Chapter 13

Sea-Cliff Interferometry: Dover Heights, 1946

> I am sorry that Appleton is making a song and dance about our letter to *Nature*, but I suppose he is just expressing his well-known "ownership" of all radio and ionospheric work.—Bowen to White, 26 April 1946[1]

By mid-November 1945, Pawsey had begun planning for an observational programme in the post-54RS era. Although Pawsey was clearly appreciative of the excellent cooperation of the RAAF at Collaroy, the radio group at RPL now needed a site closer to the Laboratory at Sydney University, with accessible and convenient public transport.[2] In addition, RPL needed a field station site under their own control, allowing modifications on the equipment to be made by their staff. The obvious solution was to start work at the Dover Heights ShD (Shore Defence) or C.D. (Coastal Defence) station of the Australian Military Forces. This station had been used by RPL during WWII for radar development and was only 10 km from the lab and reachable by public buses. The station was called CA No. 1 (Costal Artillery).[3] As we have seen, Pawsey had begun planning for the first observations (January 1946) the previous November. An image from the WWII era of the Shore Defence aerial at Dover Heights is shown in Fig. 13.1.

Letters and reports from NAA C3830 A1/1/11945–1946 Part 1 and A1/1/5 Part 2, Propagation Committee minutes C3830 B2/2 Part 1.

Supplementary Information The online version contains supplementary material available at [https://doi.org/10.1007/978-3-031-07916-0_13].

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[1] NAA C3830 A1/1/11945–1945 Part 1.

[2] For example, Ruby Payne-Scott could not drive a vehicle, likely due to poor eyesight. She always took the bus to Dover Heights from Central Station or Bondi Junction; the journey to Collaroy was much longer.

[3] As discussed in Chap. 9 and ESM 9.2, Radiophysics Laboratory 1940, Dover Heights was one of a series of sites for Sydney's coastal defence. Dover Heights was the main command post.

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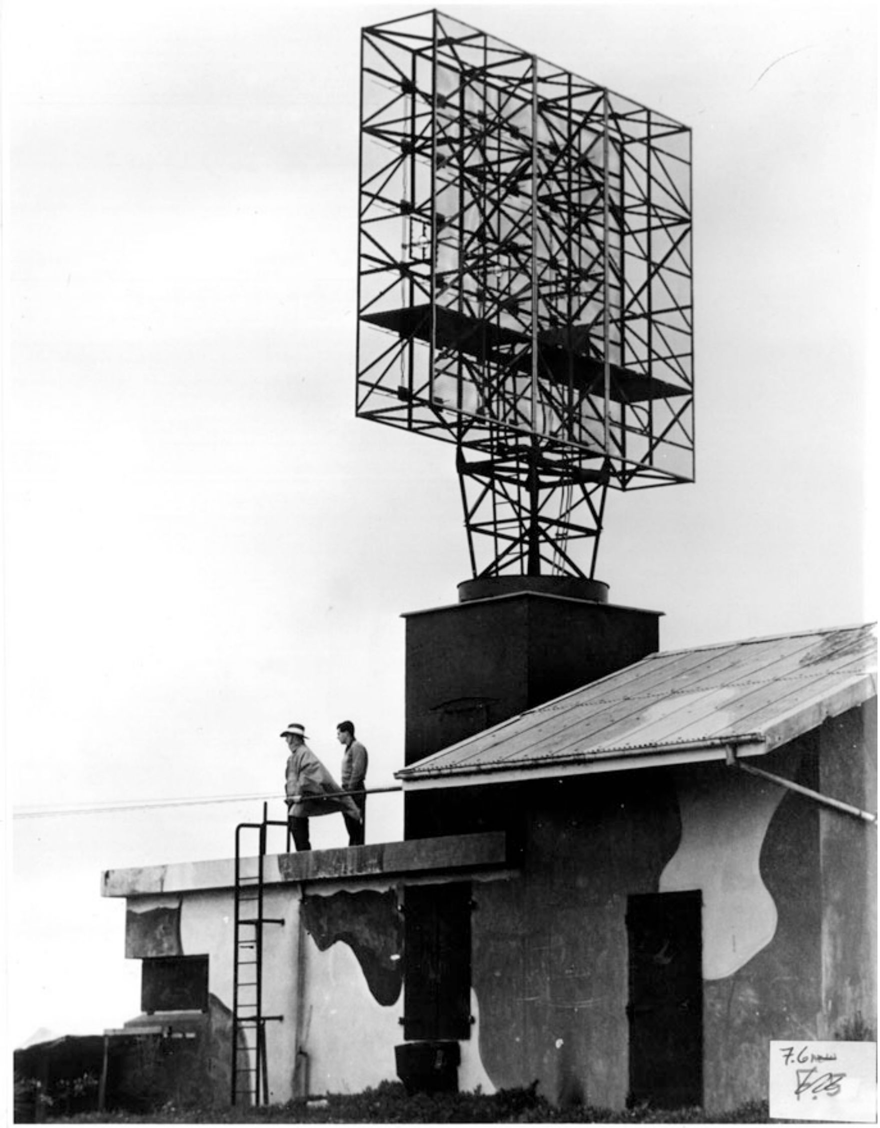

Fig. 13.1 The Shore Defence 200 MHz aerial during WWII. Elevation above the sea was 85 m. Used in January 1946 for the first radio astronomy interferometry of the sun on Australia Day (26 January); the small size of the radio emission (Type I burst) indicated a brightness temperature in the range 0.5 to 100 million K. Credit: CSIRO Radio Astronomy Image Archive JP13-1

By mid-January 1946, the solar observations had begun at Dover Heights. For example, on 24 January 1946, Briton wrote the Commanding Officer (Australian Military Forces, the army), Headquarters Coast Artillery in Watson's Bay, Sydney:

> During the ensuing weeks we intend to conduct simultaneous fading tests on extra-terrestrial radio interference (from the sun during sunspot activity) at No. 54 RAAF AW Station and your Dover Heights CD [Coastal Defence] station which you have already kindly placed at our disposal. [RPL required a dependable telephone communication between Dover Heights and Collaroy; thus, the use of the "emergency range-finding lines" were required.] We have discussed the matter with Lieutenant Clark-Duff, who can arrange the emergency link to the CD station . . . if you concur . . . [Q]uite apart from the fading tests [between Collaroy and Dover Heights] it would be very convenient for us to have access to an outside line from the CD station.

A few weeks later (7 February 1946), a Staff Captain of the NSW Fixed Defences replied that the request was granted. Clark-Duff would arrange the necessary link. Actually, the first successful joint fading tests (between Collaroy and Dover Heights) occurred on this date as shown in the publication by McCready et al. (1947): clearly the use of the special telephone connection had already been organised previously, based on informal discussions.

Later in the year, Briton wrote Colonel P.L. Moore, Commanding Officer, Fixed Defences, at South Head in Sydney with a major concern (15 May 1946):

> ... [W]e have been using the aerial . . . at Dover Heights in our investigations on radio frequency energy radiated by the sun. These investigations are yielding results of considerable scientific interest and we wish to continue them for a much longer period . . . The facilities which you have provided [200 MHz aerial and hut] located on the cliff edge and at a place of easy access [close to RPL] are ideal for our purpose. However, I understand that plans are in hand to scrap the equipment and dismantle the aerial. I should be very sorry to lose the use of the aerial at this stage, and I wonder if some arrangement could be made to allow us the use of it for another year. It may be possible to proceed with the conversion of other stations prior to Dover and so allow us the necessary time, or, alternatively of CSIR's taking over the aerial in situ from the Army, if this conformed with Army requirements.

A month later, Lt Colonel Moore replied (13 June 1946) with good news: the station would be made available until the end of the year. Apparently, in the course of 1946, the condition of the aerial had deteriorated considerably. On 13 December 1986, John Bolton wrote W.T. Sullivan[4]:

> By the time I became interested in Dover Heights—about November 1946—the antenna had been almost destroyed by vandals and only the basic steel work was left. As this was largely rusty by this time, Stanley and I cut it up with an oxy torch and dropped the bits over the cliff [!] around February 1947.[5]

Clearly the Australian Military Forces had lost interest in the Dover Heights site; this location was transferred to CSIR and used by RPL until December 1954 (Slee, 1994). The last solar data recorded by Payne-Scott was during the major sunspot of July 1946. The data were published in an internal report: "A Study of Solar Radio

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[4] Sullivan archive.

[5] From an environmental point of view in 2020, this activity is hard to imagine!

Frequency Radiation on Several Frequencies During the Sunspot of July-August 1946."[6]

Breakthroughs

After the move to Dover Heights and the closure of Collaroy 54RS in mid-March 1946, the behaviour of the radio sun during early 1946 favoured the novice Sydney radio astronomers. One of the largest sunspots appeared in early February 1946 (Newton, 1955) during the most prominent solar sunspot cycle of modern times (solar cycle 18, 1944–1954). The largest sunspot of the modern era, with a maximum area of 6150 millionths of the solar area, occurred a year later, 7 April 1947; the maximum area of the large sunspot observed by RPL in early 1946 (central meridian transit February, day 5.7) was 5250 millionths. In subsequent sunspot cycles, the maximum sunspot sizes have been much smaller.[7] For example, the large sunspot of 24 October 2014 (Active Region 2192 solar cycle 24, the weakest solar maximum in a century) had a maximum area of 2740 millionths, only roughly the 30th largest sunspot in the modern era.

The publication that presented the results of the Dover Heights research of January–March 1946 was authored by McCready, Pawsey and Payne-Scott.[8] It contained numerous breakthroughs: (1) first successful interferometry in radio astronomy; (2) the elucidation of the principle of aperture synthesis; (3) continued determination of the correlation of solar noise with sunspot area over a six-month period; (4) detection of sudden increases (bursts) extending from a second to some minutes with similar characteristics at observing sites spaced up to 250 km; (4) typical rise times of a factor of a hundred within a second with an occasional increase of 10^8 Jy per second; (5) a limit of about 6.5 arcmin established for the radio source size; and (6) location of radio emitting region coincident with the prominent sunspot of 6 February 1946, using the sea-cliff interferometer technique. The paper is included in the Sullivan publication of *Classics in Radio Astronomy*, 1982, "Solar

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[6] RPL 9, the date given only as August 1947. Goss and McGee (2009) have discussed these results in detail, page 108. Based on this data, Payne-Scott detected seconds of time frequency delays of Type III bursts, later confirmed by Payne-Scott (1949) at the Hornsby RPL field station. Also, NRAO ONLINE.20, and NRAO ONLINE.23.

[7] The fourth largest sunspot (27 July 1946) was 4720 millionths in size, observed later in 1946 by Payne-Scott at Dover Heights. The sunspot of March 1947 was number five in this ranking, observed by Payne-Scott, Yabsley and Bolton as they discovered a giant Type II burst (10^{11} Jy at 60 MHz, one of the largest extragalactic signals yet detected), accompanied by aurorae in Sydney a few days later. See NRAO ONLINE.20.

[8] In ESM 13.1, Historical Introduction, we present portions of the original text from this paper. The referee (likely Appleton) required modification to the text leading to loss of valuable historical information about the sequence of events leading to the research. The controversial use of the two WW II reports in the original version of the 1947 paper and especially in the initial RPL solar noise paper in *Nature* on 9 February 1946 is described in ESM 13.2, Fracas.

Radiation at Radio Frequencies and its Relation to Sunspots". Here we consider these achievements in more detail.

The First Fringes: Australia Day, 26 January 1946

The McCready, Pawsey, and Payne-Scott paper began by setting the scene:

> The discovery of radio-frequency radiation, with the characteristics of fluctuation noise, arriving at the earth from the direction of the Milky Way, was announced by Jansky (1933a, b). This discovery is potentially of fundamental importance to astrophysics, since it provides a source of information concerning extraterrestrial phenomena other than that obtained through the use of light. Up to the present, however, the interpretation of such observations has contributed little to astrophysics, and it appears that more complete observational data are necessary. Jansky's original work on cosmic noise was confirmed and extended by himself and others to cover the frequency range 15 to 160 MHz,[9] but, at first, no measurable radiation was observed from the sun. It was therefore suggested that the radiation originates not in the stars but in collision processes in the residual ionised matter in interstellar space. The development of microwave radar suggested the possibility of detecting at these wave-lengths the blackbody radiation from the sun to be expected on Planck's law, assuming the optical temperature of 6000°K. The intensity of this radiation per unit frequency range is proportional to the square of the frequency at radio frequencies. It is too small to be detected in the ordinary short-wave region but should be detectable at centimetre wave-lengths. In 1942 Southworth detected centimetre radiation from the sun (Southworth, 1945) and showed that it was of the order to be expected from the Planck formula.[10]

Due to the poor resolution (primary beams 10°), a major problem with these early solar radio observations was the accurate determinations of the location and size of the emitting region, assumed to be located over a small region of the solar disk (optical diameter of about 30 arcmin).[11] The RPL group used sea-cliff interferometry, a technique they had trialled without success at Collaroy. Sea-cliff interferometry had been perfected in WWII with radar aerials located on a sea–cliff; the system was a Lloyd's mirror based on interference between the direct reflection from an aircraft and the reflected radiation from the sea.[12] The technique is illustrated in Fig. 13.2. Many groups in Australia, the US and the UK had used this technique to

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[9] The authors made no explicit reference to the 160 MHz data of Reber from 1940 and 1944.

[10] To consider radio observation of the hot corona in historical perspective: Southworth was observing at a few cm and could **only** detect the photosphere. Hey's antennas at several metres were not large enough to detect the corona. Reber had detected the corona, but could not calibrate his signal; as we have seen, he did not identify what he had detected.

[11] At 200 MHz, the solar size is somewhat larger, about 40 arcmin; the range during a solar cycle is 35 to 45 arcmin.

[12] As pointed out in Chap. 7, Pawsey had carried out Lloyd's mirror interferometry during his ionospheric research at Cambridge. The low frequency system showed interference between the direct wave from the transmitter and the reflected wave from the reflection from the ionospheric layer.

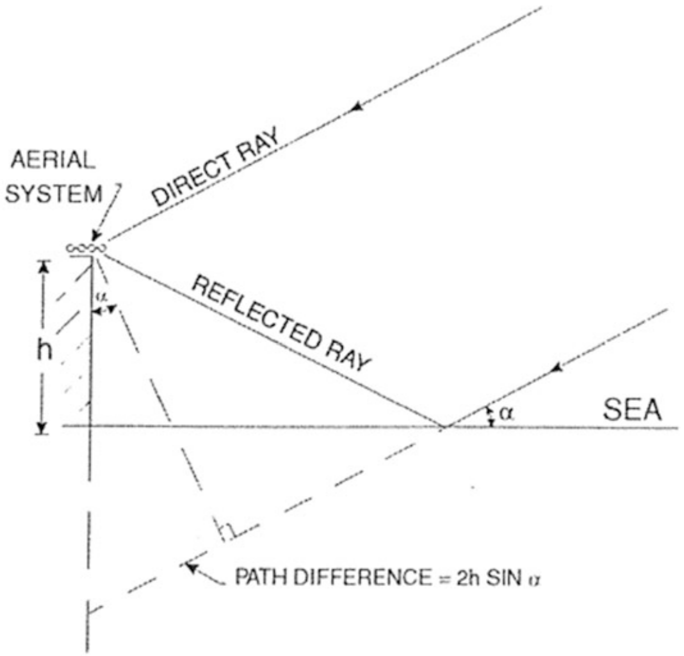

Fig. 13.2 A schematic diagram of a sea-cliff interferometer (Fig. 7.5 from ANZAAS conference). The effective baseline of the virtual interferometer is twice the cliff height. The direct ray from the radio source and the reflected ray interfere to form an interferometer. Credit: CSIRO Radio Astronomy Image Archive B1639-4

determine the height (in addition to range and azimuth) of incoming aircraft for low-frequency radars (frequencies less than a few hundred MHz).

In the publication of the results, McCready et al. (1947) wrote:

> An attempt was next made to elucidate the connection between sunspots and the radiation by means of accurate directional measurements. Because an aerial of about a mile in aperture would be required to produce a beam narrow compared with the half-degree angular diameter of the sun, the direct-scanning method is not feasible. An alternative is a method involving the use of a steerable minimum. In practice, such a method may be realised rather simply by recording the intensity variations as the sun rises over the sea. Interference occurs between the direct and reflected rays, leading to a series of maxima and minima familiar in radar as “lobes”, or in optics as “Lloyd’s mirror” interference fringes. Since the angular separation of the lobes on our equipment is about equal to the sun’s diameter [30 arcmin at Dover Heights with a height above the sea 85 m, and 20 arcmin for the higher elevation at Collaroy, 112 m above the sea], clearly defined maxima and minima will not be expected unless the radiating source is considerably smaller than the sun itself. In initial observations early in October [1945] (Collaroy), no interference pattern was observed [due to the distributed nature of sunspots at that time]. Towards the end of January, a compact sunspot group dominated the sun, and for this reason an attempt was made to detect a lobe pattern on the morning of 26 January [26 January 1946, Australia Day]. A regular series of maxima and minima was observed, with the expected period and very deep minima which were less than the limit of detection [thus implying a small angular size].

We have no record of the circumstances of the observations at sunrise (about 5:20 a.m. Eastern Australian Standard Time, Saturday 26 January). It seems likely that Cla Allen at the Mt. Stromlo Solar Observatory would have telephoned Pawsey the previous days with news of a prominent sunspot (area 1050 millionths). In an interview with Goss,[13] the late Peter G. Hall (1951–2016, son of Ruby Payne-Scott) remembered his mother's excitement as she detected fringes from solar radio emission for the first time: "[She was excited] by the realisation that the [compact] radio emission was associated with sunspots; quite late in her life, the excitement was still with her."[14]

Based on her experience in the absolute calibration of radio telescopes, Payne-Scott would have realised immediately that the size upper limit of 6.5 arcmin implied that the size of the radio source was much less than the solar diameter 30; i.e. less than 4% of the area, implying a brightness temperature of the order of 10^9 K. From McCready, Pawsey, and Payne-Scott: "Consequently, though thermal radiation will be present, it is overshadowed at 200 MHz by radiation due to some other mechanism, probably gross electrical disturbances as suggested [earlier]."[15]

The Giant Sunspot of Early February 1946

Australia Day 1946 was a rehearsal for the exciting events of a fortnight later as the giant sunspot of 7 February 1946 appeared; the flux density at 200 MHz increased by a factor of 10 (from 10^6 Jy on 26 January to 10^7 Jy on 7 February). Figure 13.3 shows some of the data starting on 7 February 1946 at Dover Heights and at Collaroy. Sea-cliff interferometry was now used at Collaroy to good effect: a recording milliammeter was taken there and used from 6 to 9 February and then from 27 February until the end of data collection at Collaroy on 15 March 1946. Note the faster fringe rate observed at Collaroy due to the increased height above the sea, about 120 m compared to 85 m at Dover Heights. The radio fringes appeared on the chart 6 min before optical sunrise; radio refraction is about 1° at the horizon compared to optical refraction, 0.5°; thus the radio fringes were observed some minutes before [optical] sunrise. We can only imagine the excitement of the 200 MHz observers seeing the radio fringes before the sun arose over the Pacific!

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[13] 12 February 2007.

[14] Of course we cannot be certain that these memories refer to Australia Day 1946 specifically.

[15] The current understanding is that Type I bursts (observed in early 1946) are thought to arise from the fundamental plasma emission process, "due to the coalescence of Langmuir waves with low-frequency waves (e.g. ion-sound waves or lower-hybrid waves) ... The short duration of individual bursts suggests local acceleration of electrons to a few times the thermal energy ...The long life of a [Type I] storm points to continuing local energy release in the columnar source region, which is probably related to magnetic field recombination after new flux intrudes into existing fields." (*Solar Radiophysics* (McLean & Labrum, 1985), chapters "Metrewave Solar Radio Bursts" by McLean and "Storms" by Kai, Melrose and Suzuki).

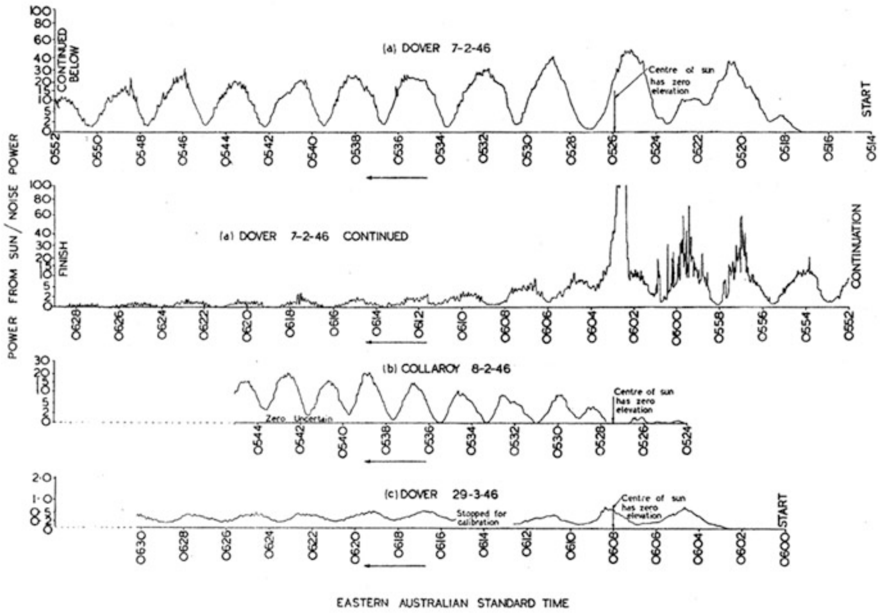

Fig. 13.3 Solar observations taken with the cliff interferometer at Collaroy and Dover Heights showing the interference fringes and strong solar activity on 7 Feb 1946. Credit: Fig. 5 in "Solar radiation at radio frequencies and its relation to sunspots", McCready, L. L., Pawsey, J. L., & Payne-Scott, R. (1947) *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, 190(1022)

Not surprisingly, the one-dimensional position of the radio source agreed well with the optical position of the giant sunspot as shown in Fig. 13.4.[16]

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[16] For a discussion of the complex role of atmospheric refraction in the determination of positions see Goss and McGee (2009), Appendix L, p. 322. Refraction effects impact the positions to first order with a sea-cliff interferometer in contrast to a "spaced interferometer" (two-element interferometer). In the latter case, for a plane parallel atmosphere the two paths to the source are equal, while for the sea-cliff interferometer the path from the direct has a shorter path length than the reflected wave from the sea.

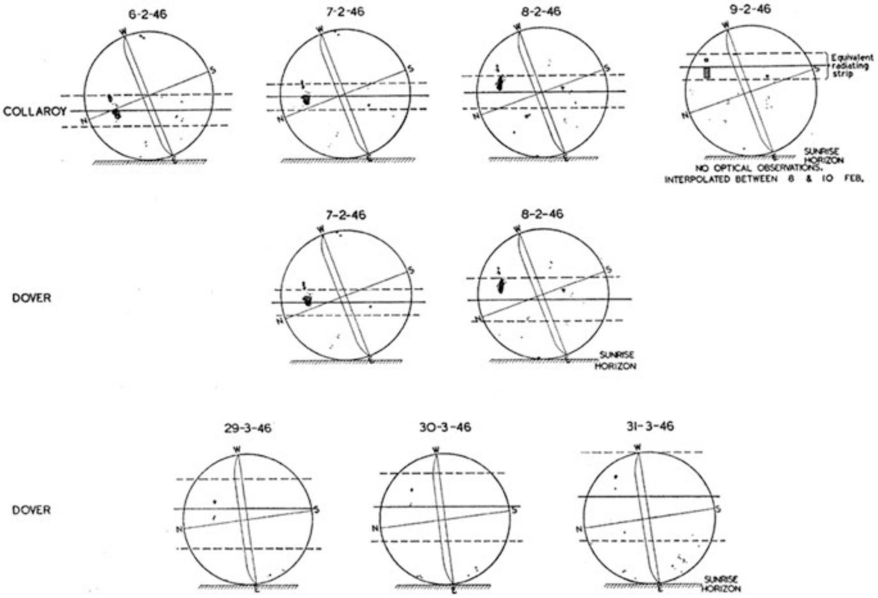

Fig. 13.4 Diagrams illustrating the determination of the location of the radio burst in relation to the position of the sunspots. Note the equator is indicated by a thin parallelogram-EW. Credit: Fig. 7 in "Solar radiation at radio frequencies and its relation to sunspots", McCready, L. L., Pawsey, J. L., & Payne-Scott, R. (1947) *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, 190(1022)

Principle of Aperture Synthesis[17]

A major contribution of the McCready, Pawsey, and Payne-Scott publication was the discussion of the principle of aperture synthesis.[18] Based on the discussion of Goss and McGee (2009, p. 101),[19] the proposal arose from Pawsey; he had initially used Fourier techniques in his MSc thesis at the University of Melbourne (Chap. 6). However, the major influence had been his use of Fourier theory to interpret his PhD work (also using a Lloyd's mirror technique, Chap. 7) on the structure of the ionosphere that would have led directly to the ideas expressed in the McCready,

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[17] See Chap. 36 for a more detailed discussion.

[18] The mathematical details in the publication were derived by Payne-Scott, "the significance of the shape of the interference pattern [of the sea-cliff interferometer]". Examples were derivation of the size of the emitting source based on the observed ratio of minimum to maximum intensity. A key equation provided the relation between the total power of the interferometer signal and a term "in the form of a Fourier cosine transform … As [the phase of the pattern] varies, this term varies sinusoidally with an amplitude given by the modulus of the component of the Fourier transform of [the true power distribution] at unit angular frequency."

[19] The discussions with the late Kevin Westfold have clarified the roles of Pawsey and Payne-Scott.

Pawsey and Payne-Scott paper. Pawsey's association of Fourier synthesis and radio interferometry was a major step forward in 1946–1947.

In the text of McCready, Pawsey, and Payne-Scott, after the mathematical details of the sea-cliff interferometer were presented, the authors wrote:

> [This term] is in the form of a Fourier cosine transform . . . Since an indefinite number of distributions have identical Fourier components at one frequency, measurement of the phase and amplitude of the variation of intensity at one place at dawn cannot in general be used to determine the distribution over the sun without further information. It is possible in principle to determine the actual form of the distribution in a complex case by Fourier synthesis using information derived from a large number of components. In the interference method suggested here Δ [phase] is a function of h [height] and λ [wavelength], and different Fourier components may be obtained by varying h or λ. Variation of λ is inadvisable, as over the necessary wide range the distribution of radiation may be a function of wave-length. Variation of h would be feasible but clumsy. A different interference method may be more practicable.

The width of the source on the sky was derived by the ratio of maxima and minima of the fringe pattern, while the position relative to the centre of the sun was "calculated from the times of occurrence of minima, measured from the time when the centre of the sun has zero elevation".

Variations Are Intrinsic to the Sun, Typical Bursts Non-thermal

In Fig. 13.5 we show the results of spaced receiver observations at about 16 km separations (Dover Height to Collaroy] obtained at sunrise 7 February 1946; all the sharp dips and peaks agree to within 1 s. (The comparison of Dover Heights and Mt. Stromlo, where observations were also being made, at a distance of 260 km, also agreed.) "It is highly improbable that variations having such a high degree of correlation at widely separated sites should be due to any effect in the atmosphere, and it seems certain that most of them are extra-terrestrial, and presumably solar, in origin."

Based on first-ever size limits determined in early February 1946 with the sea-cliff interferometer, striking lower limits on the brightness temperature were determined:

> This would mean a blackbody temperature of about 3000 million degrees, which is impossibly high compared with any known temperatures on the sun. The known temperatures range from 6000° at the visible surface to about a million degrees in the corona and a few tens of millions at the centre. Consequently, though thermal radiation will be present, it is overshadowed at 200 MHz by radiation due to some other mechanism, probably gross electrical disturbances as suggested in our previous communication (Pawsey *et al.,* 1946). The occurrence of short-duration bursts favours this hypothesis.

The summary paragraphs of McCready, Pawsey, and Payne-Scott provide a snapshot of two major conclusions as viewed from mid-1946 at RPL:

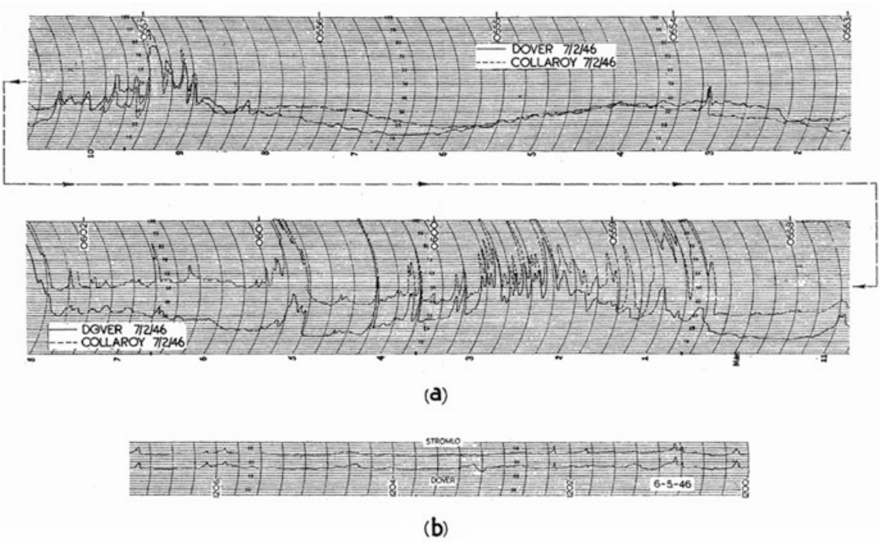

Fig. 13.5 Comparison of highly correlated bursts of solar radio emission made at Collaroy and at Dover Heights 16km away. Credit: Fig. 2 in "Solar radiation at radio frequencies and its relation to sunspots", McCready, L. L., Pawsey, J. L., & Payne-Scott, R. (1947) *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, 190(1022)

> The connection between this radiation and sunspots is established by two independent lines of evidence, the correlation of intensity with sunspot area and the coincidence of direction of origin with that of sunspot groups. No evidence is yet available as to a particular visible solar phenomenon, associated with sunspots, which gives rise to the radiation.

Apparently, Pawsey and Payne-Scott were not aware of the publication by Greenstein, Henyey and Keenan from *Nature* 15 June 1946, concerning the dilution factor of the proposed stellar emission as we discussed in Chap. 12. Stellar radiation was quite unlikely.

McCready, Pawsey, and Payne-Scott concluded with the following paragraph, an improbable prediction:

> Cosmic noise was originally attributed to radiation from interstellar matter, rather than from stars, at a time when similar radiation from the sun had not been detected. The discovery of solar noise raises the question as to whether the cosmic noise is due to similar processes in stars. The basic difficulty remains that the intensity of cosmic noise is vastly greater than it should be if the stars emitted the same ratio of radio-frequency energy to light as does the sun. Nevertheless, the great variability of solar noise suggests the possibility of vastly greater output from stars differing from the sun and it seems that data at present available leave the question completely open.

Within a short time, radio astronomers realised that a new mechanism for the galactic background non-thermal emission must be found, as we describe in Chap. 34.

The McCready, Pawsey, and Payne-Scott publication was communicated to the Royal Society by Sir David Rivett on 22 July 1946 in person. Publication in print occurred 13 months later on 12 August 1947, comparable to a typical delay at this period for this journal of about 10 months.[20] The successes of Pawsey's RPL group in 1945–1946 formed a solid foundation for radio astronomy as a new discipline in Australia, within only 12 months after the end of WWII.[21]

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[20] Goss (2013) page 127–128: "Likely in this post-war era, there was a substantial backlog of research output that had been delayed by the fact that many scientists had been involved in wartime research." The complex history of the publication of McCready, Pawsey and Payne-Scott was also discussed by Goss and McGee (2009), Chap. 8. Goss and the late John Baldwin (2010) have independently evaluated the publication delays in the *Proceedings of the Royal Society* in the post-war era.

[21] See also the detailed discussion in Goss and McGee (2009, p. 127) and Goss (2013, Chap. 7).