NRAO ONLINE 23

The Sun at Centimetre and Decimetre Wavelengths, 1947-1959: Christiansen and Colleagues

Epigraph 1: from *The Early Years of Radio Astronomy- Reflections Fifty Years After Jansky's Discovery*, edited by WT Sullivan, III, 1984, Cambridge University Press, WN Christiansen, page 113 "The First Decade of Solar Radio Astronomy in Australia":

> The Sydney group directed by E.G. Bowen had as its scientific leader J.L. Pawsey, a physicist/engineer of infectious enthusiasm with the interest and ability to contribute in detail to each of the individual research projects being undertaken. His enthusiasm, combined with the youthfulness of the group and the interest inherent in exploring uncharted territory, produced an air of excitement that few scientific groups seem lucky enough to experience. With the eagerness of the young, the scientists shared new ideas with their colleagues as soon as the ideas were formed. This continual interchange produced a group strength that was much greater than the sum of the strengths of its members. The field work had a pioneering appearance ...
>
> ... During the first decade of radio astronomy, Solar work occupied the most prominent place in Australia. After that time and the building of the Parkes telescope the interests of many radio astronomers shifted outwards from the Solar system to more distant objects. However, the construction of [the radioheliograph at Culgoora] marked a considerable step forward in Solar investigations in Australia and over twenty years filled in many of the gaps in our knowledge of processes in the Solar corona.
>
> Those of us who worked during the first decade of Solar radio astronomy feel that we were extraordinarily fortunate to be present at so many unexpected scientific events. Life at that period was indeed exciting.

Epigraph 2: Christiansen, 1989, *Proc Astronomical Soc of Australia*, vol 8, p 96, "History and Propaganda in Astronomy":

> [In the late 1950s], Australia had become one of the most important centres of radio astronomy in the world. Several outstanding discoveries had been in solar, galactic and extragalactic astronomy. Australia was the leader in inventing and developing telescopes of unrivalled resolving power. Moreover, solar radio spectroscopy was almost an Australian invention.

INTRODUCTION

By 1950, it had become obvious that there were two broad groups of radio emission from the sun: one being quasi-constant (centimetre and decimetre wavelength) in intensity and the other quite variable in intensity (metre wavelengths, see NRAO ONLINE 20). In this text, NRAO ONLINE 23, we summarise the work on centimetre and decimetre solar research at RPL in the period 1945-1949.

During this period, a number of exploratory observations in the 200 MHz band were carried out by Pawsey and Yabsley (1949, see NRAO ONLINE 20 and Chapter 14), used to determine the minimum level associated with the quiet sun. For a short period from August to November 1947, daily observations were carried out at Middle Harbour (Sydney) by Lehany and Yabsley at 200, 600 and 1200 MHz (*Australian J. Scientific Research*, vol 2, p 48 submitted 9 September 1948 and published March 1949). At the two higher frequencies the solar emission was relatively steady with variations by about a factor of two. The sunspot-free sun yielded an effective temperature of $5x10^5$ K at 600 MHz and 10^5 K at 1200 MHz. There were a few rare occasions when major "disturbances" were observed at these frequencies, with no obvious prominent outburst at 200 MHz. For example, on 4 October 1947, at 600 and 1200 MHz the solar intensity was $2x10^7$ Jy, an increase of a factor of thirty. During this period the 200 MHz intensity was only $5x10^5$ Jy, close to the expected thermal level of 10^5 Jy. (Lehany and Yabsley, 1948, *Nature*, vol 161, p 615, "A Solar Noise Outburst at 600 and 1200 MHz")

In 1948 and 1949[1], partial solar eclipses were observed in Australia. For the 1948 data, Christiansen, Yabsley and Mills (1949, *Australian J Scientific Research*, vol 2, page 506, submitted 27 July 1949 and published Dec 1949) described the data obtained at three sites on 1 November 1948 in Australia at 600 MHz (50 cm).[2] The publication illustrated the "toils and vagaries of eclipse expeditions" (Sullivan, W. T., III. (2009). *Cosmic Noise: A History of Early Radio Astronomy.* Cambridge University Press, Cambridge, UK. p296). Using the three sites (Sydney, a suburb of Melbourne and Strahan in Tasmania), observations occurred as active solar regions were occulted by the moon at different position angles (due to parallax of the

[1] The results from 22 October 1949 are described by Wendt et al (Wendt, H., Orchiston, W., & Slee, B. (2008). WN Christiansen and the initial Australian investigation of the 21cm hydrogen line. *Journal of Astronomical History and Heritage*, *11*, 185-193.) The results of this eclipse were never published. See also Orchiston, Slee and Burman, 2006, for details of the 1948 eclipse (*Journal of Astronomical History and Heritage*, vol 9, p 35, "The Genesis of Solar Radio Astronomy in Australia"); the results were published the following year in *Nature* (1949, vol 164, p 569 by Christiansen, Yabsley and Mills) and the *Australian J. Scientific Research*., 1949, vol 2, p 5

[2] The paper was Mills's first and only publication in solar radio astronomy.

moon) at different times. Thus, many of the uncertainties due to observations at a single site were removed.

The results are shown in Fig. 1. The localised region above the prominence (no. 1 on the southwestern edge) is clear evidence that the 50 cm emission arises from the solar corona. “The timing of the covering and uncovering of the areas” was used to eliminate the ambiguities in the assignments of the radio events to a particular optical feature. Six of the eight regions identified could be assigned to current or past sun spots. The emitting radio sources were about 3 arc min in size with a brightness temperature of 5×10^5 K.

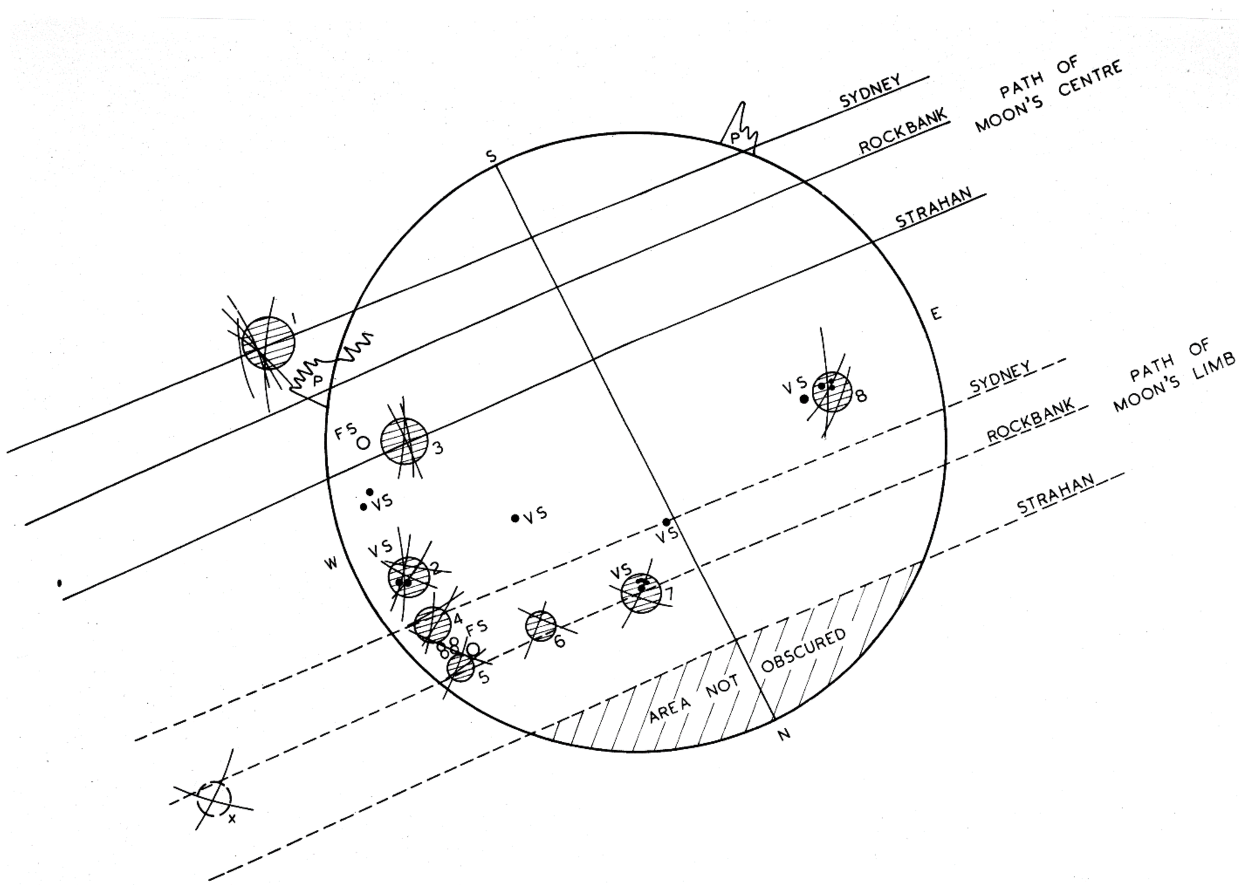

FIG. 7

Fig. 1 The eclipse image of 1 November 1949 showing the eight active regions as hatched areas. The bright optical areas are indicated 1, 2 , 3 etc. “VS”, visible sunspot ,“FS” a sunspot from the previous solar rotation, “P” a prominence. (Christiansen, W.N., Yabsley, D.E. and Mills, B.Y., “Measurements of Solar Radiation at a Wavelength of 50 Centimetres during the Eclipse of November 1, 1948”, *Australian J Scientific Research*, vol 2, p 506.)

Christiansen et al also investigated the shape of the quiet sun at 50 cm using the eclipse data. “Four-fifths of the radiation from the sun … appeared to originate in a source symmetrical with respect to the centre of the sun. The distribution of radio-brightness on this source was such that approximately 40 per cent of the radiation from the sun originated outside the visible disk of the sun. The records were consistent with a theoretically-derived distribution involving limb-brightening” extending out to 1.3 radii. However, the data were also consistent with limb-brightening similar to the model suggested by Steve Smerd.[3] Two additional groups carried out eclipse observations at 10 and 3.2 cm at Potts Hill.[4]

Christiansen (Sullivan, 1984, *The Early Years of Radio Astronomy*, “The First Decade of Solar Radio Astronomy in Australia”, 117) has written: “In order to carry out the investigation further I felt it necessary to devise some method of viewing the sun much more frequently than was possible with eclipse observations. This of course meant devising some antenna system of very high directivity.”

In the paper by Christiansen and Warburton, describing their goal in 1952 to image the sun at high resolution on a daily basis without waiting for the occurrence of infrequent (and ambiguous) solar eclipses[5], they provided an eloquent rationale for the next step:

> Another component, prominent at decimetre wavelengths, has been called the "slowly varying component”[6] of the solar radiation. Its variations show a good correlation with

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[3] Smerd, S. F. (1950). "Radio-Frequency Radiation from the Quiet Sun." *Australian Journal of Scientific Research* A Physical Sciences 3: 34.

[4] Based on their data on1 November 1948 eclipse, Piddington and Hindman (1949) suggested that their 10 cm data showed that about 30 per cent of the solar signal arose from the bright limb of the sun, i.e. limb brightening. Minnett and Labrum’s (1950) conclusions at 3.2 cm were inconclusive regarding limb-brightening due to limited sensitivity.

[5] Christiansen, W. N., and Warburton, J. A. (1955). "The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres. III. The Quiet Sun? Two-Dimensional Observations." *Australian Journal of Physics* 8, no. 4: 474-486. p 190

[6] Possibly this reference to the new term was the first to appear in English. Sullivan (*Cosmic Noise*, 2009, page 222): “Denisse (1949) was able to considerably sharpen the intimate relation … between the 10.7 cm solar intensity and sunspots. He called the week-to-week semi-periodic variations *une composante lentement variable* (1949). Soon this “slowly variable component” was recognised as the third major category of solar emission in addition to the quiet sun and the sudden bursts. (Denisse, J. F. (1949). "Relation entre les émissions radioélectriques solaires décimétriques et les taches du Soleil." *Comptes Rendus Hebdomadaires des Seances de l’Academie des Sciences* 228, no. 20: 1571-1572.). The Australians adopted Denisse’s nomenclature with no attribution.

> visible sunspot area. Radio observations during solar eclipses, commencing with those of Covington (1947), have shown that small areas of enhanced radio brightness often occur in the vicinity of sunspots, and there is little doubt that these areas are the source of the slowly varying component of the solar radiation. Eclipse observations are rare, however, and do not reveal the change with time of these regions of enhanced brightness. Insufficient information is available ...
>
> … For an aerial system in which there is a number of elements arranged at uniform intervals along a straight line, the polar diagram takes the form of multiple beams having a separation from each other which is inversely proportional to the spacing between adjacent elements [a grating or multi-element interferometer]. Such an arrangement is suitable for studying the sun, as beams of the required narrowness can be produced and sufficient elements used so that the sun will be in no more than one aerial beam at any time. Such a system is analogous to a diffraction grating or, less directly, to a multiple-beam optical interferometer. A maximum response is obtained when the optical path to adjacent aerials is the same or differs by an integral number of wavelengths.

The Potts Hill grating array was developed in 1951 with completion in November 1951, initially with the EW array of 32 dishes on the south bank of the Potts Hill Reservoir. The operating frequency was 1420 MHz with a bandwidth of 30 MHz; there was no delay compensation. Thus, observations were restricted to 2 hours around local noon to avoid loss of sensitivity due to the delay beam. Each dish was 1.8 metres in diameter (10 deg primary beam), the spacing between dishes was 7 m and the extent of the array was 215 m. The beam was about 3 arc min with a grating lobe spacing of 1.7 deg (well outside the solar diameter). Full operation began in February 1952. See Fig. 2 for an image provided by Rod Davies in 2008 to Goss during a visit to Manchester, UK. A noon time, informal cricket game is shown in Fig 3 – Christiansen and Charlie Fryer with improvised equipment at Potts Hill.

In Fig. 4 and 5 we show two of the photos made in March 1951 by the famous American photographer Frtiz Goro. (See Additional Note 1 for more details concerning Goro's life as well as his visit to Sydney in March 1951 followed by his subsequent meeting of Bowen at Harvard in October 1951.) These photos of March 1951 were obtained at Potts Hill. Fig 4 shows Pawsey in a staged photo at the south end of the reservoir at the EW arm of the 20cm grating interferometer. Fig, 5 shows Christiansen in the receiver hut at Potts Hill (Fig. 5), ensconced in paper from a chart recorder of theS20 cm grating interferometer. In addition, Goro also visited Mt Stromlo where he photographed David Martyn (NRAO ONLIINE 24) and Mark Oliphant (NRAO ONLINE 13) and Dover Heights with a number of photos including John Bolton and

Gordon Stanley (from a distance). In NRAO OLINE 23 we show an additional Goro photo of the total power 98 MHz system with Pawsey at Potts Hill. The system was used to determine the polarisation and integrated solar emission at 3 metre wavelength.

Fig. 2 A photo from circa 1953 provided by Rod Davies to Goss during a visit to Manchester, UK in May 2008. This figure shows Davies's photo of the EW grating array at 21 cm at the Potts Hill reservoir, Sydney. ©Rod Davies


Fig. 3 Lunch time cricket with Christiansen (batting) and Charles Fryer. ©Rod Davies

Fig. 4 above.

JL Pawsey and a wide view of the EW arm of the 32 aerial EW grating array at Potts Hill. March, 1951 by Goro. Photo appeared on page 136 of *Life Magazine* 17 November 1952 "Radio Astronomy, Celestial Sounds Reveal Invisible Stars and New Facts about the Sun". The caption and text did not mention Pawsey. Caption from the *Life* article with the figure reads: "An 800 Foot Row of Radio Telescopes, each 6 foot in diameter is set at edge of an Australian reservoir to catch radio waves coming from the sun." This image appears on the cover; the correct orientation of the image is shown here. The title page is reversed left-to-right to fit the title page format. This is Fig 16.3 in the main book. Credit: Getty Images, Fritz Goro, The *Life* Picture Collection, licensed by Getty November 2021 / Licence organised by Shutterstock, Inc., New York, NY (5 Nov 2021) Original , Premium Editorial All Media

Fig. 5 Christiansen, a staged photo by Fritz Goro in March 1951 with a paper chart recording from the grating interferometer. This figure is Fig 16.5 in the main book. Credit: Getty Images, Fritz Goro, The *Life* Picture Collection, licensed by Getty November 2021 / Licence organised by Shutterstock, Inc., New York, NY (5 Nov 2021) Original , Premium Editorial All Media

By August 1952 the array was proudly exhibited to the famous guests of the URSI General Assembly, including Sir Edward Appleton. See Figure 6. The NS array (16 aerials) was opened in mid-1953 on the west bank of the reservoir. Circular polarisation could also be measured. The steering of the equatorial mounting was done by hand. "Aiming the dishes was a manual operation- to track the sun, every 15 min one person [sic] had to cover the 200 m in 3 min [by bike?], moving each of the 32 dishes one notch along the EW axis.” (CN page 296). The system operated with an open wire transmission line to a single receiver.

Fig 6 Tour of Potts Hill, the 32 element 21 cm Grating Array during the 1952 URSI General Assembly in Sydney. From right Appleton, Baltasar van der Pol (Phillips Laboratory), Fred White, unknown, Chris Christiansen (tour guide) Credit: CSIRO Radio Astronomy Image Archive B2842-R66

The calibration was done by simple geometry since the centre of the radio record could be taken to correspond to the centre of the solar disk. Thus, all positions were obtained by offset from the central position. Christiansen and Warburton wrote:

> The daily records show characteristic peaks which change in position from day to day, moving at approximately the same rate as sunspots, i.e. they indicate local areas of enhanced brightness which rotate with the sun. In addition, the records appear to show a lower level below which the brightness does not fall, and this presumably represents the radiation from the quiet sun. In order to study the two components, it is necessary to separate them. The first step is to decide the contribution of the quiet sun, i.e. to determine the one-dimensional brightness distribution of the thermal component. When this is done, the contributions of the area of enhanced brightness are represented by projections about the quiet sun level. [This is shown in Fig 7– a succession of records superimposed to show the contribution of the quiet-sun.] A sequence of daily images in October 1952 are shown in in this figure (Christiansen and Warburton) for 20, 22, 24, 26 and 28 October.

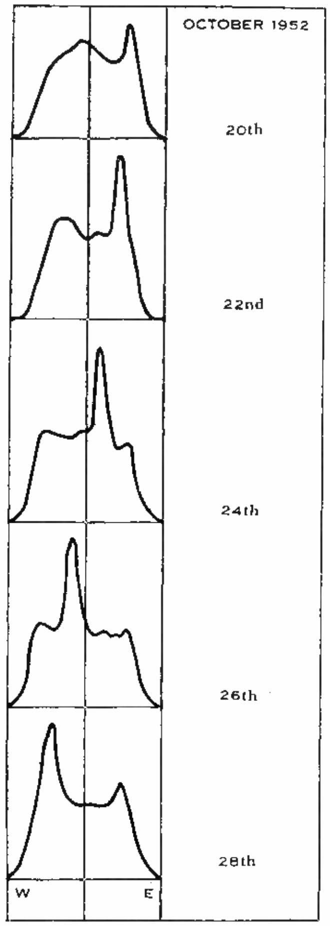


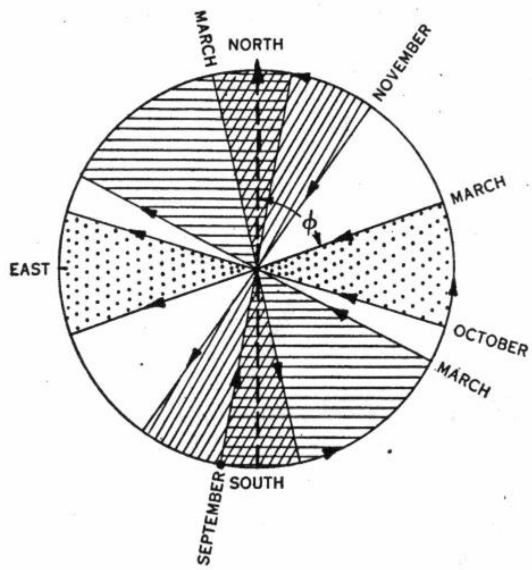
Fig. 5.—A succession of daily records showing the one-dimension brightness distribution over the solar disk.

Fig. 7 Christiansen, W. N., and Warburton, J. A. (1955). "The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres. III. The Quiet Sun? Two-Dimensional Observations." *Australian Journal of Physics* 8, no. 4: 474-486. their Fig 5. A succession of daily records showing the one-dimensional brightness distribution over the solar disk.

In 1953 a north/south arm was added with 16 antennas.[7] Now by tracking the sun each day for 2 hours, the earth's rotation could be used to change the orientation of the baselines and the resultant cuts across the sun. This is shown in Fig. 8, where the seasonal variation of the sun with respect to the two sets of aerial beams has been used to obtain records covering 140 deg out of the total possible range of 180 deg. (Scanning angle is that between the sun's meridian and the normal to the aerial beam.) The observations were made using the EW arm from April 1952 to September 1953 and then both arms from September 1953 to April 1954. For the quiet

[7] The combined data set was described in Paper III, "The Quiet Sun- Two-Dimensional Observations" by Christiansen and Warburton, *Australian J Physics,* 1955, vol 8, page 474 (submitted 25 July 1955 and published December 1955).

sun the data could be combined since no major change in either the shape or total overall size of the sun was detected in this period.



SHADING	INTERFEROMETER USED	OBSERVATION PERIOD (LOCAL TIME)
(diagonal hatching)	N.— S.	0800 ⟶ 1200 HR
(dotted)	E.— W.	1000 ⟶ 1200 HR
(horizontal lines)	N.— S.	1200 ⟶ 1500 HR

Fig. 6.—Range of scanning angles φ covered by the two aerial systems.

Fig. 8 From Christiansen, W. N., and J. A. Warburton. "The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres. III. The Quiet Sun? Two-Dimensional Observations." *Australian Journal of Physics* 8, no. 4 (1955): 474-486, their Fig 6

A major step was the removal of the radio emission from the bright regions on the sun; the method is illustrated in Fig 9 below (from Christiansen and Warburton 1955) where the non-variable quiet sun is clearly visible.

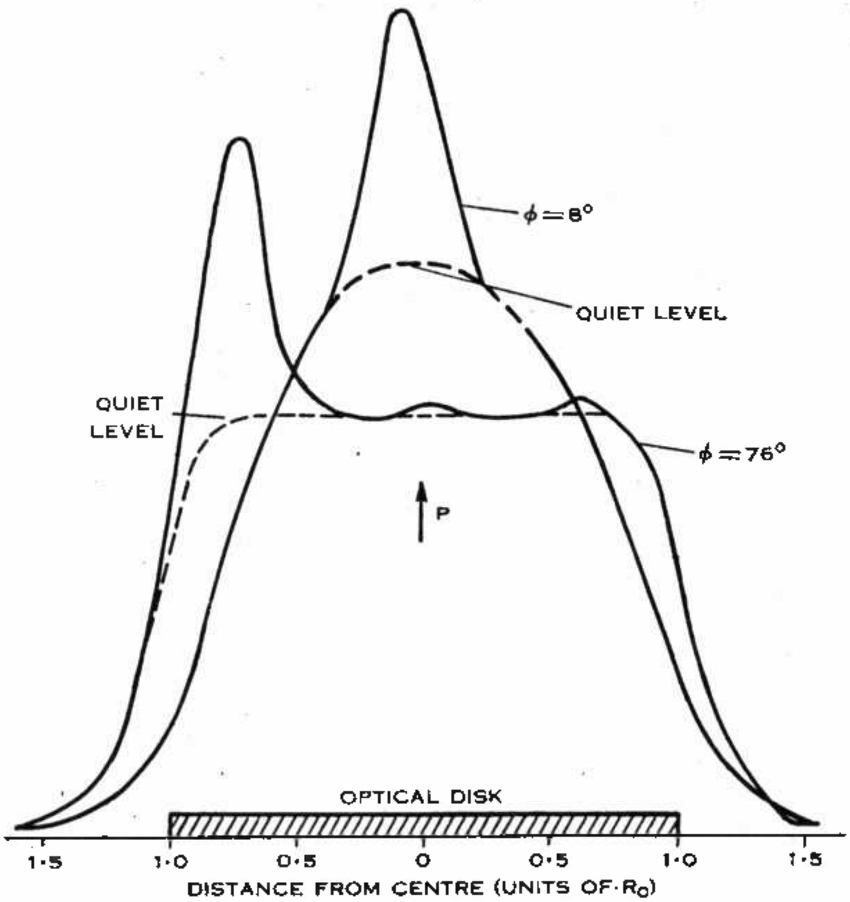


Fig. 5.—One-dimensional profiles showing the result of scanning the Sun in different directions on the same day.

Fig. 9 Christiansen, W. N., and J. A. Warburton. "The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres. III. The Quiet Sun? Two-Dimensional Observations." *Australian Journal of Physics* 8, no. 4 (1955): 474-486.

The next step in the process of imaging the detailed structure of the quiet sun at 21 cm involved a number of steps and the assistance of Govind Swarup (see NRAO ONLINE 32 and 33). Christiansen and Warburton (1955) described the problem:

> The way in which a two-dimensional radio brightness distribution may be derived from a number of one-dimensional scans is not obvious. However, rather similar two-dimensional problems have arisen in the field of crystallography, and solutions for these problems, using the methods of Fourier analysis, have been found … It is well known

that the two-aerial interferometer … measures the Fourier components of the strip integration of the real distribution, and that the frequency of the components being observed is determined by the aerial spacing. With a grating-type interferometer, as used in this work, the one-dimensional distribution is observed directly. The Fourier component of highest frequency contained in the distribution is of course determined by the length of the aerial system. Hence, if we take the Fourier transform … the subsequent solution of the two problems becomes identical.

Swarup ("Reminiscences Regarding Prof WN Christiansen", *J Astron History and Heritage,* vol 11, 194, 2008) has continued the story, filling in the details:

Chris asked me to assist in preparing a two-dimensional radio brightness distribution map based on observations that he and Joe Warburton obtained. Using an electrical calculator [and Lipson-Beevers strips, a calculating aide[8]], I first determined the Fourier Transform of each of the strip scans obtained at various position angles, plotted the values on a large piece of graph paper, made contour plots manually, determined manually strip scans of the two-dimensional plot at various position angles, calculated the Fourier Transform of each of these and finally determined the two-dimensional distribution [fig 10] of the 21 cm radio emission across the solar disk. [The whole process took six months according to Christiansen 1984.]

The central brightness temperature was found to be 4.7×10^4 K with the maximum peak brightness at the outer equator 6.8×10^4 K with an apparent disk temperature of the quiet sun of 7×10^4 K (the temperature that described the total flux density of the quiet sun).

The limb brightening was found to be confined to the equatorial regions with the peak falling just inside the optical limb. At angles less than 30 deg no limb brightening was detected, see Fig 11 which shows cross cuts at various angles (90 deg is the equator, 0 deg is the pole).

[8] Cardboard strips printed with, for a given value of A and n , the values of $A \cos nx$ in (say) 3° increments of x . By arranging these strips appropriately side by side, one could form the sums needed for the terms approximating the Fourier integral.

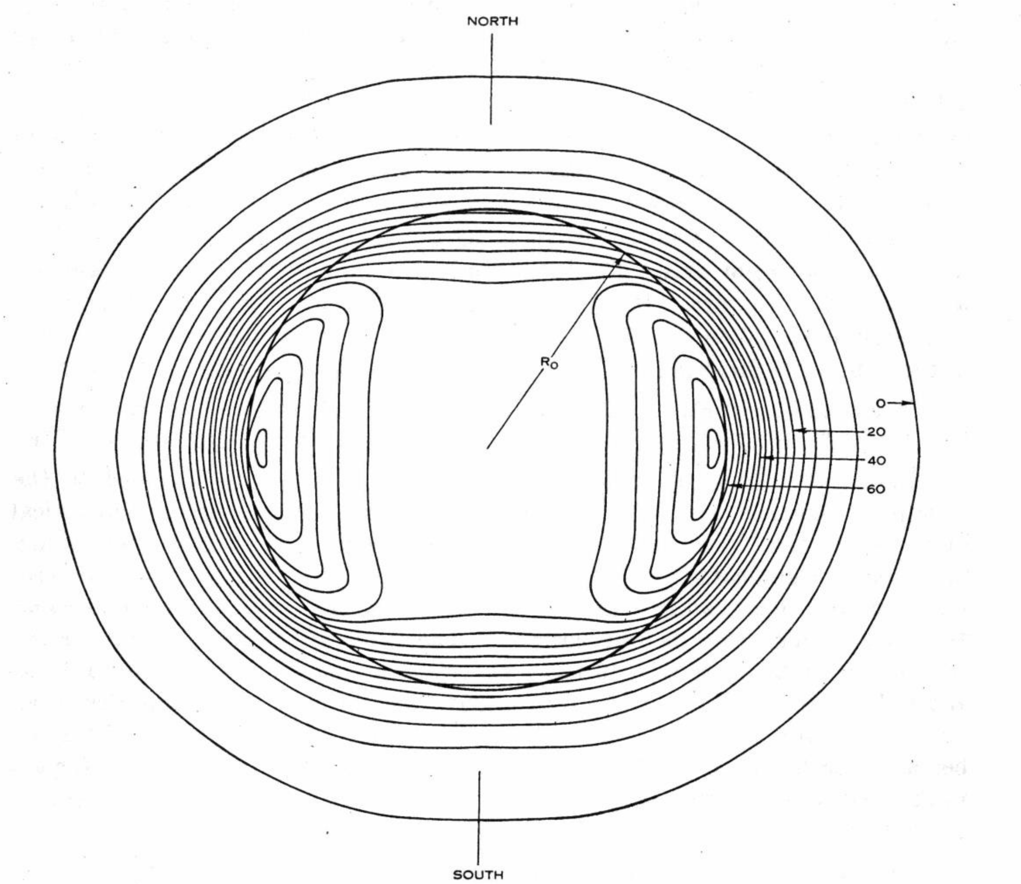


Fig 10   2 Dimensional Image with a resolution of 4.3 arc min, central brightness temperature is 4.7 x 10^4 K and the maximum is 6.6 x 10^4 K. Christiansen, W. N., and J. A. Warburton. "The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres. III. The Quiet Sun? Two-Dimensional Observations." *Australian Journal of Physics* 8, no. 4 (1955): 474-486. see main book Fig 37.11

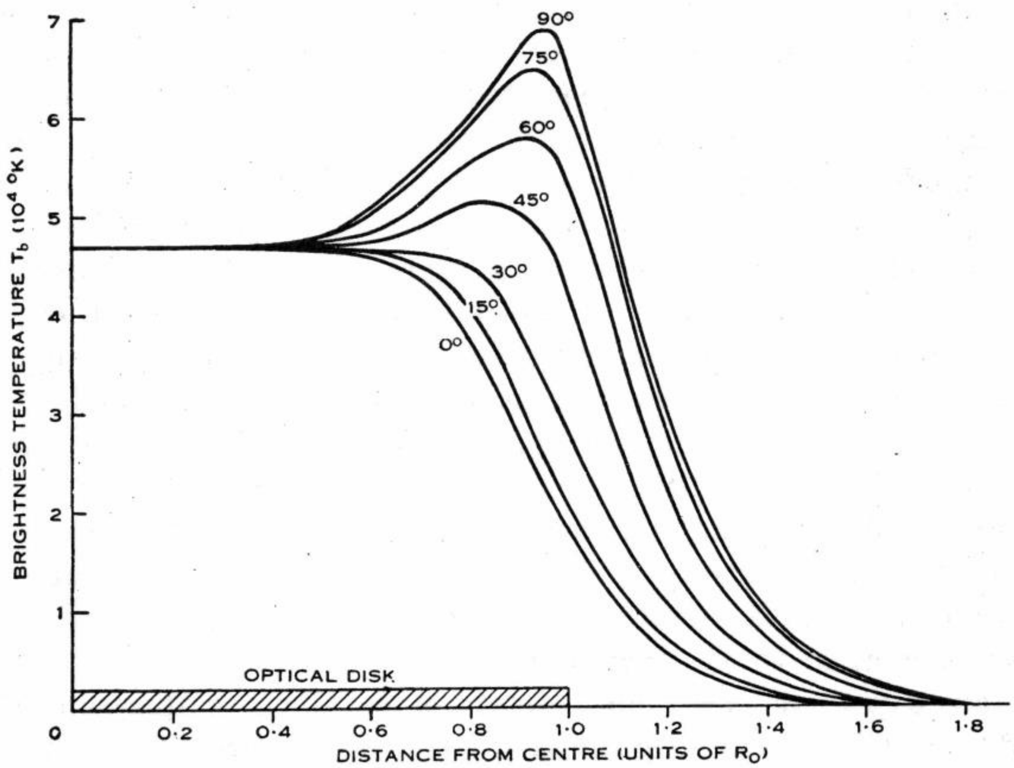


Fig. 11.—Derived radial brightness distributions in several directions with respect to the pole of the Sun.

Fig 11 Derived radio brightness distributions in several directions with respect to the pole of the Sun. Christiansen, W. N., and J. A. Warburton. "The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres. III. The Quiet Sun? Two-Dimensional Observations." *Australian Journal of Physics* 8, no. 4 (1955): 474-486.

Christiansen and Warburton (1955) provided a simple explanation for the limb-brightening at 21 cm:

> It is generally agreed that at decimetre wavelengths pronounced limb-brightening is likely to occur because of the large increase in the coronal contribution to the radiation at the limb compared to the centre of the disk. The radiation in the centre emanates mainly from the chromosphere. This is because the opacity of the corona in the line of sight is relatively small. Near the limb, however, the emergent ray is confined to the corona and, because the ray path in this region is longer, the opacity is greater. Since the electron temperature of the corona is much higher than that of the chromosphere,

> the brightness temperature observed in these regions may be higher. In the two-dimensional distribution presented in Figure 10 this brightening occurs in the equatorial region, the degree of brightness and the position at which it occurs conforming qualitatively with the values predicted theoretically from simple solar models.
>
> … [In conclusion we would like to point out], that the brightness temperatures derived from the observations, and the temperatures expected from simple models based on available optical and radio data, are not grossly at variance.

Christiansen and Warburton (1955) concluded that the chromosphere temperature was $4x10^4$ K, intermediate between the photosphere (6000 K) and the corona – 10^6 K. By the time of the next solar maximum (1958), Norm Labrum derived the radio brightness of the sun at 21 cm using the Fleurs Chris Cross. The corrections for the intense discrete sources on the sun (SVC) were substantial. The overall shape of the distribution in 1958 was essentially identical with that in 1953, but the apparent disk temperature was now $14x10^4$ K, twice the value from the solar minimum in 1953.[9]

The Slowly Varying Component during Solar Minimum 1952-1953 at 21 cm

The final publication in the Potts Hill series was "Paper IV: The Slowly Varying Component", *Australian J Physics*, vol 10, p. 491 by Christiansen, Warburton and Davies. The main goal of the paper was to investigate the assertion of Denise (1949) and Pawsey and Yabsley ((1949). "Solar Radio-Frequency Radiation of Thermal Origin." *Australian Journal of Scientific Research* A Physical Sciences 2: 198) that there was a correlation of this time varying component and the total area of sunspots. This correlation could then be used to separate the quiet sun emission and the time variable emission from single antenna determinations of the **total** flux density of the sun. With the new Potts Hill data, the details of this correlation could be determined.

Christianson et al pointed out a major problem:

[9]Later in 1955, Swarup and Parthasarathy ((1955). "Solar brightness distribution at a wavelength of 60 centimetres. I. The quiet Sun." *Australian Journal of Physics 8,* no. 4: 487-497) described the solar brightness at 60 cm as the frequency of the array was modified from 21cm. (The 32 dish EW array was used; the NS array of 16 aerials was not used.) Based on data from July 1954 to March 1955, the quiet sun one-dimensional distribution (beam size 8.2 arc min) showed prominent limb brightening, a result presented by Pawsey at the Hague URSI in 1954.

> This very close correlation between the slowly varying component and sunspot area is unexpected, since it is most unlikely that the source of radio emission can lie close to the photosphere. The first indication of this possibility was found by Christiansen, Yabsley and Mills (1949) during the eclipse of November 1948. These observations showed that regions of high radio emission were present not only in the vicinity of sunspot groups but also near places previously occupied by sunspot groups.

In the mid-1950s, the 32-element Potts Hill grating array was the only instrument with enough resolution (3 arc min) to resolve radio sources on the sun. Christiansen et al (1957): "The observations substantiate in general what was deduced from total flux and eclipse observations, but go well beyond that. They provide the basis for estimating the position in the solar atmosphere of the regions responsible for the slowly varying component."

As had occurred in the earlier Potts Hill observations of the quiet sun, the SVC observations were carried out with beams 3 arc min in width, separated by 1.7 deg from the neighbouring beam. The rotation of the earth caused each beam to pass across the solar disk; thus, examples are shown in Fig 12. The estimated position and flux density from identified bright regions were indicated above the line A.A' (top row). The quiet sun was the broad source while the localised areas of intense emission were the SVC sources. These peaks change position and in size as the sun rotates. Due to the EW geometry of the instrument, the heliographic longitude of the areas could be determined from the one-dimensional scans. Since it was close to solar minimum, most active regions were close to the solar equator. "It was noticed that the strip in which a radio source was located invariably fell close to one of these regions. It was natural to assume … that since the heliographic longitude of [active areas on the optical sun] coincided with that of an area of intense radio emission, the latitudes of the two should also coincide." In Fig. 13 we show their one-dimensional determination using the EW array for three days in 1952. In 1953, it was possible to verify the 1-D determinations when the NS arm became available. A typical location of the SVC position is shown in Fig. 14; both the EW and NS arms were used to determine one-dimensional positions at vastly different orientations, showing that the assumption was justified (i.e. the longitude determination provided a unique identification). However, the NS data was not used for most determinations since multiple radio sources on the sun (near the equator) were confused in the NS beam.

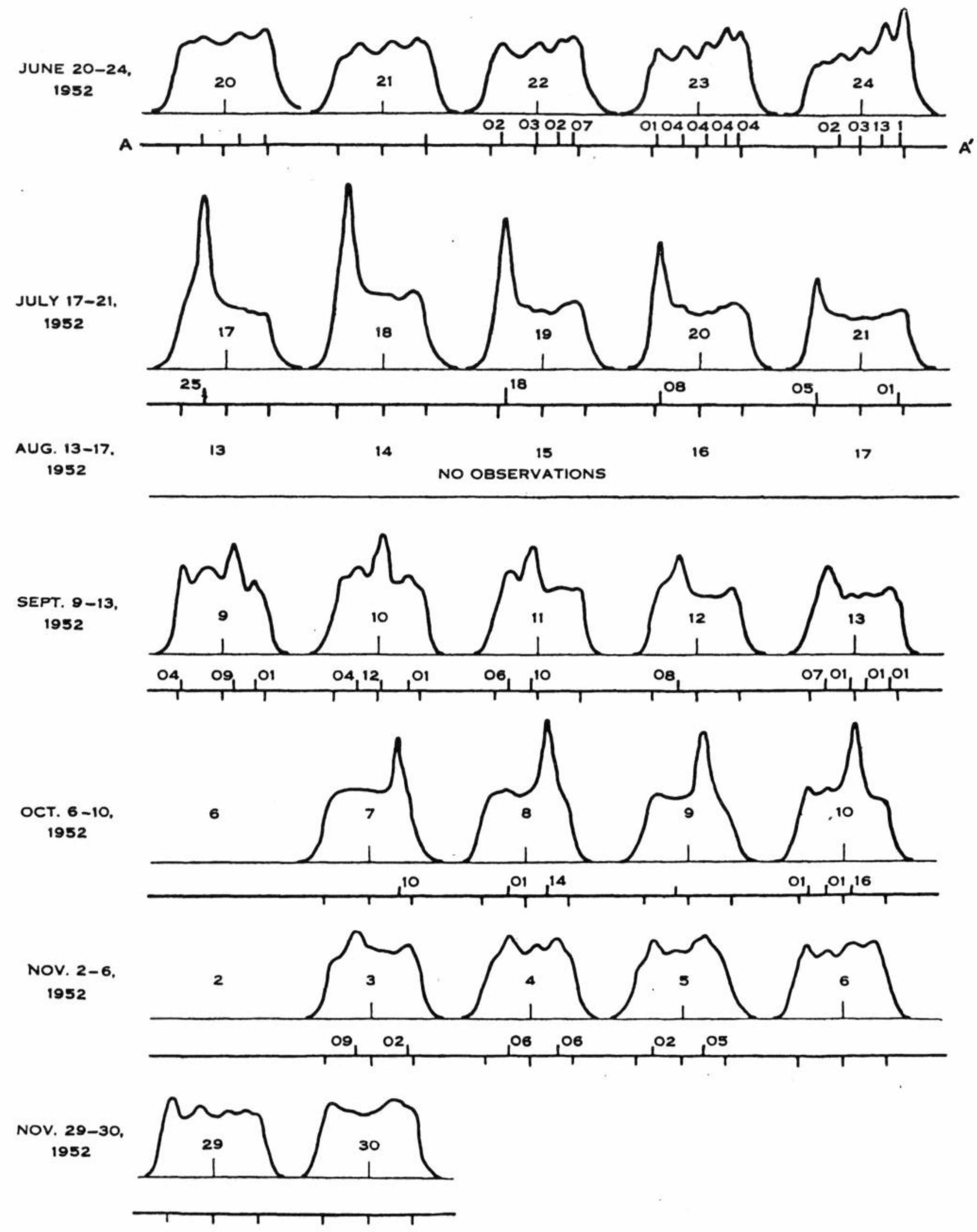


Fig. 12 Christiansen and Warburton their Fig 1a " The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres IV. The Slowly Varying Component" Australian J Physics vol 10, 1957 , p 491

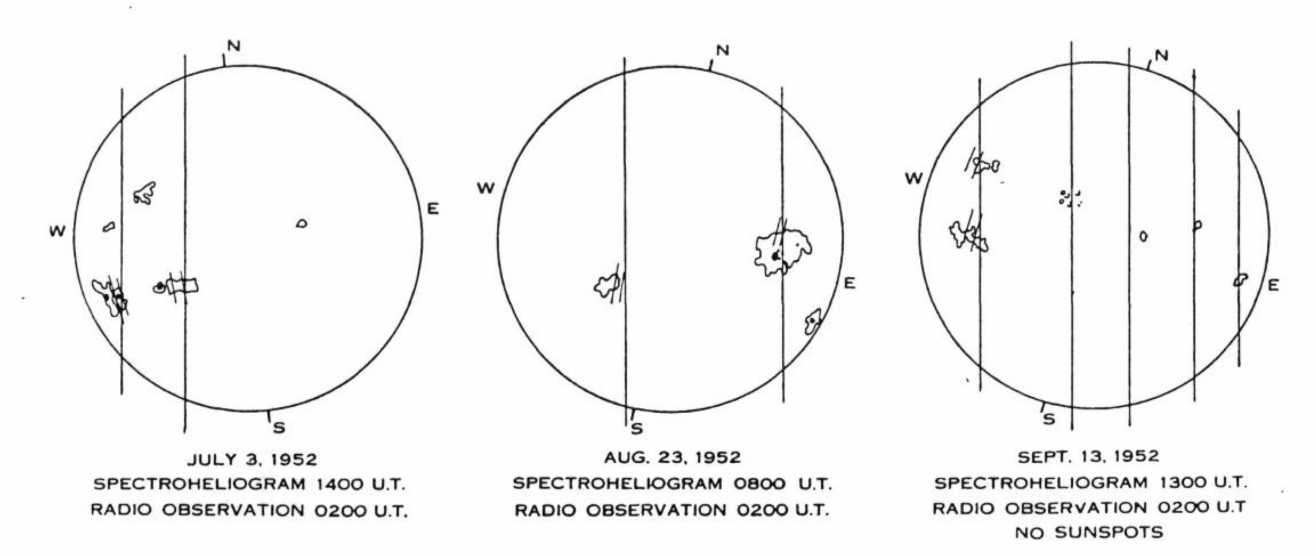


Fig. 13 Christiansen and Warburton their Fig 3 " The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres IV. The Slowly Varying Component" Australian J Physics vol 10, 1957 , p 491

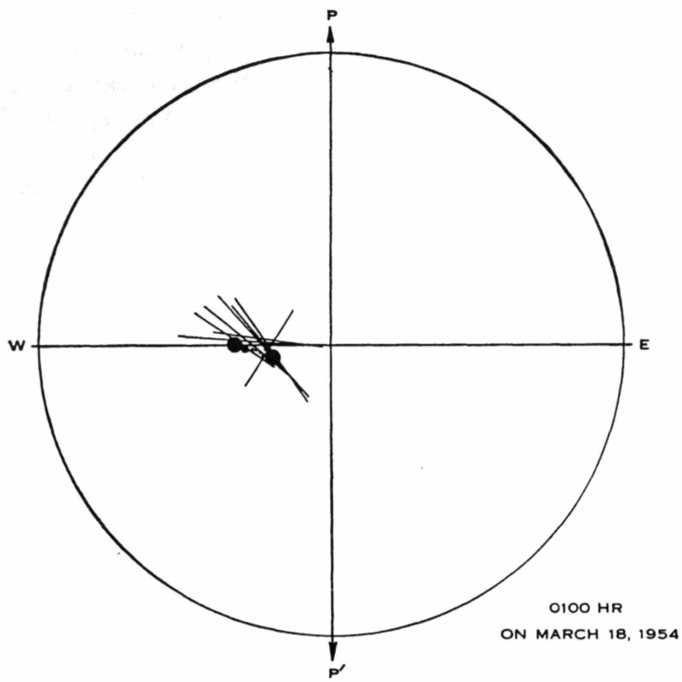


Fig. 4.—Location on the solar disk of a radio source by means of scans in several directions. The 32-element east-west interferometer and the 16-element north-south interferometer were used for these observations.

Fig. 14 Christiansen and Warburton their Fig 4 " The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres IV. The Slowly Varying Component" Australian J Physics vol 10, 1957, p 491

The assumption was made that 21 cm radio sources arose in the lower corona. In order to compare the radio source with various optical features (in the photosphere and chromosphere such as sunspots and chromospheric facules – plage faculaire[10]), the position of the radio source was more closely associated with the plages. An estimate of the height of the radio source was then obtained. The method was similar to the method used by Payne-Scott and Little (NRAO ONLINE 20) for the height of the Type I bursts at 97 MHz. Thus, the relative motion

[10] Christiansen, Warburton and Davies (Paper IV 1957 , p 503) explained: "Active regions are characterized by the appearance of photospheric and chromospheric facules (plage faculaire) in which sunspot groups grow and decay, by strong localized magnetic fields, and by enhanced emission in the corona. It is in these regions that short-term disturbances such as flares occur from time to time. There is a close correlation between the intensities of the various features of an active region, but there are marked differences in rate of decay. Sunspots appear to be the shortest lived feature (apart from temporary disturbances); chromospheric faculae and bright coronal regions have a longer life and the longest lived feature of all appears to be the associated prominences (filaments) which are visible after all the other features of an active region have disappeared."

of the radio source and the associated plage was measured as a function of longitude; the radio source moved faster than the plages. The slope of the displacement curve provided a height of 24,000 km above the photosphere (corresponding to about 0.5 arc min). The radio sources were slightly resolved with the 3 arc min resolution yielding a brightness temperature of $2x10^6$ K. Due to the fall of in brightness of the radio source as it rotated toward the limb, the authors suggested that the source had the form of a thin sheet, parallel to the surface of the photosphere. The rate of fall off in intensity of the radio source and the relative sunspot area differed; the radio source could be observed at least over two solar rotations (24 days). The 1/e time for the radio flux was 23 days and 16 days for sunspot area.

Christiansen et al summarised their conclusion about the correlation of sunspot area and radio flux density from the active sun:

> … [T]he correlation is [excellent]. In the most highly emitting regions, sunspot area is a good indicator of the radio flux, and these highly emitting regions are the dominating factor in the slowing varying component of the solar radiation … It seems therefore that the Pawsey-Yabsley method gives results that are [reasonably reliable]. …[I]t appears that the effect of the lag in radio emission in time compared with sunspots is not great enough to produce very serious errors in estimates of quiet-sun level obtained by the older methods [of Pawsey and Yabsley] ... No evidence has appeared against the simplest explanation of the [radio] emission, that is, that it results from regions of high density in the solar atmosphere, with the material having temperatures similar to that in the coronal rather than photospheric regions.[11]

The Fleurs Chris-Cross, a Radiograph based on the Multi-Element, Grating Interferometer Technique, 1957[12]- the First Crossed Grating Interferometer

[11] In 1958, Swarup and Parthasarathy ("Solar brightness distribution at a wavelength of 60 centimetres. II. Localized radio bright regions." *Australian Journal of Physics 11,* no. 3: 338-349) described data obtained at 60 cm of the SVC emission regions at this lower frequency based on data from July 1954 to March 1955; the beam size was 8.2 arc min. ("Solar Brightness Distribution at a Wavelength of 60 Centimetres II. Localized Radio Bright Regions") The maximum brightness temperature was 10^7 K. Swarup had earlier written an unpublished report (RPL 86 from November 1953) proposing the conversion of the Potts Hill grating array (EW arm of 32dishes only) to 60 cm: "Notes on the Possibility of Confirming Stanier's Distribution of Solar Brightness at 60cm". In this report, he suggested that Taurus A and Sagittarius A could be observed at 60 cm with rms noise of about 150 Jy; the signal to noise would have been about 15. However, no publication of this data has appeared.
[12] Details of the design of the Chris Cross were provided by Christiansen, W. N., & Mathewson, D. S. ((1958). Scanning the sun with a highly directional array. *Proceedings of the IRE*, *46*(1), 127-131. p 127) and Christiansen, W. N., Labrum, N. R., McAlister, K. R., & Mathewson, D. S. ((1961). The crossed-grating

The Potts Hill instrument had worked well during solar minimum when observations could be combined over multiple days to obtain cross-cuts at various position angles. This technique was thus usually cumbersome for observing the SVC sources. For this purpose, "a true 'pencil-beam' radio telescope appears to be indispensable." The solution was a combination of the grating cross and a Mills Cross. Christiansen (1984) has explained the origin:

> The two arrays placed at right angles at Potts Hill suggested a new type of antenna more suited to variable sources. While visiting Potts Hill one morning in 1953 Mills asked me why we did not couple the two arrays to produce high resolving power in two dimensions. During the ensuing discussion it was agreed that for this to be effective the centres of the two arrays must not be separated (as they were in the Potts Hill antenna), and also that some means had to be devised to multiply the outputs of the arrays. By the next morning Mills had devised the Cross Antenna consisting of a pair of thin orthogonal antennas with their outputs multiplied to give a single narrow response.

Details of the planning and construction of the Chris Cross have been provided by Orchiston and Mathewson in 2009 ("Chris Christiansen and the Chris Cross", *J Astron History and Heritage* vol 12, p. 11). Chris Christiansen had decided to build a new radio telescope during a sabbatical to France and the UK in 1954-1955[13]. By 1956 there was increased radio frequency interference at 1420 MHz at Potts Hill and the available land was limited. The choice of the existing Fleurs site was clear; the 85 MHz Mills Cross had been completed in 1954 and the larger Shain cross at 19.7 MH was built in 1956 (see the map, Fig. 15, of Fleurs which shows the proposed site of the Chris Cross at 1420 MHz.). From the time that Christiansen returned to Sydney in early 1955, he urged that the approved project begin as soon as possible. In late 1955, Matheson joined RPL in Sydney to assist with the construction of the new cross. A prototype of the new equatorial mounted (and steerable) 5.8 m dish (Fig. 16) was constructed on the NS arm at Potts Hill in November 1956. The construction at Fleurs was completed in early 1957. The system was tested for some months with the system operational for regular observations on 28 June 1957; by July daily solar images were produced. The Chris Cross was thus available for participation in the International Geophysical Year (IGY, 1 July 1957 to 31 December 1958).

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interferometer: a new high-resolution radio telescope. *Proceedings of the IEE-Part B: Electronic and Communication Engineering*, *108*(37), 48-58.)

[13] This visit was organised based on contacts Christiansen had made during the 1952 URSI in Sydney.

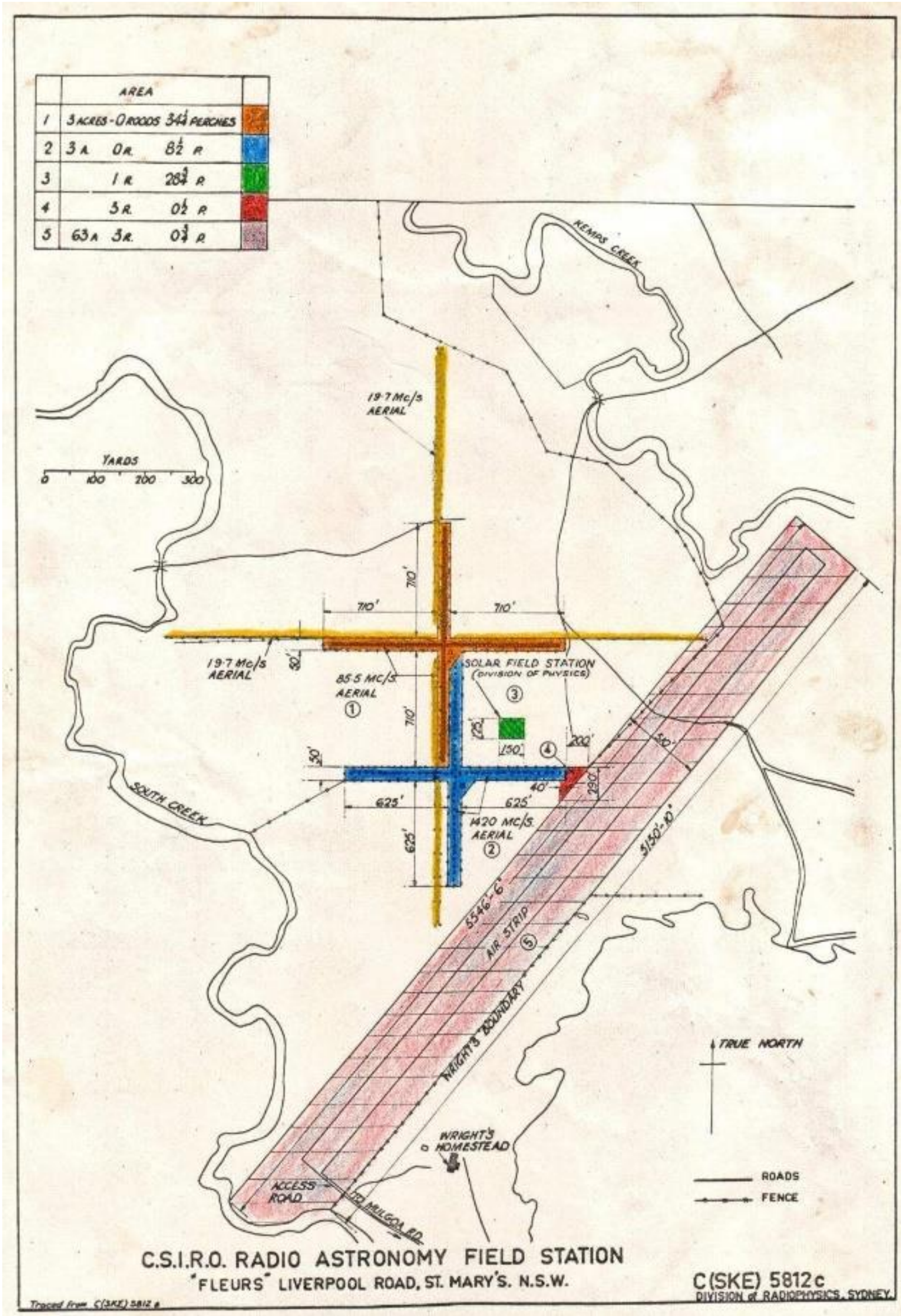


Fig 15 a map of the Fleurs site late 1950s, the 1423 MHz aerial in blue, the 85.5 MHz Mills Cross in red and the 19.7 MHz array in orange. The World War II airstrip is shown in pink- in 2022 this is the site for the new Sydney airport. Credit: CSIRO Radio Astronomy Image Archive B5815

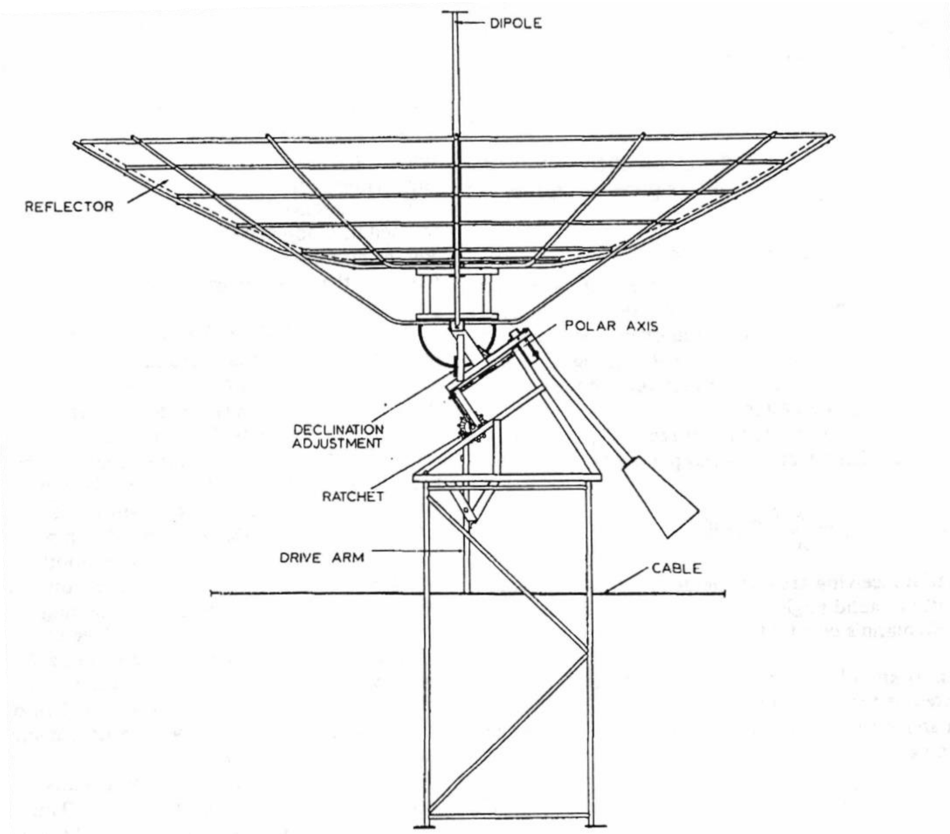


Fig. 6.—An aerial unit, showing the drive mechanism.

Fig. 16. Engineering drawing of the 19 foot (5.8m) aerial for the Fleurs “Cross Grating Interferometer”. Two long mutually perpendicular arrays, each with 32 of one of these dishes, spacing uniformly (separation 12.3m) along a 378 m arm. Credit: Christiansen, W. N., Labrum, N. R., McAlister, K. R., & Mathewson, D. S. (1961). The crossed-grating interferometer: a new high-resolution radio telescope. *Proceedings of the IEE-Part B: Electronic and Communication Engineering*, *108*(37), 48-58. Their Fig.6.

The array consisted of 32 equatorially mounted 5.8m dishes on 378 m NS and EW arms spaced at 12.3 m on 378 m long arms, combining the data from the two phases in phase and out of phase with a Ryle type phase switch. A series of pencil beams were produced, separated by 1 deg in the grating response, well in excess of the 30 arc min size of the sun. With the crossed array design the side lobes associated with the individual beams were 20 percent; a taper was supplied which increased the beam size for the EW arm to 3 arc min with sidelobes of less than 3 percent. For observations in the winter (sun at elevation of 34 deg), the NS beam increased to 5.4 arc min due to foreshortening.

The beam forming method was summarised (Fig. 17). As the earth rotated:

[T]he network of pencil beams … moved together across the sky … different pencil beams scanned successive strips of the sun, producing a series of EW profiles (Fig. 17). In reality, the scanning process was accelerated by shifting the pencil beams in declination so as to maintain a space about equal to the beam width between adjacent scans. This was accomplished by using a phase-shifting mechanism on the NS arm of the Cross so that it only took about half an hour for the sun to be scanned [in a television mode]. In this way, the distribution of radio emissivity over the whole disk is thus determined in a direct, rapid and unambiguous fashion. [Orchiston and Mathewson, 2009].

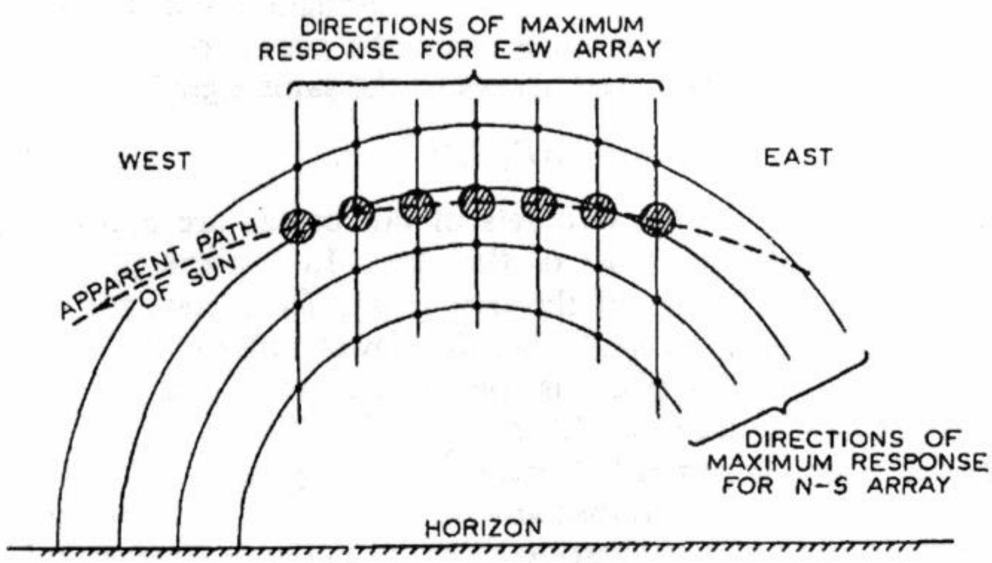
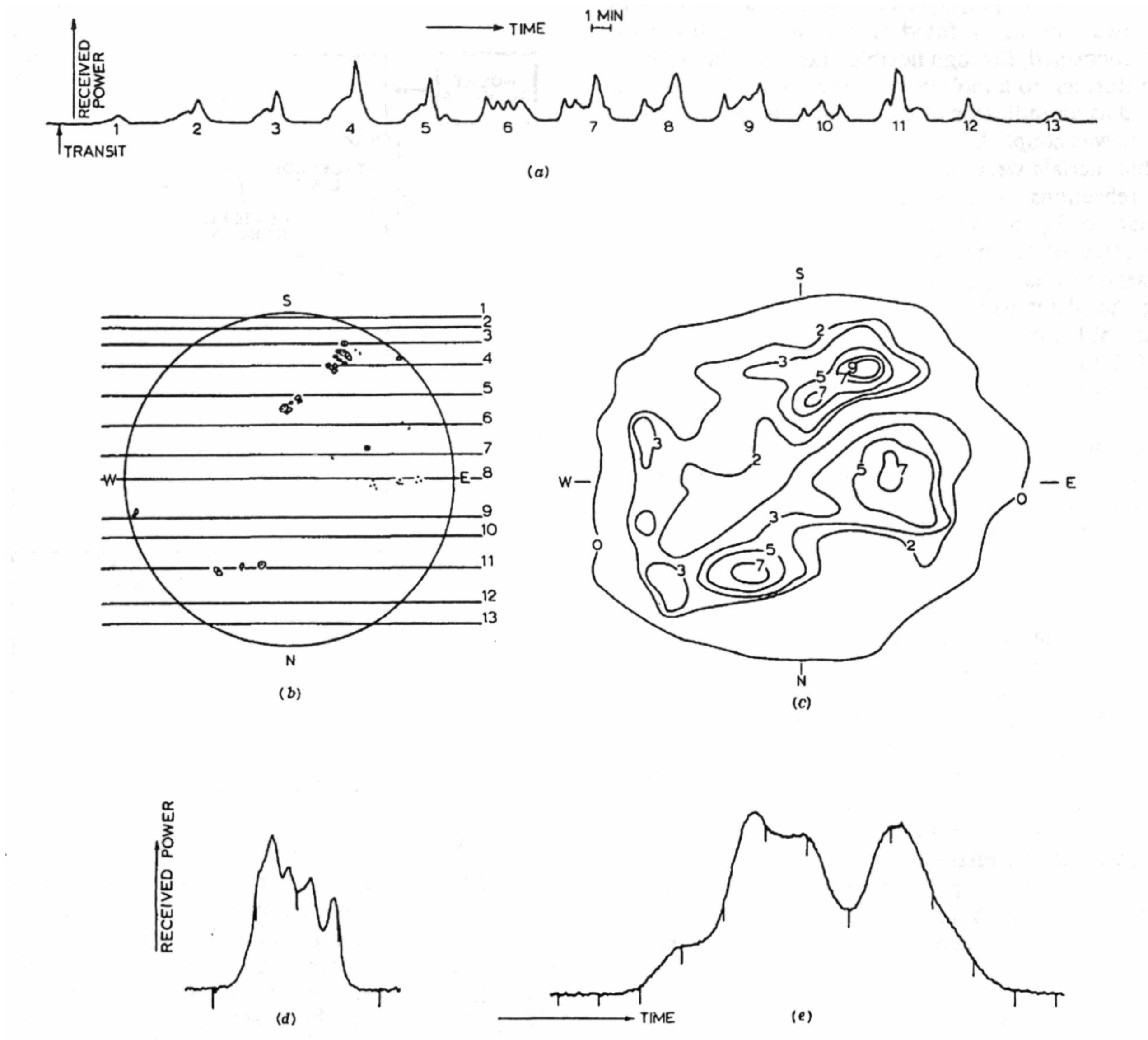


Fig. 5.—Movement of the sun across the beams of the crossed interferometer.

Fig. 17 Movement of the sun across the beams of the crossed interferometer. Credit: Christiansen, W. N., Labrum, N. R., McAlister, K. R., & Mathewson, D. S. (1961). The crossed-grating interferometer: a new high-resolution radio telescope. *Proceedings of the IEE-Part B: Electronic and Communication Engineering*, *108*(37), 48-58. Their Fig. 5



(*a*) Record of received power, as a series of pencil beams crossed the sun.
(*b*) Location of the profiles on the sun (numbered to correspond with the record). Positions of visible sunspots are also shown.
(*c*) Brightness contours derived from (*a*) and (*b*). The unit of contour height is 100 000° K in brightness temperature.
(*d*) One-dimensional scan with east–west array.
(*e*) One-dimensional scan with north–south array. On the last two diagrams, 1 min time marks are shown.)

Fig. 18 Typical radio image of the sun from 22 October 1957. The details of the reconstruction of the image are shown. Credit: Christiansen, W. N., Labrum, N. R., McAlister, K. R., & Mathewson, D. S. ((1961). The crossed-grating interferometer: a new high-resolution radio telescope. *Proceedings of the IEE-Part B: Electronic and Communication Engineering*, *108*(37), 48-58.) Their Fig.12.

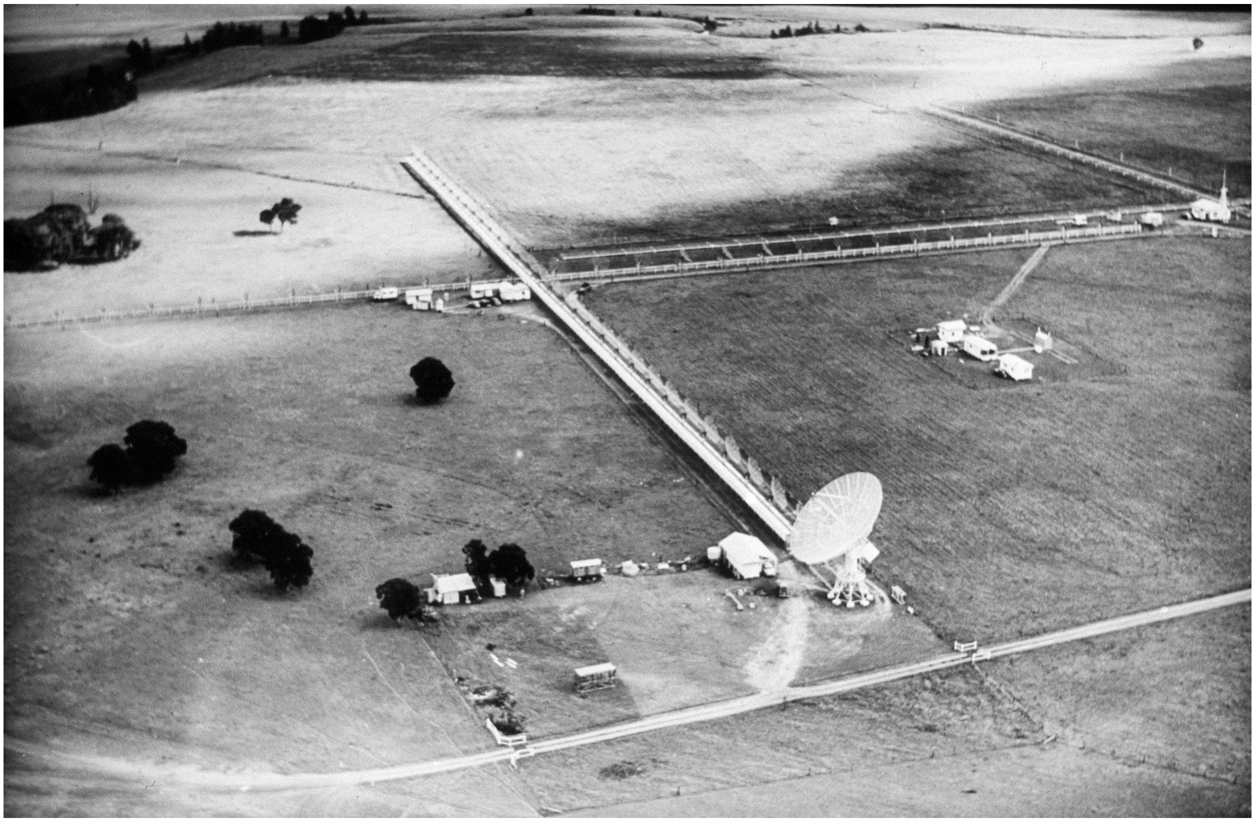


Fig. 19 An aerial view of Fleurs field station in June 1961 showing the 18 m dish “Kennedy” on the eastern end of the Chris Cross. The Kennedy dish was inaugurated on 16 May 1961 and later moved to Parkes. Together with the E-W arm of the Chris Cross, it was used as a compound interferometer operating at 1420 MHZ. The view is from the east looking west. The Mills Cross is on the right. The cluster of buildings between the Chris and Mills Cross is the Division of Physics solar station which included a coronagraph. Credit: CSIRO Radio Astronomy Image Archive B6447

Fig. 20 Centre of the Fleurs 1423 MHz array, the central 5.8m aerials are shown , in the distance the west arm. Credit: CSIRO Radio Astronomy Image Archive B5372-7

In mid-1957, as the IGY began, Christiansen, Mathewson and Pawsey announced to the world that the Chris Cross was operational in June 1957. An article was submitted to *Nature*, published on 9 November 1957, “Radio pictures of the Sun”, *Nature*, *180*(4593), 944-946.

.

> We have recently put into operation an instrument which gives a picture of the sun in the “light” of 21 cm radio waves…. With the discovery of radio emission from the sun and the recognition that this emission must, at suitable wavelengths, originate in the corona, it became possible in principle to obtain pictures of the corona over the disk. But to get a detailed picture of the sun, which is only 0.5 deg in diameter, the angular resolution required appeared prohibitive. Over the years, information was obtained by **devious** [our emphasis] methods, by circumstantial evidence based on the correlation

> between sunspots and radio emission, through eclipse observations, and most effectively, by regular day-by-day observations using knife-edge beams [Potts Hill grating array] only a few minutes of arc in width. These have demonstrated that the radio sun at decimetre wave-lengths shows a background due to thermal emission from the bulk of the lower corona, together with bright patches [called radio plages by the Sydney group] which last for periods of the order of months, are related in some way to optically active regions [lower in the solar atmosphere]. The current hypothesis concerning the cause of the bright patches is that they are due to thermal emission from unusually dense and hot regions in the corona.

Christiansen, Mathewson and Pawsey ended their publication of 9 November 1957 with a note of caution:

> Radio observations have now enabled us to study one more level in the solar atmosphere. Similar advances in the past have revealed new and unexpected phenomena, but have **contributed surprisingly little to the physical understanding of the Sun**. [our emphasis] We hope that in due course our observations may contribute both new phenomena and understanding.

A year later, a "showcase" presentation of the exciting new data from the Chris Cross at Fleurs was presented by Don Mathewson at the Paris Symposium in August 1958[14]. (Christiansen and Mathewson, 1959, *Paris Symposium on Radio Astronomy*, "The Origin of the Slowly Variable Component", p 108) (see Chapter 36 for a discussion of the Paris Symposium on Radio Astronomy, 1958.)

The main purpose of the new Chris Cross had been to elucidate the properties of the SVCs as the solar maximum began in the late 1950s. The 2-dimensional nature of this instrument enabled the RPL group to study the complex distribution of SVCs over the sun with a resolution of 3 arc min. An example of an observation on 11 November 1957 is shown in Fig. 21, Christiansen and Mathewson (1959, *Paris Symposium on Radio Astronomy*, "The Origin of the Slowly Variable Component", p 108). As was done with the Potts Hill observations, the height of the SVC radio sources was determined again with a greater accuracy. The passage of a radio

[14] After the Symposium, he started his PhD at Jodrell Bank, the University of Manchester, returning to RPL in 1960. Mathewson continued observing at Fleurs, where he worked on a continuum survey of the Milky Way at 20 cm (with Healy and Rome) with the newly arrived 60-foot Kennedy antenna. This instrument was subsequently moved to Parkes in 1963 as the movable element of the Parkes interferometer.

source centred (CMP, central meridian passage) on 27 October 1957 is shown in Fig. 22. The slope of the curve provided heights which varied from 20,000 to 100,000 km with estimated errors of 10,000 km. The average height was 40,000 km (about 1 arc min at the distance of the sun), about twice that determined from the earlier data at Potts Hill. Again, the cosine law of intensity was observed, confirming the disk like shape of the radio SVC feature, with the extension in height appreciably less than the extension parallel to the photosphere. The long-lived nature of the SVCs is shown in Fig. 23. The lifetimes were of order three months and "exhibit their own movements, expanding, contracting and changing in size but remaining essentially in the same region on the sun. No systematic trend in height, intensity or size with age of the region has ... been found."

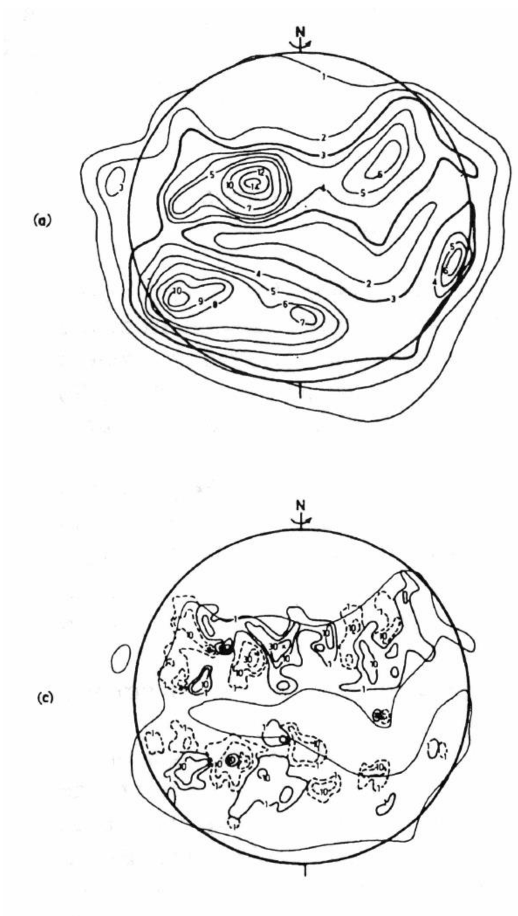


Fig. 21 Top is 20 cm image from Fleurs with contour interval 7.5 x 10^4 K. 11 Nov 1957. Below is Mt Wilson Magnetogram with units 1, 10 and 30 gauss. South polarity is dotted and solid is north. Christiansen and Mathewson, *Paris Symposium on Radio Astronomy*, 1959, p. 1099, their Fig1.

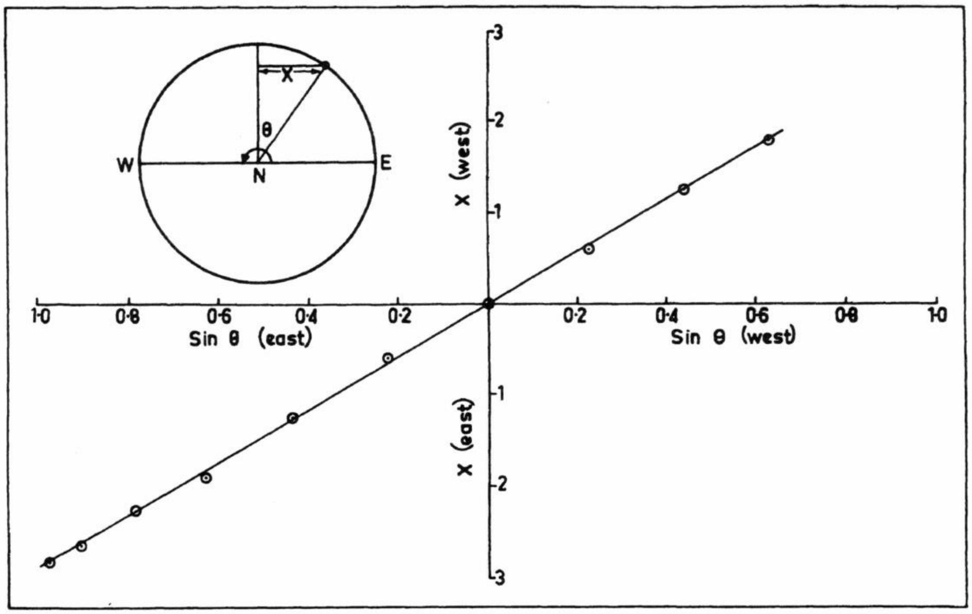


FIG. 2. The passage of a radio source (C.M.P. 1957 October 26, lat. 23 degrees S) across the disk of the sun. The displacement of the source from the central meridian on the disk is plotted against the sine of the angle of rotation of the sun.

Fig. 22 above from Christiansen and Mathewson, *Paris Symposium on Radio Astronomy*, p 108, their Fig.2 The passage of a radio source (CMP 1957 October 26, latitude 23 S) across the disk of the sun. The displacement of the source from the central meridian on the disk is plotted against the sine of the angle of rotation on the sun. The height of the radio source above the photosphere was determined to be close to 40,000 km (about one arc min).

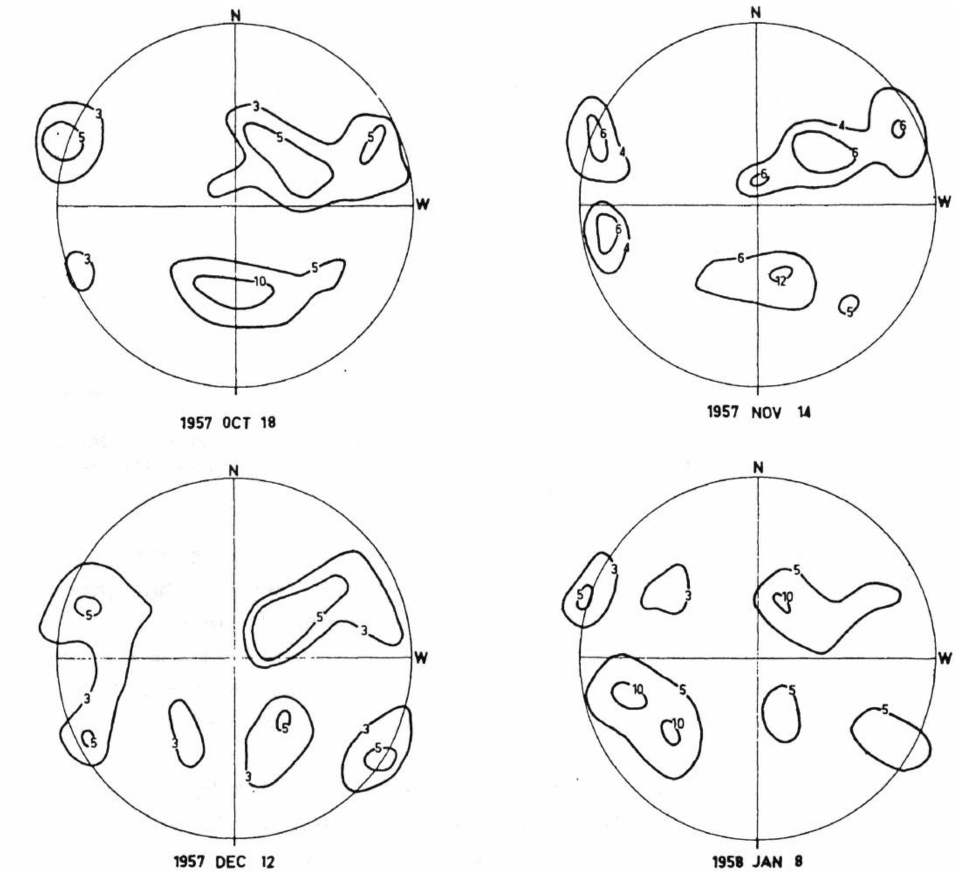


FIG. 3. Radio maps of the sun at intervals of one solar rotation. The brightness contours are marked in units of 10^5 °K.

Fig. 23 Radio images of the sun at intervals of one solar rotation. The brightness contours in units of 10^5 K. From Christiansen and Mathewson, *Paris Symposium on Radio Astronomy*, 1959, p. 108. Their Fig 3. The long-lived nature of the radio SVC feature was clearly evident after an interval of one solar rotation of about a month.

The most significant property derived was the brightness temperature of the SVC sources. Due to the improved image fidelity (two dimensional image) compared to the Potts Hill data, the brightness temperature of about 60 sources was determined, ranging from 2×10^5 K to 1.5×10^6 K with a median of 0.6×10^6 K, about a factor of three less than the earlier determination.[15] "The sharp upper limit [of 1.5×10^6 K] … is a value near the commonly accepted coronal temperature; this is strong evidence that the radio sources are simply optically dense parts of the corona."

[15] It is likely that the previous determinations at Potts Hill underestimated the size of the source due to the fan-beam nature of the observations.

A major new discovery was the lack of circular polarisation, less than 2 percent. The conclusion suggested that a non-thermal emission mechanism for the SVC was unlikely.

The identification of the SVC with the proposed “coronal condensations” of Waldmeier (*Zeit Astrof*. Vol 40, p 221 1956) was suggested by Christiansen and Mathewson, these condensations with electron densities 20 times those in the undisturbed corona. The spectral index and height of origin for the 20 cm radio emission agreed with the predictions; but the source size was in disagreement with the predicted values. Sullivan (CN page 311) has pointed out that the Piddington and Minnett model (1951) for their “S component” was also quite similar with high density (20 times normal) and 10^7 K regions extending well into the corona above sunspots (Piddington and Minnett,1951a, “Solar Radiofrequency Emission from Localized Regions at Very High Temperatures”, *Australian J. Scientific Research,* A4 ,131).

Christiansen and Mathewson suggested that the dense regions associated with the radio sources could be associated with a vertical column with a base in the photosphere, possibly associated with a chromospheric plages. “It appears that the cross-section of the dense regions is fairly constant with height and is delineated by the plage in the lower region of the sun’s atmosphere… It is possible that these regions extend right out to form the coronal streamers [observed during eclipse].”

Legacy of Christiansen

Christiansen made major contributions to the techniques of radio astronomy over many decades. A major example are the two editions of the textbook *Radiotelescopes*, written with Jan Högbom in 1969 and 1985. His contributions occurred in Australia, the Netherlands (initially the Benelux Cross and later the Westerbork Synthesis Radio Telescope), India (Tata Institute of Fundamental Research, the Giant Metrewavelength Telescope) and China (through Wang Shou-guan).

The creation of the new electrical engineering group in the early 1960s at the University of Sydney was decisive as staff members and students developed instrumentation for operational radio telescopes, including the Fleurs Synthesis Telescope. Leading individuals were Bob Frater as well as prominent members of the 802.11 wireless LAN work (John O’Sullivan, the late John Deane, Diet Ostry, Terry Percival, Graham Daniels and David Skellern). The Fleurs Synthesis Telescope provided technical and astronomical input as well as decisive expertise for the planned Australia Telescope, opened in 1988.

Frater, Goss and Wendt (2017) in the *Four Pillars of Radio Astronomy, Mills, Christiansen, Wild, Bracewell* have summarised the impact of Christiansen:

> (1) Major instrumental innovations that had an impact on radio astronomy. Earth rotational synthesis was achieved in 1955 with the Potts Hill grating array. A few years later, the crossed-grating multi-element interferometer at Fleurs was completed, an instrument based on the twin concepts of the grating array as had been used at Potts Hill and the Mills Cross technique of correlating two orthogonal arrays.
>
> (2) New astronomical understanding:
>
> (a) The pioneering HI line work in the first years of 21 cm hydrogen spectroscopy, starting in 1951. This work showed the existence of spiral arms in the gaseous component of the Milky Way; the southern galaxy was imaged contemporaneously with imaging of the northern Milky Way by the Leiden group.
>
> (b) The determination of the properties of the decimetre sun in the early 1950s at 21 cm (1.4 GHz). At 21 cm, the radiation arises from the transition region between the corona and the outer chromosphere. In this region, the changeover between the steady optical sun and the spectacularly variable metrewave sun occurs. Thus the determination of the physical conditions in this important region of solar activity. The observations were carried out at Potts Hill using the east-west and north-south grating arrays from 1952 and at Fleurs using the crossed multi-element interferometer starting in 1957, on the first day of the International Geophysical Year. The quiet sun, arising from thermal free-free emission from the solar atmosphere, was investigated in detail, with the detection of the prominent equatorial limb brightening at solar minimum using Potts Hill data from 1953. With the Fleurs array, two-dimensional images were created by scanning the sun during observations of about an hour; the image, with a resolution of about 3 arcmin, was constructed "television fashion" by using scans at different latitudes on the sun. With this method, detailed images of the "slowly varying component"[16] were obtained at a rate of one image per hour. The electron density and temperature (3 x 10^9 electrons per cubic cm and

[16] Christiansen and Pawsey championed the use of this term, invented earlier by J.F.Denisse in 1949.See *Cosmic Noise*, Sullivan, 2009, p. 222): "une composante lentement variable"- slowing varying component SVC. The latter term became the standard terminology within a few years.

2 x 10^6 K) of the radio regions were determined at elevations of ~40,000 km above the sun's surface.

The impact of Christiansen and his group on cm and dm solar research in mid-2020 has been the source of a discussion that the authors had with Stephen White. White has suggested that the impact in the mid-20th century of the Potts Hill grading interferometer and later the Fleurs Chris Cross data had a somewhat limited influence due to the solar and astronomical environment of the 1950s. A major stumbling block was that there were few facilities suitable for coronal observations at other wavelengths with which to compare the radio data. The 20 cm data at Fleurs in the 1950s had achieved high angular resolution of 3 arc min over a large field of view (30 arc min) that was only achieved somewhat later for non-solar radio imaging. The solar radio astronomers had to make do with detailed comparisons with surface features on the photosphere of the sun derived from optical data. In the next decades, techniques for wide field high resolution solar imaging in X rays, UV and IR developed.

This conclusion is consistent with a cursory comparison of the citation history of the papers from Christiansen and Warburton and a comparable set of papers by Paul Wild. The Christiansen et al papers are a set of four papers published in 1953, 1955 and 1957: "The Distribution of Radio Brightness over the Solar Disk at A Wavelength of 21 Centimetres. Paper I: A New Highly Directional Aerial System, Paper II: The Quiet Sun – One Dimensional Observations, Paper III: The Quiet Sun – Two Dimensional Observations and Paper IV[17]: The Slowly Varying Component".

The Wild papers are his series in 1950 and 1951: "Observations of the Spectrum of High-Intensity Solar Radiation at Metre Wavelengths, Paper I[18]: The Apparatus and Spectral Types of Solar Burst Observations, Paper II: Outbursts (later Type II), Paper III, Isolated Bursts (later Type III), and Paper IV (Enhanced Radiation)."

The four Christiansen et al papers have 91 citations (Astronomical Data System) in publications up to 2022 (January), while the Wild et al paper had 415. For example, the most cited Christensen and Warburton is paper III, the 2-dimensional distribution showing clear limb brightening at 20 cm with 35 citations. Wild paper number III (Type III bursts) has 161 citations. Over a period from 1945 to about 1970, Wild has about five times more citations than Christiansen. Wild's two *Annual Reviews of Astronomy and Astrophysics* articles on solar bursts were in 1963 (Wild, Smerd and Weiss) and 1972 (Wild and Smerd), with citation numbers 485 and 212, respectively.

[17] With an additional co-author R.D. Davies
[18] Co-author McCready.

Christiansen also had a review in the inaugural *Annual Reviews of Astronomy and Astrophysics* in 1963, the same volume one as Wild, Smerd and Weiss. The Christiansen review was non-solar, "RadioTelescopes" on page 1 of volume one in 1963; surprisingly there are only four citations.

Additional Note 1: "**Fritz Goro, Life Magazine Photographer at Potts Hill, Dover Heights, Mt Stromlo and Harvard University, 1951. Photographs of RPL, ANU and Harvard Scientists"**[19]

Summary, Fritz Goro (1901 to 1986)

Fritz Goro was a well-known photo-journalist who lived from 1901 to 1986. He was born Fritz Gorodiski in Bremen, Germany, died in Chappaqua, New York, on December 1986. Of Jewish origin, Goro was, by age 30, the editor of *Munich Illustrated*, a weekly magazine. As a result of the Nazi takeover of the publication, Goro and his family emigrated to France in 1933 and then to the US in 1936. He joined the Black Star Picture Agency, producing photo essays for the news magazine *Life*. In 1941, he was under contract to *Life* and in 1944 became a *Life* staff photographer for the next 27 years.

Goro is credited as the inventor of macrophotography, the form of photography that involves imaging small objects to make them look life-sized or larger in the photo.[20]

Goro's breakthrough occurred in 1937.C. Zoe Smith (1987) wrote:

> Goro was called by a *Life* editor and asked to … do two … stories on a group of scientists at the Marine Biological Laboratory in Woods Hole, Massachusetts. Meeting some of the world's greatest scientists at Woods Hole stimulated Goro's life-long interest in science. At the age of thirty-six, he took yet another turn in his career. Naive but curious about scientific subjects, Goro went on in his long career to make "a lot of pictures a professional photographer would never have done because he would have said it was absolutely out of the question; it could not be done. But I did it. I swim against the stream constantly."

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[19] Source material, (1) *New York Times* obituary 19 December 1986,(2) "Fritz Goro: Émigré Photo-Journalist" in American Journalism, vol 3, 1986, no 4, p. 206 by C.Z. Smith and (3) *On the Nature of Things: The Scientific Photography of Fritz Goro* by Fritz Goro , Stephen Jay Gould, Peter Goreau, Thomas Goreau and Stefan Goreau , 1993

[20] Examples are sharp, detailed close-up images of small objects such has flowers, plants and insects.

Smith (1986) continued, with a summary of Goro's later achievements:

> Goro's technical precision was a characteristic shared by many of the émigré photographers trained in Europe … Before going on assignment Goro did his "homework", becoming familiar with the scientist's work so he could speak his language. Within a short time, Goro felt he was an equal among the scientists whose work he photographed for *Life*. He believed he gained their respect by working in the same manner they did: carefully, thoroughly and meticulously. For Goro, it was his moral and ethical duty to satisfy the scientists he worked with; he would rather disappoint his editor than disappoint a scientist.
>
> … [Goro's fame as a photographer rested on numerous achievements.] Much of what Goro did at *Life* involved "firsts" in still photography. He was the first to show the fission of a [plutonium] atom, blood circulating in living animals, pitchblende mining (the source of uranium), and laser beams … When Goro photographed the [hydrogen] bomb tests on Bikini [in the Pacific], he was there as a member of the military-scientific task force, [not] as a regular member of the press corps.

Gerald Piel (chairman of the board of the *Scientific American* in 1986) summarised Goro's achievements in a *New York Times* obituary of 19 December 1986:

> [Goro] covered the science that went into World War II from the fermentation of penicillin to the separation of the isotopes of uranium and plutonium that made the atomic bomb.
>
> [Since World War II], it was his artistry and ingenuity that made photographs of abstractions, of the big ideas from the genetic code to plate tectonics.

Fritz Goro and Radio Astronomy, Sydney and Cambridge, Massachusetts 1951

A few details of Goro's visit to Australia in March 1951 are known. A brief mention in a letter from Bowen to White on 19 October 1951 indicates the dates of Goro's visit[21]; however, no indications of the detailed arrangements have been located in the archives. The main purpose of Bowen's letter was to complain to White as the CEO of CSIRO about Pawsey's suggested collaboration on starting radio astronomy research at the Commonwealth Solar Observatory at Mt Stromlo (as described in Chapter 27).[22]

Bowen continued his complaints about Mt Stromlo by referring to the visit of Goro to Australia:

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[21] NAA C3830 Z1/9. Bowen was in the US for a visit to Boston and later Pasadena. The letter was written on a Caltech letterhead (19 October 1951). In the 1951 chronological file, there is a reference to Goro's assistant during his visit to Australia, Axel Poignant of Mosman, Sydney Australia.

[22] "Joe is still flirting with Stromlo … I would not say that a marriage is imminent, but the engagement has been announced. The Greeks have a word for it, but I still think it's a lot of crap."

> [Bowen to White] I had one more example of this [the desire of the Stromlo staff to "cash in" on the success of RPL in radio astronomy] only two days ago. *Life* magazine will probably run a 4-page section on radio astronomy work [see below, published a year later on 17 November 1952]. One of their photographers [Goro] took a magnificent set of pictures in Sydney just after I left [mid-March 1951 for a major trip overseas[23]] and they came to discuss the layout with me a few days ago [in Cambridge, Massachusetts at Harvard on 17 October 1951]. The very first picture they had was of a familiar face looking up at the sky. [Bowen continued in his letter to White] The caption said: "D.F. Martyn, famous Australian physicist, Fellow of the Royal Society, discoverer of circular polarised waves from the sun.[24] [Bowen ended with irony]: [Martyn's] technique is masterly.

The letter to White from Bowen thus provides the dates of Goro's visit to Sydney (March 1951) and his personal visit with Bowen at Harvard (17 October 1952). [25]

Life magazine 17 November 1952 "Radio Astronomy, Celestial Sounds Reveal Invisible Stars and New Facts About the Sun" p.130 to 138

A year after Bowen met Goro in the US, the seven-page article appeared. The cover of this issue of *Life* contained the picture of the new President-elect of the US, D.D. Eisenhower and his wife. The election of the new president had occurred on 4 November 1952.

The article had no identified author, even Fritz Goro was not mentioned. The misguided acoustic theme ("sounds", "listen to sound from space") was not explained. The article contained three pages of coloured graphics showing drawings of the sun and the Milky Way (including companions the Andromeda Galaxy and the radio galaxy Centaurus A- NGC 5128). Four of the images made by Goro in Australia were shown[26]; in addition, the 50-foot paraboloid at the US Naval Research Laboratory was shown with an identification.

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[23] NAA Z1/1 Part I, 1959. Bowen left for the UK about 15 March 1951 with intermediate visits to Bangalore, India and Egypt, He arrived in London during the third week of March. He remained in the UK for over six months with shorter trips to Gothenburg and Stockholm, Sweden, later Utrecht, the Netherlands. On 19 September 1951, he travelled to the US (including Washington, Boston and Pasadena), returning to Australia on 5 December 1951 via Hawaii.

[24] This photo of Martyn taken by Goro at Mt Stromlo earlier in 1951 is shown in NRAO ONLINE 24, Fig.1.

[25] Robertson (2017) has suggested that the pictures were obtained in Sydney and Cambridge Mass USA in July 1951, inconsistent with Bowen's letter to White.

[26]Including the lead photograph, a star trail photo at Potts Hill with the 18 x 16 foot aerial. The caption read: "Radar antenna on a telescope mount 'Listens' to sound from space as visible starts circle sky, forming steaks of light in this 90-minute time exposure." The RPL version of an impressive star trail is shown in Fig 23.1b,by the outstanding RPL photographer Ken Nash. The quality is comparable if not superior to the Goro photo.

None of the Australian images were identified by location or the CSIRO; only two were attributed to an Australian location. Two of the images contain images with RPL staff, J.L. Pawsey (on page 136 Caption: "An 800-foot row of radio telescopes each a six-foot metal shell, as set at edge of an Australian reservoir to catch radio waves coming from the sun") and John Bolton in an image of the 100 MHz aerial at Dover Heights (page 136 Caption: "TV-like antenna measure size of radio stars by analysing radio star signals that bounce off ocean along with those signals that strike the antenna directly.")

The final page of the *Life* article contained four smaller images with famous radio astronomers: (1) Bowen appeared along with "Doc" Ewen and Ed Purcell (see Chapter 20, Fig 20.1). Clearly the image was made on 17 October 1951 at the Physics Department of Harvard as Bowen visited Ed Purcell and Doc Ewen, who had discovered the HI line at Harvard earlier in the year, 25 March 1951[27]. (Chapter 20). The caption read: "Pioneer radio astronomers, who located the hydrogen clouds are Edward Purcell (left) – who last week [early November 1951] won a 1952 Nobel Prize for work in nuclear physics and H.I. Ewen (right), here meeting with Australia's E.G. Bowen. (2) a portrait of Martin Ryle of Cambridge University called an "air expert" due to his study of ionospheric scintillation (see Chapter 16), (3) a portrait of Hendrik van de Hulst from Leiden University who was studying hydrogen clouds in the outer Milky Way (Chapter 20) and (4) a sketch of the 250 foot telescope planned for Jodrell Bank by A.C.B. Lowell, one of Britain's "most eminent radioastronomers". The telescope "will be able to pick up signals impossible for other receivers to catch."

[27] At least eight additional images from Goro's visit to Harvard on 17 October 1951 were located in the online Goro radio astronomy archive; six of the images show Ewen with the equipment he had used earlier in 1951 for the first detection of a spectral line by radio astronomers, the 21 cm hydrogen line.