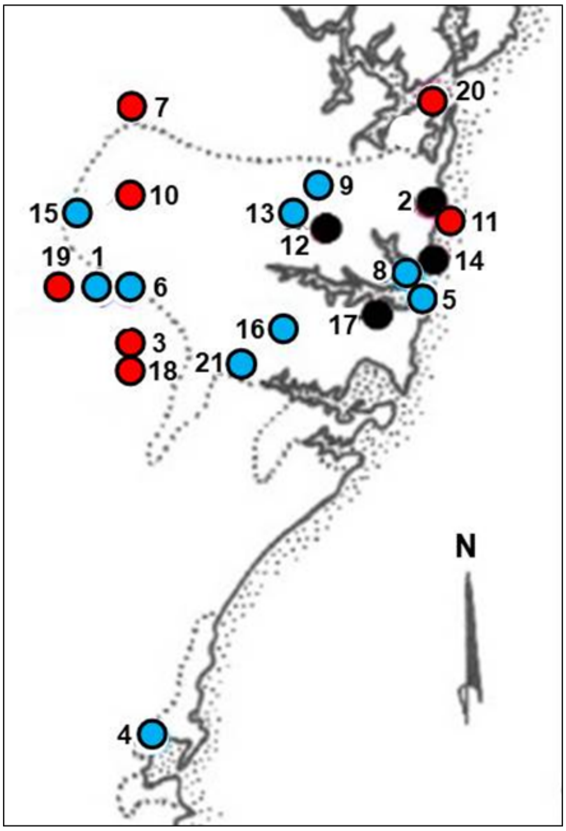


Figure 3: A map showing CSIRO Division of Radiophysics field stations (blue circles), remote sites (red circles) and other localities (black circles) in the Sydney (upper dotted boundary) and Wollongong (lower dotted boundary) regions between 1945 and 1965. Key: 1 = Badgery's Creek; 2 = Collaroy Plateau; 3 = Cumberland Park; 4 = Dapto; 5 = Dover Heights; 6 = Fleurs; 7 = Freeman's Reach; 8 = George's Heights; 9 = Hornsby Valley; 10 = Llandilo; 11 = Long Reef; 12 = Marsfield (Radiophysics headquarters, from 1968); 13 = Murraybank; 14 = North Head; 15 = Penrith; 16 = Potts Hill; 17 = Radiophysics headquarters, to 1968; 18 = Rossmore; 19 = Wallacia; 20 = West Head; 21 = Bankstown Aerodrome. Field stations discussed in this paper are Fleurs (6), Hornsby Valley (9) and Potts Hill (16). Scale: site 15 to site 11 ≈ 60 km (map: Wayne Orchiston).

> Quite frequently there was interference from atmospherics and radio stations; *thus no particular significance was attached to the occurrence of occasional groups of bursts during the night*. (Shain, 1956: 62; our italics).

However, upon investigation, Shain (1955; 1957) determined that much of this 'interference' in fact emanated from Jupiter. Examples of groups of Jovian bursts recorded at Hornsby Valley in 1950 and 1951 are shown in Figure 4.

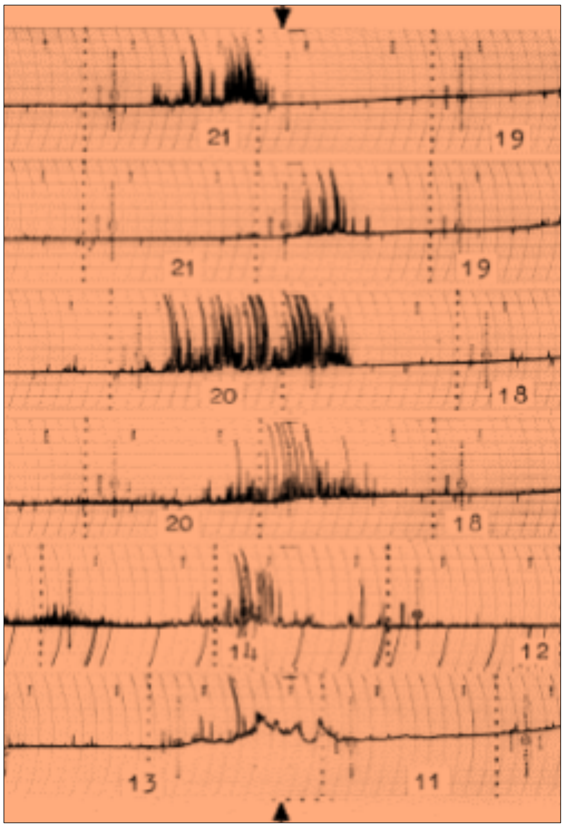


Figure 4: Examples of strong 18.3 MHz Jupiter bursts recorded by Shain and Higgins at Hornsby Valley in 1950 and 1951. The records (top to bottom) date to 11, 19, 29 October and 3 November 1950, and 11 February and 18 March 1951. Local times (in hours) are shown, and the records are aligned so that the times of transit of Jupiter are on the line joining the two arrows (after Shain, 1956: 63).

But Shain (1956) went further, and not only found that the location of the emitting region clustered in Jovicentric longitude (Figure 5) and had a rotation period of $09^h\ 55^m\ 13{\pm}05^s$—very close to Jupiter's System II rotation period—but was almost identical to a conspicuous white spot in the South Temperate Belt. He therefore suggested that this spot was the source of the radio emission.

## 2 THE 1955–1956 RESEARCH PROJECT

### 2.1 Introduction

Understandably, Shain was eager to follow up these published results with further observations, because

> At this stage our knowledge of the basic facts concerning the radiation was too incomplete for the drawing of worthwhile conclusions about the mechanism of generation of the radiation. (Gardner and Shain, 1958: 55).

However, by this time (1955) the Hornsby Valley field station was closed (Orchiston et al., 2015b), and the Radiophysics low-frequency research program had been transferred to Fleurs field station (Orchiston and Slee, 2002; Site 6 in Figure 3) where the 19.7 MHz Shain Cross was under construction.[6]

## 2.2 The Radio Telescopes

In the interim, Shain and fellow Radiophysics research scientist, Francis Frederick (Frank) Gardner (1924–2002; Figure 6; Milne and Whiteoak, 2005),[7] decided to erect three simple low-frequency radio telescopes at Fleurs in 1955, that they could use to observe Jupiter. And because

> … the radiation from Jupiter is very variable and bears some resemblance to interfering signals from terrestrial atmospherics, solar noise, and radio stations, which can be very severe at frequencies near 20 Mc/s, it was considered essential to have a good system for identifying the radiation from the planet (Gardner and Shain, 1958: 56).

The main radio telescope was a 19·6 Mc/s interferometer, and each aerial consisted of four full-wave dipoles,[8] suspended between poles and each a quarter-wavelength above the ground. The two aerials were spaced 12 wavelengths apart (183 m, or 600 feet) in an east-west direction, and each aerial

> … was phased to produce maximum response to the north at a zenith distance of about 50°. Since the aerial was only moderately directive in azimuth, Jupiter could be observed over a period of about 5 hr per day. (ibid.).

This interferometer was operational from June 1955, and the system diagram is shown in Figure 7. The aerials were connected to two receivers that were isolated from one another, one using the aerials in-phase, the other out-of-phase. Gardner and Shain (ibid.) stressed that this system had the advantage "… that even short duration bursts can be identified as Jupiter radiation by the ratio of the outputs of the two receivers." Thus, instances of terrestrial interference were easily isolated.

Later in the year, in October, two further low frequency radio telescopes were completed. These operated at 14 MHz and 27 MHz, and comprised single in-line arrays of four and eight half-wave dipoles respectively.[8]

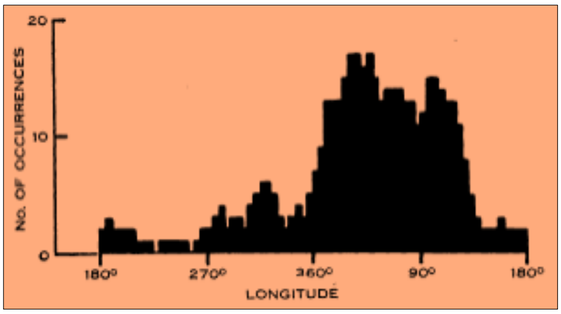


Figure 5: A histogram of the occurrence frequency of 18.3 MHz Jupiter bursts recorded in 1950–1951 plotted against Joviocentric longitude, showing clustering between $l_J$ = 240° and 140° (after Shain, 1956: 68).

Until recently, we were under the impression that no photographs existed of any of these antenna systems, as in an earlier review of images preserved in the CSIRO's incomparable Radio Astronomy Image Archive (CRAIA; see Orchiston, 2001; Orchiston et al., 2004), all Fleurs images of low frequency antennas were erroneously assumed to relate to the 19.7 MHz Shain Cross, which was constructed in 1955–1956. However, a recent detailed re-examination of images in the CSIRO radio astronomy photo archive has revealed the existence of three photographs that all undoubtedly show a part of one of these low frequency antenna systems. Two of these photographs are shown here in Figures 8 and 9. Unfortunately, all those who worked at Fleurs field station in 1955–1956 have now passed away, and there is no documentation with the negatives that reveals which radio telescope is shown in these images.

Nor is the *precise* location of any of the antenna systems known. The first author of this paper only began working at Fleurs in Novem-

Figure 6: Frank Gardner in 1983, 27 years after the Fleurs Jovian observations (courtesy: CRAIA).

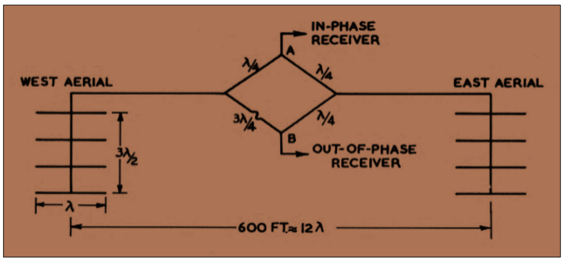


Figure 7: 19.6 MHz system diagram (courtesy: CRAIA, B4060-2).

Figure 8: This 22 February 1956 photograph shows one of the low-frequency radio telescopes at Fleurs used for observations of Jupiter in 1955–1956. The array was erected just south of the eastern arm of the Mills Cross. The presence of four sets of poles (with no indication that the array extended to eight dipoles) suggested that this was either the 14 MHz array or one of the 19.6 MHz interferometer elements. Note that the poles are aligned perpendicular to the Mills Cross (which is in the background), with the low frequency dipoles running E-W (courtesy: CRAIA, B3932-14).

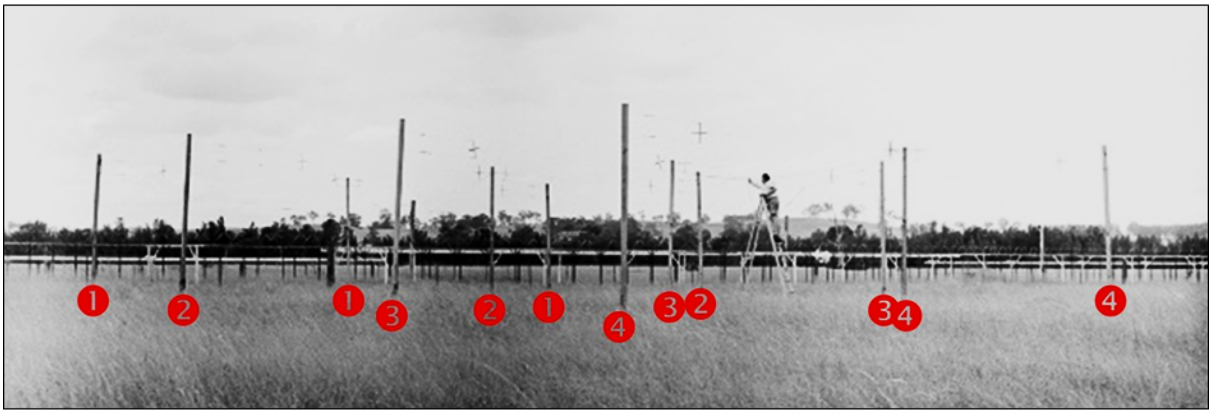


Figure 9: Another photograph taken on 22 February 1956 showing poles and dipoles of one of the low frequency arrays. Once again, the eastern arm of the Mills Cross is clearly visible in the background. Because of perspective and fore-shortening effects, this photograph does not provide a clear indication of the array design, so we have marked on the photograph the four different sets of three poles that supported the half-wave dipoles (and their associated insulators). For scale, note the radio astronomer on the ladder, attending to one of the dipoles (courtesy: CRAIA, B3923-13).

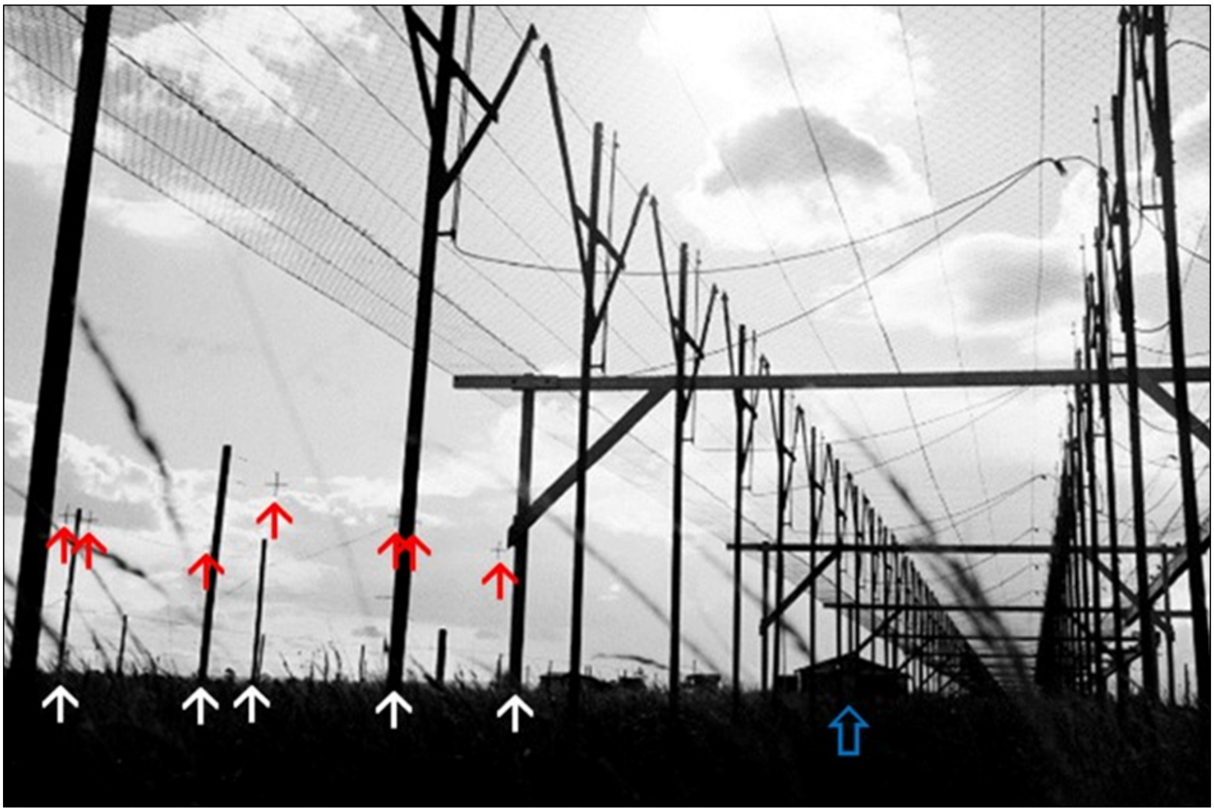

Figure 10: An enlargment of a photograph taken on 30 November 1955 from directly underneath the eastern arm of the Mills Cross, looking west towards the Mills Cross receiver hut (indicated by the blue arrow). On the left (i.e. to the south of the eastern arm of the Mills Cross, are some of the poles (white arrows) that supported the half-wave dipoles of the 14 MHz or the 19.6 MHz arrays. Both radio telescopes had been constructed and were operational by the time this photograph was taken. The second, fourth and fifth white arrows from the left indicate the positions of the poles that supported the first dipole in the array, with the last two poles hidden behind the infrastructure of the Mills Cross. The first and third white arrows mark two of the three poles that supported the second dipole. The red arrows indicate the insulators associated with the first and second dipoles (courtesy: CRAIA, B3868-2).

ber 1961, assisting Bruce Slee and Charlie Higgins with observations of flare stars using the Shain Cross, and by this time the low-frequency arrays discussed in this paper had been removed. Our original intention was to research and write this paper in 2016 as Number 5 in the series on Early Australian Low Frequency Radio Astronomy, so that it immediately followed the Hornsby Valley paper (Orchiston et al., 2015b), and Bruce Slee would then have identified the locations of the arrays and written up this section of the paper. Instead, Martin George's Tasmanian low frequency research for his doctorate was given priority (see George et al., 2015c; 2016; 2017a; 2017b; 2018), and sadly, in the interim Bruce passed away.

Prior to this, all that Bruce Slee (1924–2016) mentioned when we raised the location of the antennas with him was that they were adjacent to the east-west arm of the Mills Cross (Bruce Slee, person comm, 2016). This was partially confirmed when we enlarged three different CRAIA images taken on 30 November 1955 from directly underneath the eastern arm of the Mills Cross, and looking west towards the receiver hut sited very near the centre of the Mills Cross. All three photographs showed poles that would have supported low frequency dipoles at this time, and an enlarged section of the most detailed of these photographs is shown in Figure 10. This appears to show the same array represented in Figure 8 and 9, but what is equally clear is that no other aerials are visible between this array and the Mills Cross receiver hut.

Figure 7 indicates that the two elements of the 19.6 MHz interferometer were located 300 feet to the east and west of the Mills Cross receiver hut, and when an aerial photograph of part of the Fleurs field station taken on 22 February 1956 was enlarged (see Figure 11), it clearly showed what must be the eastern element of this array. Some of the poles also correlate with those shown in Figures 8–10. Figure 12 indicates the relative positions of the Mills Cross, Shain Cross and Chris Cross at Fleurs field station. Each arm of the Mills Cross was 432.8 m (1420 feet) long, and on this scale and using the drain seen running diagonally across the aerial photograph and the road that is alongside the Mills Cross we can pinpoint the

Figure 11: An aerial photograph[10] of Fleurs field station taken on 22 February 1956 showing the Chris Cross receiver hut (upper left), the Chris Cross under construction, the southern and eastern arms of the Mills Cross and the Mills Cross receiver hut (extreme right). The large inset shows a close-up of the eastern element of the 19.6 MHz interferometer and the Mills Cross receiver hut, with the bases of the poles that supported the four dipoles marked with red circles. Within the red box are what appear to be some of the poles associated with the western element of the interferometer (CRAIA, B3923-14; photograph modifications: Wayne Orchiston).

position of the low frequency array shown in Figure 11, which is indeed 300 feet from the receiver hut. There can be no doubt that the antennas shown in Figures 8–11 therefore represent the eastern element of the 19.6 MHz interferometer. The Figure 11 aerial photograph only shows the start of the western arm of the Mills Cross, but faintly visible within the red box are what appear to be five of the poles that supported two of the four dipoles of the western element of the interferometer. From data provided by this photograph and Figure 7, and the known measurements of the Mills Cross, we were able to mark the position of the western element of the 19.6 MHz interferometer on the map shown in Figure 12.

The 14 MHz and 27 MHz radio telescopes became operational in October 1955, but unfortunately there is no sign of them in Figure 11 or in any of the other late 1955–early 1956 photographs in the CSIRO photo archive. However, existing photographs show that they were not located anywhere to the north of the east-west arm of the Shain Cross, so we must assume that they were somewhere to the west of the western element of the 19.6 MHz interferometer.

Apart from Shain and Gardner, a third Radiophysics staff member, technician Les Clague (see Figure 13), assisted with the construction of the arrays, and subsequently with the observations. He was a substitute for Shain's previous assistant in low-frequency radio astronomy, Charlie Higgins, who had been assigned to another Fleurs project.

Whilst most of the 1955–1956 Jovian project was carried out with the simple purpose-built arrays at Fleurs, some observations were

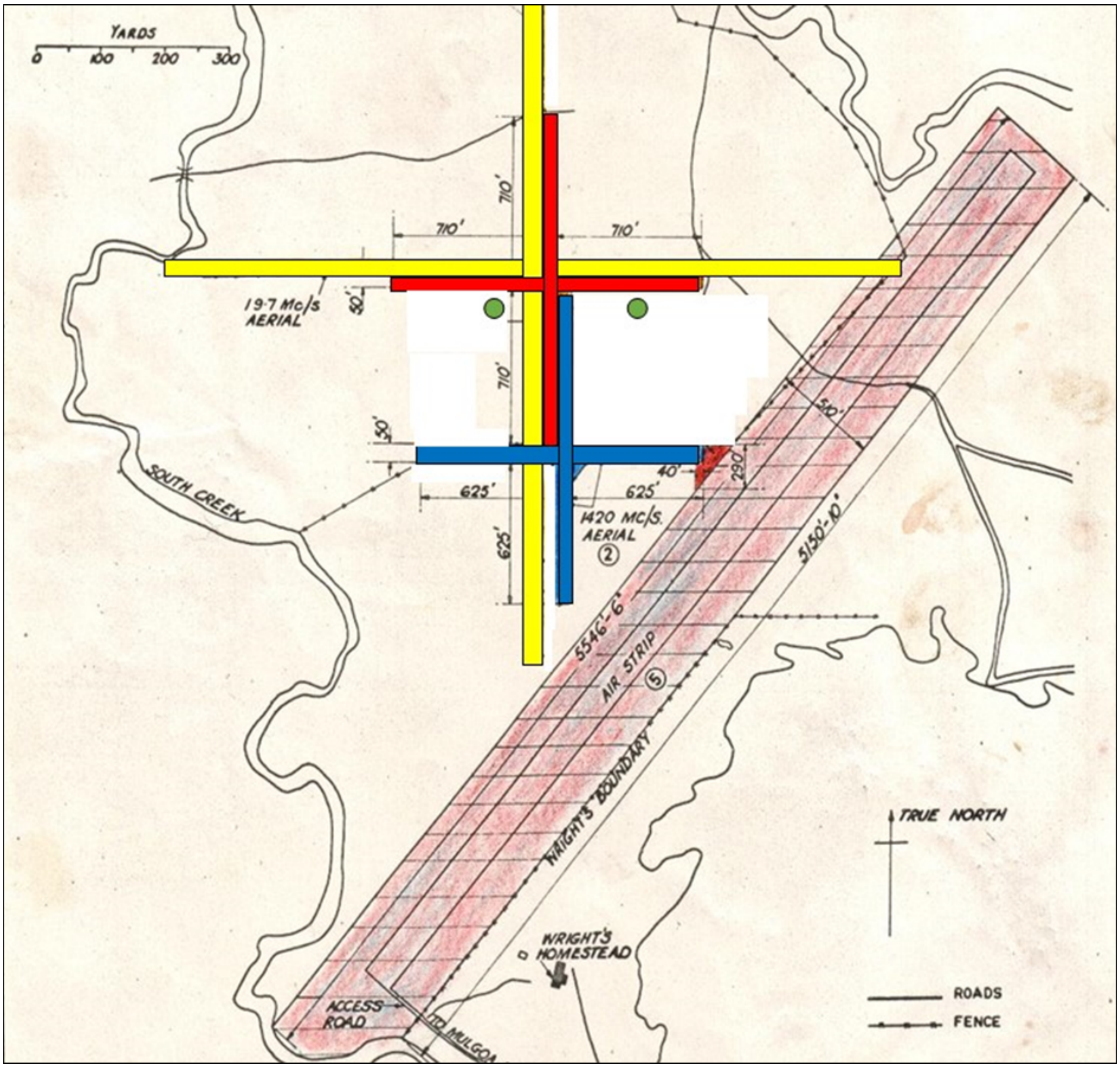


Figure 12: A map of the Fleurs field station showing the WWII air strip, and the sites of the Mills Cross (red), Chris Cross (blue) and most of the Shain Cross (yellow) radio telescopes. The two green circles mark the locations the 19.6 MHz antennas. We believe that the 14 MHz and 27 MHz arrays were to the west of the 19.6 MHz interferometer, just south of and adjacent to the western arm of either the Mills Cross or the Shain Cross (original CRAIA map extensively modified by Wayne Orchiston).

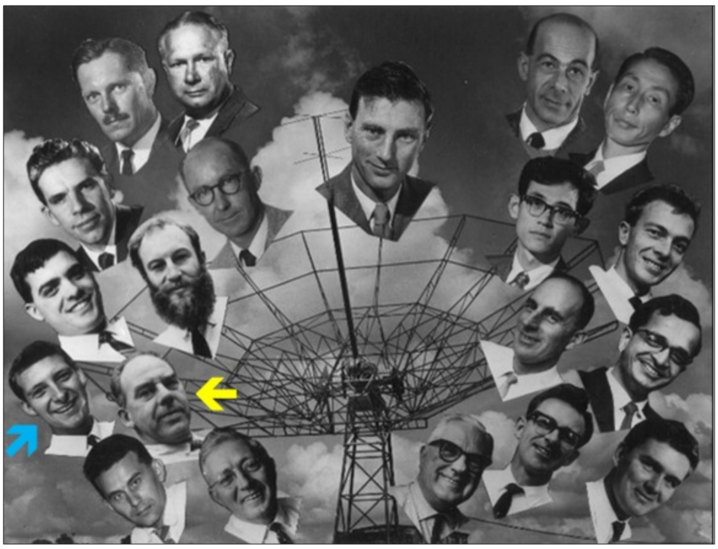

Figure 13: This historic collage was assembled by the Radiophysics Photo Lab in January 1968 for the farewell card that was presented to the first author of this paper when he left Radiophysics in order to complete his Honours degree at the University of Sydney and pursue graduate studies. It shows most members of the Solar Group, led by Paul Wild (top centre). Les Clague, who assisted Shain and Gardner with the 1955–1956 Jovian project at Fleurs is in the second-to-bottom row, second from the left (yellow arrow). Beside him, on the left (blue arrow), is the first author of this paper, who was then at 24 years of age the youngest member of the Solar Group (Orchiston Collection).

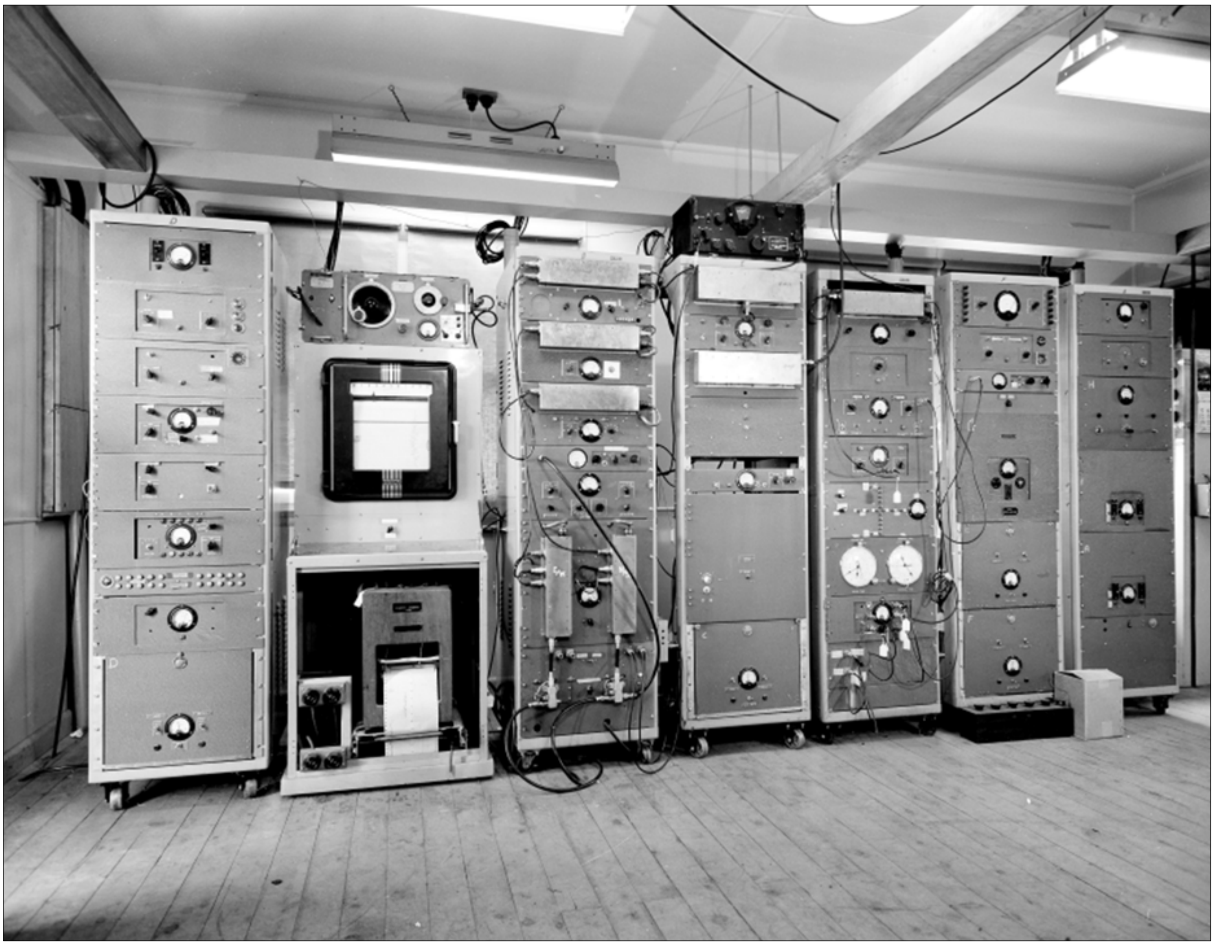

Figure 14: The various receivers in the Mills Cross receiver hut, as photographed on 22 February 1956. The racks second and fourth from the right were not present in photographs of the receiving equipment taken on 7 October 1954 when only the Mills Cross receiver was installed in this hut. We can therefore assume that one of these two racks contains the Shain Cross receiver, and the other housed the three Jovian radio telescope receivers (courtesy: CRAIA, B3923-1).

made with the newly completed east-west arm of the 19.7 MHz Shain Cross. This was completed during 1956, and was 1,036 m (3,400 feet) in length. There were 132 dipoles 4 m above the ground and strung between telegraph poles, with the ground serving as a reflector.

The receivers connected to the Shain and the 19.6 MHz interferometer and the 14 MHz and 27 MHz antennas were housed in the nearby Mills Cross receiver hut, and by a process of elimination we can identify all of the low frequency receiver racks in Figure 14 by comparing this photograph with images of the Mills Cross receiver racks shown in Radiophysics photographs taken prior to 1955. Thus, we know that of the seven racks shown in Figure 14, those second and fourth from the right contained low-frequency receivers. Unfortunately, there are no comparable photographs of the receiving equipment in 1957–1960, after the three temporary low frequency radio telescopes had been removed, that would have allowed us to identify which of the two aforementioned racks housed the Shain Cross receiver.[11]

In addition to the Fleurs equipment, some Jovian observations were made simultaneously with a simple 19.6 MHz antenna erected especially for the purpose at Potts Hill field station, 25 km east-southeast of Fleurs (site 16 in Figure 3). This was

> … part of a spaced-aerial experiment to determine if the scintillations in the radio emission were inherent in the source itself or caused by the ionosphere. (Wendt, et al., 2011: 420).

Consequently, the Fleurs and Potts Hill 19.6 MHz radio telescopes were not set up as an interferometer, but so that they could record independently. To our knowledge, there are no extant photographs of the 19.6 MHz equipment at Potts Hill (although some of the destroyed negatives may originally have shown it).

## 2.3 The Observations

Between June 1955 and March 1956 (inclusive) Jovian observations were made at Fleurs field station at 14, 19.6 and 27 MHz, although most of the observing was carried out with the previously described 19.6 MHz interferometer.

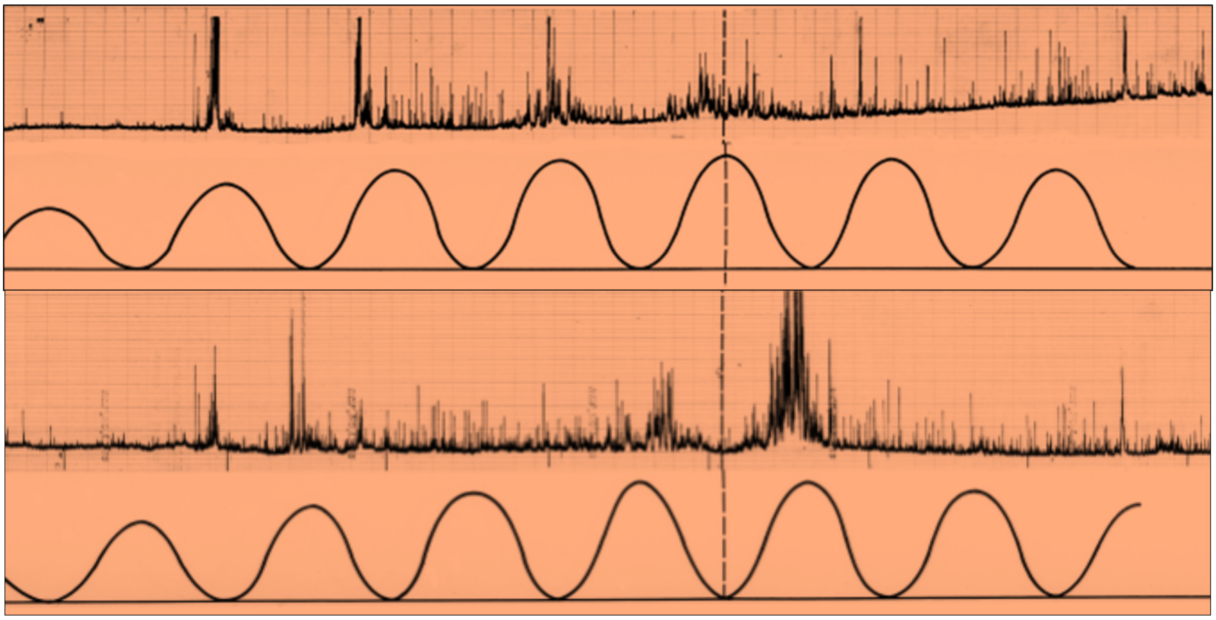

Figure 15: Typical records obtained with the 19·6 MHz interferometer on 28 June 1955. At the top is the in-phase record and below the out-of-phase record, with the sine waves indicating the expected responses of the two receivers to a steady source of Jupiter emission. The fine spikes on the records are atmospherics, while all other increases in signal level are Jupiter bursts (after Gardner and Shain, 1958: 57).

### 2.3.1 The 19.6 MHz Jovian Emission

Observations at 19.6 MHz were carried out almost every day from mid-July 1955 to the end of March 1956, and although Jovian emission was not recorded on every day,

> … on [those] days when it did occur the average overall duration of the activity was about half an hour out of the possible observing time of 5 hr. (Gardner and Shain, 1958: 58).

Figure 15 shows a typical record of bursts recorded with the 19.6 MHz interferometer over an interval of 2 h 28 m on 28 June 1955.

Gardner and Shain (ibid.) note that a distinctive feature of Figure 15

> … is the occurrence of groups of bursts of radiation lasting for times of the order of a minute … [where] fluctuations within each burst are very pronounced. Frequent breaks of a minute or so occur, during which there is no radiation from Jupiter.

In order to study the fine structure of the bursts Gardner and Shain (1958: 59) used a high-speed Brush Electronics oscillograph with a response time of a few milliseconds,[9] and found that there were "… no significant bursts much shorter than 1 sec …"

When heard on a loudspeaker in the Mills Cross receiver hut, Jovian bursts more closely resembled solar bursts than terrestrial interference, sounding like

> … thermal noise varying rapidly in intensity, but only at a rate which the ear can follow ... The time structure appeared similar to that of enhanced solar radiation at about 100 Mc/s. (Gardner and Shain, 1958: 59).

But in contrast, the maximum burst intensity was only about the same order of magnitude as a small solar outburst (ibid.).

When the occurrence frequency of the emission received with the 19.6 MHz interferometer was plotted the histogram showed a skewed unimodal sine wave with a peak of activity in November (Figure 16, left), but Gardner and Shain (1958) rightly reasoned that interference probably masked the true pattern, given that the average level varied greatly with time of day, and that

> … the observed frequency of occurrence would be expected to depend on the local time of transit, with a maximum during the early morning hours when interference is generally low.

Consequently, they carried out observations with the east-west arm of the Shain Cross, which were less susceptible to interference, and the resulting plot (Figure 16, right) seemed to confirm their suspicions—although they admitted that "There may, however, be a true maximum in Jupiter activity in November." (Gardner and Shain, 1958: 61).

When Alex Shain (1956) had analysed the 1950–1951 Hornby Valley observations, one of the important results to emerge was that

> … Jupiter radiation in 1951 had a strong tendency to recur at intervals of a rotation period, an indication that the active centres

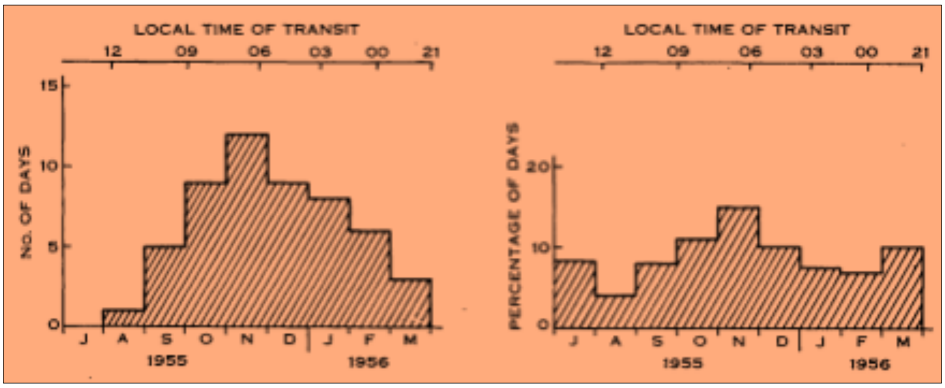


Figure 16: Histograms of the monthly occurrence frequency of 19.6 MHz Jovian bursts recorded with the interferometer (left) and the east-west arm of the Shain Cross (right) between August 1955 and March 1956 (after Gardner and Shain, 1958: 61).

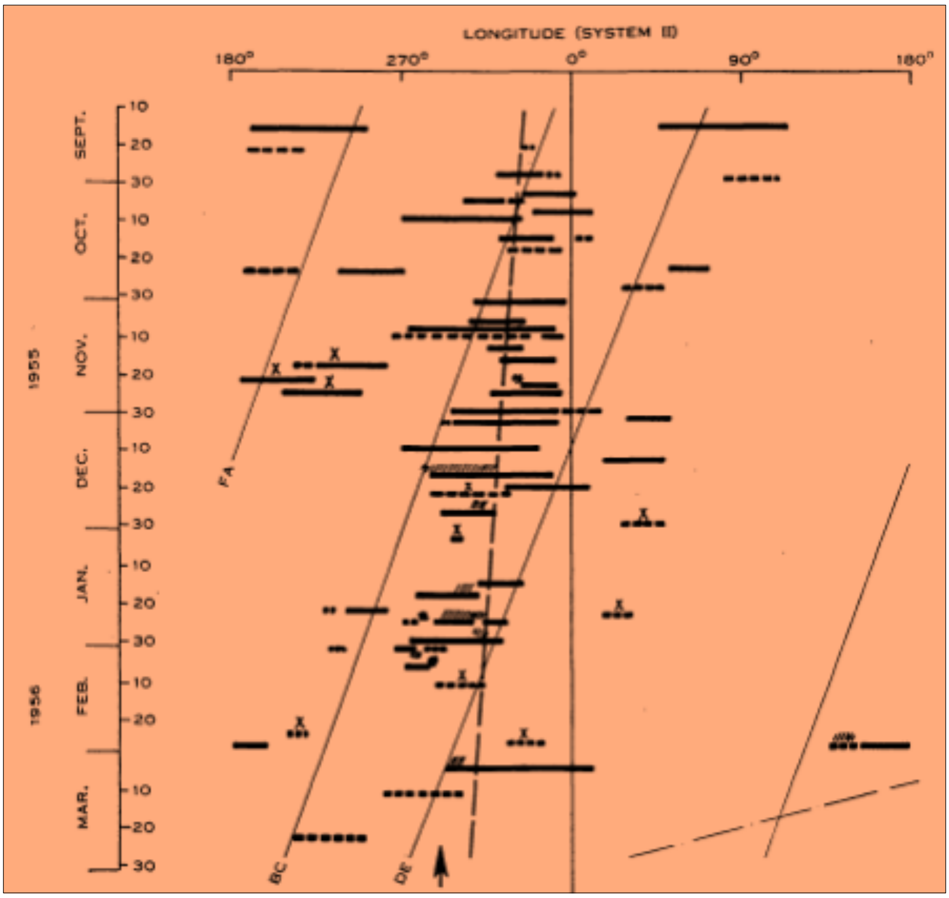


Figure 17: A diagram showing the central meridian longitude (System II) of Jupiter at times when there were radio bursts. The thick horizontal lines show intense 19.6 MHz emission; the dashed horizontal lines weak 19.6 MHz emission; the hashed horizontal lines 27 MHz emission; and 'X' shows absence of 27 MHz emission. The near-vertical dashed line shows the motion of the major source of 19.6 MHz emission relative to the System II rotation and reveals a period of $9^h$ $55^m$ $30{\pm}3^s$. White spots in Jupiter's atmospheric belts are indicated by FA, BC and DE; and the Great Red Spot by the arrow at bottom centre (after Gardner and Shain, 1958: 65).

> on the planet were of small area and persisted for more than one rotation. (Gardner and Shain, 1958: 64).

This recurrence tendency was still prominent in 1955–1956, as shown in Figure 17. Here the times when Jovian bursts occurred were converted to central meridian longitudes in System II, where 360° relates to a rotation period of $9^h$ $55^m$ $40^s$. The rotation period of the main Jovian source can be determined from the slope of the dashed line in Figure 17, and was found to be $9^h$ $55^m$ $30{\pm}3^s$. While this rotation rate is significantly faster than Jupiter System II, it lies within the range determined for the main source observed in 1951, which was 9h 55m $13{\pm}30^s$.

Shain (1956) postulated that the primary source visible in 1951 was associated with a prominent white spot in the South Temperate Belt (S.T.B.) but when Gardner and Shain (1958: 65) examined the 1955–1956 Jovian emission they could not find any obvious link between several white spots then visible in the S.T.B and the Jupiter bursts. Although some of these optical features had comparable rotation periods, Gardner and Shain (ibid.) regarded this as purely fortuitous. They also said that "It is worth noting that the [Great] Red Spot was definitely not the main source of the 1950-51 radio noise."

Drawing on the data presented in Figure 17, Gardner and Shain (1958: 66) plotted the occurrence frequency of 19.6 MHz Jovian emission in 1955–1956 against relative longitude, and came up with the histogram shown in

Figure 18. This shows that there is a strong main source, between about –50° and +50° relative longitude; possibly two weak partially-overlapping sources centred on about –90° and –130°; and a further weak source at around +80°.

### 2.3.2 A Multi-Wavelength Analysis

Gardner and Shain (1958: 62) noted that

> Between November 1955 and February 1956, when Jupiter was transiting between midnight and sunrise, interference on 27 Mc/s was negligible …

and observations were conducted at 19.6 MHz and 27 MHz on 52 different evenings. The number of nights when Jovian emission was recorded is listed in Table 1.

Note that no 19.6 MHz or 27 MHz Jovian bursts were received on 61.5% of those days when observations were made at both frequencies. Another remarkable statistic of Table 1 is that 27 MHz bursts were never observed alone —on every day that they were recorded, bursts also were received at 19.6 MHz. However,

> The peak intensity on 27 Mc/s was generally only about one-third of that on 19·6 Mc/s, and on those days on which 27 Mc/s radiation was received the duration of the activity was only about one-half of that on 19·6 Mc/s. (Gardner and Shain, 1958: 62–63).

Meanwhile, Figure 19 shows that although a few bursts were received at both frequencies, the majority were not.

Gardner and Shain (1958) also investigated the relative longitude of the 27 MHz emission, and although the number of bursts in their sample was limited, as Figure 20 shows, almost all of the emission derived from the 'main source'.

The results of observations at 14 MHz were disappointing because of the high level of interference from radio stations. Nonetheless, from observations that were made Gardner and Shain (1958: 63) were able to conclude that

> … unless the association between days of activity on 14 and 19.6 Mc/s is worse than between 19.6 and 27 Mc/s, it is reasonably certain that both the peak intensity and the mean duration of active periods on 14 Mc/s are lower than on 19.6 Mc/s.

Upon reviewing all of their spectral observations, Gardner and Shain (ibid.) estimated that the maximum level of Jovian burst activity was between 14 and 27 MHz, and probably near 20 MHz.

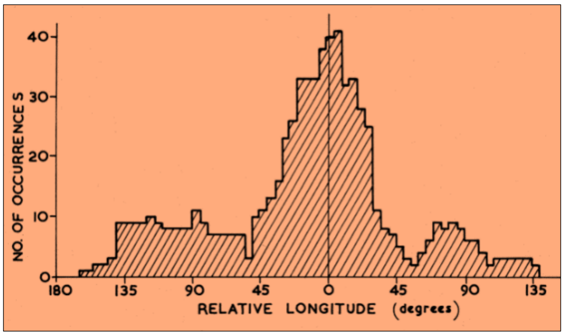


Figure 18: A histogram of the occurrence frequency of 19.6 MHz Jupiter bursts recorded in 1955–1956 and plotted against relative longitude, showing one main source and several weak secondary sources (after Gardner and Shain, 1958: 66).

### 2.3.3 The Role of the Earth's Ionosphere

Gardner and Shain also were interested in the effect of the ionosphere on Jovian bursts, and

Table 1: Simultaneous observations of Jupiter at 19·6 MHz and 27 MHz (after Gardner and Shain, 1958: 62).

| Frequencies at which Jupiter Bursts were Observed | No. of Days |
|---|---|
| 19·6 MHz and 27 MHz | 10 |
| 19·6 MHz but not 27 MHz | 10 |
| 27 MHz but not 19·6 MHz | 0 |
| No bursts at either frequency | 32 |
| Total number of days when 19.6 and 27 MHz observations were made | 52 |

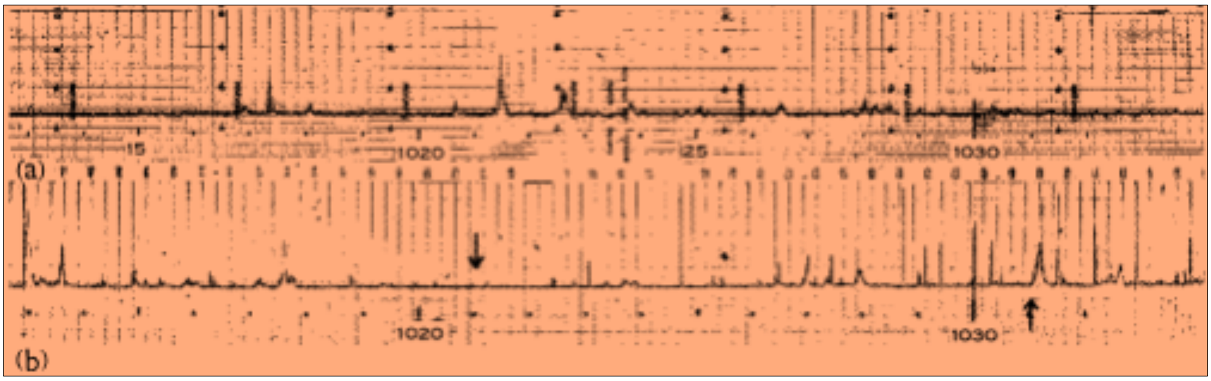


Figure 19: Chart records of simultaneous observations of Jovian emission at 27 MHz (top) and 19.6 MHz (bottom), made at Fleurs on 26 February 1956. With the lower (interferometer) record, the time of maximum response is shown by the upward-pointing arrow and the time of minimum response by the downward-pointing arrow (after Gardner and Shain, 1958: 62).

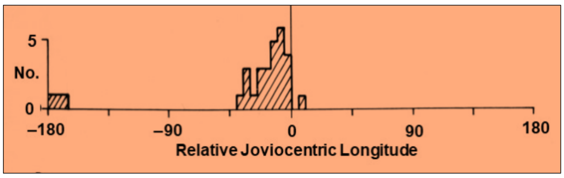


Figure 20: A histogram of the occurrence frequency of 27 MHz Jupiter bursts recorded in 1955–1956 and plotted against relative Joviocentric longitude (adapted by Wayne Orchiston from Gardner and Shain, 1958: 66).

during February and March 1956 they conducted a short series of parallel 19.6 MHz observations at Fleurs and Potts Hill between 2300 h and 0200 h local time. The receivers at both sites were closely tuned to avoid discrepancies caused by sharp spectral variations in the burst signals.

Unfortunately, high levels of radio interference at Potts Hill threatened this project, and only three pairs of results were available for comparison (and a short section of one of these pairs is shown in Figure 21). Yet these limited observations were enough to show that there were

> … significant differences between the two sites with some bursts observed at only one of the two sites. There also appeared to be timing differences between the sites and some differences in the burst characteristics. (Wendt et al., 2011: 420–421).

Similar differences were found with the other two records, and Gardner and Shain (1958: 60) concluded that the ionosphere had a considerable effect on the Jovian radiation.

### 2.3.4 Polarisation and the Source of the Jovian Emission

One of the objectives of the research project was to determine whether Jovian bursts were polarised. If they were, this would denote the presence of a magnetic field and possibly throw some light on the nature of the sources generating the emission.

In order to measure polarisation, the east-west arm of the Shain Cross (Figure 22) was

> … used as an interferometer in conjunction with a small array whose individual dipoles were in the north-south plane and also perpendicular to the direction of Jupiter at transit. (Gardner and Shain, 1958: 57).

Because of the narrow beam of the long east-west array, polarisation measurements were confined to times within 10 min of transit (ibid.).

Unfortunately only one reliable record was obtained, which was on 24 January 1956 when the 'main source' (as identified in Figure 18) was being observed. At this time, the Jovian bursts exhibited right-hand circular polarisation (Gardner and Shain, 1958), indicating the existence of a magnetic field in the vicinity of the source of the bursts—as reported earlier by Franklin and Burke (1956b). Gardner and Shain (1958: 64) noted that since the same type of polarisation was reported by northern and southern hemisphere observers then "… the Earth's ionosphere cannot be the medium which impresses circular polarization on the Jupiter radiation." This led them to conclude that their observations

> … suggest an origin of the noise in some type of resonance oscillation in Jupiter's atmosphere, but optical data give no clues as to where or why such oscillations occur. (Gardner and Shain, 1958: 56).

## 3 CONCLUDING REMARKS

In 1955, immediately after completing his analysis of the pre-discovery 18.3 MHz Jovian detections made at the CSIRO's Division of Radiophysics Hornsby Valley field station in 1950–1951, Alex Shain teamed with Frank Gardner to conduct further research on the enigmatic radio emission from the planet Jupiter.

By this time the Hornsby Valley field station was already closed down, so they and Les Clague decided to install three temporary low frequency radio telescopes at Fleurs field station, which they could use immediately for their investigation, pending the completion there of

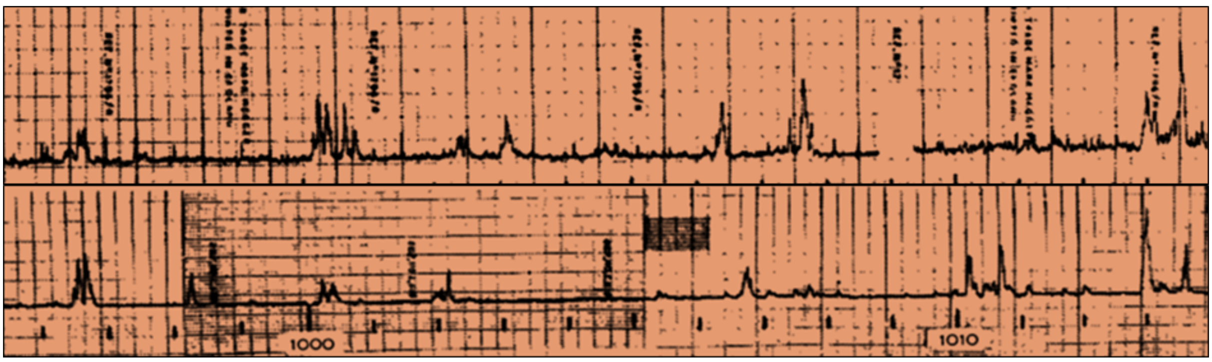


Figure 21: The spaced-receiver records for Potts Hill (top) and Fleurs (bottom) taken at 19.6 MHz on 26 February 1956. Time is shown in sidereal time, where 1000 hrs = 2330 hrs Eastern Australian Standard Time (after Gardner and Shain, 1958: 60).

Figure 22: A view looking east along the east-west arm of the Shain Cross, showing the poles that supported the dipoles and the transmission line. On the left is 'Flo', the mobile field laboratory that was used when servicing and checking the Mills Cross and the Shain Cross. Occasionally it got bogged after heavy rain, and the radio astronomers then had to ask help from a local farmer in order to extricate it (courtesy: CRAIA, B3923-4).

the 19.7 MHz 'Shain Cross' radio telescope. This stop-gap measure involved a 19.6 MHz two-element interferometer, and single 14 MHz and 27 MHz antennas. Once the east-west arm of the Shain Cross was operational they also used this (in conjunction with other aerials) to explore the polarisation of Jupiter bursts, and in order to investigate the role of the Earth's ionosphere in modifying the Jovian emission they also installed a simple 19.6 MHz antenna at Potts Hill field station.

Most of the observations Gardner, Shain and Clague carried out at Fleurs were made at 19.6 MHz, and these yielded results that differed in various ways from those obtained when Shain researched the 1950–1951 18.3 MHz Jovian emission.

For a start, the 19.6 MHz 'spaced-receiver experiment' involving Fleurs and Potts Hill revealed that the form of the Jovian decametric emission received at the Earth was not intrinsic to the bursts themselves, but appeared to be caused by the terrestrial ionosphere. [More than a decade later, Slee and Higgins (1968) from Radiophysics would use what was then regarded as long-baseline interferometry to show that the bursts were in fact due to scintillations that were caused by diffraction in the solar wind.]

Meanwhile, the 19.6 MHz observations at Fleurs showed that most of the Jovian emission derived from just one primary source, a very different result from 1950–1951 when three major partially-overlapping sources were involved (cf. Figures 18 and 5). Yet the rotation period of the 1955–1956 main source ($9^h\ 55^m\ 30{\pm}3^s$) did not differ significantly (at $1\sigma$) from the mean rotation rate of the 1950–1951 main sources. But what Gardner and Shain were able to do was eliminate Jupiter's Great Red Spot and a number of conspicuous white spots in the North Temperate Belt (NTB) as the origin of the radio emission. This negated an earlier finding where Shain had linked the 1950–1951 Jovian bursts to a white spot in the NTB.

With the benefit of the instrumentation that was newly available in 1955, Gardner and Shain also were able to see that the 19.6 MHz

Jovian bursts were polarised. This confirmed the involvement of a magnetic field in the generation of the emission, and they suggested that some type of resonance oscillation in Jupiter's atmosphere was the cause. Only later would we learn that Jovian bursts

> … are associated with spiraling electrons in the magnetic torus that extends from the inner moon, Io, to Jupiter's magnetosphere … [and] have nothing whatsoever to do with the spots or other features seen in Jupiter's ever-changing atmospheric 'cloud belts' (Orchiston et al., 2020: 143).

As we have seen, Gardner, Shain and Clague carried out multi-wavelength observations in 1955–1956, which gave them an enhanced perspective on the Jovian burst emission. Bursts at 27 MHz were much rarer than those received at 19.6 MHz—they were only detected on about 20% of all observing nights—while terrestrial interference hampered observations at 14 MHz. Nonetheless, Gardner and Shain were able to conclude that the peak burst intensity occurred at around 20 MHz. Meanwhile, it appeared that almost all of the 27 MHz emission derived from the primary 19.6 MHz source, and 27 MHz emission only occurred on days when there also were bursts at 19.6 MHz.

Despite reliance on simple makeshift radio telescopes erected in 1955 solely for the purpose of elaborating on Shain's 1950–1951 investigation, the Fleurs observations carried out in 1955–1956 led to a greater international understanding of the nature of Jovian decametric emission. Further low frequency observations of Jupiter by Shain would have to await completion of the Shain Cross, and these will be discussed in a later paper in this series.

## 4 NOTES

1. This is the tenth paper in a series that aims to document pre-1980 low frequency (<30 MHz) radio astronomy in Australia. The first two papers overviewed the research by staff from the CSIRO Division of Radiophysics near Sydney (Orchiston et al., 2015a) and the efforts in Tasmania by Grote Reber and staff from the Physics Department at the University of Tasmania (George et al., 2015a). Subsequent papers looked in depth at individual field stations in Tasmania (see George et al., 2015b; 2015c; 2016; 2017a; 2017b; 2018) and at Hornsby Valley near Sydney (Orchiston et al., 2015b).
2. Bernard Flood Burke and Kenneth Franklin both received PhDs in 1953, from MIT and the University of California (Berkeley) respectively, and when they detected Jovian decametric emission were employed by the Department of Terrestrial Magnetism at the Carnegie Institution of Washington to conduct research in low frequency radio astronomy. Burke later built a distinguished career in astrophysics at the Massachusetts Institute of Technology, while Franklin became well known for his activities in astronomy education while at the Hayden Planetarium (from 1956 to 1984).
3. Prior to this, the Jovian emission had been announced at a meeting of the American Astronomical Society in Princeton, New Jersey, just one week after its discovery (Ken Kellermann, pers. comm., March 2021).
4. Charles Alexander ('Alex') Shain (1922–1960; Figure 2a) was born in Melbourne, and after completing a BSc at the University of Melbourne and serving briefly in the military he joined the CSIR's Division of Radiophysics in November 1943 (Orchiston and Slee, 2005). He assisted in the development of radar during WWII, and from late 1946 he was one of those scientists charged with identifying peacetime research that would take advantage of the war-time technological achievements of the Division. It is important to remember that at this time

   > Radiophysics was CSIR's glamour division, arguably containing within its walls the densest concentration of [radar-related] technical talent on the continent ... (Sullivan, 2009: 122; cf. Robertson, 1992).

   Shain was among a coterie of young researchers who would quickly make Australia a world leader in the newly-emerging field of radio astronomy, and he pioneered research at low frequencies. Unfortunately, Shain's inspiring lead in this field was cut short prematurely when he succumbed to cancer on 11 February 1960, just five days after his 38th birthday. This was a tragic loss for Australian and international radio astronomy, as documented by Dr Joseph Lade ('Joe') Pawsey (1908–1962), the Deputy Chief of the Division of Radiophysics, who described Alex Shain as "... a wonderful colleague in the laboratory, imaginative, well balanced, exceedingly unselfish, and a real friend to all." (Pawsey, 1960: 245).
5. Fleurs field station (Site 6 in Figure 3) was founded in 1953 and ended up being home to three different 'cross-type' radio telescopes, modelled predominantly on the Potts Hill prototype designed by Bernie Mills and Alec Little (Wendt et al., 2011: 406–407). The Fleurs 'crosses' were the 85.5 MHz Mills Cross, completed in 1954 (see Orchiston and Slee, 2017: 548–555); the 19.7 MHz Shain Cross (completed in 1956) and

the 1421 MHz Chris Cross solar grating array designed by W.N. (Chris) Christiansen and completed in 1957 (see Orchiston and Mathewson, 2009). This innovative last-mentioned radio telescope combined the principles of Bernie Mill's classical cross-type antenna (see Mills and Little, 1953), and the two solar grating arrays that Christiansen had erected earlier at Potts Hill field station (see Wendt et al., 2008).

6. The Shain Cross (see Shain, 1958)

> … was built alongside the Mills Cross, operated at a frequency of 19.7 MHz, and had a beam width of 1.5°. It evolved out of Shain's earlier exploits at the Hornsby Valley and the 19.6 MHz interferometer at Fleurs, and drew inspiration also from the Mills Cross concept. The N-S arm was 1,151 m in length and contained 151 dipoles, while the E-W arm was a little shorter, at 1,036 m, with 132 dipoles. The dipoles were 4 m above the ground and strung between telegraph poles, with the ground serving as a reflector ... (Orchiston and Slee, 2017: 556).

7. Frank Gardner (or 'FF' as we all called him at Radiophysics) was born in Sydney in 1924 and died in 2002. Milne and Whiteoak (2005: 33) reveal how FF

> … graduated from the University of Sydney in Science in 1943 and with First Class Honours in Electrical Engineering in 1945. Quiet and unassuming, he worked on ionospheric research at the Cavendish Laboratory from 1947 to 1949 graduating with a PhD from Cambridge University. Returning to Australia, he joined the CSIRO's Division of Radiophysics in 1950 …

Initially he worked on ionospheric research, before transferring to radio astronomy, and the Fleurs Jovian project was to be his sole foray into low frequency research *and* Solar System radio astronomy. Then once the 64-m Parkes Radio Telescope was commissioned (late 1961), FF became an acknowledged receiver expert, but he also was "… more or less forced to become a 'radio astronomer'." (Milne and Whiteoak, 2005: 34). Over the years he worked on a wide range of galactic and extragalactic projects, and was a pioneer in polarisation and spectral line studies.

8. Gardner and Shain (1958: 56) claimed that they used full-wave dipoles, but the accumulated evidence, including Figures 8 and 9, clearly shows that they in fact used half-wave dipoles.

9. We could find no evidence to explain why Shain and Gardner decided to observe at 19.6 MHz instead of 18.3 MHz (using the receiving equipment they had developed at Hornsby Valley), unless it was because they already planned to make some of their observations with part of the Shain Cross as it became operational. But then the question arises as to why they chose 19.6 MHz instead of 19.7 MHz, which was the operating frequency of the Shain Cross. Nor could be find out why Shain and Gardner selected 14 MHz and 27 MHz as the frequencies for the other observations they would make at Fleurs.

10. Unfortunately, some of the negatives dating to 1955–1956

> … were found to have suffered irreparable damage owing to the use at the time [by the Radiophysics photographers] of what later proved to be faulty film. These degraded negatives were too damaged for further use and [most] were disposed of … (Orchiston, et al., 2004: 47).

The left-hand half of the negative used to create Figure 11 was badly damaged and useless, but the right-hand half of the negative, although degraded and unclear in places, is still able to provide information useful for this paper. We know that many other photographs of Fleurs field station and its radio telescopes taken at this time were destroyed, and we can be certain that some of these originally would have provided details of interest to us. This is yet another instance of the source limitations that we sometimes face when researching the history of astronomy.

11. Had this paper been written as initially planned, then Bruce Slee would quickly have identified which of the racks housed the Shain Cross receiver. This is yet another reminder of how important it is for those studying the history of radio astronomy to utilise the memories, photographs, letters, reports and other archival records of the few pioneering radio astronomers who are still alive.

12. This was loaned to Shain and Gardner by Grote Reber, the American radio astronomy pioneer (see Kellermann, 2005) who at the time was living in the Australian island state of Tasmania where he was conducting research on low frequency radio astronomy (e.g. see George et al., 2015b; 2015c). Reber tended to work in isolation (ibid.), and this is one of the few instances where he is known to have assisted his professsional radio astronomical colleagues.

## 5 ACKNOWLEDGEMENTS

We wish to thank Ken Kellermann for providing information relevant to this paper. We also are grateful to the CSIRO's Australian Telescope National Facility for providing many of the images used in this paper. We also made use of ADS while researching this paper. Finally, we would like to dedicate this paper to Bruce Slee. Had circumstances been different, he would have been a co-author of this paper.

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**Dr Wayne Orchiston** was born in New Zealand in 1943, and works at the National Astronomical Research Institute of Thailand. He also is an Adjunct Professor of Astronomy at the University of Southern Queensland in Toowoomba, Australia. In the 1960s Wayne worked as a Technical Assistant in the CSIRO's Division of Radiophysics in Sydney, and forty years later joined its successor, the Australia Telescope National Facility, as its Archivist and Historian.

He has a special interest in the history of radio astronomy, and in 2003 was founding Chairman of the IAU Working Group on Historical Radio Astronomy. Through James Cook University and the University of Southern Queensland he has supervised six PhD or Masters theses on historic radio astronomy, and has published papers on early radio astronomy in Australia, France, India, Japan, New Zealand and the USA.

He also has published extensively on the history of meteoritics; historic transits of Venus and solar eclipses; historic telescopes and observatories; the history of cometary and asteroidal astronomy; the early development of astrophysics in Asia and Oceania; and Indian, SE Asian and New Zealand ethnoastronomy. In 2016 and 2017 Springer published his books, *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits* and *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe* (co-editored by Tsuko Nakamura), both of which contain various chapters on early radio astronomy. His latest Springer book is *Golden Years of Australian Radio Astronomy: An Illustrated History* (2020, co-authored by Peter Robertson and Woody Sullivan).

Currently, Wayne is the President of IAU Commission C3 (History of Astronomy), and he is a co-founder and the current Managing Editor of the *Journal of Astronomical History and Heritage* and a Co-editor of Springer's book Series on Historical and Cultural Astronomy. In 2013 the IAU named minor planet 48471 Orchiston after him, and in 2019 he and former PhD student, Dr Stella Cottam, were awarded the Donald E. Osterbrock Book Prize by the HAD/American Astronomical Society for their Springer book, *Eclipses, Transits and Comets of the Nineteenth Century: How America's Perceptions of the Skies Changed*.

**Dr Martin George** is responsible for the planetarium and astronomy collections at the Queen Victoria Museum and Art Gallery in Launceston, Tasmania, and is a former President of the International Planetarium Society.

He has a special research interest in the history of radio astronomy, and completed a PhD on the development of low frequency radio astronomy in Tasmania through the University of Southern Queensland, supervised by Professors Wayne Orchiston and Richard Wielebinski (and originally also by the late Professor Bruce Slee). Martin was the Administrator of the Grote Reber Medal for Radio Astronomy, and is a member of the IAU Working Group on Historical Radio Astronomy.

He has published extensively on early Tasmanian radio astronomy, along with several papers on seventeenth century Jesuit astronomers in Siam (*aka* Thailand).

**Dr Harry Wendt** is an Adjunct Research Fellow in the Astrophysics Group at the University of Southern Queensland.

He has a long-standing interest in early Australian radio astronomy and in 2009 completed a PhD thesis on "The Contribution of the CSIRO Division of Radiophysics Potts Hill and Murraybank Field Stations to International Radio Astronomy" through James Cook University (Townsville, Australia), supervised by Professor Wayne Orchiston and the late Professor Bruce Slee.

Harry has since published a series of papers based upon his thesis and subsequent research, and the book *Four Pillars of Radio Astronomy: Mills, Christiansen, Wild, Bracewell* (2017, Springer, co-authored by Bob Frater and Miller Goss). Harry is a member of the IAU Working Group on Historical Radio Astronomy.

**Professor Richard Wielebinski** was born in Poland in 1936, and moved with his parents to Hobart, Tasmania, while still a teenager. Richard completed BE (Hons.) and MEngSc. degrees at the University of Tasmania. In his student days he met Grote Reber and was involved in the construction of a low frequency array at Kempton. After working for the Post Master General's Department in Hobart he joined Ryle's radio astronomy group at the Cavendish Laboratory, Cambridge, and completed a PhD in 1963 on polarised galactic radio emission.

From 1963 to 1969 Richard worked with Professor W.N. (Chris) Christiansen in the Department of Electrical Engineering at the University of Sydney, studying galactic emission with the Fleurs Synthesis Telescope and the 64-m Parkes Radio Telescope. He also was involved in early Australian pulsar research using the Molonglo Cross.

In 1970 Richard was appointed Director of the Max-Planck-Institut für Radioastronomie in Bonn, where he was responsible for the instrumentation of the 100-m radio telescope at Effelsberg. In addition, he built up a research group that became involved in mapping the sky in the radio continuum, studying the magnetic fields of galaxies, and pulsar research. Further developments were the French-German-Spanish institute for millimetre-wave astronomy (IRAM), and co-operation with the Steward Observatory, University of Arizona, on the Heinrich-Hertz Telescope Project.

Richard holds Honorary Professorships in Bonn, Beijing and at the University of Southern Queensland. He is a member of several academies, and has been awarded honorary doctorates by four universities. After retiring in 2004 he became involved in history of radio astronomy research, and is a former Chairman of the IAU Working Group on Historical Radio Astronomy.