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Résumé de l'article

Après la Seconde guerre mondiale, les études sur les ondes radio extraterrestres se répandirent à l'échelle mondiale et se fractionnèrent rapidement en disciplines distinctes. La radio astronomie solaire sur des ondes de 10,7 cm débuta en 1946 à la station d'écoute radio du Conseil national de recherches du Canada. Cet article retrace les recherches dans ce domaine au cours des quinzek années suivantes effectuées à l'Observatoire de radio-astronomie de Goth-Hill, près d'Ottawa. Après 1962, ces travaux relèvent de l'Observatoire radio-astronomique Algonquin.

SOME RECOLLECTIONS OF THE RADIO AND ELECTRICAL ENGINEERING DIVISION OF THE NATIONAL RESEARCH COUNCIL OF CANADA, 1946-1977

Arthur E. Covington[1]

Abstract

Studies of extraterrestrial radio noise became world wide after WWII, and were rapidly separated into a number of disciplines. Solar radio astronomy, at a wavelength of 10.7 cm, was initiated in 1946 at the Radio Field Station of the National Research Council. Its development at the Goth Hill Radio Observatory outside Ottawa is outlined until 1962, when the work was transferred to the Algonquin Radio Observatory.

Résumé

Après la Seconde guerre mondiale, les études sur les ondes radio extraterrestres se répandirent à l'échelle mondiale et se fractionnèrent rapidement en disciplines distinctes. La radio astronomie solaire sur des ondes de 10,7 cm débuta en 1946 à la station d'écoute radio du Conseil national de recherches du Canada. Cet article retrace les recherches dans ce domaine au cours des quinzek années suivantes effectuées à l'Observatoire de radio-astronomie de Goth-Hill, près d'Ottawa. Après 1962, ces travaux relèvent de l'Observatoire radio-astronomique Algonquin.

Introduction

A radio hissing noise originating from outside the earth's atmosphere from the direction of our galactic centre was established by Karl G. Jansky in 1933 at the Bell Telephone Laboratories.[2] His discovery, and the subsequent work by Grote Reber, are well known and described.[3] Reber's entry into the new astronomy was made in 1937 at Wheaton, Illinois, by building a 32 ft diameter radio telescope

1 131 College St., Kingston, Ontario, K7L 4L7.

2 Karl G. Jansky, 'Directional Studies of Atmospherics at High Frequencies,' **Proc.IRE** 20 (1932), 1920.

and confirming Jansky's observations, using a high quality 160 MHz receiver in the winter of 1943/44; interestingly, both men made their discoveries during a sunspot minimum.[4] The intensity of cosmic noise was plotted as a contour map by Reber to show a number of peaks associated with bright areas in the Milky Way; this map can be regarded as the first chart of the radio sky. He also noted an extra radio source which was recognized as originating from the sun. The observation of solar radio noise by Reber was presented in the open literature, unlike the earlier observation of solar noise which had been discovered by J.S. Hey in the operation of the British radar network in 1942. Somewhat later that year, microwave solar emissions were also found by G.C. Southworth of Bell Telephone Laboratories using radar receivers, but publication was delayed.

While attending UBC in the fall of 1939, I can recall browsing through the journals to find an illustration of Reber's parabolic mirror, and wondering how lightning discharges could originate in space. The unique mirror was discussed with amateur astronomical friends without any intention of making observations, since I was working on a thesis on a simple electron microscope. After obtaining an MA degree (Maths and Physics) in 1940, I enrolled as a graduate student in physics at the University of California in Berkeley. Circumstances changed drastically with the bombing of Pearl Harbor, and early in 1942 a position was accepted in Ottawa in the Radio Branch of the National Research Council of Canada (NRC) without knowing the nature of the work I would be involved in. However, as a former wireless operator I had expectations using my experiences in one of the radio communication networks in what was a global war.

Radio Branch of the National Research Council, Ottawa

The trans-continental train from Vancouver arrived in Ottawa on 25 June 1942 and I reported for work at the Radio Branch of NRC on Sussex Drive. Two days later, after various formalities had been completed, I was driven south of Ottawa to the Radio Field Station (RFS), where I would work until the fall of 1953. At a time when private transportation was limited, this travel arrangement was a service provided on a daily basis by volunteer Red Cross Drivers using NRC station wagons. Don McKinley met me at the Guard House and we proceeded to his office for discussions of problems. He was then Head of the Airforce Section, later

3 W.T. Sullivan III, editor, **The Early Years of Radio Astronomy** (Cambridge, 1984), 2-42.

4 Grote Reber, 'Cosmic Static,' **Ap.J.** 100 (1944), 279.

Director of the Radio and Electrical Engineering Division (REED), and still later Vice President of Research for NRC. He and Peter Millman became well known for their radar observations of meteors. Since I had no experience with standing wave measurements, he assigned me to Ken MacKay, to learn while helping him. Adjacent to the station, there was a small wartime housing project popularly called 'Dog Patch', to relieve living accommodations in crowded wartime Ottawa and to compensate for the inconvenience of the isolation of the field station for some of the staff. Others had to live in Ottawa and commute to and from the site. Gasoline rationing was in effect. Gordon Retallack, classmate and friend from UBC and Berkeley, had taken an earlier position in the Radio Branch, and it was a pleasure to see him again. His experience at the RFS softened the strangeness of a new environment for me.

Engineering Design of Radar Sets at the RFS

A radar set uses an antenna, often the paraboloid reflector, to transmit pulses in narrow beams to distant objects. Conversely it receives the reflected radio waves, greatly reduced in signal strength, from certain directions. The inclusion of a transmit-receive tube (TR box) in the transmission line between receiver and transmitter enables the same antenna to be used for dual functions. The German radio astronomer, Hackenberg, recalled (according to A.C.B. Lovell) that even though he knew about the closely guarded magnetron, the functioning of an 'empty' glass tube found in the transmission line of a grounded plane was a mystery.[5] Meteor radar astronomy makes full use of the components of the radar set, while radio astronomy uses only the antenna and the receiver to detect the natural emissions of objects. Special instruments such as the cathode ray tube, loud speaker, and recording meter, are used in both applications to present the data, as shown in the schematic diagram of figure 1.

The receiver is of the superheterodyne type to convert the high frequency of the signal to a lower frequency where most of the amplification occurs. As in the early days of radio, a tungsten 'cat's whisker' was critically adjusted to provide maximum conversion from the signal's high frequency to an intermediate one of 30 MHz, and then potted with wax in a small cylinder. The performance of a radar set, or of a radio telescope, requires that many components meet their specifications, and that the overall operation be undertaken with established standards. In the early days at the RFS it was customary to regard the echo from

5 Bernard Lovell, 'Blumlein Crash,' New Scientist (8 December 1977), 659.

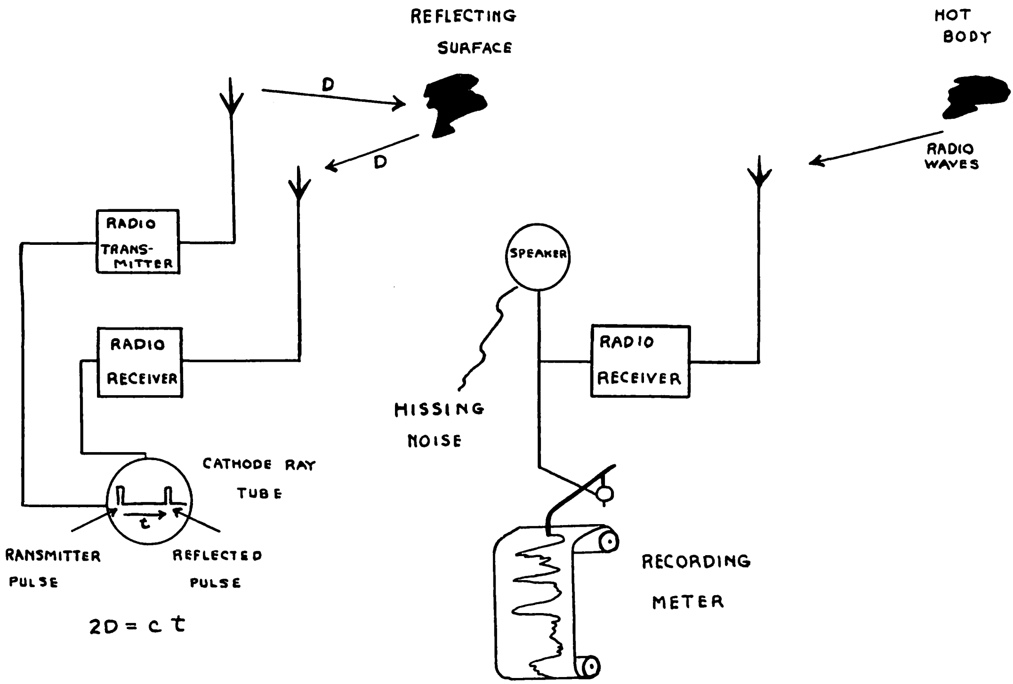

Figure 1. Components Used in Radar Set and Radio Telescope. Left: Pulse transmitter, separate transmitter and receiver antennas, radio receiver and oscilloscope for determining time separation of pulses for callibration of distance of object. Right: Loud speaker, recording meter, receiver and radio telescope for capturing natural radio emissions from a distant source.

the Peace Tower in Ottawa as a standard, in order to evaluate design changes. However, specialized instruments and procedures were soon developed to measure the power output of the magnetron, and the gain and equivalent temperature of the crystals used in the receiver. Thus at the end of the war, radio astronomy would readily have the use of the best technology of the times.

B.G. Ballard, President of NRC, 1962 - 1966

In 1930, B.G. Ballard was appointed Assistant Research Physicist, although a graduate in electrical engineering from Queen's University, with experience at Westinghouse Electric.[6] He was assigned various tasks, including that of Secretary for the new Associate Committee on Radio Research, established on 12 September 1930, under Dean A.S. Eve of McGill. During the war, he was engaged in degaussing vessels in the Halifax area, and had returned to a much larger laboratory in Ottawa. On 15 December 1945, Ballard was appointed Officer-in-Charge of the combined Division of Electrical Engineering and the Radio Branch. One of his most urgent tasks was to bring the widely scattered staff members together in one building. This was not achieved until 1954, when the REED was established in a modern distinctive brick building, M-50, in a laboratory on the Montreal Road grounds of NRC. By 1949, Ballard was so impressed with the post-war scientific activities that he felt the necessity for a formal Canadian National Committee to subscribe for membership in the Union Radio Scientifique Internationale (URSI). A lecture on Radio Astronomy, jointly sponsored by the local Engineering and Astronomical societies in Ottawa was given by the Dutch radio astronomer, H.C. van de Hulst. He was thanked by Ballard.[7]

The URSI committee was constituted on 21 September 1951 with D.W.R. McKinley as chairman, J.C.M. Scott of the Canadian Radio Wave Propagation Committee (CRWPC) as secretary, and R.E. Williamson, Professor of Astronomy[8] at the University of Toronto, as Chairman of Commission 5 on Radio Astronomy – with A.E. Covington as the only member. In October, 1953, a joint Canadian-USA URSI meeting for the presentation of fifty-eight papers was held

6 W.E.K. Middleton, **Physics at NRC of Canada,1929- 1952** (Waterloo, Ontario 1979), 23-30.

7 Meetings of the Society, **J.Roy.Astron.Soc.Can.** 46 (1952), 125.

8 A.E. Covington, 'Ralph E. Williamson--an Appreciation,' **J.Roy.Astron.Soc.Can.** 77 (1983), 97.

in Ottawa. In August of 1954, eight Canadian delegates attended the General Assembly of URSI in The Hague.

One transition to a new program quickly became visible in July, 1946, when a radio telescope was constructed and mounted on the roof of Building #2 at the Radio Field Station, as illustrated in a Reber Symposium paper.[9] At the beginning of the program, however, very weak signals of celestial origin were often masked by signals from nearby radar sets and from the Ottawa Airport, to the extent that in September of 1948, the continuation of the program required moving the equipment to an interference free locality on the Goth farm at South Gloucester, some five miles away from the RFS. This site had been located the previous fall by W.J. Henderson and Covington, so that construction of a building could start in the spring of 1948. The site gradually became known as the Goth Hill Radio Observatory (GHRO), and was dismantled in 1971. Figure 2 (upper and lower) show the observatory in 1950.

Calibration of a Radio Telescope

Figure 3 is a photograph of a small 10.7 cm dipole and parasitic reflector dipole, placed with their mid point at the focus of the four foot reflector used for a radio telescope. In this photograph, taken at the GHRO in 1965, a Radio Black Box is about to be closed, thereby placing the simple antenna unit in the thermal radio emission inside the box. The 'blackness' is formed from a resistive liner, a carbon coated cloth, spaced one quarter wavelength from the sides of the metal box. The recorded signal corresponds to the temperature of the box as determined by a thermometer.[10] A second level is required for a calibration of the radiometer, and is obtained by removing the box and pointing the beam toward the zenith, which provides a temperature shown to be close to absolute zero. A series of measurements made by W.J. Medd and Covington provided a value of 5.5 degrees K.[11] These two levels provide the means to establish a temperature scale for an output recording meter when the radio telescope is pointed toward an ob-

9 Covington, 'Origins of Radio Astronomy in Canada,' **J.Roy.Astron.Soc.Can.** 82:4 (August 1988), 165-78.

10 A connection between the fluctuating noise voltage and temperature of the resistance is given by Nyquist's Theorem.

11 W.J. Medd and Covington, 'Discussion of 10.7-cm Solar Radio Flux Measurements and an Estimation of the Accuracy of Observations,' **Proc.IRE** 46 (January 1958/Radio Astronomy issue), 112-118.

Figure 2. Goth Hill Radio Observatory, South Gloucester, Ontario (south of Ottawa), Exterior and Interior Views September 1950. Upper, from left to right: Polar mounted, four foot parabolic reflector on platform, microwave horn antenna mounted on MEW tower and 200 MHz yagi antenna mounted on a steerable ground screen. Lower, inside building: Dicke type radiometer mounted on a shelf continuously switches a superheterodyne receiver between a waveguide line from the radio telescope and a resistor at ambient. The modulation signal is amplified and recorded.

ject. In the case of a six foot dish, such as the one used at the Algonquin Radio Observatory (until recently) and another at the Dominion Radio Astrophysical Observatory, when pointing toward the sun there is an equivalent temperature of about 300 degrees K at sunspot minimum, and up to a few thousand degrees at sunspot maximum. The total solar disc flux is obtained, since the angular width of the sun is much smaller than the antenna beamwidth. The two widely separated radio telescopes extend the hours of observation for solar bursts. Figure 3 records a re-enactment of a daily calibration of the four foot reflector used in 1946 during a press interview with Richard Jackson.[12]

A New Astronomy

The record of monitoring the total 10.7 cm radio wave emission from the sun during the partial eclipse of 23 November 1946, established that a high temperature of 1.5 million degrees K was associated with a large sunspot, and that the one half degree solar disc was considerably cooler, about 50,000 degrees.[13] Such high temperatures had been indicated by the presence of certain spectral lines in the solar corona, and in the bright light from condensations of ionized gases seen near sunspots on the solar limb. The radio picture is in contrast to the optical picture which shows a cool spot on a hotter background (6000 degrees).

Visit of Edward V. Appleton

Two or three days after the solar eclipse of 23 November, the Radio Field Station was visited by E.V. (later Sir Edward) Appleton on his return journey to England from Boston. On 19 November, he had presented the inaugural Memorial Lecture for the Arthur D. Little Institute entitled Science, Government and Industry.[14] His allocated time for the visit at the Radio Field Station was so short that

12 The release appeared in the Ottawa **Journal**, 30 December 1946, with the headline 'RESEARCH COUNCIL NOW BREAKS WAR SECRETS HIDDEN IN METCALFE ROAD LABORATORIES OVER THE PAST FEW YEARS.' The article also has photographs of F.M. Hanna with an NRC development for guiding TCA planes, and G.A. Miller pointing to one of the many radar antennas at the RFS.

13 Covington, 'Micro-Wave Solar Noise Observations During the Partial Eclipse of November 23, 1946,' **Nature** 159 (22 March 1947), 405.

14 His experiments in 1925 had established the basis of ionospheric studies, and in 1932 he had

a special stairway was erected to bypass the security fence. Under no circumstance would more than two minutes be assigned to me to describe the radio astronomy work as he passed through the microwave section. However, when the record of the variation of solar flux during the eclipse was shown, he enthusiastically wanted to know all the details, and I soon realized that more than the allotted time had passed. Even though the Dominion Observatory had been fortunate to obtain excellent photographs of the event, they were being processed and little more could be said than a large sunspot on the solar disc was occulted when the radio emission was rapidly changing. Appleton had just written a letter to Nature[15] about the polarization of solar emissions from sunspots and how the mathematical propagation of radio waves could be applied to the emissions in the solar atmosphere. By now, I realized that too much time had been taken; ultimately President C.J. Mackenzie had to mention that there were other projects to visit, and the small party moved on. Several weeks later, a copy of another letter to *Nature*[16] was received, in which Appleton closes with one of the earliest uses of the word 'radio telescope.' I cannot recall whether or not he used the word in conversation, but he certainly conveyed the idea that with large microwave antennas and the sharp beams, one could look inside a radio-sun-spot. Our brief conversation was informative, I think, for both of us. Eleven years later, in 1957 at the URSI Boulder, Colorado General Assembly, he recognized me once more for a few minutes of conversation on the college campus.

However, to return to Ottawa at the end of the week, Appleton gave a series of talks on scientific developments which had occurred in the United Kingdom during the war: radio propagation of a global nature, metric solar noise observations, and meteor observations. He referred in general terms to the problems of rewarding the back room scientist upon whom so much depends, but presented no clear answers. Frank T. Davies, from the Radio Propagation Laboratory (RPL) of DRB, thanked Appleton and commented on the importance of the ionosphere work in Canada and that it had been inspired by Appleton. Peter Millman told me in reply to my query many years later, that Appleton's lecture had made him realize that radar studies of meteors should be undertaken

undertaken ionospheric soundings in Norway during a total eclipse of the ionosphere. He was president of URSI 1932-54 and wartime secretary of DSIR in England.

15 E.V. Appleton and J.S. Hey, 'Circular Polarization of Radio Noise,' **Nature** 158 (7 September 1946), 339.

16 E.V. Appleton, 'Departure of Long-Wave Solar Radiation from Black-Body-Intensity,' **Nature** 156 (3 November 1946), 534.

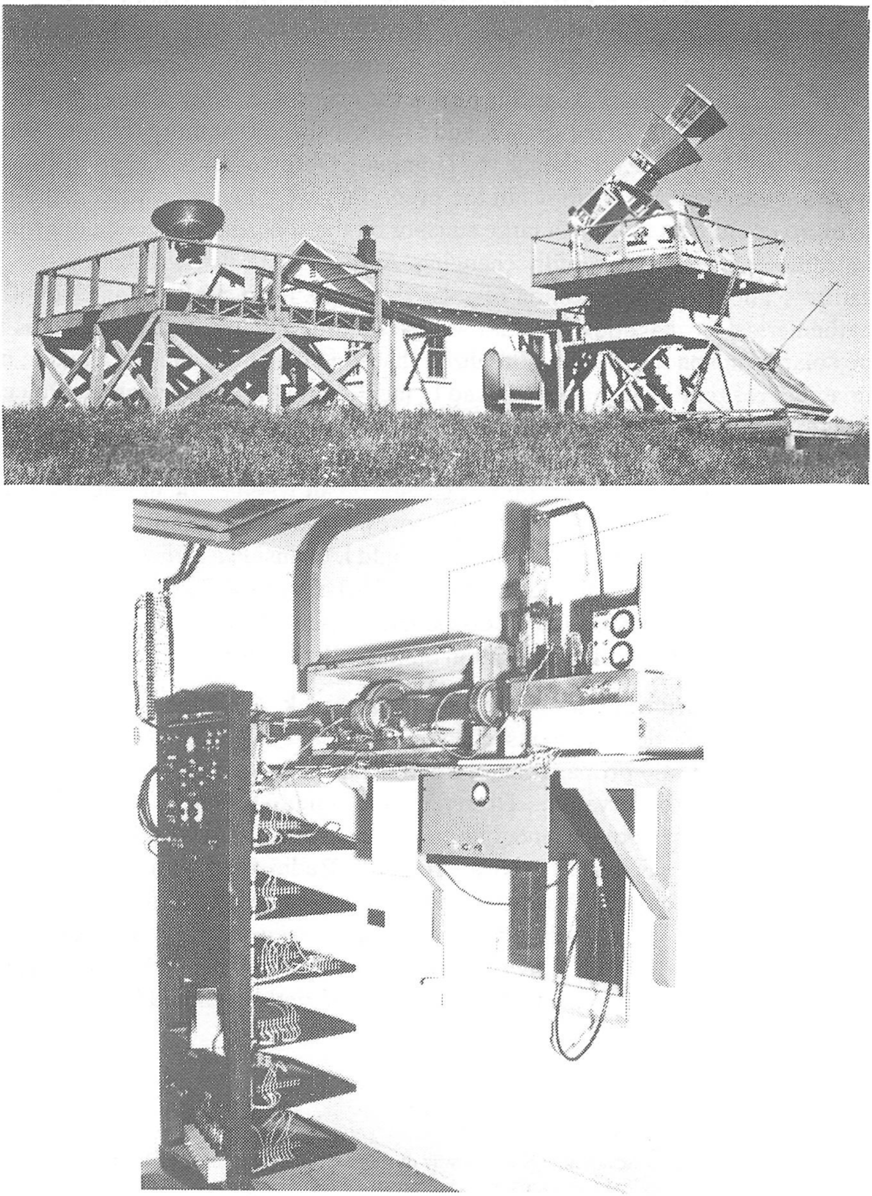

Figure 3. Calibration of Radio Telescope and Radiometer. This is done by placing a cubical Radio Black Box on the parabolic reflector so that the dipole unit at the focus is at the centre of the box. Cover about to be closed. Carbon cloth inside box provides known thermal radio emissions.

somewhere in Canada. Consequently, he wrote a letter to C.S. Beals proposing a cooperative radio and optical program for studying meteors.

Daily Solar Noise Observations

The discovery of two components of the total disc radio flux, later designated as the slowly varying and the quiet sun components, was made unexpectedly with the four ft diameter radio telescope at the Radio Field station of the National Research Council just south of Ottawa. In February, 1947, daily monitoring of the sun was started with the view of studying how well the total radio flux would correlate with the number or area of sunspots. Day to day variations in intensity were recorded with occasional enhancements of the total radio flux lasting tens of minutes. A third component, the microwave solar noise burst, had been found.[17] The onset was soon found to be closely related to the sudden interruption of radio transmissions of distant radio stations, known as Sudden Ionospheric Disturbance (SID). From studies made a few years earlier by Dellinger and others,[18] one knew that a solar flare had occurred, with accompanying emission of intense uv and x-ray emissions and sometimes solar particles. The direct cause of these daylight interruptions arises from the absorption of the short wavelength emissions in the earth's upper atmosphere at the time of the flare, as well as geomagnetic storms and aurora from the slower particles.

1947 Presentation of Observations to Joint Meeting of URSI American Section and Institute of Radio Engineers

When the American section of URSI and the IRE announced the resumption of their joint meetings in Washington, DC, for 5-7 May 1947, G.A. Miller suggested that a paper on solar radio waves should be submitted. Daily observations had been made for three months, and had shown that microwave bursts occurred infrequently, and that the daily level changed slowly. The material was outlined under the title, 'Paper No.45 – Microwave Solar Noise Observations at Ottawa, Canada.' Grote Reber followed with 'Paper No.46 – Solar and Cosmic Radio

17 The first discoveries were made in the spring of 1947 and reported to the URSI-IRE October meeting in Washington as paper #10 after 14 events had been recorded and analysed.

18 J.H. Dellinger, 'Sudden Disturbances of the Ionosphere,' Proc.IRE 25 (October 1937), 1253-90.

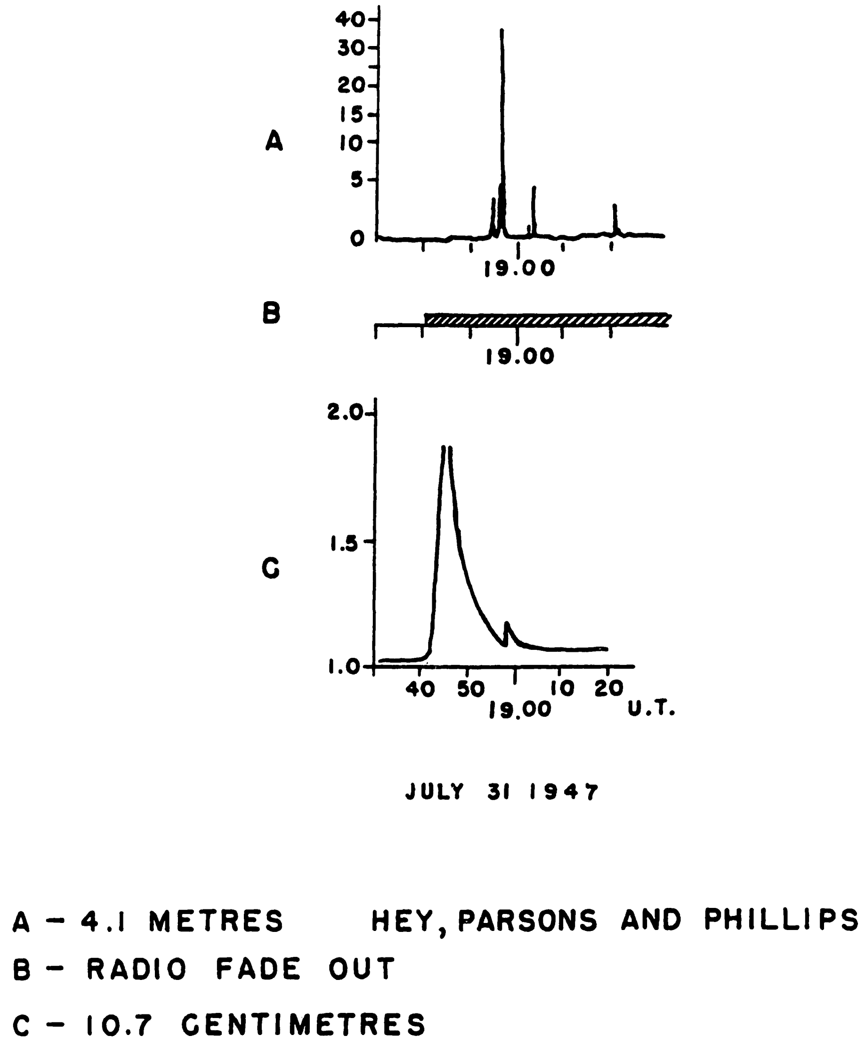

Figure 4. Associated Phenomena Reported with Solar Flare of 31 July 1947. Curve A: Solar noise enhancement at 5.1 metre wavelength; Curve B: Sudden interruption of radio sky wave transmission shown by a black bar (curves A and B adapted from J.S. Hey et al., 'Solar Radio Emission.'); Curve C: Solar noise enhancement at 10.7 centimetre wavelength. (Profile adapted from HIA-NRC Records and REED Report ERA-192, 1950).

Waves', and then 'Paper No.47 – Cosmic Noise' was presented by Jack W Herbstreet, NBS, Washington DC. These were the only papers devoted to radio astronomy, along with 95 papers dealing with other radio problems. Afterward, I had the opportunity to meet Karl Jansky, who had discovered radio noise of extraterrestial origin in 1933, and Grote Reber, who had constructed the first radio telescope. A.H. Shapley, V.J. Lincoln, and others from various institutions were also present. The discussions were inevitably about the approaching new era in radio science.

At the fall 1947 URSI-IRE meeting, my second paper, #10, entitled 'Solar Noise Bursts, 10.7 Centimeters' was presented. Radio astronomers from the Naval Research Laboratories (NRL), John P. Hagen, F. Haddock, E.F. MacLean and others had returned from the spring eclipse expedition. J.F. Denisse, then visiting scientist from France at the National Bureau of Standards, (NBS), was very interested in high energy theoretical ideas which would be needed to explain the microwave observations. 'Tables of Daily Intensity and Outstanding Disturbances of 10.7-cm Solar Radiation, 1946-49', A.E. Covington, Ottawa, 1950, is the early catalogue of solar noise observations, and lists the event of 14 March 1947 as the first. It is small and has no clear associations with other events. A better example is the burst of 31 July 1947 starting at 1841 UT. It was also simultaneously observed and reported[19] at a wavelength of 5.1 metres as well as with a flare and its associated disturbances (Figure 4). After returning to Ottawa, there was an invitation to submit a formal article to the Proceedings of the IRE. The second presentation was essentially a report of a continuing program which was seen even at that early time to have the potential of providing an important measure of solar activity. In the background were recollections of the solar observations which had been made in the mid 1930s and the realization that a satisfactory proof would require observations over at least one sunspot cycle. Consequently a single paper with 9 months of data was submitted.[20] Sufficient daily levels of solar flux had accumulated to show graphically [21] that a high correlation existed between the American relative sunspot number and the 10.7 cm total solar flux. In that paper, two radio bursts and SIDs were reproduced.

The first radio flux minimum occurred in synchronism with the sunspot cycle in 1954 when the slowly varying component became vanishingly small, and the opti-

19 J.S. Hey, S.J. Parsons, and J.W. Phillips, 'Some Characteristics of Solar Radio Emissions,' **Monthly Notices of Roy.Astron.Soc.** 108 (1948), 354.

20 Covington, 'Solar Noise Observations on 10.7 cm,' **Proc.IRE** 36:4 (April 1948), 454-7.

21 Ibid. fig 1.

cal observations showed a spotless sun with a mottled appearance. For many days there was only the steady emission from the quiet sun. Later, when selected strip scans from the multi-element interferometer at the Algonquin Radio Observatory (ARO) were analyzed in conjunction with optical data, support was found for the suggestion of a small increase of the quiet sun solar flux at other times than radio spot minimum.[22]

W.R. Piggott of the Radio Research Station, Slough, UK, made two extensive visits to the Ottawa scientific community in the spring and fall of 1947. It was with his encouragement that a standard ionosphere sounder was modified by Bill Torrington for monitoring a fixed frequency at the RFS to observe the onset of a SID. The program did not become fully operational since Torrington became employed elsewhere, and there was a lack of staff. The building of a new automatic frequency swept sounder needed for RPL was also delayed, but other arrangements were made for its completion by the Marconi Company in Montreal. Once more, flare data was inferred from the occurrence of a SID. Monitoring of the WWV transmissions was resumed, and lists of events became available in 'Solar Geophysical Data', published by the Central Radio Propagation Laboratory of the National Bureau of Standards, Washington DC.

A study[23] was prepared before cataloguing the solar radio data. This basic data had been requested by both the International Astronomical Union (IAU) and the Union Radio Scientific International (URSI) for inclusion in the Quarterly Bulletin of Solar Activity, beginning with the first quarter of 1949. The materials prepared upon a monthly basis had been sent, and on 16 December 1949 a letter from Max Waldmeier of the Swiss Federal Observatory informed me that the data had been received.[24] He wrote one of the earliest general books on Radio Astronomy in 1954, with several references to the Canadian program.[25] The reporting of the data to the World Day Center in Boulder, Colorado for global dissemination for the IGY program was recommended by Commission 5 of URSI in 1954 at the General Assembly held at The Hague.[26] It was reaffirmed at the 1957

22 Covington, 'Coronal X-ray Holes and the Quiet Radio Sun at 2800 MHz,' **Solar Physics** 54 (1977), 393-402.

23 Covington, 'Some characteristics of 10.7 cm Solar Radio Emission,' **J.Roy.Astron.Soc.Can.** 45:1 (1951) Part I, 15-22 and 45:2 (1951 Part II, 49- 61).

24 M. Waldmeier, to A.E. Covington, 16 December 1949, REED file 45-2-136.

25 Max Waldmeier, **Radiowellen aus dem Weltraum** (Zurich, 1954). In Special Collections (Riche-Covington Collection), Douglas Library, Queens Univ., Kingston, Ont.

26 URSI, 'On Basic Solar Index,' **Proceedings of the XIth General Assembly**, 10:5 (the Hague,

General Assembly meeting in Boulder, Colorado when Sydney Chapman was chairman. The 10.7 cm daily solar flux was included in the 'URSIgram' and in 1971 became part of the Geophysical Data announcement over Radio station WWV every hour, at 18 minutes after the hour.

Comparative Studies of Solar Noise Bursts and H Alpha Flares

In 1948, Gladys A. Young, later Mrs Harvey, joined the group to manage the taking of records and their publication as a monthly report of the REED. From time to time a collection of these and related materials was bound and deposited in the NRC Library under call QB 475 N27. The observations of events have continued to be made ever since, with very little interruption. Helen Dodson Prince and Ruth Hedeman of the McMath-Hulbert Observatory in Pontiac, Michigan undertook a detailed statistical study of the occurrence of optical flares and the 200 mhz bursts observed at Cornell University.[27] They then initiated a similar co-operative study with the REED to establish the relationship between the 10.7 cm bursts which originate in a lower level in the solar atmosphere, and the optical flare. The study[28] is based upon previously established burst characteristics,[29] using the same format as the Cornell study to examine a large number of events.

Dodson and Hedeman visited the RFS in February, 1953, with the optical material, and upon arrival were most anxious to examine the profile of the burst of 19 May 1951. The spectroheliogram of the associated flare had shown the ejection of a dark cloud of helium over a bright plage. What would the radio profile show? The record was quickly found, and after the sudden increase of flux was noted, there was an abnormally low post burst level, which had prompted me to examine the radiometer and to initiate a second calibration. This event established that 10 cm radiation can, on occasion, be absorbed.[30] Until then, several hundred enhancements had been recorded in emission, but none in absorption.

September, 1954), 110.

27 H.W. Dodson, E.R. Hedeman, and L. Owren, Ap.J. 118 (1953), 169.

28 Dodson, Hedeman, and Covington, 'Solar Flares and Associated 2800 Mc/sec (10.7 cm) Radiation,' Ap.J. 119:3 (May 1954), 541-63.

29 Covington, 'Some Characteristics of 10.7-Centimeter Solar Noise,' Laboratories of the National Research Council of Canada, Report ERB 242 (April 1950).

30 Covington and Dodson, 'Absorption of 10.7- centimetre Solar Radiation during Flare of May 19, 1951,' J.Roy.Astron.Soc.Can. 47:5 (September 1953), 207-11.

The study showed that there is a 10 cm radio event only when a flare or sub flare is in progress, and that the commencements of burst and flare coincide within a few minutes.

Canadian Radio Wave Propogation Committee

The transmission of short radio waves over great distances may change irregularly from day to day in addition to the slower eleven-year sunspot variation. The coordination of vital radio communications across the North Atlantic was undertaken as early as 1941 by an inter-service government committee, later the Canadian Radio Wave Propogation Committee (CRWPC).[31] The variations in solar ionizing emissions during the total solar eclipse of 9 July 1945 were studied by expeditions to the path of totality in the Canadian prairies. Unfortunately a major expedition with optical equipment was clouded out. Nevertheless, Alfred E. Johns recorded the apparatus setup.[32] Donald H. Menzel, USNR (Harvard College) was the leader, accompanied by C.S. Beals, Dominion Astrophysical Observatory and Gerhard Herzberg, then of the University of Saskatchewan and eleven others. The site was selected by Squadron Leader John Abrams, who later became interested in the history of science. In early 1947, Beals was appointed Dominion Astronomer; in 1949, Menzel became a member of the USA National Committee of URSI.

The CRWPC also supported other programs, such as the radio propogation studies at the Suffield Range in Alberta under G.A. Miller. After the war, in 1946, he became Section head of the Microwave Section in the REED and was responsible for managing a number of programs, including radio astronomy. The early funding for radio astronomy was minimal, since there was naturally little status for a very young discipline. After Miller had attended a meeting of the CRWPC, probably in 1948, he reported to me that Beals had wanted to start a program in radio astronomy and that F.T. Davies had insisted that Covington continue his work where he is for a while, until the new field had become defined and suitably trained individuals were available. In the 1983 study, Phillipson records that the Radio Propogation Committee was dissolved after DRB created its Radio Physics Laboratory (RPL) and authorized NRC to take up radio as-

31 D.J.C. Phillipson, **Associate Committees of the National Research Council of Canada, 1917-1975** (Ottawa, 1983), 26.

32 Alfred E. Johns, 'The Total Solar Eclipse of 1945,' **J. Roy. Astron. Soc. Can.** 40:3 (March 1946), 81-99.

tronomy. It was only in the spring of 1956 that Beals was able to reconsider a radio astronomy program which ultimately resulted in the establishment of the Dominion Radio Astrophysical Observatory in 1960 near Penticton, BC.

The operation of the solar patrol was simple and not excessively time consuming. Other experiments were undertaken, such as the construction of a quarter wave plate to fit over the four foot reflector. The observations showed that there were small variations in circularly polarized flux as the sunspot configurations changed. This was regarded as the imprint of the action of the changing orientation of the spots and the radio emission from electrons spiralling around magnetic fields with high velocity in the solar atmosphere, as in a cyclotron.

Goth Hill Radio Observatory

The 81st meeting of the AAS was held at the Dominion Observatory in Ottawa from 19-23 June 1949. Fifty four papers were presented, including six on radio astronomy and one on radar astronomy. Medd and I presented profiles of the same event observed simultaneously at 2800 MHz and at 200 MHz. At this time there were very few profiles of microwave events to compare with the metric wavelength events (Figure 4). The differences in starting times of the two bursts, measured from the onset of the flare, were interpreted using the model of an outward moving cloud exciting lower and lower frequencies. Ultimately, for the major flares at least, there is a likelihood of solar particles striking the earth's atmosphere to give rise to auroral displays. The determination of the velocity of ejection from the sun would soon benefit by the development of a frequency swept spectrometer by Paul Wild and others in Australia.

Several radio astronomers from the meeting visited the Goth Hill Radio Observatory and discussed critically three years of the 10.7 cm solar patrol observations. The instrumentation for the solar monitoring was stable, in large measure due to the brass transmission lines and components, designed for the high power of radar sets. The 200 MHz observations were made to obtain simultaneous profiles of bursts for comparison with the event at 2800 MHz, and for a while these bursts were compared with those taken at Cornell. Local interference was evident and would increase in time. At this time the Naval Research Laboratory (NRL) was preparing instruments to record mm wavelength radio events for comparison with optical features. John P. Hagen reported the commitment of NRL to have a 50 ft precision reflector constructed. There was much interest in this undertaking which would open up a new region of the spectrum for radio astronomy.

Large Radio Telescopes

In 1946, Grote Reber had joined the NBS with plans to transfer his 32 ft radio telescope to the Washington area from Wheaton, Ill. At this time the only other radio telescopes of comparable size made use of the German reflectors known as 'Wurzbergs.' Several observatories used them for a quick start of a program in Radio Astronomy. Reber obtained three (in addition to the Wheaton reflector), which were ultimately relocated in Boulder, Colorado, by the Central Radio Propagation Laboratory (CRPL) for a solar program. By 1949, many investigators were proposing the building of much larger parabolic reflectors; foremost among designs was one developed by Reber which was never made, and a 250 ft diameter reflector initiated in 1950 for Lovell. As is well known, the latter was fortunately completed in time to be used in tracking Sputnik.

Slotted Waveguide Array at Goth Hill Radio Observatory

Whenever I visit a harbour or pass through an airport, there is a good chance that I will see a long slim radar antenna which probably uses a slotted waveguide array. This was designed by W.H. Watson and E.W. Guptill who worked on an NRC project at McGill University. The antenna, when rotating, sweeps a narrow fan shaped beam around so that a picture is formed on a cathode ray tube. It was first incorporated into a 10 cm radar at the RFS in 1944 and a small production run of seven units made. After the war, the sets which had been installed at Dorval, Quebec and Stevenson, Manitoba airports were modified for civilian use.[33]

Following the AAS Ottawa meeting in June, 1949, and the URSI-IRE meeting held in Washington in November, there was considerable interest in the design and the construction of a large radio telescope. G.A. Miller, H.E. Parsons and others held discussions on the possibility of using the slotted waveguide array placed on the line focus of a large parabolic cylinder. The planning was essentially an extension of the experience gained with the 30 by 6 ft MEW cylinder. On 8 August 1949, a memorandum was sent to Ballard listing possible programs for a radio telescope, using a large paraboloid cylinder, 150 ft by 24 ft. The construction could be in two stages; the first would be the construction of an unprecedentedly long 150 ft slotted waveguide which would collect radio energy at the line focus of some future large cylinder. Whether or not such a length would

33 Wilfrid Eggleston, **National Research in Canada--the NRC, 1916-1966** (Toronto, 1978), 310.

function satisfactorily was not known. After being made, the fan shaped beam could be tested by using it to observe the sun. In order to increase the signal strength, the collecting area was increased by making the array the bottom of a small wide horn and adding two short walls to form a trough (sometimes referred to as the 'hog trough'). This trough was mounted on a long shaft, and the assembly in turn mounted on bearings on a long E-W concrete wall. The trough could be set at various elevations to follow the seasonal elevations. In the ultimate design with a large cylinder, the trough would be mounted on the line focus of the large cylinder which had as yet to be designed. Until the array had been made and tested, Parsons would postpone the design of the large cylinder. However, since the land immediately around the small telescope was inadequate for the erection of the E-W wall, additional new land was leased in a lower field adjacent to the four foot reflector. A later study was made for the design of a 300ft array but was never seriously considered. The magnitude of the large antenna program meant that whatever resources became available, the exploratory program using 200 mhz would soon be discontinued.

In the summer of 1950, H. Gruenberg graduated from Cal Tech and accepted a position in the Antenna Section to start the design of the 150 ft slotted waveguide array. The construction was started in late 1950 and proceeded smoothly. N.W. Broten had been a summer student in 1949, had graduated the following year from the University of Western Ontario and had accepted a position with REED. He and W.J. Medd started designing a receiver for the new antenna, which was placed in operation for the long array in October, 1951. At the end of 1952, 270 records were available and analysed.[34]

In the initial examination of the data, one intense point-like, drift curve was found and compared to the theoretically calculated antenna pattern. The close agreement was taken as showing that the slotted array performed as designed.[35] This use of natural radio emissions from a point-like source – a sunspot – was very fortunate; otherwise the antenna pattern would have been derived more laboriously from the far-field antenna patterns.

The interpretation of the strip curve scan for 16 October 1951 is significant when compared with a 'synthetic drift curve' made from a spectroheliogram taken at the McMath-Hulbert Observatory.[36] The intercomparison shows that there were

34 Covington and N.W. Broten, 'Brightness of the Solar Disk at a Wave Length of 10.3 cm,' **Ap.J.** 119 (1954), 569-589.

35 H. Gruenberg, 'A Waveguide Array for Solar Noise Studies,' **IRE Trans.** AP-3 (October 1954), 147-52.

two strong radio sources and one weak one, and that distinct plages can be found for all three radio emissive regions. The absence of a dark sunspot for one plage illustrates the often preferred use of the spectroheliogram for studying solar activity, and the significance of the radio flux in providing a readily available index.

Awareness of Need For a Solar Weather Service

Donald Menzel of Harvard presented a paper at the first post-war meeting (1947) of URSI-IRE, entitled 'Wanted, New Indices of Solar Activity' (paper 23) in which he described studies at high altitudes underway at Climax, Colorado. The staffs of the High Altitude Observatory of Harvard University and the University of Colorado were studying variations of the solar corona in relation to conditions in the earth's upper atmosphere. During the presentation I realized that the 10 cm flux would be a good candidate. Upon my return to Ottawa, the customary report of visits and discussions held was prepared as report No. ERB 168 and submitted to the section head, W.J. Henderson and the Officer in charge, G.B. Ballard. Sometime later on a Saturday morning, I was able to discuss privately with Ballard the solar observations and the hope of Menzel to create a solar weather service to predict transmission operating conditions for radio circuits. He showed much interest and asked specifically if I had been discussing any of this with the astronomers at the Dominion Observatory. I recalled one visit to Ralph DeLury in which he suggested that I start monitoring the solar ultraviolet emissions which filter through our atmosphere and see how they would compare with the radio emissions. At that time in his studies he was interested in seeking evidence of the sunspot cycle in growth of trees, grains, weather etc. Ballard listened with interest and recommended that our associations be continued. At this time, in 1947, it was not possible to follow his suggestion. Beals showed much interest in the radio astronomy programs; in 1949, he informed me in a letter written on 18 October that 'the Dominion Observatory is taking steps to acquire a Lyot Filter [optical] for [Balmer hydrogen-alpha] observations of solar disturbances.' The filter for hydrogen light arrived in February, 1952, and was put into service photographing flares for the IGY in the spring of 1957.[37] In 1967, V. Gaizauskas, solar astronomer at the Dominion Observatory, recom-

36 Helen W. Dodson, 'Intensity Measures of Calcium Plages for Comparison with 10.3-Centimeter Solar Radiation, October 16, 1951,' ApJ. 119:3 (May 1954), 564-8.

37 V. Gaizauskas, Personal communication, February 1992.

mended to Bruce G. Cumming, of the Canada Department of Agriculture, the use of the solar radio flux for his studies of outside factors in the germination rate of a particular seed under very controlled conditions at the nearby Experimental Farm.[38]

Conclusion

After World War II, Canada played a significant role in the rapid growth of radio astronomy in the Radio and Electrical Engineering Division of the National Research Council. The records show that unexpectedly intense radio sun spot emissions were observed in July and on 23 November 1946, and how quantitative daily measures of the total radio flux became widely used as a measure of sunspot activity. The index was one of several used during the IGY, and the program has continued to this day, although at the Dominion Radio Astrophysical Observatory in Penticton, BC. In 1947 the Goth Hill Radio Observatory at South Gloucester, Ontario, was established as part of the Microwave section of the Radio and Electrical Engineering Division (1948-1975) formed under the direction of B.G. Ballard (NRC President 1963-1967). This historical review has not discussed all programs performed at the Goth Hill Observatory. In the beginning, only the solar emissions were strong enough to record. In 1959 the use of a travelling wave tube increased the sensitivity of the radiometer so that Medd and Broten were able to use the ten foot parabolic reflector at the Goth Hill Radio Observatory to observe the cosmic noise from our galaxy. Shortly afterward, in 1960, the Radio and Electrical Engineering Division undertook the development of the first stage of the national radio observatory at Lake Traverse, which became widely known as the Algonquin Radio Observatory (ARO).

38 Bruce G. Cumming, 'Germination, as Influenced by Light and Temperature, Particularly in Chanopodium spp.,' Can.Jour.Botany 45 (1967), 1105.