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HIGHLIGHTING THE HISTORY OF JAPANESE RADIO ASTRONOMY. 6: EARLY SOLAR MONITORING AT THE RADIO RESEARCH LABORATORIES OF THE MINISTRY OF POSTS AND TELECOMMUNICATIONS, HIRAISO

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Abstract: During the 1950s a small group of scientists and technicians involved in telecommunications research also monitored solar radio emission at 200 MHz from their field station at Hiraiso, near Tokyo. In this short paper, we review the Hiraiso instrumentation and observations, and how the latter were used to further our knowledge of metre wave emission from the Sun.

Keywords: Japanese solar radio astronomy, Ministry of Posts and Telecommunications, Radio Research Laboratories, Hiraiso, Obayashi

1 INTRODUCTION

Japan has a long history of radio astronomy (see Ishiguro et al., 2012; Orchiston and Ishiguro, 2017; Tanaka, 1984), but

> … the path of progress … [in] post-war Japan was a slow and arduous one. Unlike in the Allied countries, there were no military radar sites available for research. The struggle with small budgets and ill-equipped facilities (although staffed by dedicated astronomers!) continued into the 1960s … (Takahashi et al., 2000: 2).

The first deliberate attempt by a Japanese scientist to detect radio emission from an extra-terrestrial object can be traced back to the Tokyo observations at 3 GHz by Koichi Shimoda (b. 1920) of the partial solar eclipse on 9 May 1948 (Shimoda et al., 2013) and observations of solar noise at 3.3 GHz by Minoru Oda (1923–2001) and Tatsuo Takakura (1925–2001) in November 1949 from Osaka. However, these observations were experimental and the Osaka initiative was short-lived because Oda's interest shifted to X-ray astronomy (Orchiston et al., 2017).

More enduring were the radio astronomy groups founded in 1949 by Takeo Hatanaka (1914–1963) and Haruo Tanaka from Tokyo Astronomical Observatory (TAO) and the Research Institute of Atmospherics at Nagoya University. The TAO established a radio astronomy precinct at their Mitaka headquarters near Tokyo, while the Nagoya University group set up their Toyokawa Observatory at a radio-quiet site 60 km south-southeast of Nagoya. Throughout the 1950s and 1960s the dynamic Tokyo and Toyokawa groups were the mainstays of Japanese radio astronomy (see Deguchi, 1995; Tanaka, 1984). For Japanese localities mentioned in this paper see Figure 1.

Later a fourth Japanese solar radio astronomy group was formed at Hiraiso on the east coast of Honshu, about 150 km northeast of Tokyo. In 1949 the Radio Division of the Government's Radio Agency joined with the Radio Department of the Telecommunications Research Institute, and established the Ohi Radio Observatory. One year later this research facility was transferred to Hiraiso, and in August 1952 it officially became a branch office of the Radio Research Laboratories of the Ministry of Posts and Telecommunication. This paper examines the solar research program pursued at Hiraiso[1] up until 1968 and is based largely on a research paper written by Takahashi et al. (1954) and reminiscences published by Wakai (1988).[2] Wakai explains:

Figure 1: Japanese localities mentioned in the text. Key: 1 = Hiraiso; 2 = Tokyo; 3 = Mitaka; 4 = Toyokawa; 5 = Nagoya; 6 = Osaka; 7 = Ohi (map: Wayne Orchiston).

> … I decided to introduce mainly the unknown stories and the unpublished photos. Although it was not intended, the content was biased towards topics related to Communication Research Laboratories.
>
> The reason is that it was easy to collect old materials and photos and the footprint of the solar radio research on the same place is an indication that there was not much announcement so far compared with other research institutions.[3]

2 SOLAR RADIO ASTRONOMY AND THE RADIO RESEARCH LABORATORIES OF THE MINISTRY OF POSTS AND TELECOMMUNICATIONS

2.1 Introduction

The Ministry of Posts and Telecommunications (MPT) was responsible for Japan's international telecommunications network, and its involvement in monitoring solar noise was a by-product of this:

> … comprehensive data of ionospheric conditions and related astronomical and geophysical phenomena are collected promptly to evaluate the latest radio propagation condition. The visually recording magnetograph … and continuous data of short wave reception conditions over various routes are the most important aid to noticing the onset of a magnetic or ionospheric storm and its development. *On the other hand the observations of solar radio emission and sunspots are also useful for the prediction of the active period a few days in advance*. (Obayashi, 1954: 55–56; our italics).

By the end of WWII staff at the MPT were already expert in antenna design and construction, and it was this fact that led them to construct a broadside array for the fledgling solar radio astronomy group at Tokyo Astronomical Observatory (TAO). Since the design and construction of this antenna foreshadowed the emergence of solar radio astronomy at Hiraiso and was not detailed in our earlier paper in this series by Nakajima et al. (2016), let us pursue this further here.

At the time, Noboru Wakai (1927–2009; Smith, 2009) worked at the what would soon become the MPT's Radio Research Laboratory and he, reported that around 1947 Takeo Hatanaka and others at TAO

> … who were interested from the standpoint of astronomy, asked Kin-nosuke Kawakami of the Central Radio Observatory (the predecessor of the Radio Research Laboratory) who was interested from the standpoint of radio engineering to construct a 200 MHz solar radio telescope … 1949. (Wakai, 1988).

Wakai (ibid.) reveals that he and Hatanaka (from TAO) built the receiver. First Wakai surveyed the available literature on the subject, and had discussions with TAO people about radio reception technology. Then

> I collected vacuum tubes and parts for the receiver at my institute.
>
> I also designed the antenna, but one company that was asked for an estimate requested an extraordinary price because that company had never made an equatorial mounting before.
>
> At that time the Observatory had a budget of only 60,000 yen, but Mr. Saburo Matsuo from the [Electrical Communication Research] Institute found a further one million yen to add to the Observatory's budget, and a company introduced by Mr. Takeo Kawahara (who was actively involved with the Ministry (of Posts and Telecommunications) agreed to construct the antenna for 1.05 million yen. (ibid.).

The antenna was made of wood, with an iron equatorial mounting (see Figure 2), and was completed in September 1949. It was installed at TAO in Mitaka, where Hatanaka, Shigemasa Suzuki and Fumio Moriyama soon began making solar observations. However,

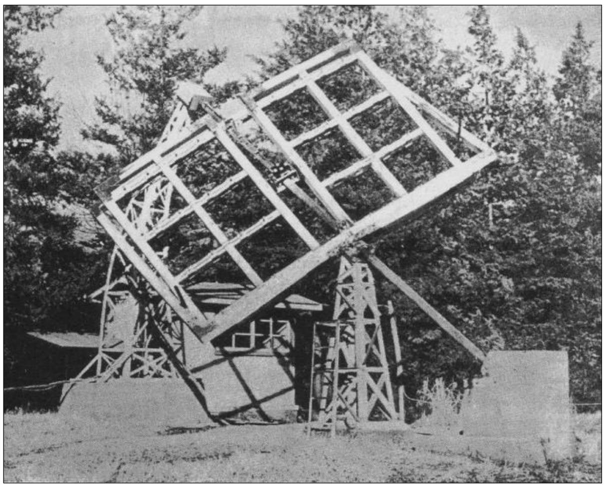

Figure 2: The broadside array that the Ministry of Posts and Telecommunications constructed for the Tokyo Astronomical Observatory in 1949. The receiver was housed in the hut behind the antenna (after Suzuki and Shibuya, 1952).

> … it would have been very difficult for the observer because of manual tracking every 30 minutes. [Fortunately,] At that time it happened to be a period of high solar activity and there were frequent solar bursts.

2.2 The Ohi Radio Telescope

This exercise by the MPT obviously inspired them, because in November 1949 the Radio Division of the Radio Agency and the Radio Department of the Telecommunications Research Institute began building their own radio telescope (Wakai, 1988) and this was installed at Ohi Radio Observatory, a radio-quiet location 45 km north-west of downtown Tokyo.[4] This would be used to monitor solar noise in connection with Japan's international telecommunications network (Obayashi, 1954).

The Ohi radio telescope comprised an 8 × 8 element broadside array (see Figure 3), which was attached to a receiver that operated at 61.2 MHz. Wakai (1988) recalls that

> Unfortunately this antenna had structural defects and it soon collapsed, but although it only

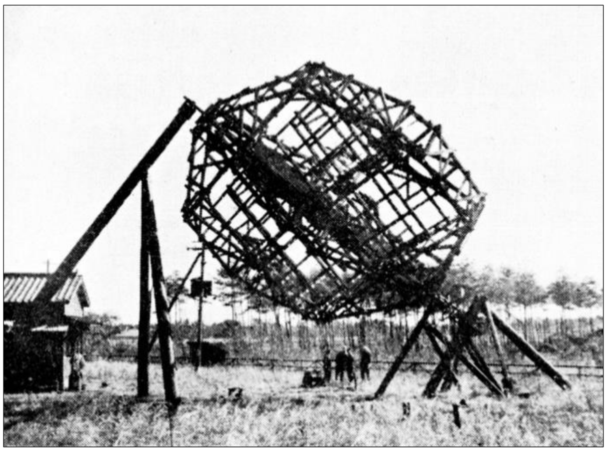

Figure 3: The wooden 8 × 8 broadside array at Ohi Radio Observatory (after Wakai, 1988).

> functioned for a short time, during February and March 1950, it succeeded in detecting radio emission from an active region on the Sun.

This solar detection is not mentioned in Tanaka's (1984) classic paper on early Japanese radio astronomy, or in our own overview papers (Ishiguro et al., 2012; Orchiston and Ishiguro, 2017), and it deserves to be recognized and applauded.

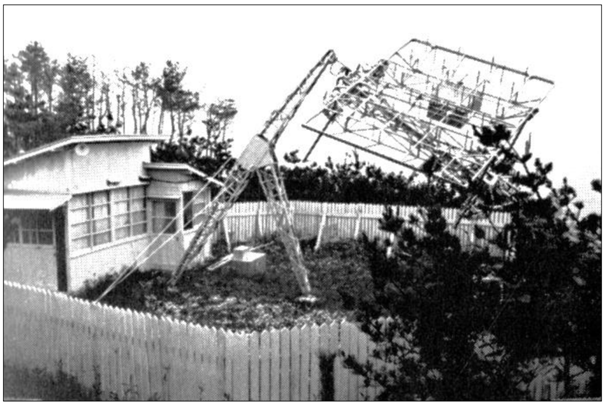

Figure 4: The equatorially-mounted 6 × 4 broadside array at Ohi Radio Observatory (after Wakai, 1988).

So, after Shimoda's 1948 eclipse observations, and solar monitoring in 1949 by the fledgling TAO, Toyokawa and Osaka groups, the MPT group was the next group to detect solar radio emission, and Ohi Radio Observatory must be added to the map of successful early Japanese radio astronomy sites.

2.3 The Hiraiso Radio Wave Observatory

Learning from their abortive Ohi Radio Observatory exploits, the Radio Wave Supervision Committee (the successor of the Radio Agency) then

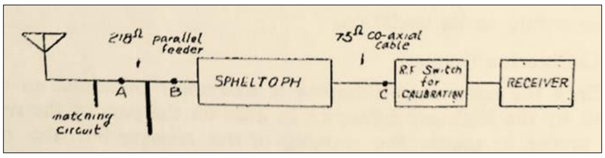

Figure 5: The coupling between the antenna and receiver (after Takahashi et al., 1954: 42).

built a new 200 MHz broadside array with an equatorial mounting (Figure 4), and in March 1952 installed this on a coastal terrace at Hiraiso Radio Wave Observatory 125 km east-northeast of Tokyo.

The antenna comprised an array of 6 × 4 half-wave dipoles backed by a reflecting screen. Furthermore,

> Parallel feeders of 218 ohms are used between the feeding point and the spheltoph through a matching trap; the power output from the spheltoph is fed to the receiver through 75 ohm [12 m long] coaxial cable. (Takahashi et al., 1954: 41).

This is shown in Figure 5.

The receiving system (Figure 6) was a

> … double-superheterodyne on 200 Mc. F (noise figure) is approximately 4, or 5 including the switching circuit. Bandwidth is approximately 80 K; gain approximately 130 db. (Takahashi et al., 1954: 42).

The output went to a meter and a chart recorder

A signal generator was used to calibrate the system, and since

> … the solar noise intensity is extremely small and an observational error is caused by the slightest difference in gain on the part of the receiving set, it is not only proper to secure the stability of the receiver but also necessary to increase the accuracy of measurement by repeating calibration as often as possible. Therefore, calibrations were made every 8 minutes. (Takahashi et al., 1954: 41).

The antenna was mounted equatorially so that it could track the Sun

> … from sunrise to sunset—not continuously, but by advancing 2 degrees every 8 minutes. The plane of polarization is parallel to the declination which is manually regulated day-by-day according to its variation. (ibid,).[5]

The Hiraiso radio telescope was used as a total power radiometer, and solar monitoring began in March 1952. The objective was to record the mean quiet Sun 200 MHz flux level on a daily basis. Allowance was made for loss due to the co-axial cable from the antenna, while variations in receiver noise were found to be negligible (Takahashi et al., 1954: 44–45). Details of how the readings made during the observations were converted into daily flux densities are outlined on pages 45–48 in Takahashi et al. (1954).

The next major instrumentation development at Hiraiso is reported by Wakai (1988): in order to identify the positions of radio sources in the corona a two-element interferometer was installed. This comprised two 8 × 8 element broadside arrays, which were completed in 1955 and 1956 respectively. They were separated by 30 m, giving an angular resolution of about 20 arcminutes. Figure 7 shows the 1956 antenna, and also reveals that their mountings were a major shortcoming, in that

> The antennas could be moved only in elevation angle so that daily observation was done only

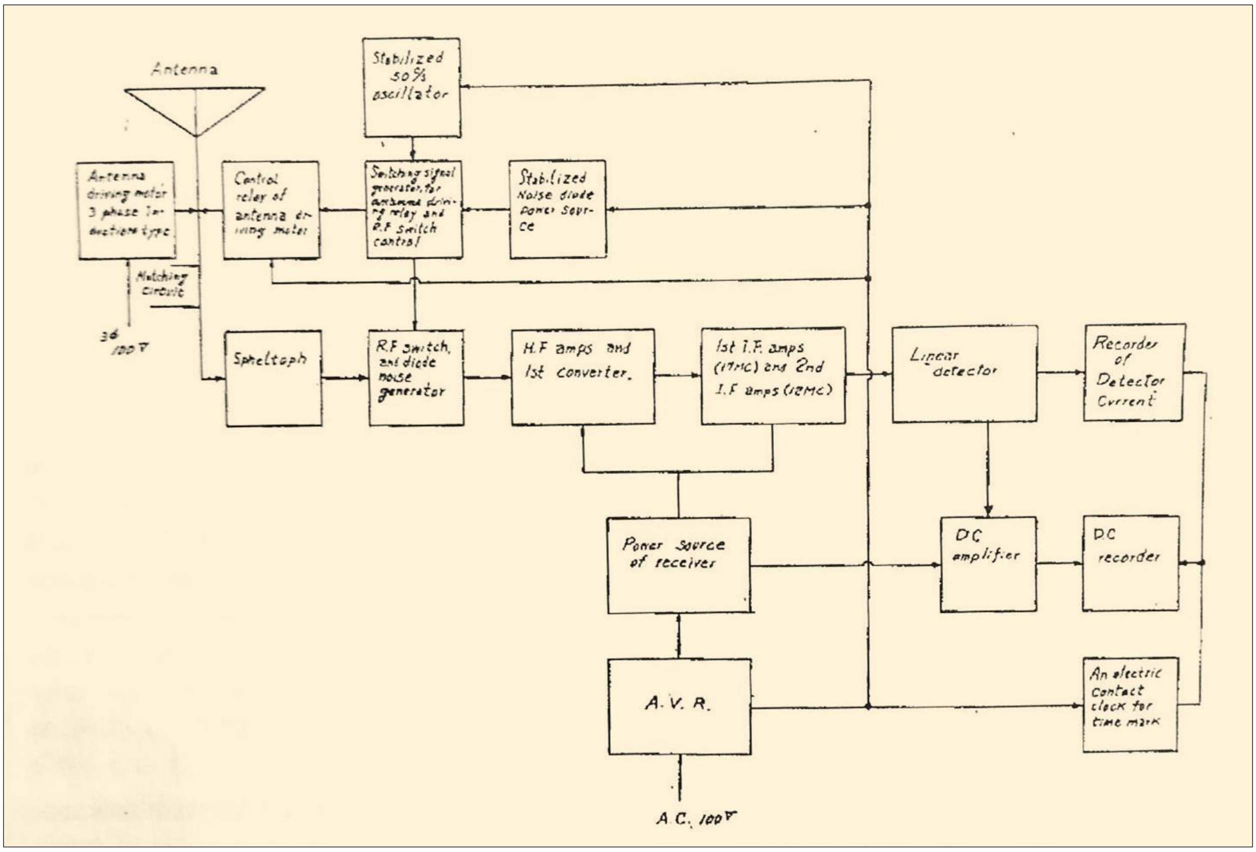

Figure 6: The receiver block diagram (after Takahashi et al., 1954: 46).

just before and just after the transit time of the Sun. (ibid.). Apparently, the original plan was to improve the resolution by increasing the number of antennas in the array, but this never happened.

Wakai (1988) also reports that in the lead-up to the International Geophysical Year (1957–1958) the various Japanese research groups involved in solar radio astronomy agreed to rationalize their observing frequencies:

> The purpose of the coordination was that due to a limited budget for science and technology in Japan, each organization made an effort to minimize the overlap in the observing frequency and make their contribution as unique as possible.

As a result, Hiraiso "… decided to place an emphasis on the metric wave band (200 MHz and 500 MHz), which is related to the occurrence of geomagnetic storms." (ibid.). Consequently,

> A 5-m parabolic antenna for 500 MHz … and a 10-m parabolic antenna for 200 MHz … were installed in 1961 and 1967, respectively. In 1968, observing capability at 100 MHz was added to the 10-m antenna, and polarization observations became possible during the IASY [1969–1971]. (ibid.).

The 5-m and 10-m parabolic antennas are shown in Figures 8 and 9 respectively.

2.4 Publications on Solar Radio Astronomy

Despite the growth in instrumentation at Hiraiso during 1952–1968, we have only been able to trace

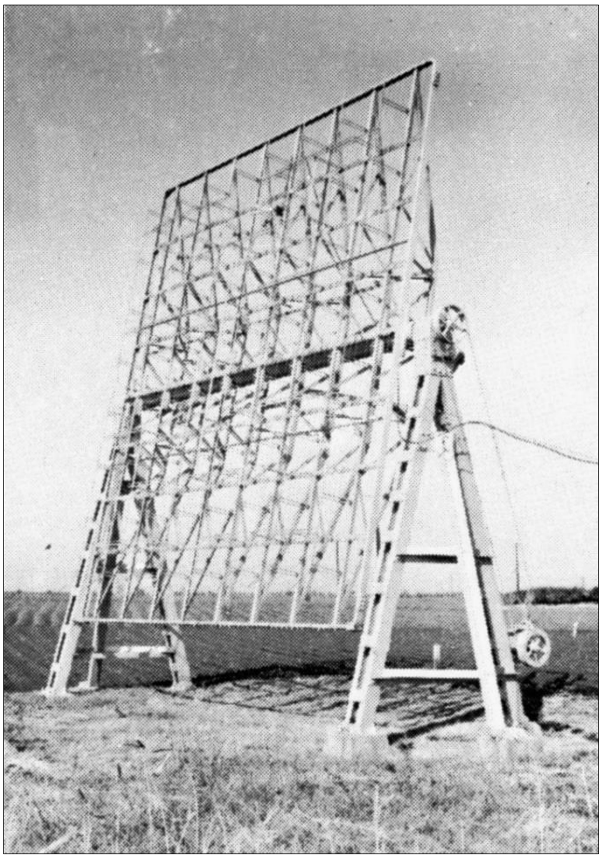

Figure 7: The 8 × 8 element broadside array that was installed at Hiraiso in 1956. This was part of a 2-element interferometer designed to pinpoint the location of 200 MHz radio sources in the corona (after Wakai, 1988).

Figure 8: The 5-m parabolic antenna installed at Hiraiso in 1961 and used at 500 MHz (after Wakai, 1988).

two research papers on solar radio astronomy that were written by Hiraiso staff. The first of these appeared in 1954 and the second in 1966.

Although the Hiraiso Radio Wave Observatory was basically set up to contribute solar data that could be used in providing shortwave radio disturbance warnings, between January and September 1954 Takahashi, Onoue and Kawamaki (1954) carried out a comparison of the 200 MHz flux densities observed at Hiraiso with those obtained at Mitaka (TAO), Nera (in the Netherlands) and Sydney (Australia). They found the daily mean flux densities were similar at the four different sites (e.g. see Figure 10) and that

> … increases in solar noise intensity for two or three days centring on September 11 and October 16, 1953, and March 15, 1954, were the common phenomena of the various places. However, the rates of increase and their absolute values differed much from one to another. (Takahashi et al., 1954: 52).

Figure 9: The 10-m parabolic antenna installed at Hiraiso in 1967 and used at 100 and 200 MHz (after Wakai, 1988).

By way of illustration, Takahashi et al. (ibid.) compared flux values for outbursts that were observed at Hiraiso and Nera on 15 July 1954—see Table 1, below.

The only other Hiraiso solar radio astronomy paper was co-authored by T. Goh and is titled " A collection of spectral diagrams of solar Type IV events" (Fokker et al., 1966). In this paper Goh assembles two different spectra for the Type IV events of 13 May 1960 and 26 September 1963 by combining single frequency observations made between 200 MHz and 9.4 GHz and 15 MHz and 9.5 GHz respectively. These are reproduced here in Figures 11 and 12. One of the points that Goh makes is that spectra can change markedly through the inclusion of more frequency 'data points', and he illustrates this in Figure 11 by comparing the spectrum assembled earlier by Takakura and Kai (1961) that lacks Hiraiso observations, with one that includes many more observations, including 200 MHz data from Hiraiso. As we have noted, by 1963 facilities had expanded at the Hiraiso Radio Wave Observatory, and so we see that Hiraiso observations made at 200 and 500 MHz and 9.5 GHz were used in assembling the 16 September 1963 spectrum. This Hiraiso focus on solar Type IV events is interesting in light of the afore-mentioned paper by Takakura and Kai (1961) that is discussed in Section 3.2 below.

Table 1: Flux densities of outbursts observed at Nera and Hiraiso on 15 July 1954.

Radio Observatory	Time (UT) h m	Duration m s	Flux Reading 10^{-22} W m^{-2} (c/s)$^{-1}$
Nera	07 16	1 51	81 – ~100
Hiraiso	07 16	~1 40	139

3 DISCUSSION

3.1 The Hiraiso Observations Viewed in Context

It is easy to be critical of the minimal astronomical research output of the Hiraiso radio telescopes, but it is important to see this in context because the Hiraiso Radio Wave Observatory was never set up to research the Sun *per se*.

By the early 1950s, radio astronomers in Australia had identified a slowly-varying component of solar radio emission that mimicked sunspot activity and three different types of energetic bursts, dubbed 'isolated bursts', outbursts' and 'noise storms' (see Orchiston et al., 2006). New technological advances then made it possible to investigate these in detail, which meant that it became increasingly more difficult to conduct cutting-edge solar radio astronomy by carrying out total power observations at a single frequency—as was occurring at Hiraiso.

Even if they were content to work at just a single frequency, solar radio astronomers wanted to investigate the positions in the corona and motions of the sources of the solar radio emission. They could do this by using a position interferometer or a solar grating array, both of which would

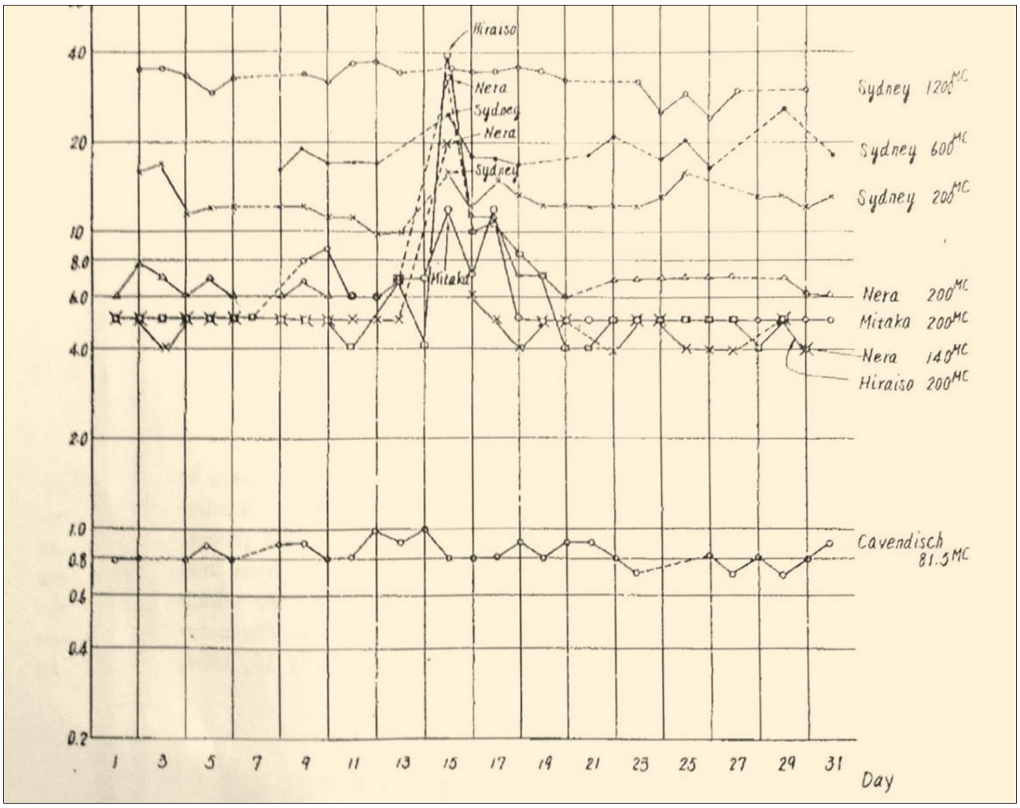

Figure 10: Daily variations in mean solar noise intensity at different sites and at different frequencies during March 1954 (adapted from Takahashi et al., 1954: 51).

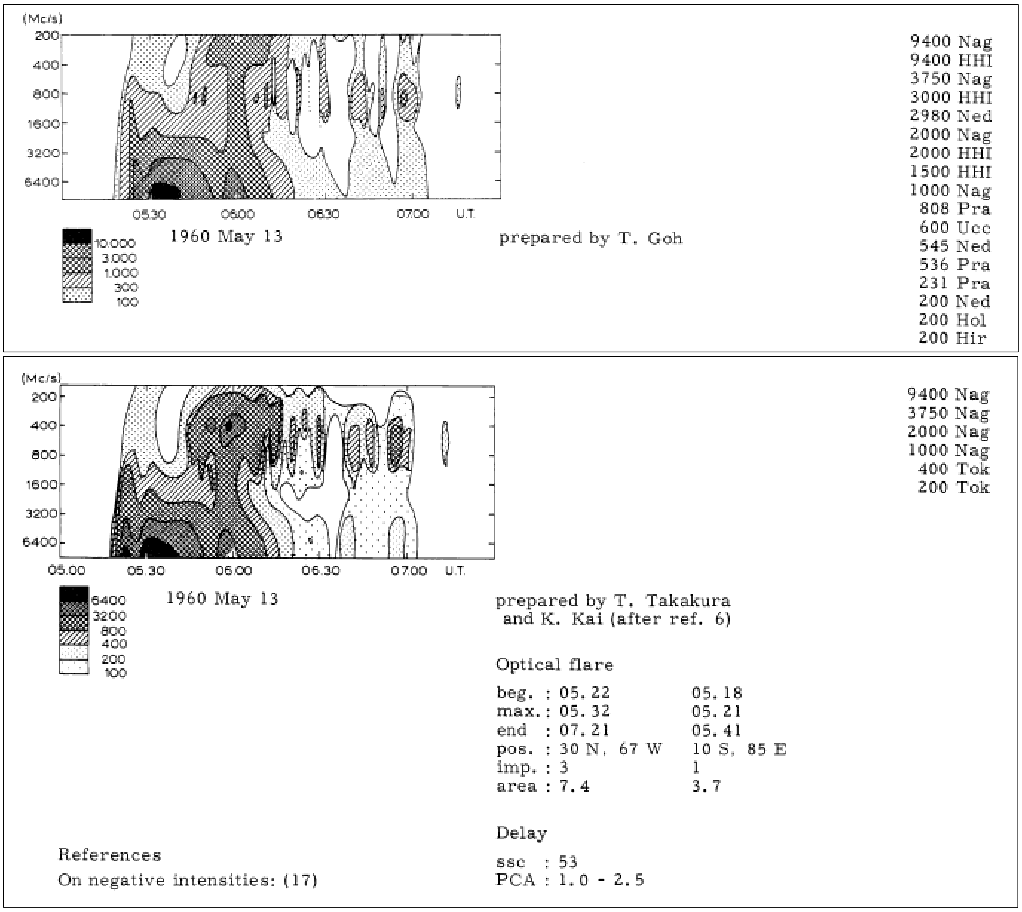

Figure 11: Spectra of the Type IV burst of 13 May 1960 constructed by T. Goh from the Hiraiso Radio Wave Observatory (top) and Takakura and Kai, 1961 (bottom), based on single frequency observations. The contributing radio observatories and associated frequencies are listed in the right-hand column, where '200 Hir' represents 200 MHz data from Hiraiso. Note the very different spectra (after Fokker et al., 1966: 316).

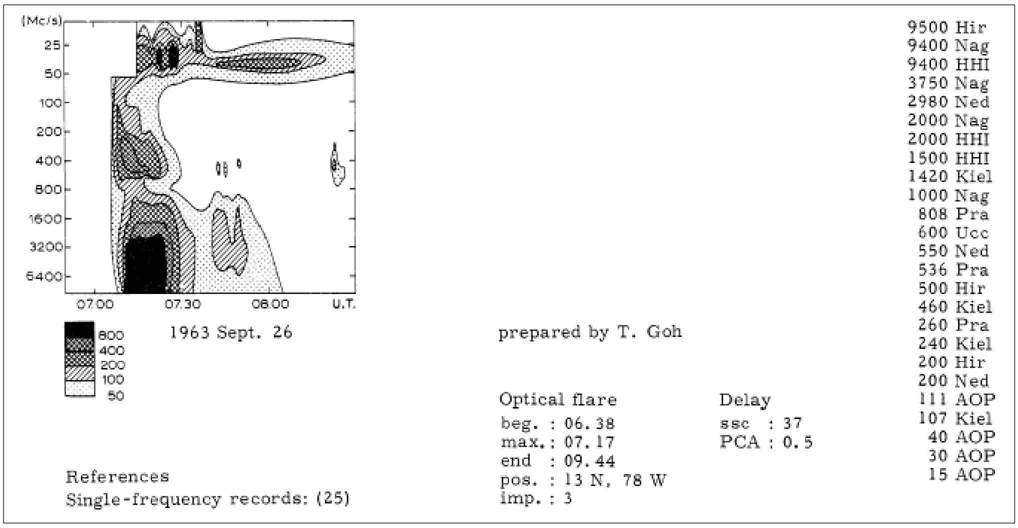

Figure 12: The spectrum of the Type IV burst of 26 September 1963 constructed by T. Goh from the Hiraiso Radio Wave Observatory (top), based on single frequency observations. The contributing radio observatories and associated frequencies are listed in the right-hand column, where we can see that Hiraiso ('Hir') contributed 200 and 500 MHz and 9.5 GHz data (after Fokker et al., 1966: 322).

later be used with considerable success by Japanese radio astronomers at Mitaka and Toyokawa, respectively (Ishiguro et al., 2012; Orchiston and Ishiguro, 2017).

The world's first position interferometer was perfected by Ruby Payne-Scott (1912–1981; Goss and McGee, 2009) and Alex Little (1925–1985; Mills, 1985), and was used very effectively at Potts Hill field station in Sydney (Australia)—e.g. see Payne-Scott and Little (1951; 1952). This was a swept-lobe interferometer that operated at 97.5 MHz (Little and Payne-Scott, 1951), and "… had good enough angular and time resolution to track the location of a burst from second to second." Sullivan, 2009: 300).

Meanwhile, a Potts Hill colleague of Payne-Scott and Little, Wilber N. (Chris) Christiansen (1913–2007; Frater et al.; 2017; Wendt et al., 2011) built the world's first solar grating array in 1951 (Wendt et al., 2008), although the Osaka radio astronomy group in Japan independently and concurrently came up with the same basic design (see Wendt et al., 2017)—though this was never built. The Sydney grating array (Christiansen, 1953; Christiansen and Warburton, 1953a) provided the east-west positions of the sources of 1.42 GHz radio emission in the solar corona (Christiansen and Warburton, 1953b).

But there was a serious problem in trying to interpret single frequency observations, even if several different radio telescopes tuned to different frequencies were used simultaneously. This problem first emerged in Sydney on 12 August 1946 when Lindsay McCready (1946b) reported that

> Two large sunspots have been on the sun lately. Almost continuous observations have been made from 22nd July to 12th August, dawn to sunset on 200, 75 and 60 Mc/s … Sometimes there appears to be a lag at lower frequencies in individual bursts.

This possibility of a time delay between burst onset at different frequencies

> … was confirmed in a remarkable fashion on 8 March 1947 when a very large bipolar sunspot appeared on the limb of the sun. Bolton, Payne-Scott and Stanley observed an intense 'outburst' at all three frequencies, which lasted for about 15 minutes. Although the 200 MHz receiver at Dover Heights was not working at the time, a record of the outburst was obtained at the Commonwealth Solar Observatory and was used in their analysis. The outburst showed a systematic delay of several minutes between its commencement at 200, 100 and 60 MHz … suggesting the possibility that the source moved outwards through the corona. (Stewart et al., 2010: 4).

Takakura (1954) also reported similar results from Japan.

The relationship between the various types of bursts and the mystery of the time-lag in burst onset at different frequencies would be solved when J. Paul Wild (1923–2008; Frater et al., 2017; Stewart et al., 2011b)—also from the Division of Radiophysics in Sydney—developed the world's first solar radio spectrograph at Penrith field station near Sydney in 1948 (Wild and McCready, 1950). This was attached to a rhombic aerial, and

> … solar radio emission was received by sweeping over the frequency range 70–130 MHz, and was displayed on a cathode ray tube where it was photographed. Successive photographs could be taken at intervals of one-third of a second, which allowed the radio astronomers to investigate the ways in which burst intensity changed with frequency and with time … (Orchiston and Slee, 2017: 540).

The results were outstanding, and after only a few months observing Wild was able to identify three spectrally-discrete types of solar bursts that he named Type I, Type II and Type III (see Wild and McCready, 1950; Wild, 1950a; 1950b; 1951). Later Wild and his Solar Group would establish a new field station at Dapto to the south of Sydney and install three radio spectrographs there that (initially) spanned the frequency range 40–240 MHz (for details, see Stewart et al., 2011a).

Once solar radio spectrographs became the norm worldwide (one was soon installed at Mitaka), single frequency radiometer observations became unpopular.

Even so, if the instrumentation at Hiraiso constrained the type of solar research that could be successfully carried out, were there still projects —other than the comparison of data with other radio observatories—that could have been pursued? Given that sunspot, geomagnetic, ionospheric and radio propagation data were all regularly supplied to Hiraiso, one particular project that immediately comes to mind would be to investigate the relationship between 200 MHz solar emission and (a) optical solar activity, and (b) the terrestrial effects of any bursts that were recorded. Although both topics had been the subject of earlier studies (e.g. see Allen, 1947; Hatanaka, 1950; McCready et al., 1947) there was still potential for a detailed investigation, especially of the terrestrial effects (as indeed was published by Davies in *Monthly Notices of the Royal Astronomical Society* in 1954—the very same year that the Hiraiso paper by Takahashi, Onoue and Kawamaki appeared).

3.2 Hiraiso and the Tokyo Astronomical Observatory Type IV Study

In 1957 the French solar radio astronomer André Boischot was the first to recognize the existence of a new type of non-storm, flare-related continuum emission at 169 MHz, which he dubbed Type IV emission (following Types I, II and III that were identified earlier by Paul Wild).

Soon afterwards, Tatsuo Takakura and Masaki Morimoto at TAO and Keizo Kai at Gakugei University in Tokyo began an intensive research program on the Type IV event, and during the 1960s published a succession of research papers in Japanese and international journals. Early in their studies, Takakura and Kai (1961) wanted to try and unravel the complex nature of the typical Type IV event, which seemed to exhibit several different components that were chronologically discrete and/or separated by frequency. They therefore analysed a sample of 14 Type IV events using observations that spanned from 67 MHz to 9.4 GHz and mainly derived from TAO and Nagoya University's Toyokawa Observatory. But (Takakura and Kai, 1961: 95) also mention that

> Recent records at 500 Mc and a few records at 200 Mc were available courtesy of Messrs. Hakura and Go [*sic*] of Hiraiso Radio Wave Observatory, Radio Research Laboratories.

But because TAO also contributed 200 MHz observations and the 500 MHz Hiraiso observations are not distinguished in the constructed spectra, we cannot assess the value of the Hiraiso data. However, Takakura and Kai do present a schematic diagram of a typical Type IV event, where 500 MHz observations inform on their A-B subgroup (see Figure 13).

3.3 'Anomalous Scintillations'

In the course of researching TAO solar observations, Atsushi Tsuchiya and Masaki Morimoto (1961) noted that at frequencies below I GHz often there were sudden changes in the level of solar emission, and at times it would even oscillate. They mentioned that various overseas solar radio astronomers had also noted this characteristic, but no-one had subjected it to detailed analysis. They therefore proposed to do so, and to start by naming this feature 'Anomalous Scintillations'.

For their analysis, Tsuchiya and Morimoto used TAO 201 MHz polarimeter and position interferometer data, and compared these to simultaneous 200 MHz observations supplied by Drs F. Yamashita and Yukio Hakura from Hiraiso. They found that

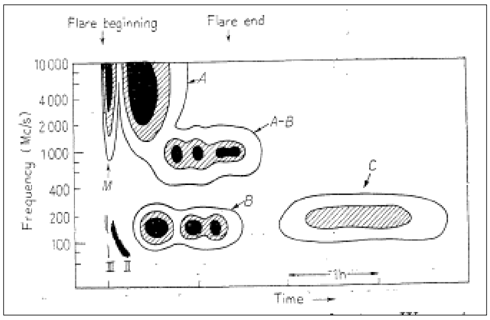

Figure 13: Schematic diagram of a typical Type IV event (after Takakura and Kai, 1961: 102).

> … no definite correlations between the records observed at [the] two stations can be found. Sometimes a scintillation appears at only one station, and no trace is found on the records of the other station. Even when the scintillations are observed at both stations, the time of occurrence, the duration and the shape of the scintillations are exceedingly different. (Tsuchiya and Morimoto, 1961: 305).

They concluded that anomalous scintillations originate in the Earth's troposphere.

What we find a little surprising about this paper is that there were only two authors, and both from TAO. Drs Yamashita and Hakura supplied critical observations that made the TAO-Hiraiso comparison possible, and they also provided ionospheric information that assisted Tsuchiya and Morimoto in isolating the region of the Earth's atmosphere responsible for this phenomenon. Although the TAO radio astronomers carefully defended their own 'research territory', they were happy to write joint papers with their Toyokawa colleagues when pooled data were required. We suspect that had a paper on the anomalous scintillation been co-authored by Tsuchiya, Morimoto, Yamashita and Hakura, this would have served as a catalyst to encourage the Hiraiso group to conduct more solar research and publish it.[6]

4 CONCLUDING REMARKS

From 1952 the Radio Research Laboratories of the Ministry of Posts and Telecommunications maintained a modest research facility at Hiraiso that could have been used for solar research at 200 MHz (and later at higher frequencies), but the focus was on ionospheric research with a special emphasis on shortwave disturbance warnings and only two radio astronomy papers were published (but see Sinno and Hakura, 1958). So the RRL made little contribution to international radio astronomy.

However, all this was to change. On 29 November 1965 the Canadian ionospheric research satellite Alouette II was launched, and it remained in orbit for the next decade. During this period the Hiraiso group analysed solar bursts recorded by the satellite and published several papers on this work (e.g. see Hakura et al., 1970)—but details of this interesting research lie outside the time-frame of our present study.

But even more importantly,

> The Communications Research Laboratory (CRL; formerly Radio Research Laboratories, RRL) started to develop a VLBI system independently in 1975. At that time, CRL was the only Japanese national organization having the necessary technologies such as space communications, radio propagation and standard for frequency and time. RRL completed the first VLBI system … in 1976 … (Kunimori et al., 1993: 65).

The CRL went on to become Japan's leading 'player' in VLBI, but with the initial focus on plate tectonics rather than astrophysics. Nonetheless, its future in radio astronomy was assured.

5 NOTES

1. Previous papers in this series began with a chronological overview (Ishiguro et al., 2012), followed by Shimoda's 1948 solar eclipse observations (Shimoda et al., 2013), early solar research at Tokyo Astronomical Observatory, Mitaka (Nakajima et al., 2014); early solar research in Osaka (Orchiston et al., 2016); and the solar grating array proposed by the Osaka group in 1950 (Wendt et al., 2017).
2. Note that as with the papers mentioned in Note 1, above, we were unable to trace any archival records pertaining to the pioneering endeavours at Hiraiso. But at least during our study of the early radio astronomical work at Tokyo Astronomical Observatory (Nakajima et al., 2014) we could draw on the reminiscences and personal records of radio astronomers and technicians who once worked at Mitaka, and data they provided complemented information derived from publications. Unfortunately, during the present study we could not trace any scientists or technicians who worked on the solar research carried out at Hiraiso and were able to assist us.
3. We use the Japan-language paper by Waikai (1988) extensively in this paper, and all quotations given here are based on our Japanese-to-English translations.
4. The town on Ohi was also known as Ōi, and on 1 October 2005 it merged with the city of Kamifukuoka to create the new city of Fujimino. This is now part of the greater Tokyo metropolitan area.
5. Curiously, Wakai (1988) claims that the Hiraiso radio telescope was used as a cliff interferometer:

   > This antenna was built on a plateau about 30 m above sea level facing the Pacific Ocean and was used as a cliff interferometer … at the time of sunrise.

   The cliff (or sea) interferometer technique, was extensively used by the early Australian radio astronomers (see Orchiston and Slee, 2017), and had many inherent problems (e.g. see Bolton and Slee, 1953). It is apparent from the detailed account by Takahashi et al. (1954) that the Hiraiso radio telescope did not function as a cliff interferometer, but was used to track the Sun from sunrise to sunset on a daily basis. This avoided the short-comings associated with cliff interferometers, and exploited the full potential of the equatorial mounting.
6. It is unfortunate that both Tsuchiya and Morimoto died before we began the Hiraiso phase of the Early Japanese Radio Astronomy Project, so we did not have a chance to ask them about the authorship of the 1961 research paper.

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