SIXTY YEARS IN RADIO ASTRONOMY: A TRIBUTE TO BRUCE SLEE

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Abstract: Bruce Slee is one of the pioneers of radio astronomy. After recording solar emission during World War II, he joined what was then the Council of Scientific and Industrial Research's Division of Radiophysics in Sydney, Australia, and went on to make important contributions to Solar System, Galactic and extra-galactic astronomy. Since his retirement, in 1989, he has continued his research as an Honorary Fellow of the Australia Telescope National Facility. Now in his early 80s, Bruce Slee is one of the few radio astronomy pioneers of the 1940s who is still actively contributing to astrophysics. This issue of the *Journal of Astronomical History and Heritage (JAH^2)*, and the two that will follow it, are a tribute to this quietly-spoken scientist and his remarkable 60-year involvement in radio astronomy.

Keywords: Bruce Slee, Dover Heights, 'radio stars', Fleurs, MSH Catalogue, Parkes Radio Telescope, active stars, Culgoora Circular Array, clusters of galaxies

1 INTRODUCTION

In 1945, towards the end of World War II, a youthful Bruce Slee (see the photograph on the cover of this issue) carried out observations of solar radio emission with a 200 MHz Royal Australian Air Force radar antenna, launching a life-long career in a field that would soon become known as 'radio astronomy'. In the immediate post-War years, the celebrated trio, Bolton, Stanley and Slee, were largely responsible for solving the mystery of the 'radio stars', and during the 1950s his name remained in the international arena through the 'MSH Catalogue'. Further avenues of research came with the advent of the Parkes Radio Telescope, the Culgoora Circular Array (CCA) and ultimately the Australia Telescope Compact Array (ATCA). Now 80 years of age, Bruce Slee continues to research the properties of stellar atmospheres and clusters of galaxies using this last-mentioned instrument and the Very Large Array (VLA). Bruce Slee may be the only pioneering radio astronomer from the 1940s who is still active in astrophysical research.

I first met Bruce Slee when I was schoolboy and conducted visual observations of flare stars in conjunction with his radio monitoring at Fleurs. At the end of my school years he arranged for me to join the Division of Radiophysics as a vacation scholar (a remarkable privilege, I later learnt, for someone without a university background), and after accepting a permanent post and joining the Solar Group I sometimes was seconded to the Parkes Group and joined Bruce in observing programs with the Parkes Radio Telescope (e.g. see Slee and Orchiston, 1965). During these halcyon years Bruce became my friend and confident, my advisor, my teacher, and—despite his quiet, shy, nature—an ideal role model when it came to research. It was therefore a great joy to re-activate our collaborative research in 2001—fully 40 years later—when I joined the Australia Telescope National Facility as their part-time Archivist and Historian and he was an ATNF Honorary Fellow. This time, our observing programs were carried out with the ATCA at Culgoora, a far cry from those 'primitive' days at Fleurs during 1961-1963, and our collaborative research also extended to astronomical history. This expanded research portfolio was only natural given that Bruce occupies an important place in the history of Australian radio astronomy.

This paper is my personal tribute to Bruce. In it I briefly review his research achievements, and thereby 'set the scene' for the Australian papers that follow in this issue of JAH^2 and in the December 2005 and June 2006 issues of the journal.

2 BIOGRAPHICAL BACKGROUND

Owen Bruce Slee (Figure 1) was born in Adelaide on 10 August 1924, the second of three children. His father was a carpenter, but work was hard to find during the Great Depression. The family lived in a number of different country towns and it was only upon completing secondary school that Bruce Slee returned to Adelaide. Armed with good Leaving Certificate grades, he was employed by the Lands Department, but one year later joined the Royal Australian Air Force.

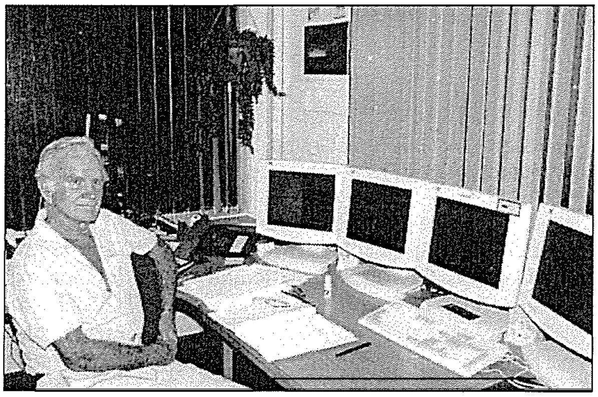

Figure 1: Bruce Slee (1924–) at the control desk of the Australia Telescope Compact Array in 2002.

After training in Melbourne and at Richmond (near Sydney), he served at RAAF radar stations at Albany, Onslow, Melville Island and Lee Point (near Darwin). It was at this last radar station (Figure 2) that he independently detected solar radio emission in October 1945 (see Orchiston and Slee, 2002a; Orchiston, Slee and Burman, 2005). Straight after the War, Bruce married Nan Linnett, and they moved to Sydney. There he joined the Council of Scientific and Industrial Research's Division of Radiophysics (henceforth RP), beginning a life-long career in radio astronomy. Along the way he studied evenings, completing two Technical College diploma courses. He then studied part-time for a B.Sc. degree at the University of New South Wales, graduating with First Class Honours in 1959. Later, in 1971, he was awarded a D.Sc. by this same University for his assembled publications in radio astronomy.

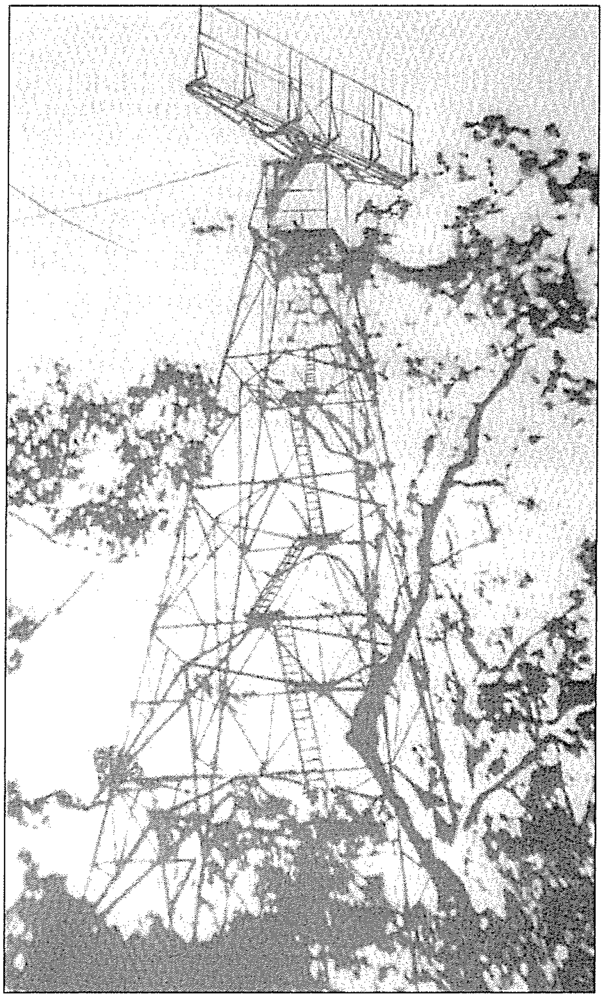

Figure 2: The Lee Point radar antenna (after Fenton and Simmonds, 1993: 27).

Bruce Slee transferred to the Australia Telescope National Facility (henceforth ATNF) in 1988 when this new Commonwealth Scientific and Industrial Research Organisation Division was formed, and retired the following year. He then became an Honorary Fellow, and has continued his astrophysical research through to the present day.

3 RESEARCH WORK

A detailed account of Slee's research work while employed by RP and the ATNF is contained in an earlier paper (Orchiston, 2004) and need not be repeated here. Instead, all I will do is summarize his main fields of research and highlight the principal research achievements. Observational aspects are discussed in Sections 3.1 through 3.12, and his research on the history of Australian radio astronomy is dealt with in Section 3.13.

3.1 'Radio Stars'

At the end of WWII radio astronomy was in its infancy. The Sun was known to be a radio emitter, and Jansky and Reber had established that radio waves emanated from the entire sky, but with stronger emission along the Galactic Plane (see Reber, 1984; Sullivan, 1984b). Consequently, Hey's announcement in 1946 of an anomalous 'radio star' in Cygnus came as a complete surprise, and it initiated a whole new field of radio astronomy. During 1947-1948, Bolton, Stanley and Slee (BSS) used a number of simple Yagi antennas at Dover Heights field station and near Auckland, New Zealand, to investigate Cygnus-A and other radio sources they discovered, in the process helping solve the mystery of the 'radio stars' (for details, see Bolton, 1955; Orchiston 1994; Slee, 1994). Far from being 'stars', all were discrete sources; Taurus-A (the Crab Nebula) lay within our Galaxy, but the other early 'radio stars' (Centaurus-A, Cygnus-A, and Virgo-A) were extragalactic objects—a pair of colliding galaxies and two individual radio galaxies.

With the passage of time, BSS and Westfold used increasingly more sophisticated Yagi arrays to search for new sources, and their final survey, which was conducted in 1951-1952 with a 12-Yagi antenna, yielded 104 sources. Most of these were eventually shown to be extragalactic objects.

3.2 The 'Hole-in-the-Ground Antenna', the Galactic Centre and Sagittarius-A

One of the last projects carried out at the Dover Heights field station prior to its closure was a survey of the Galactic Centre region carried out with the remarkable 'hole-in-the-ground antenna'. When RP could not fund a major new radio telescope at Dover Heights in 1951, BSS decided to construct one themselves as a secretive lunchtime project. Using shovels and a wheelbarrow they spent three months excavating a 21.9-m (72-ft) parabolic depression in the sand, consolidated the surface with ash, laid strips of metal to provide reflectivity, installed a mast and dipole, connected this transit instrument to a 160 MHz receiver, and recorded a strong discrete source (Sagittarius-A) near the Galactic Centre.

This novel radio telescope was then expanded to 24.4-m (80-ft) and the surface was coated in concrete with embedded wire mesh. It was then used by McGee, Slee and Stanley (MSS) to plot the distribution of 400 MHz radio emission along the Galactic Plane. As Figure 3 illustrates, Sagittarius-A is particularly conspicuous, and MSS and Bolton advanced the view that it was intimately associated with the Galactic Centre, mirroring an identical but little-known claim made three years earlier by Piddington and Minnett (see Orchiston and Slee, 2002b). Subsequently the IAU adopted the position of this source as the fundamental datum for the Galactic co-ordinate system.

It should be no surprise that Slee (and various collaborators) later continued to probe this remarkable source as improved instrumentation came to hand, first with the Mills Cross, later with the CCA, the Parkes Radio Telescope and 64-m Tidbinbilla antenna (as part of a VLBI project) and the VLA. These observations, and others, showed that the supposedly 'simple' source of the early 1950s in fact comprised three principal components and a number of discrete sub-components.

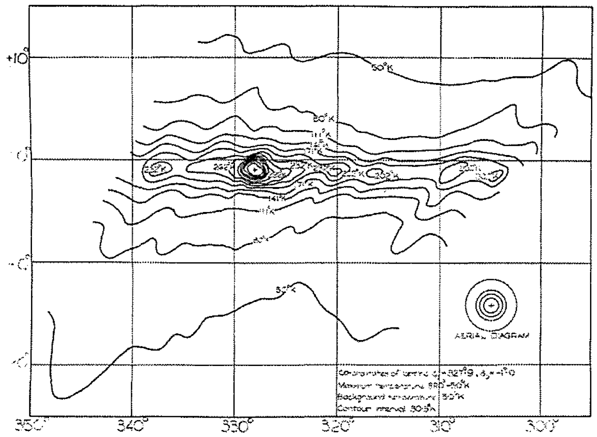

Figure 3: Isophotes of 400 MHz Galactic Plane emission. The conspicuous source is Sagittarius-A (after McGee, Slee and Stanley, 1955: 356).

3.4 The MSH Catalogue

After transferring to Fleurs field station in 1954, Slee joined Mills and Hill to conduct an 85.5 MHz survey of the sky from declination +10° to –80° using the innovative new Mills Cross radio telescope (Figure 4). In all, they detected more than 2,000 sources, and the celebrated MSH (Mills-Slee-Hill) Catalog was published between 1958 and 1961 in three seminal papers.

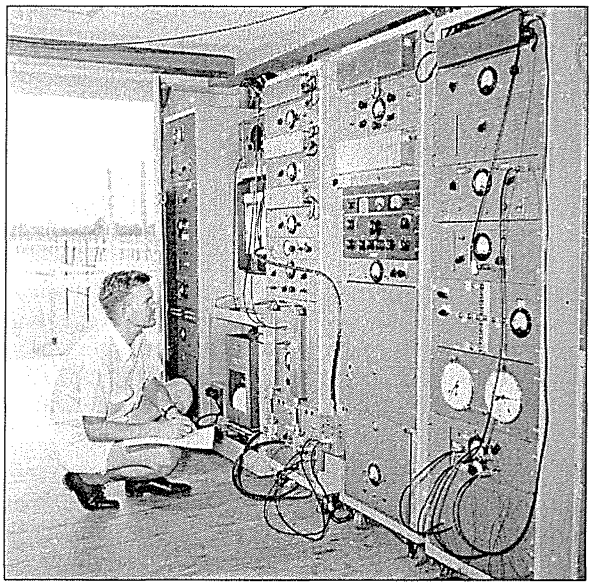

Figure 4: Bruce Slee examines the Mills Cross chart recorders and receivers in 1955 (ATNF image: 3868-10).

Most of the MSH sources were extragalactic objects, and this lay at the core of the infamous 'Log N – log S Controversy' that was to embroil British and Australian radio astronomers for years to come. In 1955 radio astronomers at Cambridge University published their 2C Catalogue, and felt justified in using the source data in it to disprove the validity of the steady-state Universe theory. The only problem was that when Mills and Slee compared identical areas of sky surveyed by the Cambridge and Fleurs groups they came up with very different source distributions. Clearly one of the catalogs was in error. Mills and Slee were convinced the problem lay in mother England, not in the 'colonies', and when they voiced this view internationally a heated controversy erupted which was to sour relations between Cambridge and RP astronomers for many years. Eventually it was conceded that 'instrumental effects' plagued the Cambridge interferometer and that many of the 2C 'sources' simply did not exist. For fuller accounts of this incident see the historical papers by Mills (1984) and Sullivan (1990).

3.5 The Solar Corona and Interplanetary Medium

For millennia the solar corona has captivated humans during total solar eclipses, but its solar association and composition were only demonstrated during the second half of the nineteenth century. In 1946 the head of RP's radio astronomy group, Joe Pawsey, published the surprising figure of 1 million degrees for the temperature of the corona, and this initiated a full-scale RP attack on thermal and non-thermal emission from the Sun (see Christiansen (1984) and Orchiston, Slee and Burman (2005) for accounts of the early years).

One ingenious way of investigating the spatial extent of the outer corona was to observe radio sources as they were occulted by the Sun, and in 1956-1958 Slee used the Mills Cross and an 85.5 MHz interferometer to observe occultations of Taurus-A and document large-scale irregularities in the corona. He took this project further in 1960, and over a four month period observed thirteen different sources with low ecliptic latitudes as they passed close to the Sun. On this occasion, Slee was able to document the consistent existence of coronal scattering out to 60 solar radii in an equatorial direction (and occasionally out to 120 solar radii) but only out to 40 solar radii in a polar direction (Figure 5).

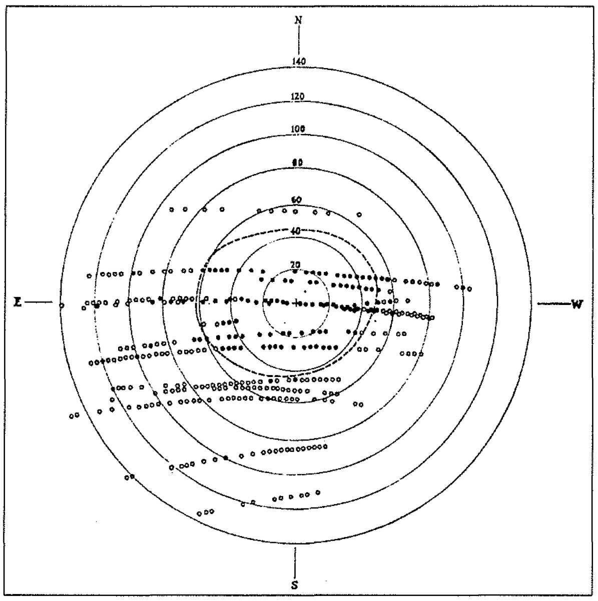

Figure 5: Evidence of coronal scattering is indicated by filled circles and is primarily restricted to the region enclosed by the dashed line. The Sun is marked by a cross, and the concentric circles are at 20 solar radii intervals (after Slee: 1961: 227).

Looking beyond the solar corona, Slee and Higgins then used scattering suffered by 19.7 MHz

Jovian emission to identify diffraction patterns and irregularities in the interplanetary medium out to distances of 4 astronomical units from the Sun.

3.6 Jovian Decametric Emission

In 1955, Burke and Franklin surprised the astronomical world by announcing their serendipitous discovery of decametric burst emission from Jupiter, and by the time Slee became involved in this area of research an association with the Jovian system III longitude was already well established. But the identity and nature of the emitting source was still a mystery. During the oppositions of 1962 through 1964, Slee and Higgins carried out interferometric observations of Jupiter at 19.7 MHz and were able to confirm that most of the emission derived from a single source and to demonstrate that this was probably less than 1″ in diameter.

Slee spent 1965-1966 in England at the Royal Radar Establishment (Malvern). During this visit, he carried out 20 MHz interferometric observations of Jupiter in collaboration with H. Gent, and they discovered a new type of submillisecond burst.

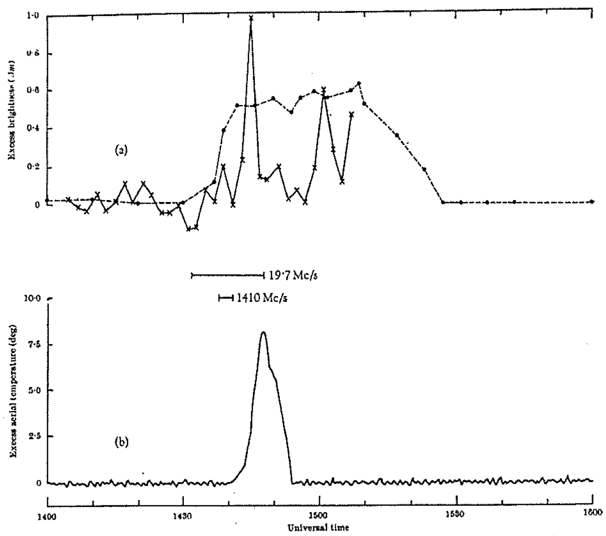

Figure 6: Optical and radio flaring of V371 Orionis on 30 November 1962. (a) Optical light curves (solid line = Baker-Nunn photographs; dashed line = amateur observations). (b) Smoothed line = 410 MHz Parkes plot; time intervals with 19.7 MHz (Fleurs) and 1410 MHz (Parkes) emission are also indicated (after Slee, Solomon, and Patston, 1963: 993).

3.7 Flare Stars

By 1960 the non-stellar identity of 'radio stars' was beyond dispute, and the only genuine star known to emit radio waves was the Sun. It was time to beginning searching for radio emission from other stars and the obvious first choice were the dMe flare stars, whose optical outbursts—while on a very much enhanced scale—were in some ways reminiscent of solar flares and their accompanying radio outbursts. Bernard Lovell and the RP team of Slee and Higgins, were the pioneers in this new field, and each group made successful detections. Between September 1960 and May 1962 Slee and Higgins used the 85.5 MHz Mills Cross, the 19.7 MHz Shain Cross and (eventually) the Parkes Radio Telescope (at 410 and 1410 MHz) to monitor UV Ceti, Proxima Centauri, V371 Orionis and V1216 Sagittarii. Collaborative optical observations were made by teams of amateur astronomers (one of which at the time was led by the author of this paper). Optical flaring of UV Ceti on 13 November 1961 was accompanied by radio bursts at both 19.7 and 85.5 MHz. The Parkes Radio Telescope had only just been commissioned, so it was not involved in this particular program, but it was used on 30 November 1962 when a powerful optical flare was accompanied by radio emission at 19.7, 410 and 1410 MHz (see Figure 6).

For the last four decades, Slee and various collaborators have continued to research the radio properties of flare stars using a range of different instruments, including the Parkes Radio Telescope, CCA, ATCA and the VLA. He has also participated in various multi-wavelength flare star campaigns, including the very first one, in November-December 1975, which involved co-ordinated X-ray, optical and radio observations of YZ Canis Minoris.

3.8 Other Active Stars

If flare stars were radio emitters, then why not other stars? In 1981, this notion motivated Slee to begin searching for radio emission from 21 different RS CVn and related stars at Parkes, in collaboration with Australian and New Zealand colleagues. Three radio detections were made, from two RS CVn stars (HD 22468 and HD 195040) and an early K type giant (HD 101379). These initial successes led Slee and two RP colleagues to launch the 'Australian Radio Star Survey' (ARSS), where they searched for radio emission from a wide range of binary and single stars. This project spanned six years, attracted many Australian and overseas collaborators (from both optical and radio astronomy), and at one time or another involved the Parkes Radio Telescope, Fleurs Synthesis Telescope, the ATCA and the VLA. There were many detections, and results were published in a succession of research papers. Spinning out of the ARSS project were a series of in-depth studies of individual stars or related groups of stars; some of these were multiwavelength campaigns involving ground-based and space-based instrumentation. It was during one of this projects, in April 1992, that the first 'radio map' of an active star was obtained with the ACTA.

Over a period of more than two decades Slee and his collaborators have made major contributions to our understanding of active stars. Quiescent and/or outburst emission has been detected from Algol, AM Her, Am, BY Draconis, F supergiant, FK Comae, RS CVn, red giant, dwarf pre-Main Sequence, and unspecified Ca II emitting types of stars. Studies of these different stars—and the classical dMe flare stars mentioned in Section 3.7—have supplied information on radio luminosities, flaring characteristics, spectra, polarization, coronal electron densities, magnetic field strengths, and the generating mechanisms associated with the radio emission.

3.9 Pulsars

For the past three decades Australia has maintained an enviable reputation in pulsar astronomy, largely due to the efforts of the RP (and later, ATNF) team led by

R.N. Manchester. While he was never a member of this consortium, Slee and his RP and international colleagues also carried out valuable research on pulsars during the late 1960s through to 1980 using, in the main, the CCA at the relatively low frequencies of 80 and 160 MHz. Their investigations were reported in seven research papers, and these provided useful data on pulse widths, energy fluxes, spectra, amplitude variations and periodicities.

3.10 The Culgoora Source Survey

The Culgoora Radioheliograph was a novel radio telescope specifically designed for solar work, and was completed in 1967. It comprised 96 equatorially-mounted 13.7-m parabolic antennas spaced round the circumference of a circle 3km in diameter (Figure 7). Initially the array operated at 80 MHz, but subsequently it was upgraded in order to work also at 160 and 327.4 MHz.

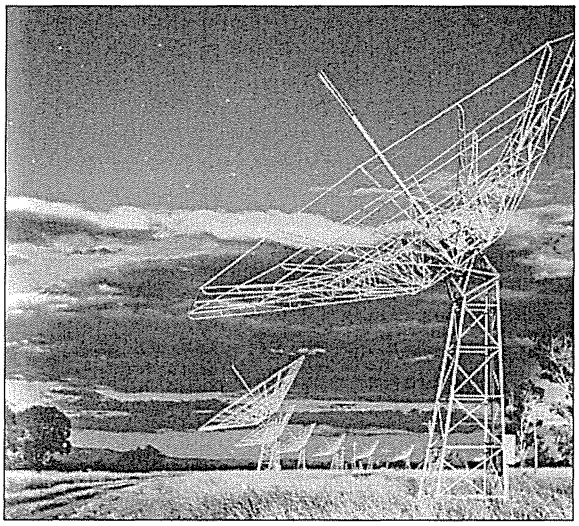

Figure 7: View showing some of the 13.7-m antennas in the CCA (ATNF image: 8553-6).

Slee was the first to realize the non-solar potential of what he preferred to refer to as the Culgoora Circular Array (CCA). At 80 MHz it had a 3.7 arc min beam and a resolution more than an order of magnitude better than the 85.5 MHz Mills Cross, the last radio telescope that had been used for an extensive southern source survey. Slee took advantage of this, and made extensive night-time use of this incomparable radio telescope from 1967 right up until the array was closed down in 1984. During this period, three substantial Culgoora Source Lists were published in the Astrophysical Supplement Series of the *Australian Journal of Physics*. These reported observations or attempted observations of more than 2,800 individual sources, and positions, flux densities and angular sizes were recorded for those that were detected. Once the 160 MHz upgrade was completed, Slee was also able to include isophote plots for the 163 sources that were resolved by the 1.9 arc min beam. Most of the sources were radio galaxies or quasars (QSOs), but some Galactic objects (mainly supernova remnants and pulsars) were represented.

A number of interesting projects spun off the Culgoora Source Lists. One of these investigated the spectra of ~2,000 individual radio sources, which at the time was the largest analysis of this kind ever undertaken. Slee and his colleagues also looked at possible relationships between spectral index, redshift, radio power and galaxy dimensions. Another major project was an investigation of temporal intensity variations in 412 different galaxies and QSOs.

3.11 Clusters of Galaxies

In 1978, Slee began researching the radio properties of clusters of galaxies, a project that would extend to the present day and attract other Australian and international collaborators. The observations would involve the ATCA, CCA, Molonglo Synthesis Telescope, Parkes-Tidbinbilla Interferometer and VLA, and span frequencies from 80 to 8400 MHz.

Typical of this long-running project was the 'VLA Survey of Rich Clusters of Galaxies', which examined spectral indices, morphologies, optical associations, source ages and lifetimes, polarisation, radio fluxes, and associated X-ray luminosities.

Since the late 1990s, there has also been an interest in 'relics' (Figure 8), those arc-like steep-spectrum components of clusters of radio galaxies that "... show a remarkable variety of fine structure that takes the form of arcs, filaments, and loops of enhanced surface brightness. Most ... are barely resolved (5 kpc) in their transverse directions, but they can have projected lengths of up to 100 kpc." (Slee, Roy, Murgia, Andernach, and Ehle, 2001: 1173).

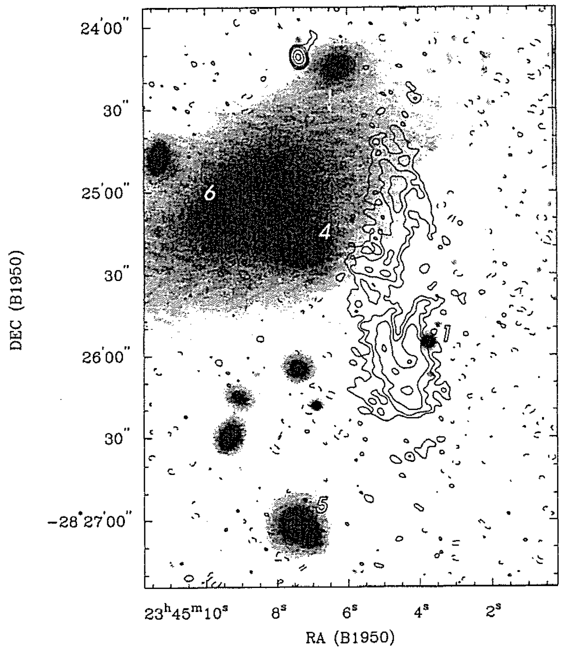

Figure 8: VLA 1425 MHz isophote map of the steep-spectrum relic A4039_9. The extremely large bright galaxy immediately to the left of the upper part of the relic is at the centre of the optical cluster (after Slee and Roy, 1998: L87).

3.12 Other Observational Projects

In addition to the aforementioned research projects, Slee was the first to prove that the enigmatic fluctuations so characteristic of the first radio star, Cygnus-A, were caused by scintillations and were not intrinsic to the source itself. Once at Fleurs and Culgoora, he used source scintillations to investigate geomagnetic activity and electron densities in the ionosphere.

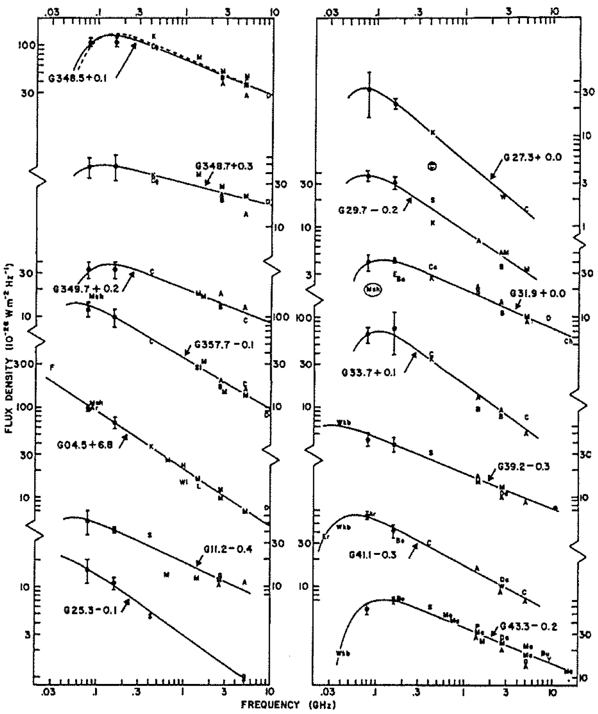

Figure 9: Spectra of 14 SNRs and least-squares fits, showing spectral turnovers at ~100 MHz which were attributed to free-free absorption in the ISM (after Dulk and Slee, 1975: 64).

Together with a number of RP and international colleagues, Slee investigated the plasma tails of Comets 1P/Halley, C/1986 P1-A (Wilson) and C/1989 X1 (Austin) as they passed in front of known radio sources.

In 1964 Slee tried unsuccessfully to observe Uranus with the Parkes Radio Telescope, and in 1970, he and Dulk used the CCA to investigate Jupiter's 80 MHz flux and its radio spectrum.

During the early 1960s, Slee and Orchiston used the Parkes Radio Telescope to carry out the first detailed radio survey of southern planetary nebulae, and the following decade he and Dulk investigated the properties of Galactic supernova remnants (SNRs).

Between 1965 and 1980 Slee and his Australian and international collaborators carried out a number of different projects aimed at investigating electron densities and HII absorption in the Interstellar Medium (ISM) (see Figure 9). Instruments used were a 38 MHz interferometer at the Royal Radar Establishment and Jodrell Bank, the CCA, Parkes Radio Telescope, and the Ootacamund Radio Telescope, and sources involved in these investigations included pulsars, SNRs, radio galaxies and QSOs.

While based in England, Slee became interested in long-baseline interferometry of QSOs and radio galaxies in an attempt to establish their angular sizes and temporal variations in their fluxes. In 1982, long after returning to Australia, he was one of many Australian, South African and US radio astronomers who participated in SHEVE (the Southern Hemisphere VLBI Experiment), when they researched the fine-scale angular structure of selected southern radio sources (but mainly radio galaxies and QSOs). Between 1988 and 1991, Slee and some Australian collaborators followed up with Parkes-Tidbinbilla Interferometer and ATCA observations of selected spiral and elliptical galaxies, in order to research their core luminosities, flux variability and spectra. Seyfert galaxies were of particular interest.

Finally, since 2003, Slee has collaborated with Australian and overseas radio astronomers in researching the radio properties of microquasars.

3.13 History of Australian Radio Astronomy

In 1994 Slee published his first paper on astronomical history in a volume dedicated to the memory of the late John Bolton. In "Some memories of the Dover Heights field station, 1946–1954" he discussed the instruments, scientific achievements and some of the personalities associated with the field station.

Since my appointment to the ATNF, Slee and I have devoted some of our spare time to systematically documenting the history of the field station era (Figure 10), drawing on his long involvement with RP and the ATNF, his personal knowledge of many of the other 'key players' in early Australian radio astronomy, and his personal experiences at the Radiophysics Laboratory, at Parkes, and at the Dover Heights, Georges Heights and Fleurs field stations. We have written one major review paper, papers about early 'solar noise studies', about notable individuals, individual field stations, individual radio telescopes, early Australian radio observations of historic supernova remnants, and even about the commemoration of one of the leading field stations.

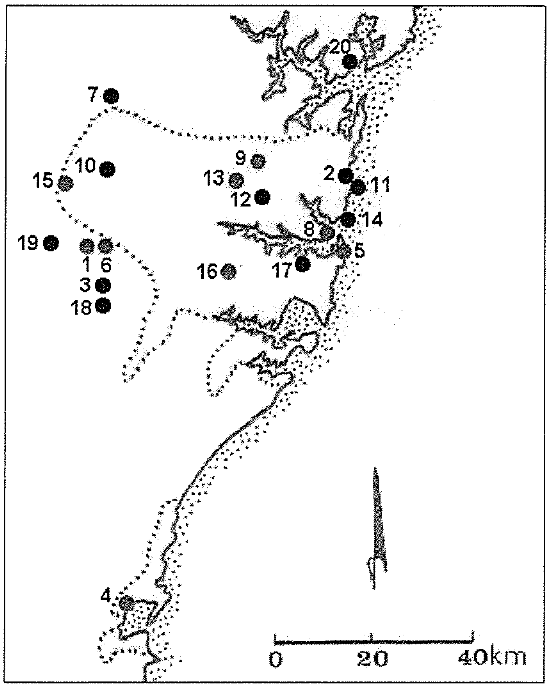

Figure 10: Map of the Sydney-Wollongong regions (dotted lines) showing locations, RP field stations and remote sites used for radio astronomy, 1945-1963, and discussed by Orchiston and Slee in their papers. Key: 1 = Badgerys Creek, 2 = Collaroy, 3 = Cumberland Park, 4 = Dapto, 5 = Dover Heights, 6 = Fleurs, 7 = Freeman's Reach, 8 = Georges Heights, 9 = Hornsby Valley, 10 = Llandilo, 11 = Long Reef, 12 = Marsfield (ATNF Headquarters), 13 = Murraybank, 14 = North Head, 15 = Penrith, 16 = Potts Hill, 17 = Radiophysics Laboratory (Sydney University grounds), 18 = Rossmore, 19 = Wallacia, 20 = West Head.

In addition, Slee presented a research paper on early Australian studies of source sizes in one of the historic radio astronomy meetings at the 2003 IAU General Assembly, and it is hoped to publish this in a future issue of *JAH*^{2}, along with an historical review of the non-solar radio astronomy accomplished with the CCA.

4 RECENT PUBLICATIONS

The Slee biography published in 2004 contained a tally of his 166 astronomical publications as of August 2002. Here we update that list (see Table 1), adding those papers published during the intervening period.

Table 1: Slee's astronomical publications, as at May 2005.

Publications Title	No. of Papers
Astronomical and Astrophysical Abstracts	2
Astronomical Journal	8
Astronomy and Astrophysics	1
Astrophysical Journal	14
Astrophysical Letters (later *and Communications*)	6
Astrophysics and Space Science	1
ATNF News	4
Australian Journal of Astronomy	1
Australian Journal of Scientific Research and *Australian Journal of Physics*	39
Journal of Astronomical History and Heritage	3
Mitteilungen der Astronomische Gesellschaft	1
Monthly Notices of the Royal Astronomical Society	23
Nature	15
New Astronomy	1
Planetary and Space Science	1
Proceedings (later *Publications*) *of the Astronomical Society of Australia*	26
Proceedings of the Institute of Radio Engineers	1
Proceedings of the Institute of Radio Engineers Australia	1
Radio Science	1
Sky and Telescope	1
The Observatory	3
Turkish Journal of Physics	1
Papers in conference proceedings	24
Total:	178

The twelve post-August 2002 publications represented in this Table relate to flare stars (Slee, Willes, and Robinson, 2003), other active stars (Budding et al., 2005; Slee, Budding, Carter, Mengel, Waite and Donati, 2004), microquasars (Tsarevsky et al., 2003), clusters of galaxies (Fujita et al., 2002; 2004) and history of astronomy (Kellermann et al., 2005; Orchiston and Slee, 2005a, 2005b, 2005c; Orchiston, Slee and Burman, 2005; Orchiston et al., 2006).

5 CONCLUDING REMARKS

Bruce Slee is one of the international pioneers of radio astronomy, and over the past sixty years has made wide-ranging contributions that extend from the Solar System (the ionosphere, solar corona, interplanetary medium, Jupiter, and comets) to the Galaxy (pulsars, various types of active stars, gaseous nebulae, the ISM), and beyond to QSOs, galaxies and clusters of galaxies. This reflects an overwhelming commitment to and passion for astronomy, and his ambition "... to contribute in a broad range of astronomical areas, with emphasis on observational and analytical aspects rather than on instrumentation development or theoretical issues ..." (Orchiston, 2004: 64).

With the recent passing of other retired colleagues, Slee has added the history of radio astronomy to his research portfolio, and realises that as one of the few survivors from the field station era he has a responsibility to document and promote Australia's remarkable early radio astronomical heritage (see Orchiston and Slee, 2005b; cf. Sullivan, 1988, 2005).

Although 80 years of age, Slee remains an Honorary Fellow at the ATNF in Sydney, and he continues to research the atmospheric properties of various types of active stars and the radio properties of clusters of galaxies. Through this issue of the journal, and the two that will follow it, we salute his valuable life-long contribution to astronomy.

6 ACKNOWLEDGEMENTS

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