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THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 11: THE SHAIN CROSS AT FLEURS FIELD STATION NEAR SYDNEY

Harry Wendt
Centre for Astrophysics, University of Southern Queensland, Toowoomba, Queensland 4350, Australia.
E-mail: harry.wendt@gmail.com

and

Wayne Orchiston
University of Science and Technology of China, Hefei, Anhui 230026, China; and Centre for Astrophysics, University of Southern Queensland, Toowoomba, Queensland 4350, Australia.
E-mail: wayne.orchiston@gmail.com

Abstract: During the 1950s and 1960s, Australia was a world leader in the specialised field of low-frequency radio astronomy, with two geographically distinct areas of activity. One was in the Sydney region, and the other was on the island of Tasmania to the south of the Australian mainland. Research in the Sydney region began in 1949 through the CSIRO's Division of Radiophysics. Initially, it was carried out at the Hornsby Valley field station before transferring to the Fleurs field station. This paper details the low-frequency radio astronomy carried out at the Fleurs field station between 1956 and 1961 using the 19.7 MHz Shain Cross.

Keywords: Australian low-frequency radio astronomy, CSIRO Division of Radiophysics, Alex Shain, Shain Cross, Fleurs field station.

1 INTRODUCTION

As described in earlier papers in this series (George et al., 2015a; 2015b; 2015c; 2016; 2017a; 2017b; 2018; Orchiston et al., 2015a; 2015b; 2021a) Australia was an early international leader in low-frequency[1] radio astronomy, with two centres of excellence: one near Sydney and the other in the island state of Tasmania, south of the Australian mainland.

The Sydney initiatives were under the auspices of the CSIRO's Division of Radiophysics (henceforth RP), which, from 1946 through into the early 1960s, maintained a large number of field stations and remote sites, mainly in and around Sydney (see Orchiston and Slee, 2017; Orchiston et al., 2021b). Two of these field stations, Hornsby Valley (Orchiston and Slee, 2005) and Fleurs (Orchiston and Slee, 2002), were involved in low-frequency radio astronomy (see Figure 1).

This paper details pioneering low-frequency radio astronomy carried out at Fleurs field station by Charles Alexander (Alex) Shain (1923–1961; Figure 2)[2] using the 19.7 MHz Shain Cross between 1956 and his untimely death in 1961.

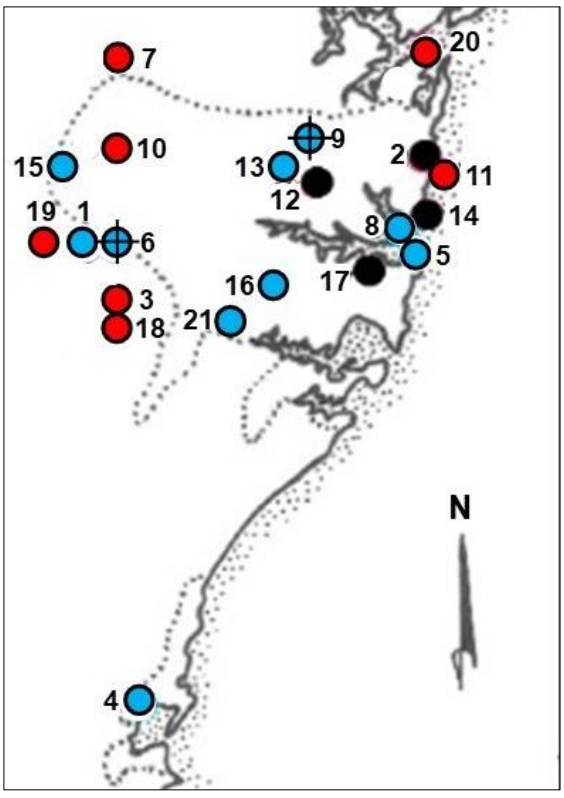


Figure 1: RP field stations (blue circles), remote sites (red circles) and other radio astronomy locations. The two low-frequency field stations, Fleurs (6) and Hornsby Valley (9), are indicated by the blue circles with crosses. The dotted lines show the boundaries of suburban Sydney (to the North) and Wollongong (near site 4, Dapto) in 1960 (map: Wayne Orchiston).

2 THEORIES OF GALACTIC RADIO EMISSION

In a review of Australian low-frequency radio astronomy, it is worth briefly revisiting the foundations of knowledge of Galactic radio emission

leading up to 1956, when construction of the Shain Cross commenced.

Radio astronomy began with Karl Jansky's discovery of the background continuum radiation associated with our Galaxy, the Milky Way (Jansky, 1933). Serendipitously, Jansky was observing at a time of a solar minimum and, hence, minimal ionospheric effects at 20.5 MHz and with low aerial resolution. At this frequency, the Galactic background continuum radiation is near its peak. As Sullivan (1982, Pt 1: 1) notes:

> Jansky's pioneering work at 20.5 MHz was complete enough to establish, right from the start, almost all of the basic empirical features of the background radiation, namely (a) the concentration to the plane of the Milky Way, (b) the maximum in the direction of the galactic centre, (c) the relatively high values at high galactic latitudes, and (d) the fact that its intensity was far above that expected to arise from thermal radiation of interstellar material.



Figure 2: Charles Alexander (Alex) Shain photographed in 1952 at Hornsby Valley field station during the 1952 URSI meeting (courtesy: CSIRO RAIA B2842-133, cropped).

In a solo effort, Grote Reber built a parabolic radio telescope and confirmed Jansky's discovery of 'Cosmic Static' (Reber, 1940a; 1940b; 1944). Initially unable to detect emission at 3300 MHz, it was not until Reber moved to the lower frequency of 160 MHz and later 480 MHz that he was successful, and this provided a strong indication of the non-thermal nature of the emission. Based on Reber's observations, Henyey and Keenan (1940) set out to examine free-free emission from interstellar gas at radio wavelengths. While they concluded that Reber's observed brightness temperature could be produced by free-free emission, they could not reconcile Jansky's observed brightness temperature of ~100,000 K at 20.6 MHz with thermal emission. The source mechanism of this emission remained a mystery.

Over the following years, researchers persisted with theories focusing on the background source originating from hot interstellar gas and possibly the integrated effect from unresolved 'radio stars'. Still, none of these theories could successfully account for all the observed characteristics. In 1950, inspired by Alfven and Herlofson's (1950) suggestion of the synchrotron mechanism as the cause of emission from radio sources, Kiepenheuer (1950) directly linked cosmic rays as the source of relativistic electrons spiralling in magnetic fields to produce the general Galactic emission. Interestingly, in the conclusion of his short paper, he thanked Grote Reber for helpful discussions, although Reber did not subsequently pick up on Kiepenheuer's findings.

Despite correctly identifying synchrotron emission as the source of the Galactic background emission, it would be many years before Western scientists accepted this theory, although Soviet scientists quickly adopted it. For example, Sullivan (1982: 89) noted that the first textbook on radio astronomy by Pawsey and Bracewell (1955) did not mention the synchrotron mechanism despite being published some five years later. Sullivan (2009: Chapter 15) and, more recently, Goss et al. (2023: Chapter 34) have extensively discussed the social and technical reasons why it took so long to accept synchrotron emission in the West. A lack of familiarity with relativistic theory and an unwillingness to abandon existing theories delayed the widespread recognition of the synchrotron mechanism as the source of the background emission.

While the source of the Galactic background radio emission remained unclear, it was considered that the interstellar gas must significantly affect radio brightness distribution across the sky. Scheuer and Ryle (1953) were perhaps the first to evaluate the effect on Galactic radio frequency radiation of ionised hydrogen (HII) regions. Using an interferometer at 81.5 and 210 MHz, they observed a narrow, bright region along the Galactic Equator, which they attributed to thermal radiation from HII regions.

However, noting a much higher temperature than theory would predict. It would later be shown that the bright emission band is mainly attributed to synchrotron emission associated with Galactic magnetic fields rather than thermal emission at these frequencies.

From the Australian context, the first formal acknowledgement of the synchrotron mechanism came in April 1955 when Bernie Mills (see Frater et al., 2013) submitted a paper on his preliminary observations using the new Mills Cross operating at 85.5 MHz. He concluded:

> In general terms, although not altogether in detail, these results support conclusions reached by Shklovskii concerning the distribution of radio emission in the Galaxy; also, his interpretation of the spherical distribution as the result of relativistic electrons radiating in weak magnetic fields is examined, and found, with some modifications, to afford a plausible explanation of the observed differences between the radiating efficiencies of different types of galaxies. (Mills, 1955).

3 THE SHAIN CROSS

3.1 Motivation for Building the Shain Cross

Based on his 18.3 MHz Galactic survey (Shain, 1954a) from the Radiophysics Hornsby Valley field station, Alex Shain found clear evidence of absorption affecting the brightness distribution as compared with a 100 MHz survey (Bolton and Westfold, 1950), particularly in the area of the Galactic Centre (see Figures 3 and 4). He a concluded that

> … at present, the variations in T_{18}/T_{100} can best be accounted for in terms of absorption in interstellar gas, the radio observations being consistent with optical evidence concerning the characteristics of the gas.

However, the 18.3 MHz survey's resolution was too low to associate this absorption with the narrow HII bands in the Galactic Plane.

At high frequencies, where the non-thermal component is weak, the HII regions should appear bright against a low-temperature background. At low frequencies, where the non-thermal component is strong, it should appear in absorption. Shain (1958b) later noted that

> Because the absorption processes are similar, this is closely analogous to the study by radio engineers of the D region of the ionosphere through its absorption of radio waves reflected from the E and F regions.

With the invention of the Mills Cross radio telescope (Mills and Little, 1953), a means to build a low-cost, low-frequency, high-resolution instrument was now possible. This type of instrument would allow Shain to investigate absorption from HII regions in detail and was the initial scientific motivation for building the Shain Cross at Fleurs field station.

3.2 Design of the Shain Cross

The scientific leader of RP, Joseph Lade (Joe) Pawsey (1908–1962; Goss et al., 2023; Figure 5), supported the priority of examining low frequencies at high resolution. In the July 1954 report of the Radio Astronomy Group, Pawsey outlined the overall proposed research program, including the objectives for the investigation of the category of 'Cosmic – Continuous Radiation' in three broad areas:

1) A high-resolution (say ¾°) survey of a large part of the sky at one frequency.
2) Duplication at a limited number of higher and lower frequencies.
3) Special studies of particular objects:
   a. angular distribution (resolution of minutes of arc)
   b. spectra

To address the first item in the research program, the 85.5 MHz Mills Cross was to be constructed at Fleurs to conduct a high-resolution survey of the southern sky. To tackle the second item of the research program, a second low-frequency (20 MHz) cross was proposed, leaving higher frequency observations for a future giant parabola (ultimately the 64-m Parkes Radio Telescope, now known as Murriyang). Alex Shain was assigned to prepare a plan for constructing a 20 MHz Cross, later known as the 'Shain Cross', with construction to begin when facilities were available with the completion of the Mills Cross. Mills was assigned as the leader responsible for coordinating the experimental and observational work of the 'Cosmic – Continuous Radiation' sub-group, with Jack Piddington, Ron Bracewell and Lindsay McCready (Convenor) forming the Radio Astronomy Steering Committee.

The specification for the proposed 20 MHz 'Cross Array' was documented in a three-page report (Shain, 1954b). The proposal left many design decisions open, but included a rough sketch of the array configuration (Figure 6). The proposed array was nearly 1.2 km by 1 km, making it the largest cross array to be constructed by RP and the largest that could be built within the bounds of the Fleurs field station.

The 12 October 1956 report of the Radio Astronomy Group (Pawsey, 1956) notes there were three focuses for study using the new cross:

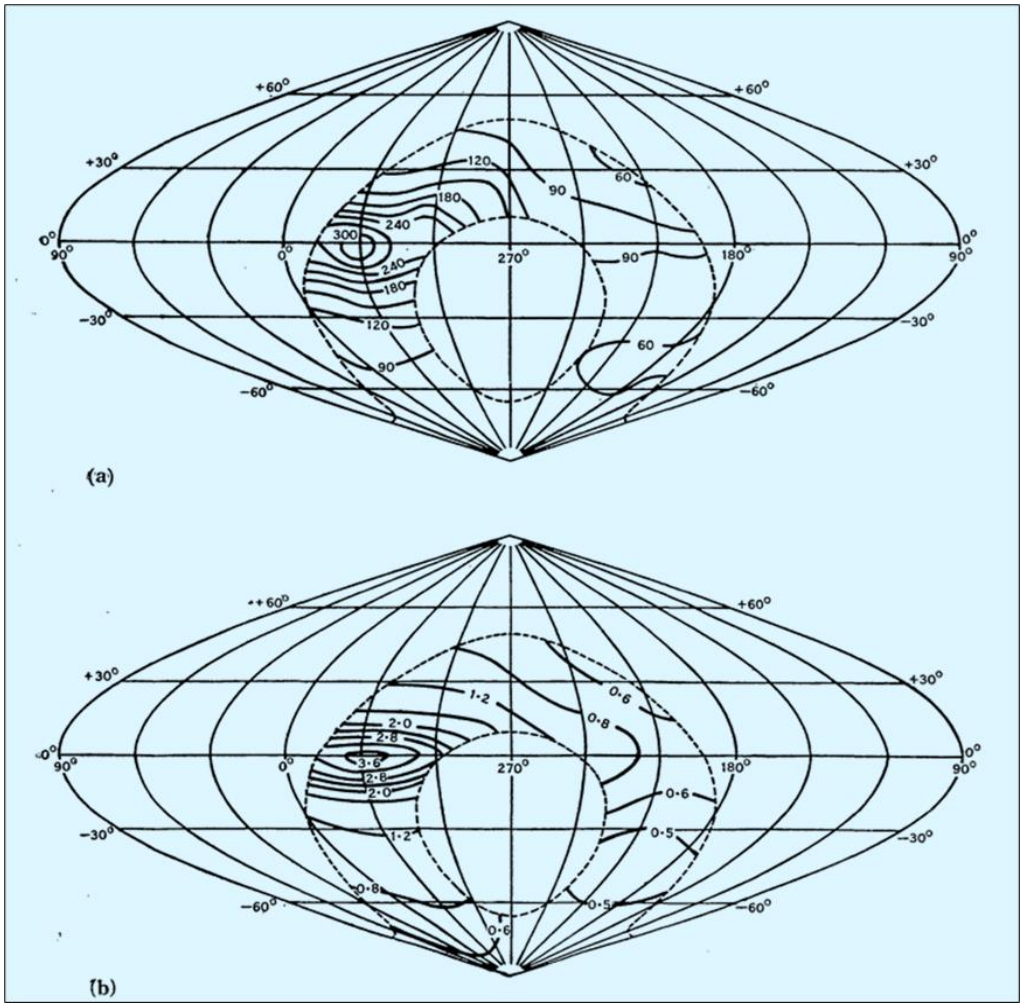


Figure 3: Contours of observed brightness temperatures (unit 1000K). Note that owing to the array beam orientation and size, only limitwed sky coverage was possible. Top (a) is the 18.3 MHz survey from Hornsby Valley field station. Bottom (b) is the 100 MHz survey from Dover Heights field station. In each case, the contours correspond to the brightness temperatures which would have been observed with similarly idealised aerials having a main-lobe beamwidth of 17° (after Shain, 1954a: Figure 1).

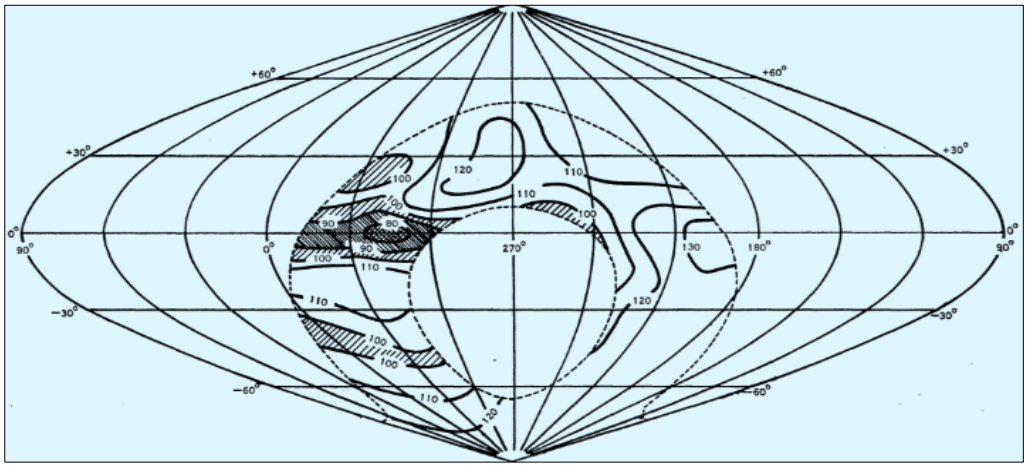


Figure 4: Contours of the ratio of antenna temperature at 18.3 MHz and 100 MHz survey (T_{18} / T_{100}). Shaded areas have lower ratios (absorption at 18.3 MHz). The strongest absorption coincides with the Galactic Centre. The highest ratio is toward the Northern Pole, Note, again, that owing to the array beam orientation and size, only limitwed sky coverage was possible. (after Shain, 1954a: Figure 2).

1) Spectra of radio sources
2) Ionised interstellar hydrogen (HII)
3) The ionosphere

Shain was assigned as a Principal Research Officer, supported by two Technical Assistants. The report noted that close cooperation with Mount Stromlo Observatory would be required to identify HII regions for investigation. The Shain Cross was expected to be completed in early 1957.

The Report also noted that no other type of instrument, radio or optical, so sensitive for studying ionised interstellar hydrogen exists elsewhere and that it was at that time the largest radio telescope in the world. A smaller version[3] of this type of cross-array had earlier been built in Washington by the Department of Terrestrial Magnetism (DTM) of the Carnegie Institution of Washington (Burke, 1956) and serendipitously discovered radio bursts from Jupiter (Burke and Franklin, 1955).

The design of the Shain Cross was consistent with the design principles for a cross-array first proposed by Mills and Little (1953). Essentially, two long arrays, oriented North–South and East–West, are connected to a receiver through a phase-switching system. The output of the phase switch is a modulated signal at the switching frequency, which effectively produces a pencil beam response from the area of the sky common to the two arrays.

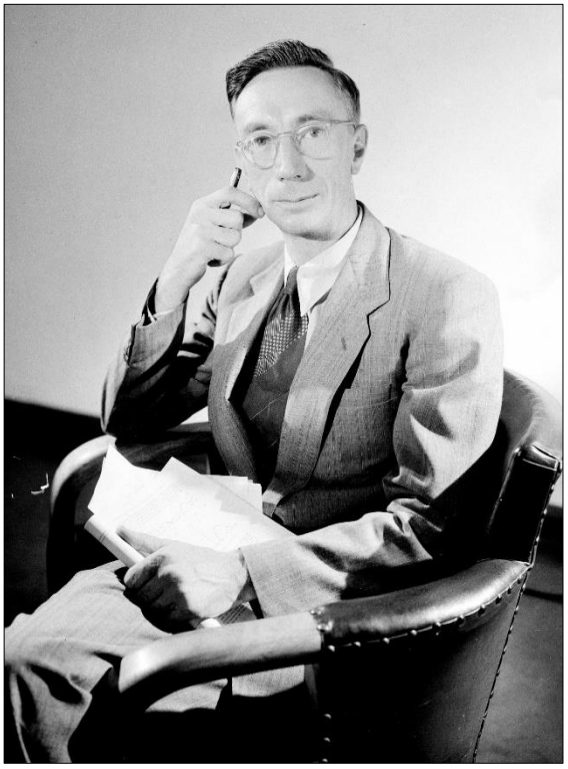


Figure 5: Joesph Lade (Joe) Pawsey (courtesy: CSIRO RAIA B7454-2).

The main design concern was that the proposed operating frequency of 20 MHz was significantly below that of the 85 MHz Mill Cross, so several design changes were necessary to

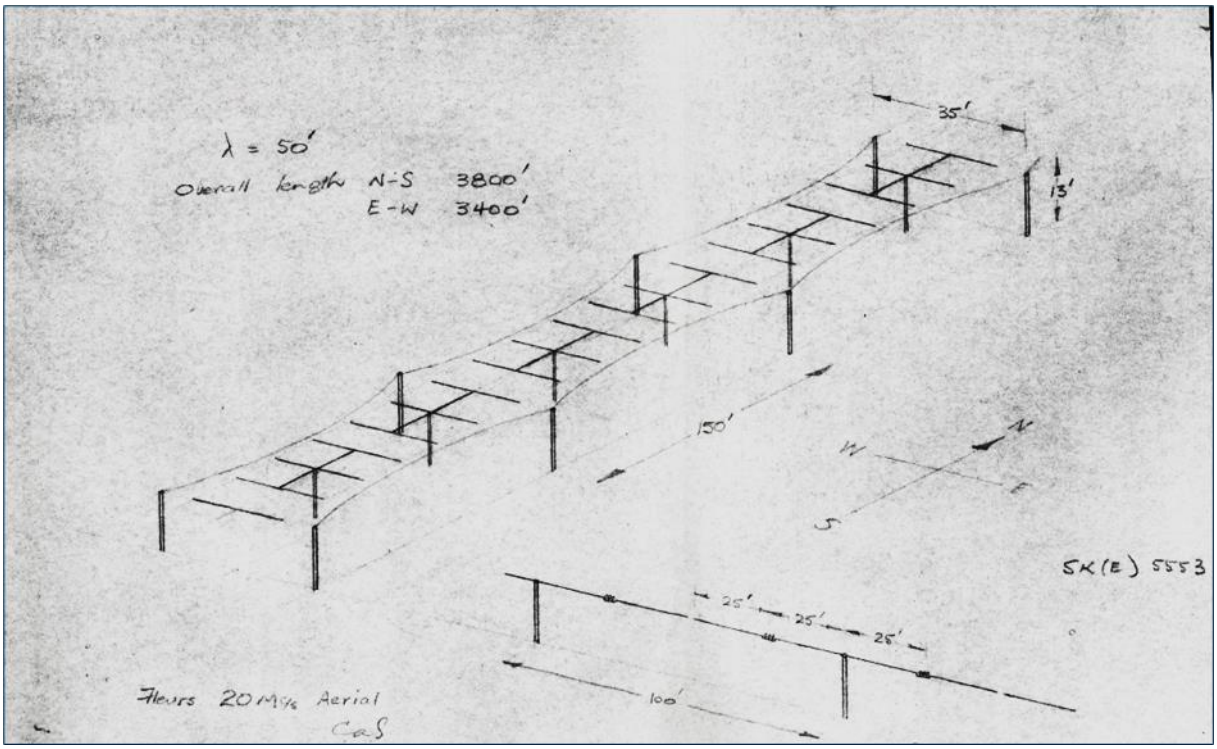


Figure 6: A preliminary design sketch of the 20 Mc/s Array from the original proposal dated 20 September 1954 (Shain, 1954b). The array dimensions proposed were N–S 3800 ft (1158 m) and E–W 3400 ft (1036 m) (NAA C3830 A3/3/37).

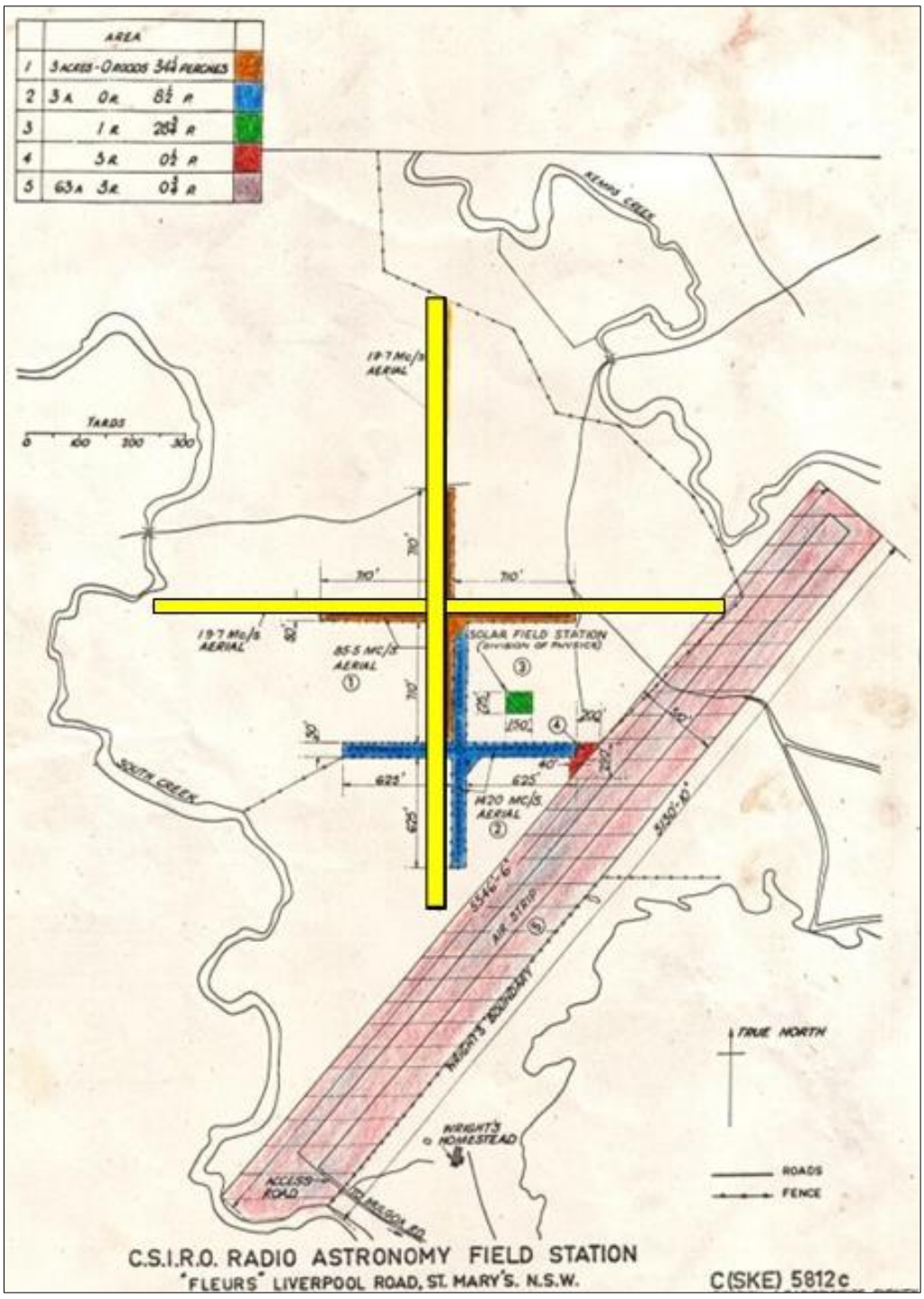


Figure 7: A map of the Fleurs Field station showing the location of the 19.7 MHz Shain Cross (yellow) relative to the 85.5 MHz Mills Cross (brown) and the 1420 MHz Chris Cross (blue). The red triangle at the eastern end of the Chris Cross marked the site of the '60-ft Kennedy Dish', which was subsequently transferred to Parkes. The air strip was used during WWII, but was no longer operational when Fleurs field station was founded (base map courtesy: CSIRO RAIA B5815: map modifications: Wayne Orchiston).

counter difficulties arising at the lower frequency. Of particular concern were sidelobes, and to minimise these, it was necessary to taper the the current distribution of both arrays heavily. Matching networks were also introduced at regular intervals along each array to reduce standing waves and give an acceptable band-width.

As shown in Figure 7, the cross had two long arms. The N–S array consisted of half-wavelength dipoles suspended parallel between insulators connected to cables running between wooden posts. In the E–W array, the dipoles

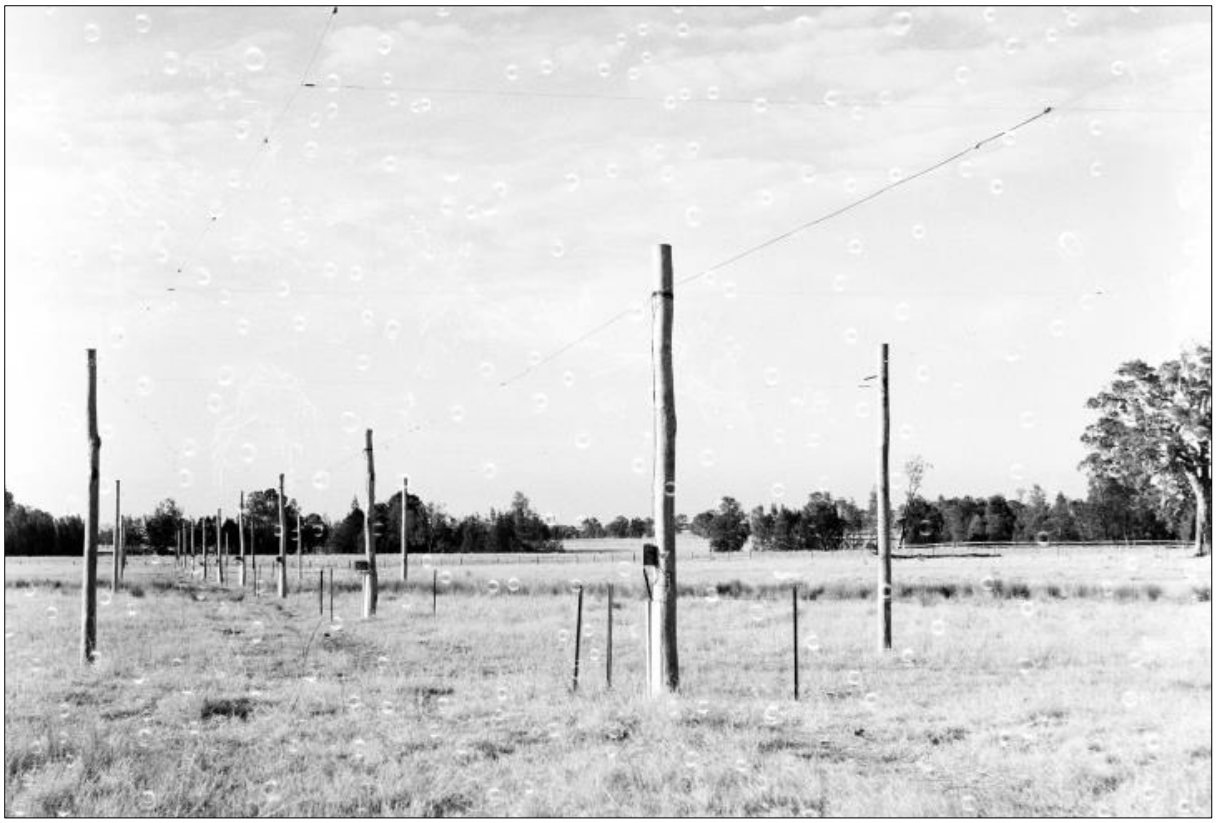


Figure 8: The northern section of the Shain Cross N–S array in 1956. The view is looking to the north. Visible on each of the central posts is one of the phase switch boxes used to change the declination of the N–S array beam. The outer posts are connected by cables used to suspend the half-wavelength dipoles. These are connected in groups of three to the central coaxial feed line (courtesy of CSIRO RAIA B5002-1).

were suspended end-to-end. The N–S array was 1108 m long, while the E–W array was 1036 m long. Along each array ran a coaxial feeder cable to which the dipoles in each array were lightly coupled. Because of the low frequency used, unlike the Mills Cross, the Shain Cross used the ground as a reflector rather than a suspended mesh. Figure 7 shows a plan of the Fleurs field station with the Mills Cross, Chris Cross and Shain Cross locations.

As a cross is essentially a transit instrument, it was necessary to introduce phase changes in the N–S array to steer the beam response in declination. This was achieved by adding additional coaxial lines to the main feeder line at fixed contact points and switches. These were connected to adjacent groups of three dipoles through a capacitor connected to the moving section of the switch. This allowed switching between five closely spaced beam positions with a separation of 33′ at the zenith using relay-operated phase switching networks controlled from a central hut. It was also possible to manually adjust the dipole switches to reach declinations further from the zenith, but this required at least 20 minutes as there were 51 switch boxes mounted on the central posts of the N–S array (see Figure 8 and 9).

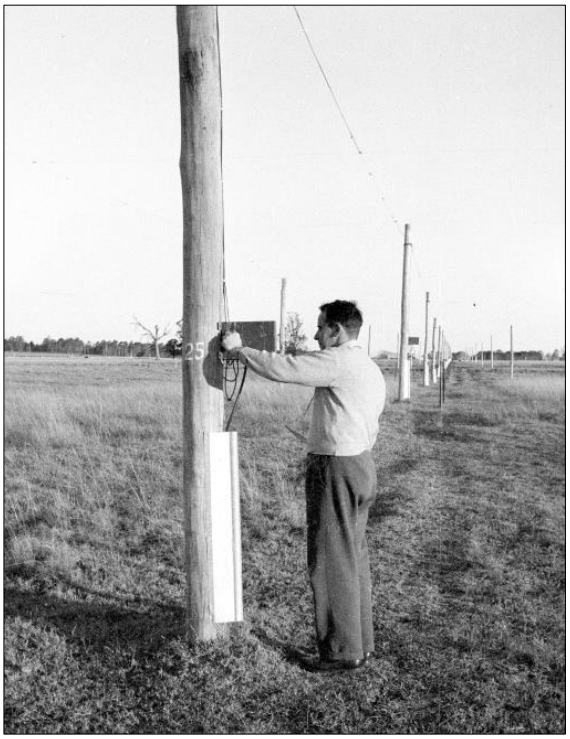


Figure 9: Alex Shain manually adjusting a phase switch on central post 25 of 51 on the N–S array of the Shain Cross in 1959 (courtesy: CSIRO RAIA B5743-3).

A key challenge in designing the receiver operating around 20 MHz was interference from short wave radio stations. From their earlier work at 18.3 MHz, Shain had often found clear gaps several kHz wide around this frequency. The challenge was to balance sensitivity by choosing a band-width sufficiently wide while excluding interference. They also found that by observing from midnight to dawn, there were often periods due to the poor ionospheric propagation conditions where there were very few interfering radio signals. After experimentation, they chose 19.7 MHz as the central operating frequency and designed the receiver to maximise bandwidth by taking advantage of gaps around this frequency. They did this using a 100 kHz band-pass filter, which was then further passed to five separate adjustable narrowband channels that could be tuned to avoid interference signals within the overall passband. Combining the outputs of the five narrowband channels gave an overall bandwidth of 26 kHz, with the output response appearing as a comb-like pattern. The central narrowband channel was fixed at the central frequency, while each of the two channels on either side could be tuned independently to avoid interference. While sensitivity was still limited, it was an effective method to avoid interference.

A Mills Cross does not act as an absolute radiometer. The modulated output measures the difference between the brightness in the main beam (the pencil beam intersection of the two array fan beams) and the average brightness seen by each array's fan beam. This complicates calibration and causes issues interpreting the observation of extended sources. For the 85.5 MHz Mills Cross, the unmodulated output of the two fan beams was used to measure a base temperature level. This was then compared to the modulated output (pencil beam) temperature to establish an absolute temperature. At the lower frequency of 19.7 MHz, the uneven ionospheric absorption and refraction patterns across the wide fan beams made measurement of absolute temperatures much more difficult.

In the 85.5 MHz cross design, the pencil beam temperature and the power of the N–S array were recorded simultaneously. However, for the 19.7 MHz cross, these values were recorded independently. The 19.7 MHz pencil-beam temperature output record consists of a saw-tooth pattern with each 'tooth' height proportional to the beam temperature integrated over 12 seconds (sidereal time). Each 'tooth' represented the adjacent declinations of the five-position cycle. The output of the total N–S array was recorded on a separate chart recorder.

Data reduction was performed in a series of manual steps based on the two recordings. The first step was the separation of the five declinations of the pencil-beam records. For each of these, the average temperature was computed at 4-minute intervals to reduce the effect of ionospheric scintillations. The N–S component was added to give five constant declination profiles of brightness temperature. The next step was to correct the measured declinations and Right Ascensions for refraction effects. Over time, Shain and Komesaroff[4] developed improved refraction correction techniques based on hourly ionospheric soundings (see Komesaroff, 1960). The corrected mean brightness temperatures were then transferred to a rectangular grid of Lund Galactic coordinates, and a correction was applied to allow for the effect of side lobes. Finally, smoothed contour lines were drawn by hand through points of equal brightness temperature. Most of the arduous manual data reduction was performed by women (first Mrs. J. Raengel and later Miss W. Wolfe) working as human computers.

3.3 Observations Using the Shain Cross

The three main observational programs proposed for the Shain Cross were outlined in the 12 October 1956 report of the Radio Astronomy Group (Pawsey, 1956). These were to examine HII regions, the spectra of selected sources, and the investigation of ionospheric propagation.

Observations were planned from midnight to dawn to help address the issues of radio station interference. Unfortunately, this was also the period where ionospheric scintillations were at their worst. Scintillations were so severe at 19.7 MHz that carrying out broader survey work to detect weaker discrete sources would require repeating multiple scans to attempt to average out their effect. Shain (1958b: 88) felt this approach would be impractical. Instead, he proposed observing only the stronger sources from the 85.5 Mills Cross survey to examine their spectral classes.

The main observational program was to examine the zone ~15° wide (later reduced to 10°) about the Galactic Plane containing a concentration of HII regions. At 85.5 MHz, the brightness temperatures show a sharp ridge of non-thermal emission with a maximum near the Galactic Centre; in contrast, Shain found that at 19.7 MHz, absorption commonly outweighed the non-thermal increase in brightness (see Figure 10).

3.4 The Galactic Centre in Absorption

The first results from the new 19.7 MHz Cross were published in early 1957 (Shain, 1957).

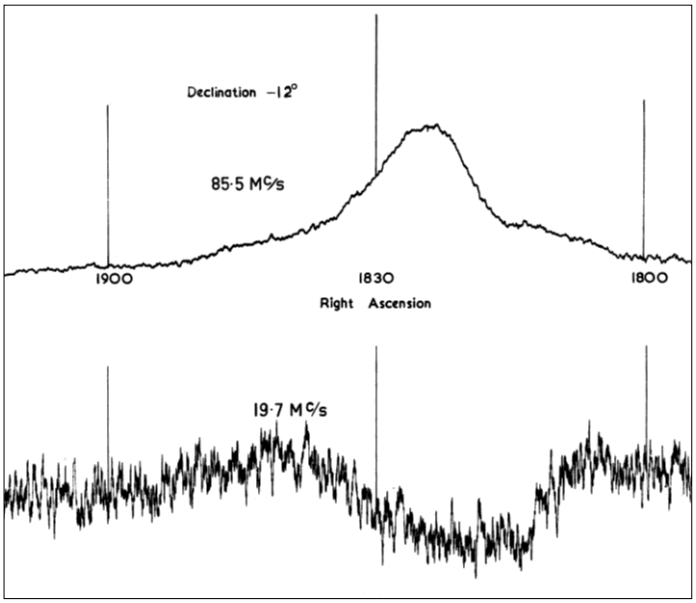


Figure 10 (right): Example of the brightness temperatures at 85.5 MHz (top) and 19.7 MHz (bottom) for a sweep across the Galactic Plane at a declination of –12°. The top chart shows a sharp ridge of non-thermal emission, while the bottom chart shows a trough due to interstellar absorption (courtesy: CSIRO RAIA B5268-4).

These preliminary results confirmed the presence of absorption at 19.7 MHz, seen consistently across the Galactic Plane due to absorption from HII regions. Shain (1957; 1959a) concluded that from observations using the narrow 1.4° beamwidth of the Cross, there was only a small angular width of the equatorial absorption band. Therefore, even at frequencies as high as 600 MHz, thermal radiation could only contribute a small fraction of the observed emission.

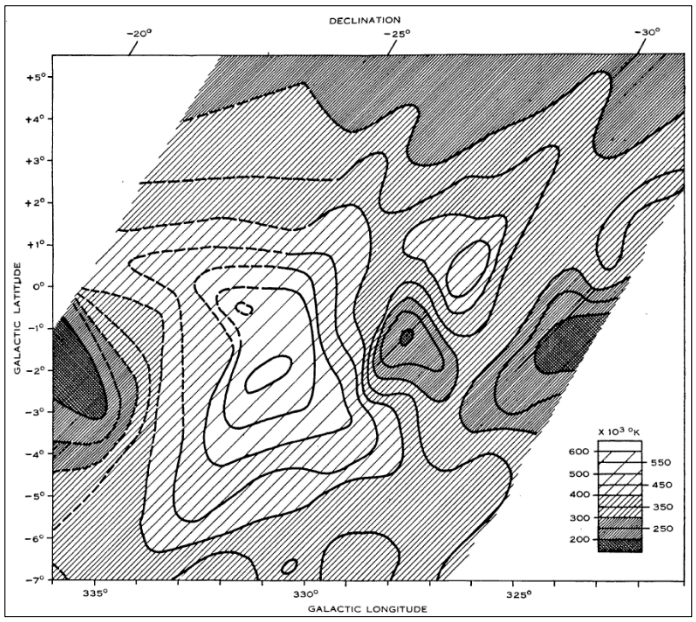


Figure 11 (right): Isophotes of 19.7 MHz observed brightness temperatures near the Galactic Centre. The source Sagittarius A is shown in absorption near the centre of the plot. The dashed contours on the left-hand side of the plot are where there were insufficient observations to give full details. Note that the Galactic coordinates are before the 1958 revision, which recognised the radio centre of the Galaxy (after Shain, 1957: Figure 2).

A more detailed study of the Galactic Centre region was made in these initial observations. Shain found a very pronounced local minimum coincident with the strong radio source Sagittarius A, seen at higher frequencies and associated with the Galactic Centre (Figure 11). He concluded that the observations were readily explained by an HII region or regions in front of, or partly in front of, a more extended non-thermal source.

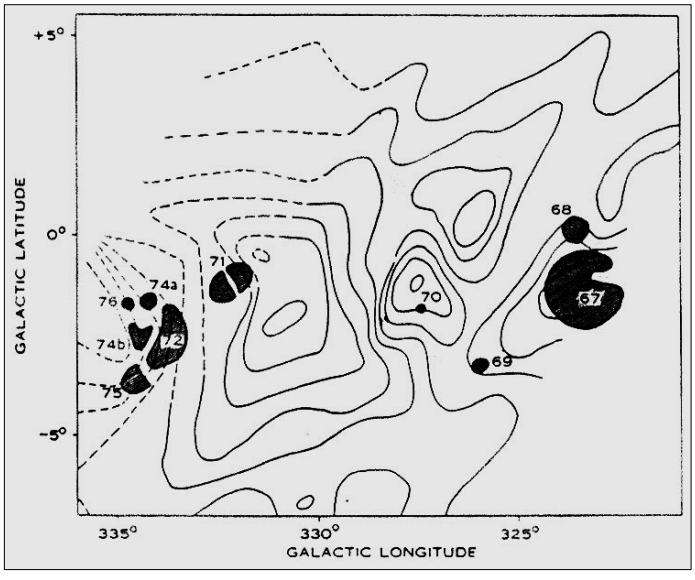


Figure 12 (right): A plot of HII emission regions (in black) recorded by Colin Gum and superimposed on Shain's 19.7 MHz isophote plot (after Shain, 1957: Figure 3). The HII region numbers are from Gum (1955).

Shain explored this explanation for the absorption in the Sagittarius A region by plotting HII regions reported by Colin Stanley Gum (1955) who had continued a project initiated at the Commonwealth Observatory (now Mount Stromlo Observatory), Canberra (Australia), by Claborn Walter (Cla) Allen in 1950. From 1951 to 1954 Gum took a series of Hα photgraphs of the Galactic Plane with an f/1 10-cm Schmidt camera. As Figure 12 indicates, these photographs revealed the presence

Table 1: Details of the HII regions shown in Figure 12, using original Galactic coordinates (after Gum, 1955: 161).

No.	*l*	*b*	Size (′)	Star (HD)	Spectrum	m_{pg}	NGC	Notes
67	323.4	–1.3	120	159176	O8	6.1	6383	1.
68	323.6	+0.2	35	158186	B3	7.3	----	2.
69	326.0	–3.2	20	161853	B3	8.2	----	3.
				318406	B0	----	----	
70	327.5	–1.8	10	----	----	----	----	4.
71	332.2	–1.1	80 × 50	162978	B0	6.6	----	5.
72	333.7	–2.6	95 × 45	----	----	----	6523	6.
74a	334.2	–1.6	25	----	----	----	----	7.
74b	334.4	–2.5	30	164971	B0	9.1	6526	
				165132	B3	7.9	----	
75	334.6	–3.6	35	165921	B0	7.2	6559	8.
76	334.7	–1.7	20	164492	O7	6.8	6514	9.

Notes (after Gum, 1955: 165):

1. Almost a complete disk with HD 159176 central. HD 158859, m_{pg} = 7.2 (B3) may also be involved.
2. Half a circular disk of nebulosity. HD 158186 would be central if the disk was complete.
3. Also in the nebula is HD 161839, m_{pg} = 9.2 (B5).
4. HD 316326 (B2) is nearby, just outside the nebulosity. Within the nebula is a small cluster whose principal star is HD 316329 (A0).
5. The nebula is in two sections, on either side of HD 162978, probably due to intervening obscuration. Towards one side of the nebula in the variable star HD 162718, mean m_{pg} = 9.1 (B0).
6. This is the Lagoon Nebula, M8, which includes the following stars: HD 164794, m_{pg} = 6.2 (O5); HD 164816, m_{pg} = 7.3 (O6); HD 165052, m_{pg} = 7.0 (Oe5); HD 164706, m_{pg} = 7.6 (B(o)ne). The Galactic cluster NGC 6530 is also within this Nebula.
7. Both of these HII regions are very faint. There may possibly be nebulosity linking them to No's 72 and 76.
8. This is almost joined to No. 72, with the separation due to a lane of foreground obscuration. In this region are a number of 'nebulous' stars and faint patches of nebulosity.
9. This is the Trifid Nebula, M20.

of HII regions, but a surprising paucity of them at the precise location of Sagittarius A. Information about the ten HII regions plotted in Figure 12 is provided in Table 1.

Upon reviewing the Shain Cross observations Shain (1957: 199) pointed out that

> If the H II region is sufficiently large to fill the aerial beam the full effect of the absorption will be observed. Smaller regions will show absorption effects in the ratio of the solid angle subtended by the H II region to that of the aerial beam. The effects of most of the H II regions shown … [in Figure 12, above] will be reduced in this way.

Shain (1957) also noted in this paper that it may be possible to determine the distance of HII regions based on the strength of radiation remaining at 19.7 MHz in cases where near total absorption occurred from an HII region. This was because the source of any remaining radiation must occur between the HII and the observer. If background radiation was consistently produced, it may be possible to determine a distance to the HII region (Shain, 1959a). However, given the difficulty in achieving an accurate absolute calibration of the 19.7 MHz Cross, this method was never subsequently used.

3.5 Emission from Comets

In April 1957, the 19.7 MHz Shain Cross was opportunistically used to search for emission or absorption from Comet Arend–Roland. No emission or absorption was detected, nor any at 85.5 MHz by Bruce Slee using the Mills Cross (Shain and Slee, 1957). Only a potential upper limit from any cometary emission could be determined. Earlier, some international observers[5] reported radio frequency detection, while others could not reproduce the results, and doubts remained whether cometary emission had been detected.

3.6 External Galaxies

The 29 July 1957 Reports on the Current Work to the Radio Astronomy Group stated that the

> … 19 Mc/s aerial had been operating with scanning since November 1956 and appears to be working satisfactorily. The receiver now has five separate I.F. channels in the second I.F. amplifier. One of these has a Collins mechanical filter (which meets the maker's claims), and the other four can be tuned between 200 and 300 kc/s. So far, interference has been troublesome, but some records can be obtained each night. (Pawsey, 1957).

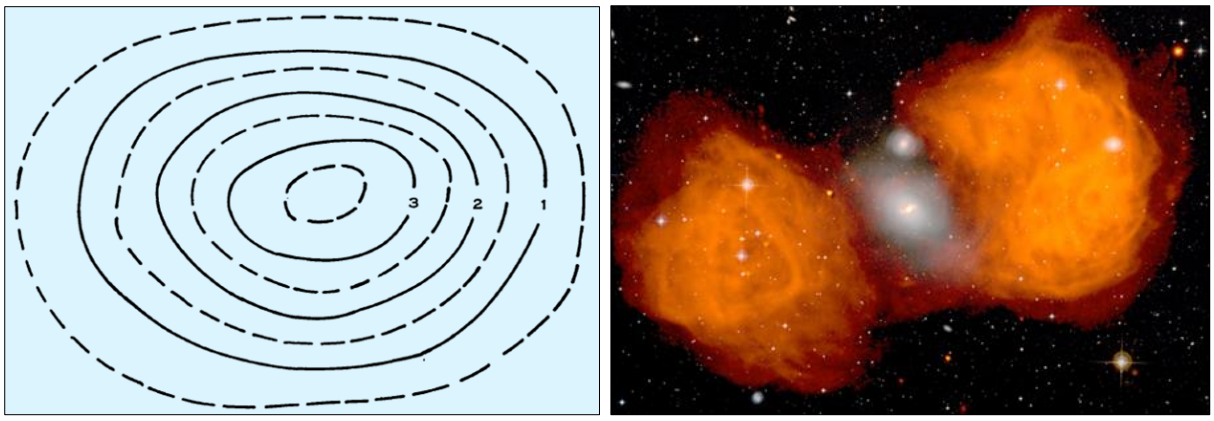


Figure 13: Fornax A. The 19.7 MHz isophotes (left) of apparent brightness temperature in units of 108,000°K are compared to a VLA image in local intensity, and L-band overlaid on an optical image of NGC 1361 (right). The field of view is approximately similar in both images (after Shain, 1958: Figure 2 and courtesy: NRAO/AUI/NSF, observers Ed Fomalont (NRAO), Ron Ekers (ATNF), Wil van Breugel (UC-Berkeley), and Kate Ebneter (UC-Berkeley)).

In 1958, Shain published the results of observing two external galaxies, Centaurus A and Fornax A, at 19.7 MHz (Shain, 1958a). This was part of the program to compare results to sources detected during the 85.5 MHz survey and obtain the spectra of these sources. Shain found marked similarities between the general appearances, linear dimensions, spectra and radio frequency strengths of the sources.

At 19.7 MHz, there was no indication that the Fornax A source was other than an extended source with approximate dimensions of 0.8° × 1.1°. At 85.5 MHz, Sheridan (1958) noted that the complexity of the contours indicated some small-scale structure may be present. We know today that Fornax A (NGC 1316) is a large double-lobe radio source with a black hole at the galaxy's centre, producing jets that collide with intergalactic material, producing large radio lobes. Figure 13 compares the 19.7 MHz isophotes with a modern radio image of Fornax A.

The Centaurus A source has a much larger angular extent at 19.7 MHz than Fornax A (see Figure 14). Again, the double-lobe nature of the source was not apparent. However, Shain estimated that at least 11% of the integrated radiation came from an unresolved central discrete source. Noting the elongated nature of the source and the curving ridge of maximum intensity in the extended source, Shain speculated that assuming the observed radiation originates in an acceleration of relativistic electrons in magnetic fields (synchrotron emission), then

> The plausible model of the extended source is then a spiral … with the south-following end nearer the observer and with the plane of the spiral inclined to the line of sight. Asymmetry is produced because the great extent of the source means that the two arms are at different distances and are viewed at different angles. On any model, the greater width at 19.7 MHz is readily explained by a weakening of the magnetic fields near the edge of the system and the gradual

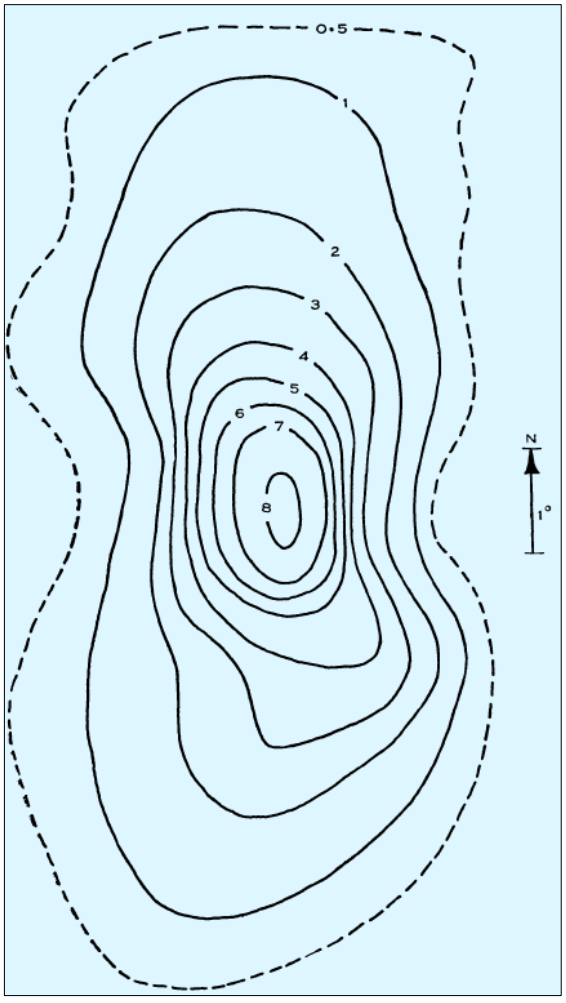


Figure 14: Centaurus A 19.7 MHz Isophotes of apparent brightness temperature in units of 100,000°K (after Shain, 1958: Figure 3).

> energy loss by the highest energy electrons as they diffuse outwards from the centre. (Shain, 1958a).

While the mechanism for accelerating electrons (or positrons) in the galaxy's core was unknown, he speculated that the shape may be a consequence of the core's rotation. While these conclusions were speculative, they were heading in the right direction. It would be many years before the energy source was recognised as a black hole at the galactic core, producing jets that resulted in the giant radio lobes. The unresolved central source was the nucleus and inner jets.

In 1958 Shain (1959) attended the International Astronomical Union/International Union of Radio Science (IAU/URSI) Paris Symposium on Radio Astronomy and presented an expanded paper on his investigations of external galaxies at 19.7 MHz, summarising his earlier ob-

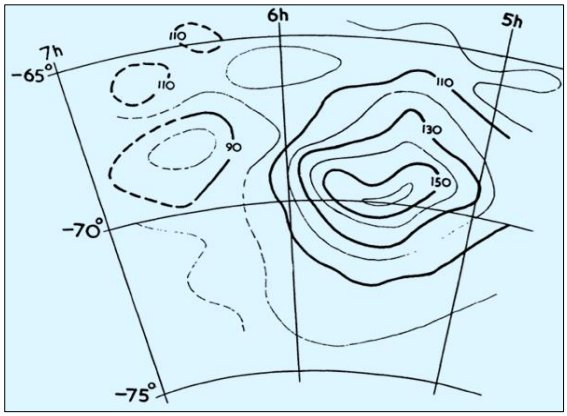


Figure 15: The region around the Large Magellanic Cloud at 19.7 MHz in units of 1000°K aerial temperature. The dashed lines indicate areas in incomplete data (after Shain, 1959: Figure 2).

servations of Centaurus A and Fornax A and providing new data on his observations of Virgo A and the Large and Small Magellanic Clouds (LMC and SMC).

Drawing on his own 19.7 MHz observations and those of Mills at 85.5 MHz, Shain noted a faint general extension of the Virgo A source that aligned with the 'jet' at optical wavelengths shown emanating from the nucleus of NGC 4486. He noted:

> If the extension to Virgo-A is physically associated with the source and particularly with the jet, the expansion must have been extremely rapid, with speeds comparable to those suggested for Centaurus-A, or must have begun before the start of the jet's ejection.

With the benefit of hindsight, this observation would prove correct, although it would be many years before sufficient evidence was gathered.

The LMC survey produced some interesting results. Figure 15 shows the area around the LMC at 19.7 MHz. Of note was the large area of absorption centred on 6h 30m, −68°, which Shain concluded was most likely associated with an HII region, likely part of Stromlo 12. The 19.7 MHz and 85.5 MHz Mills Cross observations showed the LMC in emission, covering approximately the same extent at both frequencies. The major difference between the two was that the 30 Doradus region showed a sharp emission peak at 85.5 MHz, while at 19.7 MHz, it showed absorption.

Shain noted the importance of the 30 Doradus region being well removed from our Galaxy was that it may be possible to separate the Galactic and extragalactic components of the background radiation by comparing the absorption levels at 19.7 MHz.

Only preliminary results were available for the SMC, which had a much lower brightness at 19.7 MHz. The observations showed that, in general, the 19.7 MHz and 85.5 MHz results were very similar in extent and a comparable ratio to that observed for the LMC.

3.7 Solar Radio Bursts

In 1959, Shain and Charlie Higgins[6] published the investigation results of the location of 19 MHz solar bursts based on observations made in 1957 using only the E–W arm of the 19.7 MHz Cross as an interferometer (Shain and Higgins, 1959). This research followed up on earlier work at the Hornsby Valley field station at 18.3 MHz and that of Payne-Scott and Little (1952) and Wild et al. (1959). Studying this type of radio emission was considered essential for probing the thermal plasma properties and dynamics of energetic particles in the outer corona.

The two halves of the E–W arm were configured as an interferometer. Each half of the array was connected to a separate receiver. One receiver was connected so that when the aerial beam was on the Sun the other receiver was connected to introduce a 180° phase shift (Figure 16). By comparing the ratios of amplitudes received simultaneously from solar bursts by the two receivers it was posible to determine the relative position of the burst on the solar disk (see Figure 17). Short-duration bursts were easily visible when the chart recorder ran at high speed.

Based on a series of observations, Shain and Higgins determined that at 19.7 MHz, most solar bursts were at a radial distance of 2.9 $R_{\odot}$, which they interpreted as the height in the solar corona of the fundamental plasma frequency. The height of the source in the corona was high-

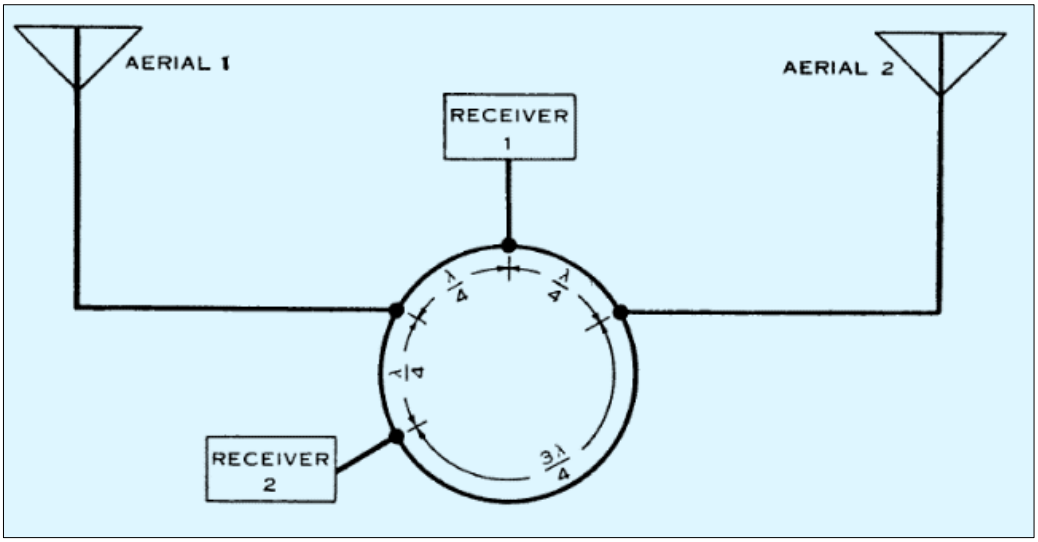


Figure 16: Configuration of the E–W arms of the 19.7 MHz Cross. The two halves of the Cross were connected to two receivers, one in-phase and one out-of-phase. A similar configuration had been used earlier at Hornsby Valley (after Shain and Higgins, 1959: Figure 1).

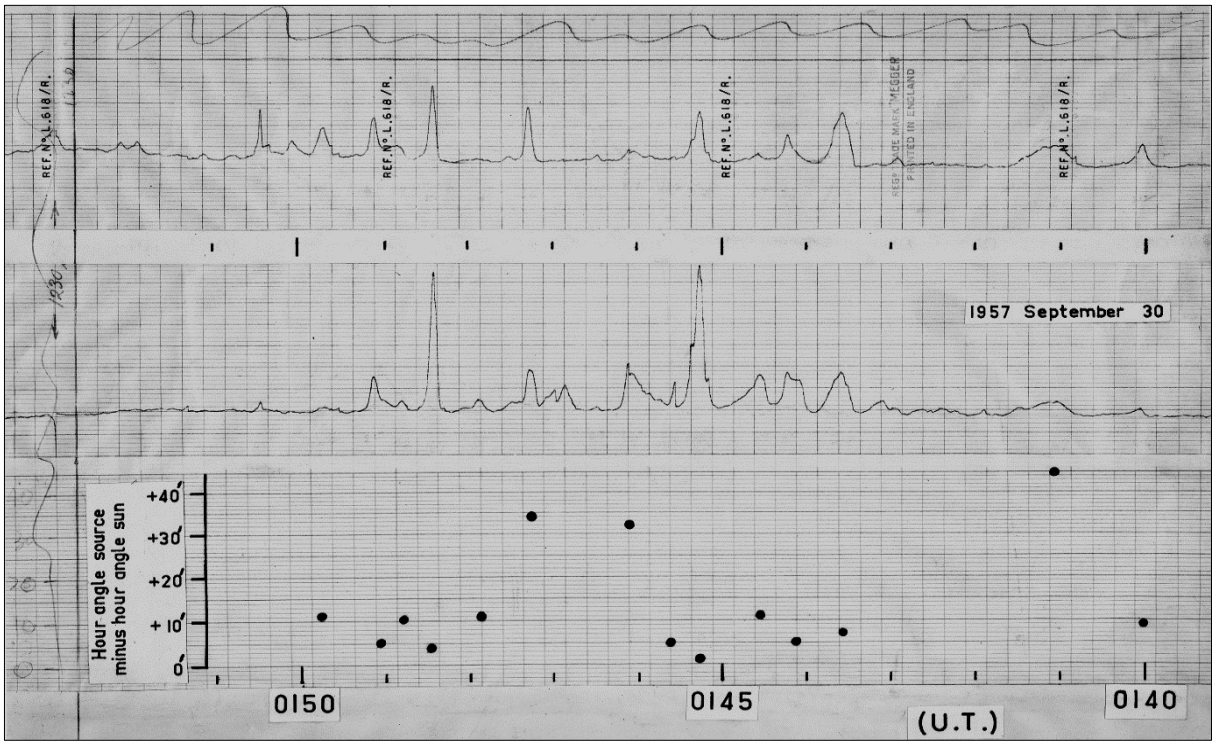


Figure 17: An example of the outputs of the E–W arm of the Shain Cross configured as an interferometer. The top two charts show the outputs from the out-of-phase and in-phase receivers. The bottom chart shows the calculated displacement of the source from the Sun based on the ratio of the intensity of the bursts from the above charts. In the example, two burst sources are present. Most bursts are from one source displaced ~10' from the Sun and three from another 35' from the Sun (courtesy: CSIRO RAIA B5850).

er than expected in models, and they attributed this to a higher local electron density driven by a streamer moving outward through the corona.

It is interesting to note that determining the location of low-frequency burst sources has remained problematic. More recent studies (Gordovskyy et al., 2019) conclude that a combination of actual density changes and strong radio-wave scattering due to plasma turbulence in the active corona causes the observed effect. On 9 July 2024, NASA's CubeSat Radio Interferometry Experiment, or CURIE, was successfully launched by ESA on an Ariane 6 rocket (Johnson-Goth, 2024). CURIE aims to investigate where solar radio waves originate in co-

ronal mass ejections and advance understanding using low-frequency radio interferometry in space. Operating from 0.1 to 19 MHz above the Earth's atmosphere, it should avoid the effects of the ionosphere, which plague low-frequency Earth-based observations.

3.8 Ionospheric Refraction

In 1959, Shain and Max Komesaroff presented a paper to the Symposium of the Ionospheric Research Committee, Agard Avionics Panel, Paris, France, on the ionospheric electron content from refraction measurements on cosmic radio sources based on their 19.7 MHz observations (Komesaroff and Shain, 1959). Komesaroff (1960) followed up with a more detailed theoretical paper in which he derived an updated method for correcting ionospheric refraction, which was used for data reduction of the 19.7 MHz survey.

One of the science objectives for the 19.7 MHz Cross was ionospheric investigations. Komesaroff showed that for a radio source at transit, the change of declination depends on the total electron content of a column of unit area through the ionosphere, together with the north–south gradient of this quantity. In contrast, the change of Right Ascension depends, to a first order only, on the east–west gradient. The study was undertaken initially to eliminate refraction effects from the 19.7 MHz observations. In doing this, they relied on comparisons to hourly ionospheric soundings, which allowed them also to gain information about the structure of the ionosphere above the F-region maximum. Using their results, they found a 'total thickness' of the ionosphere during the observing period of 355 km, which agreed with Moon-echo results.

While variation in electron density was a key factor, the effects of Faraday rotation and time and phase delays caused by the ionosphere were not understood. It has only been recently, with the renewed focus on low-frequency radio astronomy, that calibration strategies for decametre-band observations have been able to correct for the severe ionospheric image blurring below 30 MHz (see Groeneveld et al., 2024). Ultimately, ground-based observations become uncorrectable when approaching the plasma frequency of the ionosphere.

3.9 The Galactic Plane Survey and the End of the Road

In the 29 June 1959 Radio Astronomy – Projected Programme report, Pawsey (1959b) noted

> … that of the current series of observations, no less than three are unique and right ahead of overseas competition. These are (1) Wild's observations of solar bursts; (2) Mills' measurements of small-diameter radio sources; and (3) Shain's low-frequency observations.

However, notwithstanding Pawsey's praise for Shain's program, it was not prioritised for continuation, when the focus shifted to projects utilising the soon-to-be-commissioned 64-m Parkes Radio Telescope (also referred to by RP at the time as the Giant Radio Telescope, or G.R.T.). The report noted that Shain, Komesaroff and Higgins would complete the Galactic strip survey about January 1960, and further (low-frequency) work would be discontinued.

The Notes of the Radio Astronomy Program of 10 August 1959 show Shain as an 'unallocated' resource but that he would likely to be interested in experiments with the G.R.T. (Pawsey, 1959a).

In fact, Shain was suddenly diagnosed with terminal lung cancer and passed away soon after, on 11 February 1960, at the age of only 38. At the time of his death, he had nearly completed the survey of the Milky Way plane. In his obituary notice, Pawsey (1960) wrote:

> His contribution to radio astronomy lay in the frequency range around 20 Mc/s where he pioneered the study of the two features peculiar to this range of radio astronomy: absorption in ionised interstellar hydrogen (HII regions), and absorption and refraction in the ionosphere. Observations in this frequency range are particularly difficult owing to interference from radio stations and the complicating effects of the ionosphere, but they give unique information of great importance to radio astronomy. Shain's work is basic [i.e., fundamental] in this field.

Shain's colleagues, Max M. Komesaroff and Charlie S. Higgins continued work to complete the survey observations and data reductions and published the results in 1961 (Shain et al., 1961). The paper is relatively short and perhaps not suggestive of the effort required to complete the 19.7 MHz survey covering an area extending between l^{I} 224° to 16° with a 10° strip on the Galactic Plane. Some sections within this area remained incomplete due to observation difficulties due to ionospheric effects and radio frequency interference. Unfortunately, most of the observation period coincided with solar cycle 19, which peaked in ~1960 and made for less-than-ideal conditions (see Figure 18). Most findings from the survey had been published in earlier papers, so the paper served mainly as a summary. As noted earlier, the calibration of the 19.7 MHz Cross was complicated, and the absolute calibration was estimated to have a pos-

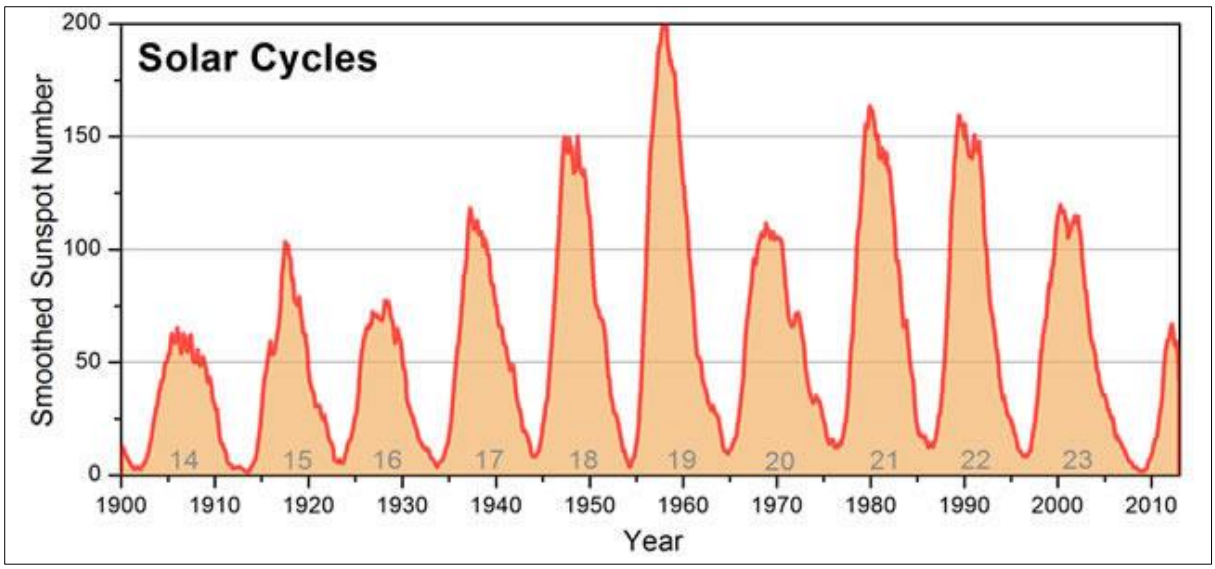


Figure 18: Smoothed sunspot numbers by year showing a peak in cycle 19 around 1960 (courtesy: NOAA Space Weather Products & Service; https://training.weather.gov/nwstc/spacewx/wmo/lesson2/solarcycle.html).

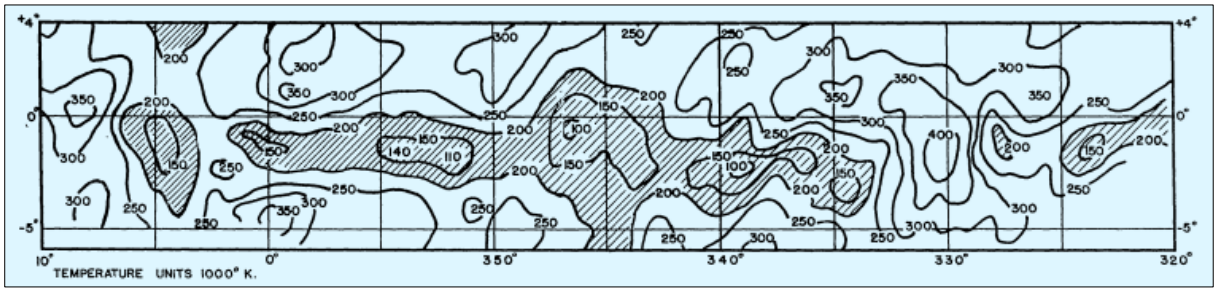


Figure 19: An example of the distribution of radio emission at 19.7 MHz from the Shain Cross Galactic Plane survey. Shaded areas represent absorption areas (after Mills, 1964: Figure 10).

sible error of ~20%. However, the relative accuracy was thought to be much higher. Figure 19 shows an example of a region of the Galactic Plane from the survey.

The final paper to appear based on the 19.7 MHz Shain Cross observations was by Max Komesaroff (1961). He examined the Galactic radio spectrum down to 19.7 MHz, concluding that the form of the spectrum changes with decreasing Galactic latitude, which was entirely consistent with a model consisting of two components: non-thermal sources of constant spectral index and ionised hydrogen of constant temperature.

4 THE INFLUENCE OF SHAIN'S RESEARCH

For the life of the 19.7 MHz Cross, Shain remained the principal researcher using the instrument. Assessing the influence of his research on the broader radio astronomy community is challenging. Pawsey (1960) considered Shain's research of primary importance, as he stated in Shain's obituary. Shain's invitation to present a paper summarising his extra-galactic observations at the IAU/URSI Paris Symposium on Radio Astronomy also provides context to the importance of his work. Examining citations provides another quantifiable, although limited, perspective, and an insight into his influence.

In the ten years 1951 to 1961, Shain was the author of 24 scientific papers, of which 19 received one or more citations.[7] These papers have received 396 citations, giving them an H-Index of 11. Nine papers relate to his research using the 19.7 MHz Shain Cross at Fleurs. Table 2, below, shows the papers ranked by citation number and the field station where the research occurred. Papers that relate specifically to observations using the Shain Cross are highlighted in yellow.

Shain's most cited work is related to his early low-frequency observations at 18.3 MHz at Hornsby Valley field station. This is followed by his confirmation of the discovery of radio bursts from Jupiter and subsequent observations. At Fleurs, he used a simple two-element interferometer for his follow-up Jupiter observations (Gardner and Shain, 1958; cf. Orchiston et al., 2021a). His work using the Shain Cross at

Table 2: RP low frequency radio astronomy research papers ranked by citation number and the field station where the research was carried out. Papers that relate to observations made with the Shain Cross are indicated by yellow highlighting.

Number of Citations	Paper Title	Year	Field Station	Shain Cross
63	The measurement of ionospheric absorption using observations of 18·3 Mc/s cosmic radio noise	1953	Hornsby	
52	Further Observations of Radio Emission from the Planet Jupiter	1958	Fleurs	
46	18.3 Mc/s Radiation from Jupiter	1956	Hornsby	
35	Observations of the General Background and Discrete Sources of 18.3 Mc/s Cosmic Noise	1954	Hornsby	
35	A High Resolution Galactic Survey at 19.7 Mc/s	1961	Fleurs	Yes
34	Observations of extragalactic radio emission	1959	Fleurs	Yes
32	The radio emission from Centaurus A and Fornax A	1958	Fleurs	Yes
18	Location of the Sources of 19 Mc/s Solar Bursts	1959	Fleurs	Yes
17	Galactic Radiation at 18.3 Mc/s	1951	Hornsby	
17	Location on Jupiter of a Source of Radio Noise	1955	Hornsby	
13	Effects of solar flares on the absorption of 18.3 Mc/s cosmic noise	1954	Hornsby	
9	Observations of Cosmic Noise at 9.15 Mc/s	1954	Hornsby	
6	Galactic Absorption of 19.7 Mc/s Radiation	1957	Fleurs	Yes
5	Absorption of 19.7-Mc/s radiation in H II regions	1959	Fleurs	Yes
5	A Comparison of the Intensities of Cosmic Noise Observed at 18.3 Mc/s and at 100 Mc/s	1954	Hornsby	Yes
4	A remarkable southern meteor shower	1957	Fleurs	
3	Changes in the absorption of cosmic noise observed during two ionospheric disturbances	1955	Hornsby	
1	Reflexion of Radio Waves from the Moon	1957	Hornsby	
1	A radio search for Comet Arend-Roland	1957	Fleurs	Yes

Fleurs accounted for 136 (34%) of his overall citations. The general policy at RP at the time was to publish most papers in the newly formed *Australian Journal of Physics*, which may have limited international readership. Publication in international journals was reserved for short papers noting significant discoveries that RP wanted to bring to the broader community's attention, for example, Shain's confirmation of Burke and Franklin's (1955) discovery of radio bursts from Jupiter, which appeared in *Nature* (Shain, 1955). A more detailed paper on the Jupiter bursts also appeared in the *Australian Journal of Physics* (Shain, 1956). All of Shain's 19.7 MHz Cross papers were published in the *Australian Journal of Physics.* The only exception was a short report on the attempt to detect radio emission from Comet Arend–Roland, which appeared in *The Observatory* (Shain and Slee, 1957).

5 CONCLUDING REMARKS

Shain's contribution using the 19.7 MHz Cross is probably best summarised by the scientific leader of the RP group, Joe Pawsey. In 1959, Pawsey noted that Shain's work, together with that of Wild and Mills, was "… unique and right ahead of overseas competition." (Pawsey, 1959b). Pawsey was well placed to make this judgement, having just visited the US, UK and Europe and attended the IAU/URSI Symposium on Radio Astronomy in Paris in August 1958, which served as a snapshot of the state of the science up to that time. Shain made essential contributions to solar, Galactic and extragalactic radio astronomy by focusing on a largely unexplored region of the radio spectrum, further consolidating Australia's early leadership in the field.

Unfortunately, the untimely deaths of Shain and Pawsey and RP's shift to consolidate their research using the 64-m Parkes Radio Telescope curtailed further exploration of low-frequency radio astronomy by the RP group, apart from further Galactic observations that Higgins briefly made with the Shain Cross (see Wendt et al., 2024).

After Higgins' observations, no further research was done using the 19.7 MHz Shain Cross, despite Grote Reber's lobbying. With the focus of research shifting to the Parkes Radio Telescope, Fleurs field station eventually was handed over to the School of Electrical Engineering at the University of Sydney (see Orchiston, 2004; Orchiston and Mathewson, 2009).

Six decades would then pass before the CSIRO returned to explore the low-frequency

spectrum, first participating in the Square Kilometre Array precursor, the Murchison Widefield Array consortium, which became operational in 2013 and then beginning construction of SKA-Low in Western Australia's Murchison shire on the traditional lands of the Wajarri Yamaji. The first element of the SKA-Low was installed on 7 March 2024 (Anonymous, 2024).

6 NOTES

1. In the historical context of this paper, we refer to the low frequency being <100 MHz, although currently low-frequency radio astronomy is often used to refer to any frequency <1 GHz.
2. Shain was born in Melbourne on 6 February 1922. He attended the University of Melbourne, where he studied Physics. After graduating with a BSc Honours in 1942 he immediately signed up for service with the Second Australian Imperial Force but was discharged on medical grounds in early 1943. Seeking another way to contribute to the war effort, he joined the CSIR's Division of Radiophysics, where he was engaged in the development of radar countermeasures until the end of the war in 1945. With the shift to peacetime research, Shain spent the rest of his career focused on decametric radio astronomy. He remained at Radiophysics until his untimely death from lung cancer on 11 February 1960, just after his 38th birthday (Orchiston et al., 2021b: 58; Pawsey, 1960).
3. Each arm of the DTM cross was 634-m long and had 66 dipoles. The operating frequency was 22.2 MHz, giving a slightly elliptical pencil beam with a beamwidth of 1.6° × 2.4° at the half-power points.
4. Max M. Komesaroff initially worked as an optometrist before studying part-time for a BSc at the University of Sydney. He joined Radiophysics in late 1953 and was based at Dapto field station where he researched researched Type III solar bursts. When the Shain Cross was erected at Fleurs field station Komesaroff was assigned to work with Shain, and he relocated to Sydney from Dapto (which to the south of Sydney, near the city of Wollongong – see Figure 1). After Shain's death and completion of the 19.7 MHz Galactic plane survey, the Radiophysics field stations were closed down (see Orchiston et al., 2021b) and Komesaroff transferred to 64-m Parkes Radio Telescope projects (Sullivan, 1978).
5. J.D. Kraus reported the detection of radio emission from the comet at 27.6 MHz in IAU Circular No. 1596 (1957).
6. Charles S. ('Charlie') Higgins came to Radiophysics in the late 1940s from a radio company. He had a certificate in radio engineering, and an interest in astronomy (Orchiston et al., 2015b). He was employed as a Technical Assistant, and initially he worked with Shain at Hornsby Valley and Fleurs field stations, and later, after Shain's death, with Bruce Slee (Orchiston, 2004a) at Fleurs. Higgins developed a passion for radio astronomy, and on various occasions he lectured to Sydney-based amateur astronomical societies. For a short time the second author of this paper worked together with Slee and Higgins at Fleurs field station.
7. Citation data were sourced from the SAO/NASA Astrophysics Data System on 15 July 2024.

7 ACKNOWLEDGEMENTS

We are grateful for access to the resources of the CSIRO Radio Astronomy Image Archive, the National Archives of Australia and the SAO/NASA Astrophysics Data System Bibliographic Services.

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Finally, we wish to thank Dr. Phil Edwards (CSIRO Astronomy and Space Science, Sydney) and Dr Peter Robertson (University of Melbourne) for reading and commenting on the manuscript.

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Dr Harry Wendt is an Adjunct Research Fellow at the University of Southern Queensland, Centre for Astrophysics.



He has a long-standing interest in early Australian radio astronomy and, in 2008, 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. He co-authored the book *Four Pillars of Radio Astronomy: Mills, Christiansen, Wild, Bracewell* (2017, Springer, with Bob Frater and Miller Goss, and is a member of the IAU Working Group on Historical Radio Astronomy.

Harry retired from full-time work in 2017 after a 28-year career in banking, including time as Chief Technology

Officer and General Manager of Digital for Westpac Banking Corporation in Australia. Before this, he worked in the computer industry and spent eight years as an aircrew officer in the Royal Australian Navy Fleet Air Arm. It was while learning to navigate using a sextant that his interest in astronomy was first kindled. He lives in Sydney, Australia, and is a keen surfer and sailor.



Professor Wayne Orchiston was born in Auckland (New Zealand) in 1943, and has BA First Class Honours and PhD degrees from the University of Sydney. Currently, he is employed by the University of Science and Technology of China in Hefei as the Co-editor of the *Journal of Astronomical History and Heritage*. He is also an Adjunct Professor of Astronomy in the Centre for Astrophysics at the University of Southern Queensland (USQ) in Toowoomba, Australia. Formerly, Wayne worked at observatories, research institutes and universities in Australia, New Zealand and Thailand. During the 1960s he was employed by the CSIRO's Division of Radiophysics in Sydney, and for a time worked at Fleurs field station near Sydney, assisting Dr Bruce Slee with observations made with the Shain Cross (the focus of this paper). At Fleurs Wayne also carried out daily solar observations with the Chris Cross.

Over the past two decades Wayne has supervised more than 35 Master of Astronomy and PhD history of astronomy research projects through three different Australian universities.

Wayne has wide-ranging research interests and more than 500 publications, mainly about historic transits of Venus; historic solar eclipses; historic telescopes and observatories; the emergence of astrophysics; the history of cometary and meteor astronomy; the astronomy of James Cook's three voyages to the Pacific; amateur astronomy and the amateur–professional interface; the history of meteoritics; Indian, Southeast Asian and Māori ethnoastronomy; and the history of radio astronomy in Australia, France, India, Japan, New Zealand and the USA.

Recent books by Wayne include *Exploring the History of New Zealand Astronomy …* (2016, Springer); *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy* (2017, Springer); *The Emergence of Astrophysics in Asia …* (2017, Springer, co-edited by Tsuko Nakamura); *Exploring the History of Southeast Asian Astronomy …* (2021, Springer, co-edited by Mayank Vahia) and *Golden Years of Australian Radio Astronomy: An Illustrated History* (2021, Springer, co-authored by Peter Robertson and Woody Sullivan). He has also edited or co-edited a succession of conference proceedings.

Since 1985 Wayne has been a member of the IAU, and he is a former President of Commission C3 (History of Astronomy). In 2003 he founded the IAU's Historical Radio Astronomy Working Group, and is the current Radio Astronomy Subject Editor for the Third Edition of Springer's *Biographical Encyclopedia of Astronomers*. He also founded the IAU Working Group on Historic Transits of Venus, is the Founding Chair of the History & Heritage Working Group of the SE Asian Astronomy Network, and is the founding Director of the Historical Section of the Royal Astronomical Society of New Zealand.

In 1998 Wayne co-founded the *Journal of Astronomical History and Heritage,* and was the Managing Editor until 31 July 2022 when he passed ownership of the journal to the University of Science and Technology of China. In 2013 the IAU named minor planet 48471 'Orchiston', and in 2019 he and Dr Stella Cottam were co-recipients of the American Astronomical Society's Donald E. Osterbrock Book Prize for their 2015 Springer book, *Eclipses, Transits and Comets of the Nineteenth Century: How America's Perception of the Skies Change*d. In 2023 Wayne was elected an Honorary Member of the Royal Astronomical Society of New Zealand, and Springer published the following Festschrift: Gullberg, S., and Robertson, P. (eds), *Essays in Astronomical History and Heritage: A Tribute to Wayne Orchiston on His 80th Birthday*. In January 2024 Wayne and Darunee Lingling Orchiston attended the Winter Meeting of the American Astronomical Society in New Orleans, where he was presented with the 2024 Le Roy E. Doggett Prize for History of Astronomy.

Wayne and Darunee Lingling live in a quiet village near Chiang Mai in northern Thailand. When not involved in astronomy he enjoys following Australian and New Zealand athletics, Formula 1 and Inycar racing, and trying to train for the Chiang Rai Cycling Classic.