PROCEEDINGS OF SCIENCE

First Interferometry in Radio Astronomy: Ruby Payne-Scott Observes Type I Solar Bursts on Australia Day, 26 January 1946

W.M.Goss[1]

National Radio Astronomy Observatory, Domenici Science Operations Center[2]
PO Box 0, Socorro 87801, New Mexico, USA
mgoss@nrao.edu

On this memorable occasion celebrating a new phase of Richard Schilizzi's career, I will summarise the first interferometry in radio astronomy. The early solar radio noise research in Sydney at CSIRO and at the Cavendish Laboratory in Cambridge played a major role in the evolution of radio astronomy techniques in the first years after World War II. Ruby-Payne is the first woman radio astronomy; she observed the Galactic plane at 11 cm in March 1944 having begun radar research at CSIR Divisions of Radiophysics in August 1941. Starting in October 1945, she began a series of solar noise observations that continued until her retirement in mid 1951. On Australia Day, 26 January, 1946, she carried out the first interferometry in radio astronomy, using the 200 MHz sea-cliff interferometer to observe solar bursts associated with a large sunspot group. Both of Richard's parents have an indirect connection with Ruby Payne-Scott. After the family arrived in Sydney on Australia Day 1951, Theodore Schilizzi worked for Amalgamated Wireless (Australasia) on radar systems for some years as an electrical engineer. Payne-Scott had worked at AWA during 1939-1941. During World War II, Richard's mother was also involved in aircraft warning radar service. Andrée Schilizzi was one of the first WAAF (Women's Auxiliary Air Force, UK) radar technicians.

[1]Speaker. W. M. Goss
[2] The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

PoS(RTS2012)001

PROCEEDINGS OF SCIENCE

Resolving the Sky - Radio Interferometry: Past, Present and Future
Manchester, UK
April 17-20, 2012

1. Introduction

I first met Richard Schilizzi in Sydney in August or September 1967. I had recently arrived at the CSIRO[3] Division of Radiophysics as a postdoc from the University of California, Berkeley. Fortunately the CSIRO radio astronomers had not yet moved from the Sydney University grounds to the new location at Epping; this move was to occur in early 1968. Thus there was almost daily contact between the Sydney University School of Physics graduate students and the younger staff at Radiophysics. I have vivid memories meeting two energetic young graduate students in physics, both working on radio astronomy: Richard Schilizzi and Peter Shaver. Little did I realise that these two would be my collaborators for the next 40 plus years. (The professional collaboration extended to close friendships among the two generations between the three families.) In 1967, I recall a long discussion with Richard about the properties and physics of interstellar OH masers. When I moved for the second time to the Kapteyn Lab at the University of Groningen in 1977, a major bonus was having Richard as a colleague, now at the Netherlands Foundation for Radio Astronomy in Dwingeloo. Richard and I worked together on many projects until I left for the VLA in 1986. These collaborations were one of the highlights of my career in the Netherlands. From Richard, I learned a great deal about VLBI astronomy, a knowledge that I have continued to use for the last 25 plus years. Richard Schilizzi and the development of interferometry are a continuation of an Australian tradition in achieving ever higher angular resolution. The beginning of this tradition was in 1945 as the former World War II radar scientists turned the aircraft warning “swords” into “ploughshares” - radio telescopes. The CSIR scientists turned to a number of peacetime endeavours, including radio astronomy, air navigation and cloud physics.

2.Early Interferometry in Australia and Cambridge UK

Interferometry in Sydney developed in early 1946 at Dover Heights and Collaroy, sites of former army and air force radar stations at two coastal suburbs of Sydney. The first observations were made at Collaroy in October 1945 and published by Pawsey, Payne-Scott and McCready in the *Nature* of 9 February 1946. The first observations had been made in October 1945; the major players were Joseph Pawsey, Ruby Payne-Scott and Lindsay McCready[4]. (See Sullivan, 1984, Robertson, 1992, Hayes et al 1996, Sullivan, 2009, Goss and McGee, 2009 and Goss, 2013 for detailed descriptions of the early years of Australian radio astronomy.) The first radio telescopes for solar noise and later cosmic noise observations (the word “radio astronomy” was invented only in early 1948 by both Pawsey and Martin Ryle) were WWII radar aerials. An example is shown in Figure 1, the Shore Defence 200 MHz radar developed by Pawsey, Harry Minnett and others early in the war. This broadside array evolved into the most successful of the

[3] Commonwealth Scientific and Industrial Research Organisation, Australia dating from 1949. CSIR, Council for Scientific and Industrial Research, 1926-1949.

[4] The paper included data obtained from 2 to 23 October, 1945; the latter date was the date of submission. This was the first published paper in Australian radio astronomy.

Australian WWII radars, the LW/AW system (Light Weight Aircraft Warning, an excellent example is displayed at the Australian War Memorial in Canberra).This radar was used throughout the South West Pacific Area during the war by Australian, New Zealand and US personnel. The use of metre wave radars at coastal sites led to a thorough understanding of the use of these aerials (movable only in azimuth) to determine bearing (azimuth) and range (based on the delay of the echo). Also, it was possible to determine a rough elevation of incoming aircraft, using the lobe pattern due to the interference of the direct and sea-reflected echo. Groups at radar labs around the world had independently solved the problem. A number of prominent scientists worked on this problem during the war: Fred Hoyle for the Royal Navy ship based radar (Mitton, 2005), J.A.Ratcliffe (in the UK; Budden, 1988) for aircraft warning and John Bolton (in the UK; Goss and McGee, 2009) also for aircraft warning. Several US groups also made major advances in understanding the Lloyd's mirror as applied to radio waves. In Australia the theory was worked out in exquisite detail by John Jaeger (1943).

The use of the "sea" or "cliff" interferometer for passive radio astronomy developed quickly after the war; the name now preferred is the "sea-cliff' interferometer (following Woody Sullivan's suggestion in 1991, see Figure 2). This instrument was a key component of successful early discoveries in Australia, both in the solar noise and cosmic noise groups. For example, the "radio stars" Taurus A, Virgo A and Centaurus A were discovered by Bolton and collaborators staring in 1947. By July 1949 Bolton, Stanley and Slee published the optical identifications of these three "radio stars." By 1952, the instrument was no longer in favour. Observations were limited to either source rising or setting. At the low elevations, refraction corrections were substantial and uncertain. (The phase of the interferometer fringes was directly affected by the differential refraction between the two ray paths.[5]) The system was also a total power instrument; phase switching was not practical. In addition no delay compensation was possible leading to the necessary use of small bandwidth. In the early 1950s the Michelson interferometer came into use in Sydney, following the example of the Cavendish group in Cambridge as discussed below.

By incredible good fortune, one of the largest sunspots of the modern era appeared in the first days of February 1946. About 0.5 per cent of the solar surface (5200 millionths of the solar surface) was covered by a single sunspot group. Even during the preceding week, strong Type I bursts (the modern nomenclature) were detected. Discovering a change in the radio flux density of the Sun by a factor of 100 to 1000 in a few seconds was remarkable for a fledgling radio astronomer. On the morning of Australia Day 1946 (26 January) Ruby Payne-Scott (the first woman radio astronomer; Figure 3) carried out the first interferometry in radio astronomy when she detected fringes from the rising run in Sydney (some 8 minutes before optical sun rise due to the increased refraction at radio wavelengths !). She realised that this meant that the size was

[5] For the sea-cliff interferometer, the correction to the phase due to differential refraction was a serious problem; the effects were substantial and variable. Thus the positions derived from the use of the sea-cliff interferometer had substantial uncertainties. McCready et al (1947) proposed a clever calibration scheme using the solar observations themselves (Goss and McGee, 2009). A few years later, Payne-Scott and B.Y. ("Bernie") Mills also worked on the problem of refraction for the Michelson interferometer. They were apparently the first to realise that atmosphere refraction cancels to first order for a plane parallel troposphere (Little and Payne-Scott, 1951, Mills 1952a).

PoS(RTS2012)001

less than about 6.5 arc min and thus considerably smaller than the 40 arc min size of the radio sun. She calculated that the brightness temperature was in excess of 3 x 10^9 K with a peak flux density of 10 million Jy. She suggested that the emission mechanism was due to "gross electrical charges" (Pawsey, Payne-Scott and McCready, 1946 and McCready, Pawsey and Payne-Scott, 1947). Most significantly the sea-cliff interferometer measured the one dimensional **position** of the emission. Identifying the position of the radio bursts with a major sunspot was a remarkable discovery in solar physics. The interferometer data from 7 February 1946 is shown in Figure 4. The deep minima showed the small angular size of the Type I noise storms (enhanced radiation); at 05 hours 59 min Type I storm bursts with time scales of several seconds were observed arising from roughly the same position. At 06 hours 02.5 min, the radio intensity was so intense that the record was off scale.

In the 1947 McCready et al publication, the principle of aperture synthesis was suggested: "It is possible in principle to determine the actual form of the distribution....by Fourier synthesis using information derived from a large number of components. In the interference method suggested here, [the phase difference; my text] is a function of h [height of the cliff] and the [wavelength]. Variation of the [wavelength] is inadvisable, as over the necessary wide range the distribution of radiation may be a function of wave-length.[6] Variation of [height of cliff] would be feasible but clumsy. A different method may be more practical." Ryle gives credit to this result in his tutorial paper of 1952: "The relation between the magnitude of the varying component of power intercepted by an interferometer and the Fourier transform of the distribution across the source was pointed out by McCready, Pawsey and Payne-Scott (1947)."

The Cavendish group was also busy starting radio astronomy in 1946[7]. Many of Martin Ryle's group had been recruited to move to Cambridge by Jack Ratcliffe as they wound up their wartime work on radar at TRE, the Telecommunications Research Establishment. The group included the young F. Graham-Smith. A photo (Figure 5) of one of the Cambridge solar noise interferometers was made by John Bolton of CSIRO during a visit to Cambridge in May 1950. About six months after the Sydney interferometry of late January, a new prominent sunspot group appeared with a size about 90 per cent that of the February sunspot. During July (beginning 17 July), Martin Ryle and Derek Vonberg (1946) observed the Sun with their "Cosmic Radio Pyrometer" at 175 MHz with baselines of 17 and 240 metres. The circular polarisation of the Type I bursts was observed in the period 27 July to 8 August. At almost simultaneous dates in late July, David Martyn (1946) at Mt. Stromlo in Australia and Edward Appleton and Stanley Hey at the Department of Scientific and Industrial Research in London (Appleton and Hey, 1946) also observed circular polarisation from the active Sun. Based on the small angular size of about 10 arc min, Ryle and Vonberg wrote: " Since the value does not greatly exceed the diameter of the visual spot, it is reasonable to relate the source of this radiation [radio] with the visual spot itself, or a region closely associated with it." In addition, a brightness temperature of several billion degrees was indicated. The Cambridge observations were the first use of a Michelson interferometer in radio astronomy. Within a few years the

[6] This is, of course, the modern bandwidth synthesis.
[7] Sullivan (2009) has provided a comprehensive history of the early Cambridge radio astronomy group in his chapter 8.

Cambridge group would succeed in measuring absolute phase of the interferometer fringes from which astronomical coordinates could be determined.

In summary, radio astronomy's rapid growth in the post war era benefited by the timing of the prominent solar cycle 18 (1947 maximum). As an example the largest sunspot of recorded history was the spot of 7 April 1947 with an area of 6100 millionths of the solar disk. (By contrast, during the current solar maximum in 2012- solar cycle 24- the typical sunspot area is much smaller; for example on 21 October 2012 a major sunspot had an area of about 15 per cent of the 1947 behemoth.)

By the end of 1946 the two solar noise groups had associated burst emission with sunspots using two types of radio interferometers (sea-cliff and Michelson). The Cambridge group had also detected circular polarisation in Type I bursts, while the Sydney group described the principle of Fourier (or aperture) synthesis. The experiences gained in the first year of radio astronomy research observing the Sun would serve both the Cambridge and Sydney groups well as they branched out into more ambitious observations of both solar noise and cosmic noise.

In addition to interferometer expertise, the solar noise observations had produced new types of radio telescopes that could study the dynamic spectra (observations of the rapidly variable structure of the emission as a function of time and frequency) of rapidly varying bursts and outbursts. Also the study of the physics of solar emission had provided insight into various types of emission mechanisms such as free-free emission, synchrotron emission and plasma emission.

Within a few years the Cambridge group concentrated on non-solar problems, while in Sydney a diversification occurred, with a strong solar programme[8] existing in parallel with an increased interest in "cosmic noise" research. Strikingly, the Sydney group built their first Michelson interferometer (the swept-lobe interferometer based on the idea of changing the phase of the local oscillator) which began solar observations at Potts Hill Reservoir in 1949 (Little and Payne-Scott, 1951). B.Y. Mills constructed a 101 MHz interferometer with three elements that enabled a survey of the southern sky to be carried out in 1950. The combination of a short (60m) and long spacing (270m) provided lobe ambiguity removal, but more importantly provided information about source **size;** sources larger than 10 arc min could be distinguished. The larger angular size galactic sources (Mills' class I sources) at low galactic latitude could be recognised as a distinct population within the Galaxy (Mills, 1952b). The more compact class II sources with an isotropic distribution with respect to the galactic plane were typically extragalactic sources at high galactic latitude.

3.The Schilizzi family's immigration to Australia

In the course of December 1950, the Schilizzi family (parents Theodore -1922-2002, Andrée -1920-2001 and the three children, Richard b.1945, Stephen b. 1947 and Lesley Anne b. 2 November 1950) left the UK by ship for Sydney. On Australia Day 1951, the family

[8] Under the leadership of J.Paul Wild, 1923-2008, the solar group flourished into the 1980s.

arrived in Sydney; see the family photo from circa December 1950, Figure7. Theodore took up a position at Amalgamated Wireless Australasia, likely working on radar systems.

4. URSI- 1952, International Union of Radio Science, Sydney, 10th General Assembly

The conference was an occasion to showcase the achievements of the CSIRO radio astronomers. The paths of Theodore Schilizzi and Ruby Payne-Scott crossed at the University of Sydney during the URSI (International Union of Radio Science) congress from 8 to 21 August, 1952. The circumstances of the international congress are described by Goss and McGee, 2009. URSI 1952 was one of the first international conferences to be held outside Europe or North America. Many attendees had come by ship from Europe with travel times of about four weeks via the Suez Canal. Some attendees, such as F. Graham Smith, travelled by air; the trip lasted nearly a week with frequent overnight stops.

Ron Bracewell was the secretary of the organising committee; a copy of the conference attendee book was given to me by Ron in 2006. His inscription reads: “To Miller Goss with the compliments of the Organising Secretary, Ron Bracewell 2006 Sept 28.” In this book Ruby Payne-Scott[9] is listed on page 11. T.E. Schilizzi is listed on the next page. Even though he worked at AWA, he did not overlap with Payne-Scott who had worked there from 1939-1941. Any direct connection between the two is unlikely.

The famous group photo of radio astronomers (Figure 8) was taken on 11 August 1952 and includes Ruby Payne-Scott in the front row. To her right are R. Hanbury Brown, C.A. Shain, S.F. Smerd, B.Y. Mills, F. Graham Smith, and W.N. (“Chris”) Christiansen. To her left are A.G. Litttle, M. Laffineur and J.G. Bolton. O.B. Slee is behind Bolton, with F.J. Kerr behind Hanbury Brown and J.P. Wild behind Mills. A group photo of the entire assembly was taken on 11 August outside the Wallace Theatre at the University of Sydney. Identifications in the photo identifications were made by Brian Robinson (2002); Theodore Schilizzi was apparently not present for the group photo.

Goss and McGee (2009) and Goss (2013) have provided descriptions of the scientific programme and the radio astronomy site visits during URSI 1952. A vast collection of images of the meeting is available in the CSIRO Radio Astronomy Image Archive and the CSIRO photo archive maintained by Rob Birtles (CSIRO, Canberra).

Goss has collected a number of humorous newspaper interviews with the Sydney press. Perhaps the Sydney reporters were inexperienced in interviewing overseas guests. For example in the *Sun* on 8 August F. Graham Smith is reported to have claimed: “Only way to find out the size of the universe is by transmitting beams.” In the same article a more sensible quote was reported from Sir Edward Appleton: “It is rather amazing the number of scientists you have for a population of eight million.” After the conclusion of URSI, Chris Christiansen (1913-2007; Frater and Goss, 2011) wrote a thorough description in the *Daily Telegraph*, describing the important discoveries made by the radio astronomers in Australia and overseas.

[9] Payne-Scott had left CSIRO about a year earlier. Her son Peter G. Hall (now professor of mathematics at the University of Melbourne) was born November 1951; there was no maturnity leave at CSIRO at this time. She did not resume her scientific career in later years (Goss, 2013). Her daughter is the well known Australian artist Fiona Hall.

PoS(RTS2012)001

As background information, Chris, who often expressed a left wing viewpoint, made the striking statement: “Radio astronomy was not born with a silver spoon in its mouth. Its parents were workers. One parent was the radio-telephone; the other was radar.” Not surprisingly this quote appears in at least one book containing memorable astronomical quotes (Gaither and Cavazos-Gaither, 2003).

References

[1] E.V. Appleton and J.S. Hey, *Circular Polarization of Solar Radio Emission*, *Nature* **158** (1946) 339.

[2] K.G. Budden, *John Ashworth Ratcliffe, Biographical Memoirs of Fellows of the Royal Society* **34** (1988) 671.

[3] R.H. Frater and W.M. Goss, *Wilbur Norman Christiansen 1913-2007, Historical Records of Australian Science,* 22 (2011) 1.

[4] C.C. Gaither and A.E. Cavazos-Gaither, *Astronomically Speaking,* Institute of Physics Publishing, Bristol 2003.

[5] W.M. Goss, *Making Waves, The Story of Ruby Payne-Scott: Australian Pioneer Radio Astronomer*, Springer-Verlag, Berlin Heidelberg 2013 (in press).

[6] W.M. Goss and R.X.McGee, *Under the Radar, The First Woman in Radio Astronomy: Ruby Payne-Scott*, Springer-Verlag, Berlin Heidelberg 2009.

[7] R. Haynes, R. D. Haynes, D. Malin and R.X. McGee, *Explorers of the Southern Sky*, Cambridge University Press, Cambridge 1996.

[8] J.C. Jaeger, *Theory of the Vertical Patterns for R.D.F. Stations, CSIR Report RP.174,* Sydney 1943.

[9] A.G. Little and R. Payne-Scott, *The Position and Movement on the Solar Disk of Sources of Radiation at a Frequency of 97 Mc./s. I. Equipment, Australian Journal of Scientific Research (Series A Physical Sciences)* **4** (1951) 489.

[10] D. Martyn, *Polarization of Solar Radio-Frequency Emissions, Nature* **158** (1946) 308.

[11] L.L. McCready, J.L. Pawsey, R. Payne-Scott, *Solar Radiation at Radio Frequencies and its Relation to Sunspots*, *Proceedings of the Royal Society, A* **190** (1947) 357.

[12] B.Y. Mills, *The Positions of Six Discrete Sources of Cosmic Radio Radiation, Australian Journal of Scientific Research (Series A Physical Sciences)* **5** (1952a) 456.

[13] B.Y. Mills, *The Distribution of the Discrete Sources of Cosmic Radio Radiation, Australian of Journal Scientific Research (Series A Physical Sciences)* **5** (1952b) 266 .

[14] S. Mitton, *Conflict in the Cosmos, Fred Hoyle’s Life in Science*, Joseph Henry Press, Washington (2005).

PoS(RTS2012)001

[15] J.L. Pawsey, R. Payne-Scott and L.L. McCready, *Radio Frequency Energy from the Sun, Nature* **157** (1946) 158.

[16] P. Robertson, *Beyond Southern Skies: Radio Astronomy and the Parkes Telescope*, Cambridge University Press, Cambridge (1992).

[17] B.J. Robinson, *Recollections of the URSI Tenth General Assembly, Sydney Australia, 1952, Radio Science Bulletin,* **300** (2002) 22.

[18] M. Ryle, *A New Radio Interferometer and its Application to the Observation of Weak Radio Stars, Proceedings of the Royal Society, A* ***211*** *(1952) 351***.**

[19] M. Ryle and D. D. Vonberg, *Solar Radiation at 175 Mc./s., Nature* **158** (1946) 339.

[20] W.T. Sullivan, *The Early Years of Radio Astronomy: Reflections Fifty Years after Jansky's Discovery*, Cambridge University Press, Cambridge (1984).

[21] W. T. Sullivan, *Some Highlights of Interferometry in Early Radio Astronomy, in Radio Interferometry: Theory, Techniques and Applications, IAU Colloquium No. 131*, editors T.J. Cornwell and R.A. Perley, Astronomical Society of the Pacific, **19** (1991) 132.

[22] W. T. Sullivan, *Cosmic Noise: A History of Early Radio Astronomy*, Cambridge University Press, Cambridge (2009).