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The Slee Celebration: Issue #1

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The *Journal of Astronomical History and Heritage* (JAH^2) is published twice-yearly, in June and December, and features review papers, research papers, short communications, correspondence, IAU reports, and book reviews.

Papers on all aspects of astronomical history are considered, including studies that place the evolution of astronomy in political, economic and cultural contexts. Papers on astronomical heritage may deal with historic telescopes and observatories, conservation projects (including the conversion of historic observatories into museums of astronomy), and historical or industrial archaeological investigations of astronomical sites and buildings. All papers are refereed prior to publication. There are no page charges, and in lieu of reprints authors are sent a pdf or Word camera-ready version of their paper.

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and should be followed carefully when preparing manuscripts. Papers and book reviews should be e-mailed to the Editor, Dr Wayne Orchiston (Wayne.Orchiston@jcu.edu.au), or posted to him at

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Enquiries concerning subscriptions, review copies of books, advertising space, or missing issues of the *Journal* also should be directed to Dr Orchiston.

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COVER PHOTOGRAPH

Owen Bruce Slee (1924–), photographed in Adelaide in 1946, shortly after making independent observations of solar radio emission with a wartime radar antenna and prior to joining the Commonwealth Scientific and Industrial Research Organisation's Division of Radiophysics in Sydney (see pages 3-10).

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EDITORIAL

This is the first issue of the *Journal of Astronomical History and Heritage* (*JAH*^{2}) to appear under the banner of the Centre for Astronomy at James Cook University, Townsville, Australia. The Centre was founded in 2003, and offers full-time and part-time internet-based masters and doctoral degrees in astronomy. History of astronomy is one of the research options available to the graduate students and is the research focus of several of the Centre's full-time and part-time staff members, so it is particularly pleasing that the *Journal* has found a new and happy home. Our special thanks go to astronomer and Deputy Vice-Chancellor, Professor Harry Hyland, for facilitating this innovation.

In addition, our heartfelt thanks and gratitude go to John Perdrix, the former Managing Editor of *JAH*^{2}, for his sterling efforts since he co-founded the *Journal* in 1998. Medical circumstances have forced John to relinquish his editorial duties, but he will maintain a close association with the *Journal* as a member of the Editorial Board.

Another new Board member is Associate-Professor Graeme White, Director of the Centre for Astronomy at James Cook University. Whilst primarily an astrophysicist, Graeme has a long-standing interest in astronomical history and has published a number of papers on aspects of nineteenth century Australian astronomy, along with the book *Under the Southern Cross* (1991), which he co-authored with Ragbir Bhathal.

The papers in this issue of *JAH*^{2} reflect the healthy mix of topics that has been a feature of previous issues, but in this instance there is a small group of papers on the history of radio astronomy. We would like to dedicate this issue of *JAH*^{2} and the following two issues, to one of radio astronomy's pioneers, Dr Bruce Slee, in celebration of his sixty-year contribution to astrophysics. Some of the radio astronomy papers in these three issues derive from two Science Meetings on historic radio astronomy that formed part of the programs of Commissions 40 (Radio Astronomy) and 41 (History of Astronomy) at the 2003 General Assembly of the International Astronomical Union—which was held in Sydney, Australia. Bruce Slee was the co-organiser of one of these meetings. Other papers in these three issues have no Sydney IAU links, but were submitted by colleagues in order to record aspects of radio astronomical history in a number of different nations. The common denominator of all of these papers is that Bruce Slee is well known to the authors; back in the 1950s he even worked with a number of them.

While we have a goodly supply of papers for the next two issues, we are always happy to receive unsolicited manuscripts. Our new web site (www.jcu.edu.au/astronomy/JAH2) includes a 'Guide for Authors', and this should be followed carefully when preparing a manuscript. Note that our referencing and bibliographical conventions side with the sciences rather than the humanities, and as such are modelled on the Harvard System.

In transferring *JAH*^{2} from Astral Press to James Cook University, we decided to make some design changes to the cover of the *Journal* and the layout of the papers. We thank Tony Cohen from the University's LogicMedia group for assisting with these, and hope that you like the 'new look' *Journal*. We welcome your feedback.

Here, then, is the 2005 June issue of *JAH*^{2}. Enjoy …

Wayne Orchiston
Editor

Journal of Astronomical History and Heritage, 8(1), 3-10 (2005).

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 reactivate 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.

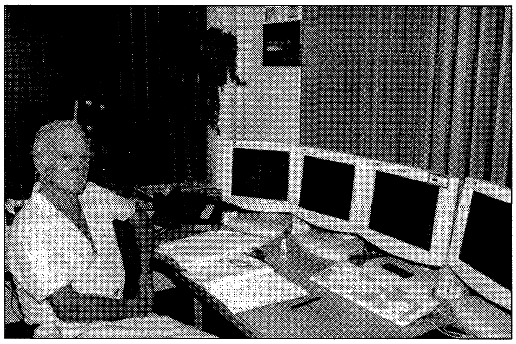

Figure 1: Bruce Slee (1924–) at the control desk of the Australia Telescope Compact Array in 2002.

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.

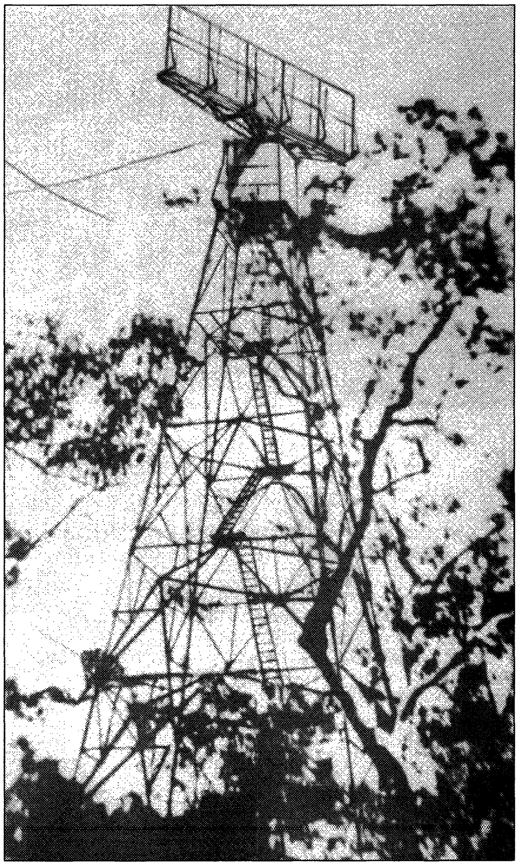

Figure 2: The Lee Point radar antenna (after Fenton and Simmonds, 1993: 27).

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.

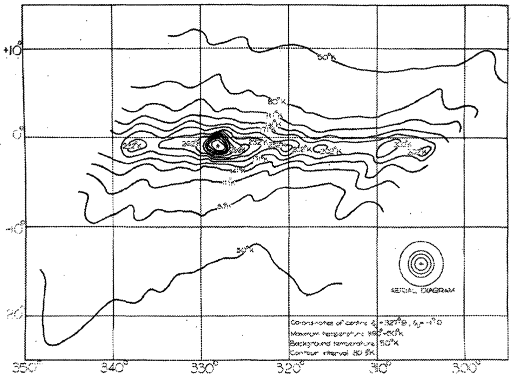

Figure 3: Isophotes of 400 MHz Galactic Plane emission. The conspicuous source is Sagittarius-A (after McGee, Slee and Stanley, 1955: 356).

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.

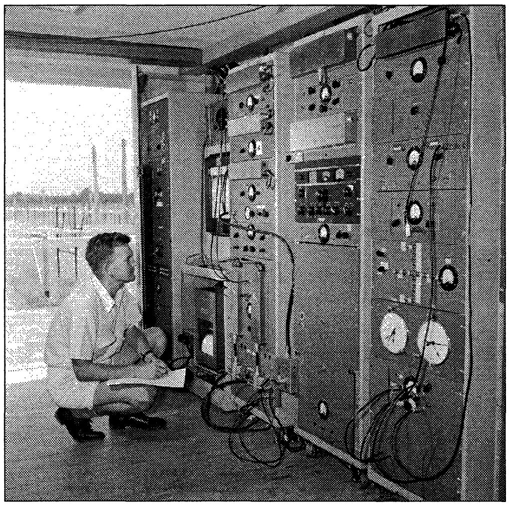

Figure 4: Bruce Slee examines the Mills Cross chart recorders and receivers in 1955 (ATNF image: 3868-10).

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).

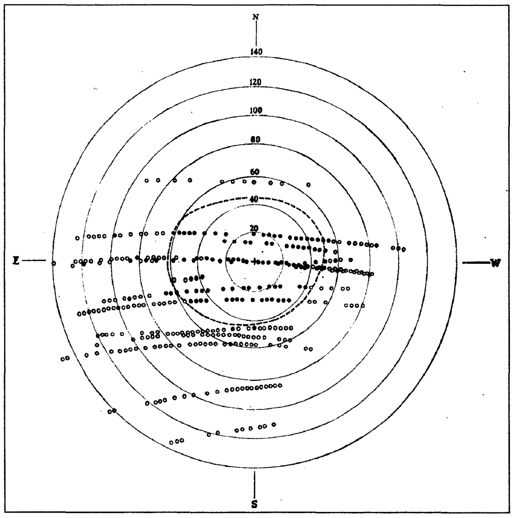

Figure 5: Evidence of coronal scattering is indicated by filled circles and is primarily restricted to the region enclosed by the dashed line. The Sun is marked by a cross, and the concentric circles are at 20 solar radii intervals (after Slee: 1961: 227).

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.

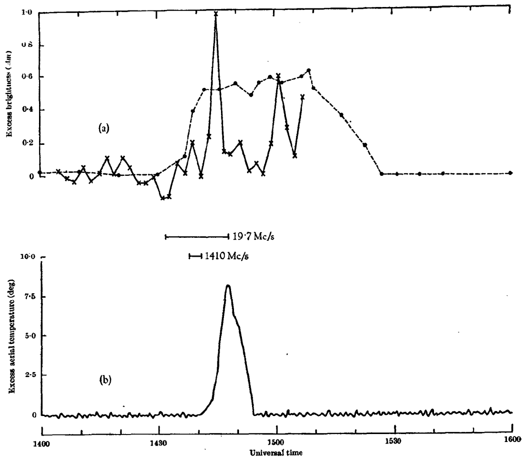

Figure 6: Optical and radio flaring of V371 Orionis on 30 November 1962. (a) Optical light curves (solid line = Baker-Nunn photographs; dashed line = amateur observations). (b) Smoothed line = 410 MHz Parkes plot; time intervals with 19.7 MHz (Fleurs) and 1410 MHz (Parkes) emission are also indicated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

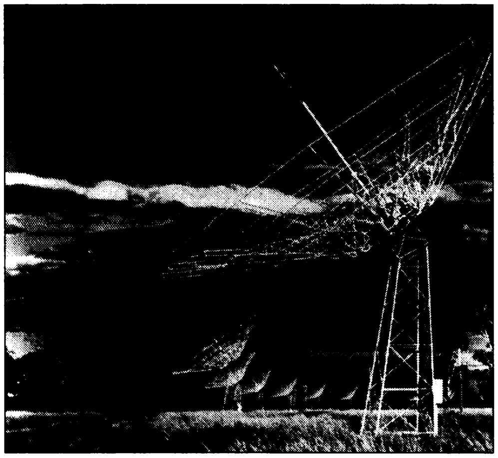

Figure 7: View showing some of the 13.7-m antennas in the CCA (ATNF image: 8553-6).

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).

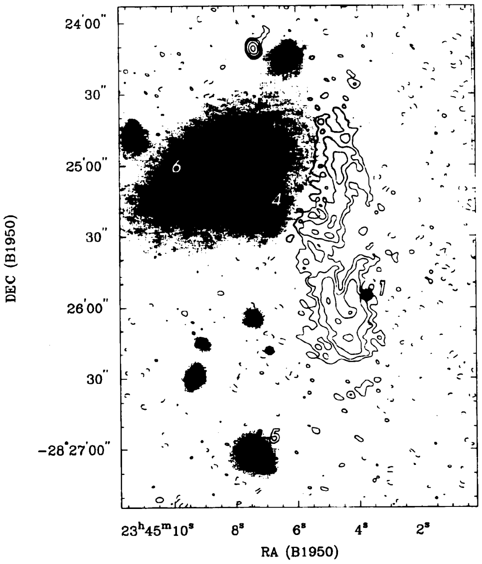

Figure 8: VLA 1425 MHz isophote map of the steep-spectrum relic A4039_9. The extremely large bright galaxy immediately to the left of the upper part of the relic is at the centre of the optical cluster (after Slee and Roy, 1998: L87).

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.

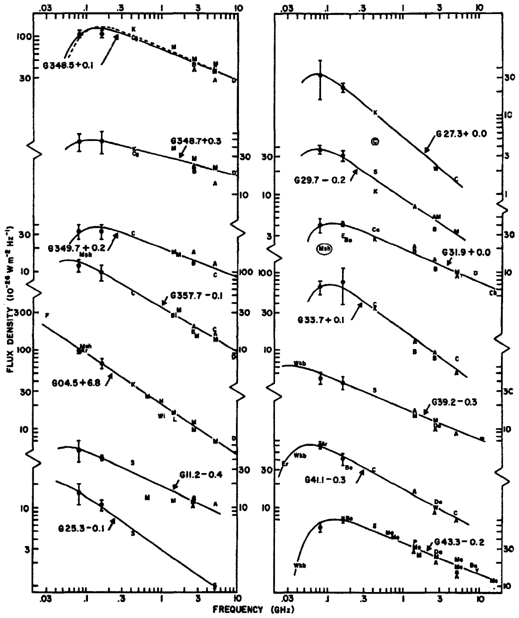

Figure 9: Spectra of 14 SNRs and least-squares fits, showing spectral turnovers at ~100 MHz which were attributed to free-free absorption in the ISM (after Dulk and Slee, 1975: 64).

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.

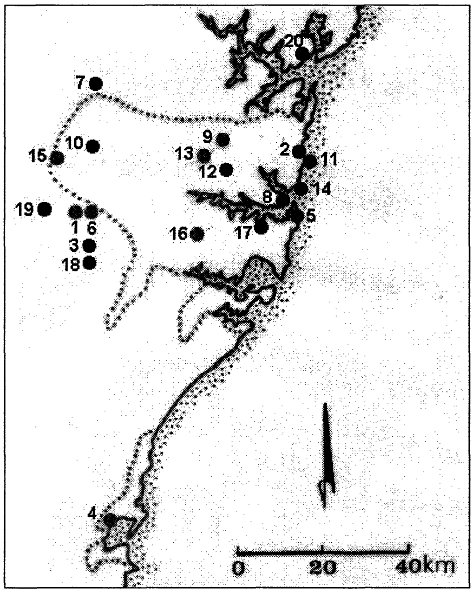

Figure 10: Map of the Sydney-Wollongong regions (dotted lines) showing locations, RP field stations and remote sites used for radio astronomy, 1945-1963, and discussed by Orchiston and Slee in their papers. Key: 1 = Badgerys Creek, 2 = Collaroy, 3 = Cumberland Park, 4 = Dapto, 5 = Dover Heights, 6 = 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

I am grateful to the ATNF for supplying Figure 4 and 7, and to Bruce Slee for his friendship, guidance and encouragement over the past 45 years.

7 REFERENCES

Bolton, J.G., 1955. Australian work on radio stars. *Vistas in Astronomy*, 1, 568-573.

Budding, E., Bakis, V., Erdem, A., Demircan, O., Iliev, L., Iliev, I., and Slee, O.B., 2005. Multi-facility study of the Algol-type binary Librae. *Astrophysics and Space Science*, 296, 371-389.

Christiansen, W.N., 1984. The first decade of solar radio astronomy in Australia. In Sullivan, 1984a, 113-131.

Dulk, G.A., and Slee, O.B., 1975. Spectral turnovers of Galactic supernova remnants. *Astrophysical Journal*, 199, 61-68.

Fenton, M., and Simmonds, E., 1993. *Pictorial III. RAAS Radar in WWII. (An Album for all Areas)*. Forster, printed for E. Simmonds.

Fujita, Y., Sarazin, C.L., Kempner, J.C., Rudnick, L., Slee, O.B., Roy, A.L., Andernach. H., and Ehle, M., 2002. *Chandra* observations of the disruption of the cool core in A133. *Astrophysical Journal*, 575, 764-778.

Fujita, Y., Sarazin, C.L., Reiprich, T.H., Andernach. H., Ehle, M., Murgia, M., Rudnick, L., and Slee, O.B., 2004. *XMM-Newton* observations of A133: a weak shock passing through the cool core. *Astrophysical Journal*, 616, 157-168.

Kellermann, K.I., Orchiston, W., and Slee, B., 2005. Gordon James Stanley and the early development of radio astronomy in Australia and the United States. *Publications of the Astronomical Society of Australia*, 22, 1-11.

McGee, R.X., Slee, O.B., and Stanley, G.J., 1955. Galactic survey at 400 Mc/s between declinations –17° and –49°. *Australian Journal of Physics*, 8, 347-367.

Mills, B.Y., 1984. Radio sources and the log N – log S controversy. In Sullivan, 1984a, 147-165.

Orchiston, W., 1994. John Bolton, discrete sources, and the New Zealand field-trip of 1948. *Australian Journal of Physics*, 47, 541-547.

Orchiston, W., 2004. From the solar corona to clusters of galaxies: the radio astronomy of Bruce Slee. *Publications of the Astronomical Society of Australia*, 21, 23-71.

Orchiston, W., and Slee, B., 2002a. The Australasian discovery of solar radio emission. *AAO Newsletter*, 101, 25-27.

Orchiston, W., and Slee, B., 2002b. Ingenuity and initiative in Australian radio astronomy: the Dover Heights 'hole-in-the-ground' antenna. *Journal of Astronomical History and Heritage*, 5, 21-34.

Orchiston, W., and Slee, B., 2005a. Early Australian observations of historic supernova remnants at radio wavelengths. In Chen, K-Y., Orchiston, W., Soonthornthum, B., and Strom, R. (eds.). *Proceedings of the Fifth Inter-*

national Conference on Oriental Astronomy. Chiang Mai, University of Chiang Mai. In press.

Orchiston, W., and Slee, B., 2005b. The Radiophysics field stations and the early development of radio astronomy. In Orchiston, W. (ed.). *The New Astronomy: Opening the Electromagnetic Window and Expanding Our View of Planet Earth*. Dordrecht, Springer. Pp. 119-169.

Orchiston, W., and Slee, B., 2005c. Shame about Shain! Early radio astronomy at Hornsby Valley. *ATNF News*, 55, 14-16.

Orchiston, W., Slee, B., and Burman, R., 2005. The genesis of solar radio astronomy in Australia, 1945–1948. *Journal of Astronomical History and Heritage*, 8, in press.

Orchiston, W., Chapman, J., Slee, B., Sharp, P., Parsons, B., and Wilcockson, B., 2006. Interpretation of the historic Dover Heights field station: an ATNF heritage project. To appear in *Journal of Astronomical History and Heritage*, 9.

Reber, G., 1984. Early radio astronomy at Wheaton, Illinois. In Sullivan, 1984a, 43-66.

Slee, O.B., 1961. Observations of the solar corona out to 100 solar radii. *Monthly Notices of the Royal Astronomical Society*, 123, 223-231.

Slee, O.B., 1994. Some memories of the Dover Heights field station, 1946–1954. *Australian Journal of Physics*, 47, 517-534.

Slee, O.B., and Orchiston, D.W., 1965. A preliminary radio survey of planetary nebulae south of declination 24 degrees. *Australian Journal of Physics*, 18, 142-148.

Slee, O.B., and Roy, A.L., 1998. An extreme example of a radio relic in Abell 4038. *Monthly Notices of the Royal Astronomical Society*, 297, L86-L92.

Slee, O.B., Solomon, L.H., and Patston, G.E., 1963. Radio emission from flare star V371 Orionis. *Nature*, 199, 991-993.

Slee, O.B., Willes, A.J., and Robinson, R.D., 2003. Long-duration coherent radio emission from the dMe star Proxima Centauri. *Publications of the Astronomical Society of Australia*, 20, 257-262.

Slee, O.B., Roy, A.L., Murgia, M., Andernach, H., and Ehle, M., 2001. Four extreme relic radio sources in clusters of galaxies. *Astronomical Journal*, 122, 1172-1193.

Slee, O.B., Budding, E., Carter, B.D., Mengel, M.W., Waite, I., and Donati, J.-F., 2004. A multiwavelength study of CC Eridani. *Publications of the Astronomical Society of Australia*, 21, 72-81.

Sullivan, W.T. III (ed.). 1984a. *The Early Years of Radio Astronomy. Reflections Fifty Years after Jansky's Discovery*. Cambridge, Cambridge University Press.

Sullivan, W.T., 1984b. Karl Jansky and the discovery of extraterrestrial radio waves. In Sullivan, 1984a, 3-42.

Sullivan, W.T., 1988. Early years of Australian radio astronomy. In Home, R.W. (ed.). *Australian Science in the Making*. Cambridge, Cambridge University Press. Pp. 308-344.

Sullivan, W.T., 1990. The entry of radio astronomy into cosmology: radio stars and Martin Ryle's 2C survey. In Bertotti, R., Balbinot, R., Bergia, S., and Messina, A. (eds.). *Modern Cosmology in Retrospect*. Cambridge, Cambridge University Press. Pp. 309-330.

Sullivan, W., 2005. The beginnings of Australian radio astronomy. *Journal of Astronomical History and Heritage*, 8, 11-32.

Tsarevsky, G.S., Kardashev, N.S., Slee, O.B., Stathakis, R.A., and Budding, E., 2003. Searching for new Galactic microquasars: a progress report. In Demircan, O., and Budding, E. (eds.). *New Directions for Close Binary Systems: "The Royal Road to the Stars"*. Çanakkale, Publications of the Çanakkale Onsekiz Mart University (Volume 3). Pp. 246-248.

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THE BEGINNINGS OF AUSTRALIAN RADIO ASTRONOMY

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Abstract: The early stages of Australian radio astronomy, especially the first decade after World War II, are described in detail. These include the transition of the CSIRO Radiophysics Laboratory, under the leadership of Joseph Pawsey and Taffy Bowen, from a wartime laboratory in 1945 to, by 1950, the largest and one of the two most important radio astronomy groups in the world (with the Cavendish Laboratory at Cambridge University). The initial solar investigations are described, including discovery of the hot corona and development of the sea-cliff interferometer. During this same period painstaking 'radio star' observations by John Bolton and colleagues led to the first suggested optical identifications of Taurus-A (the Crab Nebula), Centaurus-A (NGC 5128), and Virgo-A (M87).

The factors that led to the extraordinary early success of the Radiophysics Laboratory are analyzed in detail, followed by discussion of how the situation changed significantly in the second decade of 1955-1965. Finally, the development of major Australian instruments, from the Parkes Radio Telescope (1961) to the Australia Telescope (1988), is briefly presented.

Keywords: history of radio astronomy, Australia, CSIRO Division of Radiophysics, Sun, radio sources

1 INTRODUCTION

Australian radio astronomy has been at the forefront since its foundation during World War II, with imaginative scientists and engineers, innovative equipment, and strong sponsorship. Soon after War's end a multifaceted program, by far the largest of its kind in the world, was well established at the Radiophysics Laboratory (RP) in Sydney and continually producing pioneering results. The Australians developed fundamental methods of interferometry, discovered the Sun's hot corona, pinpointed the location of solar bursts, and discovered numerous discrete radio sources. By the late 1950s they had produced far more papers in radio astronomy than any other group in the world, and were acknowledged leaders in research on the Sun, Galactic structure, and radio sources. But as new telescope projects became ever more costly, tensions developed over which ones could be funded, resulting in many of the key researchers leaving RP in the 1960s. RP's subsequent work focused on the Parkes Radio Telescope (1961) and Culgoora Radioheliograph (1967), while Sydney University sponsored the Molonglo Cross (1965) and the Fleurs Synthesis Telescope (1973). In subsequent years, these instruments were continually improved, but to remain competitive with the rest of the world eventually a yet larger, national centerpiece was needed—this became known as the Australia Telescope (1988).

How was it that a small, isolated country such as Australia succeeded so impressively in such an arcane field as radio astronomy in the mid-twentieth century? The answers go back to World War II and Australia's relationship with the mother country, as well as the Australian government's policies toward its scientific laboratories. First, a strong community of radio physicists developed in Australia in the 1930s, based on intimate ties with the ionospheric community in England. Second, Britain shared the secret of radar with its Dominions as the War began, nurturing intense radar research, development, and manufacture in Australia. Third, the team of scientists and engineers that grew out of that effort, primarily at RP, remained intact at War's end, and soon put their new skills to use in developing peacetime research ventures. And finally, for two decades dynamic and skillful leadership was provided by E.G. 'Taffy' Bowen and Joseph L. Pawsey—two men whose styles of science and complementary personalities produced a favorable mix for exploring and exploiting the most profitable avenues into the radio-sky.

It is impossible to relate the entire story in the alloted space—major published sources for various aspects of the history of Australian radio astronomy are by Bhathal (1996), Collis (2002: Chapter 13), Goddard and Milne (1994), Haynes et al. (1996: Chapter 8), Orchiston and Slee (2005), Orchiston, Sullivan and Chapman (2006), Robertson (1992), and Sullivan (1988). More general histories, of which major portions cover Australia, are by Edge and Mulkay (1976), Hey (1973), and Sullivan (1982, 1984a, 1984b). This paper is based on and is substantially similar to Sullivan (1988), although Section 6 is wholly new. I treat the first decade after World War II in some detail, and only briefly cover the ensuing years, for it was during this period that the technical, scientific and cultural foundations were laid for many decades of success.

2 THE RADIOPHYSICS LABORATORY DURING THE POSTWAR DECADE

2.1 Transition to Peacetime

The Radiophysics Laboratory (RP) had been established in 1939 in the grounds of Sydney University as a secret branch of the Council of Scientific and Industrial Research (CSIR). Its staff was largely drawn from the strong radio ionospheric community that had been built up during the 1930s by J.P.V. Madsen at Sydney University, T.H. Laby at Melbourne University, and the Sydney research laboratory of Amalgamated Wireless (Australasia), Ltd. (AWA) (Gillmor, 1991). During World War II, RP both designed wholly new radar systems and adapted British radars to Australian needs, and by War's end the staff numbered over three hundred, of whom sixty were professionals and fourteen bore names that would later become familiar in radio astronomy.

As the War closed, various memoranda began to circulate on potential peacetime roles for the Laboratory, culminating in an agenda paper put together by Taffy Bowen (1911–1991) (Figure 1) for a meeting of the CSIR Council in July 1945 (Bowen, 1945a). Bowen, who would soon take over as Divisional Chief, had been working on radar for over a decade (Bowen, 1987). He had been trained in physics at the University of Wales and studied atmospheric physics for his Ph.D. under E.V. Appleton at the University of London in 1933. Two years later, Robert Watson-Watt coopted him into the initial team of four that developed the first operational military radar systems, which soon became vital in the defense of Britain against the Luftwaffe. He led the development of 200 MHz airborne radars, for which he flew thousands of hours (often with Robert Hanbury Brown, who would himself later become a central figure in the development of radio astronomy). In 1940 Bowen was a member of the famous Tizard Mission that delivered radar secrets to the United States, including the cavity magnetron, the first source of power sufficient to make microwave radar a feasible proposition. He remained in the USA for three years, eventually developing airborne radar systems at the MIT Radiation Laboratory. In early 1944 he went to RP as its Deputy Chief, and, although still officially on loan from the British, soon took a liking to RP and to Sydney and spent the remainder of his career (until 1971) there as Chief.

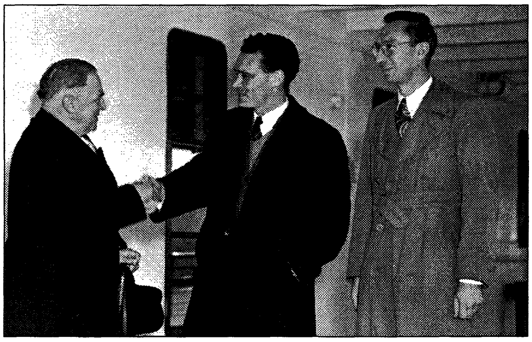

Figure 1: E.G. Bowen (center) and J.L. Pawsey (right) greet E.V. Appleton on board ship after his arrival in Sydney in 1952 for the URSI General Assembly (courtesy: ATNF Historic Photographic Archive).

Bowen's proposals for RP's peacetime role were warmly received and quickly endorsed by his CSIR bosses A.C.D. Rivett and Frederick G.W. White, a New Zealander who preceded Bowen as RP Chief for three years. Rivett felt strongly that each CSIR division should achieve a roughly even balance between free-running basic research and applied research, a vital element in the culture of CSIRO. RP's proposed program thus emphasized new scientific possibilities as well as areas where Australian commerce and industry would more immediately benefit. Bowen and his staff were clearly as excited about the potential of radar techniques in peace time as they were weary of applying them to warfare. It mattered not that RP's original *raison d'être* had disappeared—fresh directions could now be charted. The agenda paper enthused that the new radar techniques were "... perhaps as far-reaching in themselves as the development of aircraft [during World War I] or the introduction of gunpowder in a previous era." It laid out a long shopping list of possible projects in radio propagation, vacuum research (directed toward generating power at millimeter wavelengths), radar aids to navigation and surveying, and radar study of weather. These topics, along with producing the *Textbook of Radar*, which incorporated RP's knowledge and was edited by Bowen (1947b), were to form the initial postwar program.

At this time, RP was CSIR's glamour Division, arguably containing within its walls the densest concentration of technical talent on the continent, and CSIR was eager to keep this 'winner' intact. As Frank Kerr, one of RP's early staff members, recalled:

> [Basic radio research] ... was thought of as a good subject for the Lab to get into, partly in order to keep the Lab in being because it was a collection of good people, well trained in the arts of radio. Especially at that time there was a feeling that it had been a great national value to have had the Lab, and so it was possible to sell the idea to the authorities that the group should be kept in existence as a 'national asset'. (Kerr, 1971: 7T).[1]

Keeping the best of the research staff at RP was also immeasurably aided by the fact that research in physics and engineering at Australian universities after the War was minimal; Government funds for university scientific research were thirty times less than for CSIR. In contrast to the situations in England and the United States, the young cadre of RP researchers saw their wartime Laboratory as the best place to continue their peacetime careers. Despite a considerable reduction of staff at War's end, most who left were not oriented toward research. Few researchers had come from the universities (except as recent graduates) and fewer returned. Academia's role in Australian physics research would not strengthen until the 1950s when students were first able to do their postgraduate work at home (Home, 1982-83).

RP's assets included not only its scientists and engineers, but also its significant support staff of technicians, a camaraderie molded during the War, ample laboratory space and workshops, and bulging stores with the latest radio electronics. This last was considerably augmented shortly after the War's end by an extraordinary bonanza. A large amount of American and British equipment (including whole aircraft!) was being discarded by loading it on the decks of aircraft carriers, taking it a few miles offshore, and bulldozing it into the sea. Bowen got wind of this, however, and for two or three weeks was allowed to take RP trucks down to the Sydney docks and load them up with radar and communications gear, often in unopened original crates. For several years thereafter RP researchers drew on this surfeit.

While RP's continued existence was assured, its direction changed from developing military hardware to a mixture of fundamental research and applications of radio physics and radar to civilian life. This policy was one of the key ingredients of RP's postwar success; in his 1945 strategy document Bowen stated that peacetime military work by CSIR "... stifles research and seldom produces effective assistance to the Armed Forces." In 1949, CSIR became CSIRO, the Commonwealth Scientific and Industrial Research Organization, and White became its number-two man

—over the next two decades he was a major force in fostering the growth of his old division (see Minnett and Robertson, 1996).

2.2 Overall Research Program

Major programs at RP waxed and waned over the years 1946-1953. The plots of Figure 2 show the bare trends,[2] but one of the leading researchers, namely Paul Wild (1965), more elegantly likened these years to the Biblical parable:

> A sower went out to sow his seed, and as he sowed some fell by the wayside and it was trodden down and the fowls of the air devoured it. And some fell upon a rock, and as soon as it sprung up it withered away ... And other fell on good ground, and sprang up and bare fruit an hundredfold. (i.e. Luke 8: 5-8).

Vacuum physics work died away within two years and work on radar applications steadily lessened over the first five years. The two research programs that grew were radio astronomy (although note that this term was not used until the 1949 report) and rain and cloud physics. Between 1946 and 1949 these increased their share of the professional staff from 6% to 63%. Because the total staff grew by only one-quarter over this same period, there were clearly many reassignments of personnel. In terms of papers published in the scientific literature, radio astronomy and rain and cloud physics also dominated, accounting for 71% of the papers by 1949 and 65% over the eight-year span. The radio astronomy staff (compared to cloud physics) produced more than double the number of papers per person.

Rain and cloud physics, in which Bowen himself specialized and which he personally oversaw, attempted to understand the way clouds and rain behave. Microwave radar measurement of clouds and rain, often from aircraft, became a central technique. Buoyed by one of the first successes in seeding clouds, the RP group hoped that rainmaking for the dry Australian climate would ultimately become a reliable and economic proposition. Although this never happened, Bowen's group became one of the international leaders in the field (Home, 2005). This effort, as well as the development of radar systems for commercial aviation, such as a distance-measuring equipment allowing airliners to locate themselves relative to beacons, were important as practical areas balancing off fundamental research in astronomy, fast becoming RP's most visible sector (Bowen, 1984: 105-109; Minnett, 1978: 66-68T). But even radio astronomy was sometimes shoehorned into the role of practicality, as in the 1949 *Annual Report*:

> Radio astronomy has already made important contributions to our knowledge and, like any fundamental branch of science, is likely to lead to practical applications which could not otherwise have been foreseen. For example, attempts to explain how certain types of radio waves arise in the Sun are already leading to new techniques for the generation and amplification of radio waves.

Other projects included a mathematical physics section and (after the late 1940s) a group developing an early electronic computer (CSIRAC). And there were always a few ionospheric radio projects going on. The one example of a major effort that failed was vacuum physics, when costs of a desired particle accelerator became too great.

2.3 Growth of Research on Extraterrestrial Radio Noise

Buried in the twenty-four pages describing RP's postwar plan is a fraction of a page under "Radio Propagation" called "Study of extra-thunderstorm sources of noise (thermal and cosmic)":

> Little is known of this noise and a comparatively simple series of observations on radar and short wavelengths might lead to the discovery of new phenomena or to the introduction of new techniques. For example, it is practicable to measure the sensitivity of a radar receiver by the change in output observed when the aerial is pointed in turn at the sky and at a body at ambient temperature. The aerial receives correspondingly different amounts of radiant energy (very far infrared) in the two cases. Similarly, the absorption of transmitted energy in a cloud can be estimated in terms of the energy radiated to the receiver by the cloud. None of these techniques is at present in use. (Bowen, 1945a).

It was this enigmatic paragraph, with its heading designed primarily to indicate that it was *not* talking about thunderstorm noise (atmospherics), that would develop into RP's radio astronomy program! It surprisingly did not explicitly mention *solar* noise, but instead proposed an exploratory program of "very far infrared" radiometry wherein antennas would be pointed to different parts of the sky.

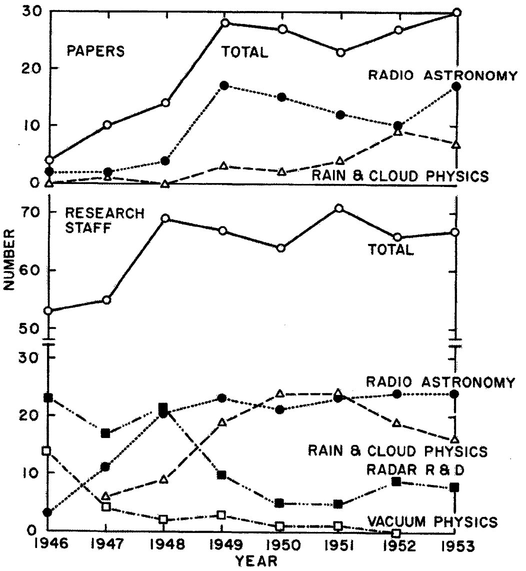

Figure 2: The growth and decline of different research areas at RP over the period 1946-1953, as gauged by the number of published papers per year and the number of research staff. Staff levels not plotted include those for ionosphere (which fell in a similar manner to vacuum physics) and mathematical physics and electronic computing (which rose to a level of about 10 by 1951-1953).

But when reports of anomalies arrived from radar stations (Section 3.1), Pawsey and his colleagues jumped on solar observations in October 1945 and never turned back. Joseph L. Pawsey (1908–1962; Figure 1) by this time had become the linchpin and recognized leader of RP's fundamental investigations through his Propagation Research Group. He had studied physics at Melbourne and obtained his Ph.D. in 1934 under J.A. Ratcliffe at Cambridge, with a dissertation on radio waves reflected off the abnormal E layer of the ionosphere. For five years he then developed equipment needed to make television a viable reality at the famous BBC station at Alexandra Palace. Pawsey's main contributions, which involved no fewer than twenty-nine patents, were in designing the transmission lines and antennas necessary for television's broad bandwidth. After the outbreak of WWII he hastened home and joined the RP staff early in 1940. He became the local 'wizard' on antennas and transmission lines, but by War's end he had also gained new skills working on receivers, operational aspects of radar systems, and atmospheric propagation. Just as importantly, the intense wartime environment had cultivated and honed his abilities to lead scientific research teams. For further biographical details of Pawsey, see Christiansen and Mills (1964) and Lovell (1964).

Work on extraterrestrial noise steadily grew, with Bowen as Chief and Pawsey as his right-hand man (in charge of most research activities) willing to shift resources toward those persons showing superior results or great promise. This flexibility was the CSIR style, largely molded by Rivett, who believed that research programs should be based on people, not topics—getting the right people and then letting them loose. As Bowen (1978: 42T) recalled:

> We tried many things, but the criterion for going on with any program was, of course, success. And the things that Pawsey was trying on the Sun and Bolton on point sources were so outstandingly successful that that's the way we went ... With our first-rate staff as a handout from the War, we had the freedom and the encouragement to find new projects.

Or as Pawsey (1961: 182) put it:

> [Scientific directors must] ... very quickly make decisions and supply facilities for the really promising developments. In all too many cases elsewhere the energies of scientists are taken up in advertising the potentialities of their prospective investigations in order to obtain any support at all.

As the years passed, work on solar and cosmic noise grew in importance at RP and a circle of group leaders emerged (most are pictured in Figure 3). Besides his overall supervision, Pawsey led a large group studying numerous aspects of the radio Sun (Section 3). In 1947 John G. Bolton began his pioneering work on discrete radio sources (Section 4) and soon had an active group around him. J. Paul Wild arrived in 1947 and, after a year languishing in the instrument test room, moved into research on solar radio bursts with a swept-frequency receiver. Bernard Y. Mills worked on a variety of projects before permanently switching in 1948 to radio astronomy; he briefly researched the Sun and then began his own program on discrete sources (see the paper by B. Slee in a forthcoming issue of this journal). W.N. 'Chris' Christiansen arrived at RP in 1948 from AWA and immediately plunged into his own solar research program. He was unique among this group in that, despite his career as an antenna engineer, he had long wanted to be an astronomer (Christiansen 1976: 1, 6T). Jack Piddington and Harry C. Minnett began a program of microwave research in 1948 (for example, measuring the brightness temperatures of the Moon), and Frank J. Kerr and C. Alexander Shain started on lunar radar in 1947 in order to study the ionosphere. Finally, Stefan F. Smerd and Kevin C. Westfold complemented all of the observational work by working on the theory of solar radio emission.

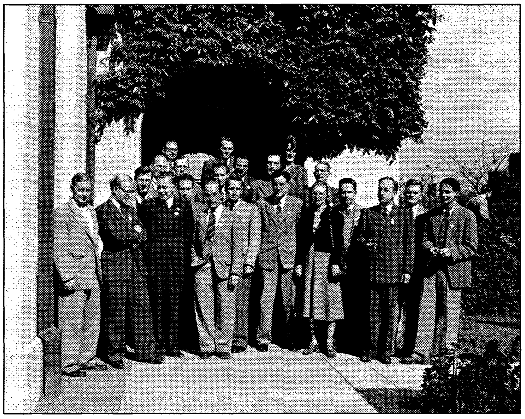

Figure 3: Radio astronomers at Sydney University for the 1952 URSI General Assembly. Left to right, ground level: W.N. Christiansen, F.G. Smith (England), J.P. Wild, B.Y. Mills, J.-L. Steinberg (France), S.F. Smerd, C.A. Shain, R. Hanbury Brown (England), R. Payne-Scott, A.G. Little, M. Laffineur (France), O.B. Slee, J.G. Bolton. First step: C.S. Higgins, J.P. Hagen (USA), J.V. Hindman, H.I. Ewen (USA), F.J. Kerr, C.A. Muller (Netherlands). Second step: J.H. Piddington, E.R. Hill, L.W. Davies (courtesy: ATNF Historic Photographic Archive).

Among all these successes the RP archives also give evidence of at least one important (in retrospect) missed opportunity, that of discovering the 21 cm spectral line arising from interstellar hydrogen. The line had been predicted in 1944 in Holland, and its 1951 discovery at Harvard and Leiden Universities was to be one of the major turning points in early radio astronomy. Pawsey first got wind of the idea in early 1948 while on a tour of the United States. His report home triggered two years of intermittent activity at RP. Wild published a full theoretical analysis, Bolton and Westfold translated a Russian paper and were eager to search for the line, and Mills also gave the hunt serious consideration. But despite all this activity, in the end the decision every time of Bowen, Pawsey and their staff was to not pursue the line. For example, Mills was looking for an independent line of research on cosmic noise in 1949. He and Pawsey discussed two main avenues:

> One was a search for the hydrogen line. Pawsey was very interested in it at the time. And the other was trying to locate very precisely the positions of radio sources. And it was a difficult decision to make. I eventually chose the precise positioning because I was more familiar with some of the techniques, and it looked as if it was something

> that would lead to an immediate result, whereas the other was extremely speculative. (Mills, 1976: 6-7T).

Mills went on to make vital contributions to knowledge of discrete sources, so the decision in his case not to pursue the hydrogen line can hardly be called a managerial mistake. Nevertheless, given its resources and technical expertise, the fact remains that RP surely would have soon succeeded in detecting the interstellar 21 cm line if it had ever made a serious effort. As it turned out, RP *did* make first-rate contributions to 21 cm hydrogen observations in the early 1950s (starting with Christiansen and Hindman, 1952), but only after others had taken the initiative.

3 EARLY SOLAR WORK

3.1 Wartime Efforts

As radar receivers during the War became more sensitive and moved to higher frequencies, concepts of receiver noise, background noise, and antenna temperature gained currency:

> Receivers were getting more and more sensitive and we were concerned with the whole thermodynamic theory of their noise level and its relationship, through the antenna, to space—if the antenna were in an enclosure at three hundred degrees, what would be the noise level? This was different from the purely circuit approach that had been worked up by Nyquist and others ... And it obviously occurred to Ruby Payne-Scott and Joe Pawsey that radiation from objects might possibly be seen. I remember that Ruby had a small paraboloid poking out a window at certain objects in the sky to see how the noise level varied. (Minnett, 1978: 10T).

Ruby V. Payne-Scott (1912–1981; Figure 3), the only woman to make a substantial contribution to radio astronomy during the postwar years, was able to do so only because she kept her marriage secret from 1944 to 1950, when CSIRO changed its policy forbidding married women to join the permanent staff. But the following year she resigned from RP in order to raise a family, and never again participated in research. She trained before the War as a physicist at Sydney University, worked on cancer radiology, spent two years at AWA, and from 1941 on at RP mainly worked on display systems and calibration of receivers. She soon became known around RP for her considerable intellectual and technical prowess, forthright personality, and 'bushwalking' avocation.

It was in March and April 1944 that Pawsey and Payne-Scott (1944) first looked at the microwave sky. In their subsequent RP report they discussed various contributions to the noise power measured by a receiver-antenna combination and cited Karl Jansky's and Grote Reber's (1940) work in the US on cosmic static. But their operating wavelength of 10 cm was far shorter than that of earlier reported work on noise from either terrestrial or extraterrestrial sources. They used a 20 × 30 cm horn connected to a receiver with a system temperature of ~3500 K, one person pointing the horn around the room or out the window in various weather conditions, the other taking readings from a meter. Changes of 20 to 300 K in antenna temperature were noted, and Pawsey and Payne-Scott were particularly struck by the apparently low absolute temperature of the sky, less than 140 K. Moreover, they noted a "most unusual" consequence of this: inserting attenuation between the horn and receiver actually *increased* the output!

They also tried to detect microwaves from the Milky Way with the same receiver and a 4 ft dish pointing first in the vicinity of Centaurus and then away. There was no detectable difference, that is, less than ¼% (<10 K), "... very much less than that observed by Jansky and Reber." (ibid.). Appealing to Eddington's work in the 1920s (about which they undoubtedly learned from a citation by Reber), they ascribed the low signal to a very low temperature for the material in space.

These Milky Way results were accompanied by a single sentence stating that they did not try for any solar radiation. It would seem that they were then unaware of either J.S. Hey's British or G.C. Southworth's American secret reports on the Sun, but given that they mentioned the Sun at all, why did they not try for it? If they had, they probably would have easily detected a change in power output.[3]

These kinds of ideas were thus in the air around RP and therefore, as already discussed, merited a short paragraph in Bowen's proposed postwar program. But the archival evidence indicates that what really galvanized Bowen and Pawsey into jumping onto solar noise was not this preliminary experiment, nor reports from overseas, nor *ab initio* calculations, but the 'Norfolk Island effect'—solar radio bursts observed by New Zealand military radar stations from as early as March 1945 (Orchiston, 2005a). When Bowen learned of this in July 1945, he was entranced:

> These results are remarkable in that while one would expect to receive solar noise radiation on S. or X. band equipment [10 or 3 cm wavelength], a C.O.L. antenna and receiver at 200 Mc/s is quite unlikely to do so. I have heard rumours of the same thing happening in England, but as far as I am aware, the subject has never been followed up. We are therefore going to attempt to repeat the observations here in Sydney to see if we can track down the anomaly. (Bowen, 1945b).

This letter testifies that in August 1945 Bowen and Pawsey knew about thermal, microwave radiation from the Sun, presumably from Southworth's restricted report or his early 1945 paper, but were unaware of Hey's low-frequency solar bursts, either from his 1942 report or its later June 1945 version. Instead, their first investigations were triggered by the New Zealand work, which itself was never published as more than a laboratory report and a short paper in an obscure journal (Alexander, 1945, 1946; Orchiston, 2005a; Orchiston and Slee, 2002). Furthermore, the thrust of these investigations was toward monitoring the Sun for non-thermal bursts of radio waves, unlike what was stated in Bowen's proposed program.

3.2 Solar Bursts and the Sea-cliff Interferometer

Pawsey swung into action and mounted an observing program on a frequency of 200 MHz using existing Air Force radar installations along the coastline near Sydney. Working with him on this were Payne-Scott and Lindsay L. McCready (1910–1976), a receiver expert, pre-war AWA engineer, and RP veteran who at the time was Pawsey's deputy and eventually head of all engineering services at RP. The first observations were on 3 October from Collaroy, fifteen miles north of Sydney (Figure 4) and one-half mile inland. The antenna was an array of 32 half-wave dipoles (Figure 5), and observations were carried out by Air Force as well as RP personnel. After only a week or two of data, Pawsey (1945) noticed that the general level of "this noise effect" was highly variable and seemed to correlate with the number of visible sunspots. For the latter information he had made contact with Clabon W. 'Cla' Allen (1904–1987), a longtime solar astronomer at the Commonwealth Solar Observatory, Mt. Stromlo (near Canberra). After three weeks of monitoring, Pawsey, Payne-Scott and McCready (1946) sent a letter to *Nature* pointing out the close correspondence between the total area of the Sun covered by sunspots and the daily noise power from the Sun. Because the antenna's elevation angle could not be changed, observations were only possible at dawn or dusk and various corrections had to be made for ground and sea reflections, but it was nevertheless clear that the daily values of solar noise varied by as much as a factor of thirty over the three weeks. They also pointed out that, for a thermally emitting disk the size of the optical Sun, their detected levels implied 'equivalent temperatures' ranging from 0.5 to 15 × 10^6 K, much higher than the Sun's 'actual temperature' of 6000 K. Such incredible signals, they reasoned, could not come from atomic or molecular processes, but more likely from "... gross electrical disturbances analogous to our thunderstorms."

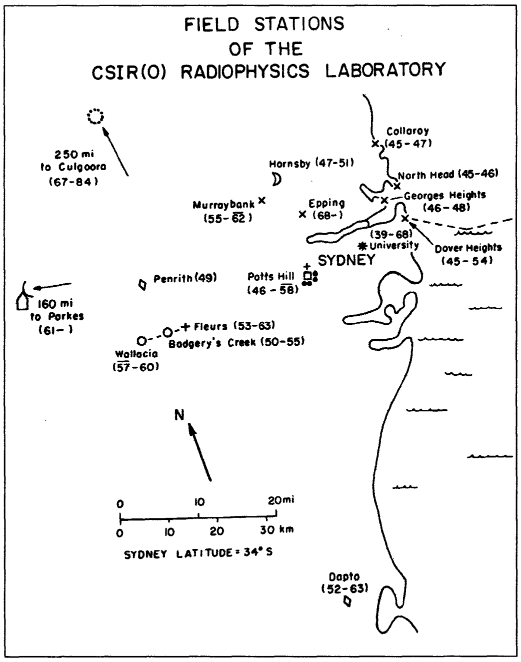

Figure 4: Sites of chief RP field stations and headquarters at Sydney University and at Epping. Each station has the years of operation indicated (years with a bar overhead are uncertain).

With such a promising start, Bowen and Pawsey decided to increase their efforts on solar noise, and continued monitoring for another ten months. Gradually Air Force personnel and equipment were phased out as RP took over. Pawsey's group made measurements at a variety of frequencies (but mostly at meter wavelengths), and used antennas (e.g. see Figure 6) located at four different coastal radar sites around Sydney: Collaroy, North Head, Georges Heights, and Dover Heights (Orchiston and Slee, 2005) (see Figure 4). And while these data rolled in, they also educated themselves about the solar atmosphere and began thinking about how it might emit radio waves. This led to Payne-Scott's discovery of incorrect calculations by Southworth, and to some changing interpretations. For instance, Bowen wrote to Appleton in January 1946 in order to comment on the latter's letter in *Nature* on radio noise and sunspots. Bowen (1946a) pointed out that RP had now obtained the "... first direct experimental verification of this effect ...", and that, unlike in the upcoming *Nature* letter from RP, he now felt that the solar noise was not "electromagnetic", but of thermal origin, either "... from the depths of the sun or in some way from the corona."

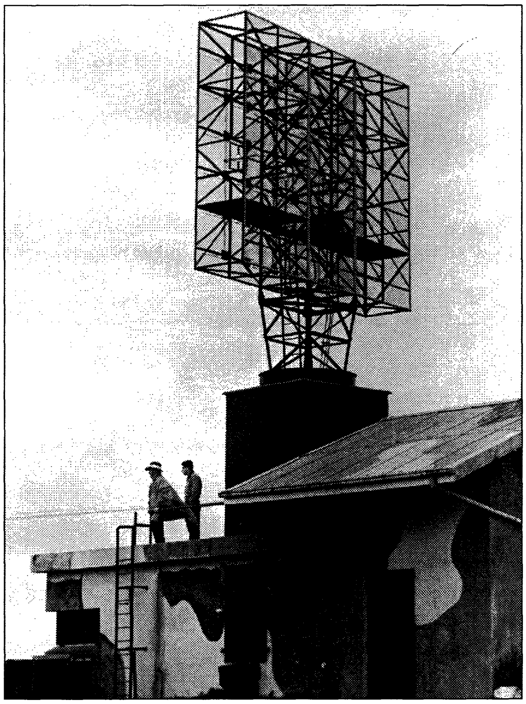

Figure 5: A 200 MHz wartime radar antenna for shore defense, consisting of a 36-dipole array rotatable only in azimuth, at Dover Heights (1941). This and a similar antenna at Collaroy were used by Pawsey's group in 1945-1946 as sea-cliff interferometers for observations of the rising Sun (courtesy: ATNF Historic Photographic Archive).

The climax of this initial period came in early February 1946 when by good fortune the largest sunspot group ever seen (until then) chose to make its appearance. When Allen phoned with news of the giant group (covering about 1% of the Sun's visible disk), the RP group intensified their monitoring and realized that they now had the opportunity to take advantage of a property of their antenna system that had previously been more bother than help. A single antenna situated on the edge of a cliff or a hilltop, looking near the horizon over a relatively smooth terrain or over the sea, in fact acts as an interferometer and can achieve far better angular resolution than would otherwise be possible. The interference in this case is between that portion of a wave-front directly impinging on the antenna and that portion reflected from the sea, which must travel an additional length equal to twice the cliff height times the sine of the source's elevation angle. In classical optics this arrangement is known as 'Lloyd's mirror', and the fringes obtained are equivalent to those with a conventional interferometer consisting of the antenna and an imaginary mirror image located under the base of the cliff. With the antennas at Dover Heights and Collaroy located 85 and 120 m above the sea, the respective fringe lobes at 1.5m wavelength were spaced by $30'$ and $21'$. In principle, then, one could locate objects with an accuracy of ~$10'$, far better than the ~6° beam of the antenna considered by itself.

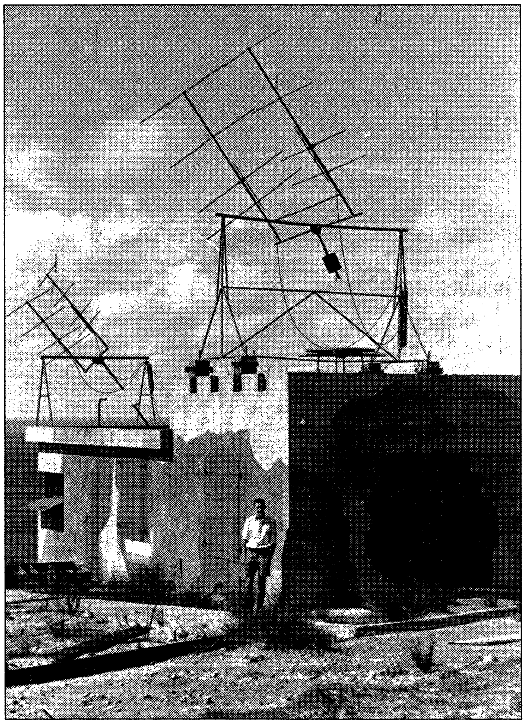

Figure 6: WWII blockhouse with 100 MHz (left) and 60 MHz (right) twin Yagi antennas at Dover Heights (1947). The same pairs, with the Yagi elements parallel and pointing toward the horizon, were used for the first studies and surveys of discrete sources by John Bolton (pictured) and his group (courtesy: ATNF Historic Photographic Archive).

This phenomenon was nothing new to those who had been developing radar systems, for during the War radar beams often pointed near the horizon, as with search radars on a ship or a coastline. The reflected signal from a distant aircraft was well known to oscillate as it passed through the fringes or lobes of such a radar. This effect was both a blessing and a curse to the radar systems designer, for it could be used to gather precise information on a target's height, but on the other hand it meant that low-flying aircraft could sneak in 'under' a radar, since the first lobe was *not* at the horizon, but above it by a considerable amount, especially if the antenna was not high above its surroundings.

So Pawsey and his colleagues used this sea-cliff interferometer[4] to advantage as the bespotted Sun rose over the ocean. The general level of solar emission was far above normal for several days and often interspersed with bursts. As before, they found that the solar signal appeared at sunrise and gradually faded as the Sun rose above the antenna beam, but now superimposed were striking oscillations, the interferometric fringes (Figure 7). And the exciting thing was that the very presence of these oscillations implied that the source of the solar signal was a good bit smaller than the spacing of the fringes (20-$30'$) and the $30'$ size of the optical Sun. Exactly how much smaller the emitting region was, as well as its location, could be worked out through details of the oscillations' amplitudes and phases. This led to Figure 8, where they inferred that the emitting region on any given day had a width of 8–$13'$ and coincided with the giant sunspot group being carried along by the Sun's rotation. Even though the fringes of the sea-cliff interferometer were oriented parallel to the horizon and thus could give no information about the azimuth of the emitting region, it seemed eminently reasonable that the sunspot group itself originated the enhanced radiation, directly confirming what Hey, Appleton and Alexander had earlier only surmised.

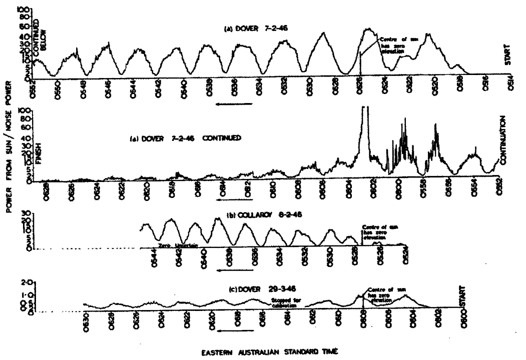

Figure 7: Sea-cliff interference patterns obtained at 200 MHz in February and March 1946. When the Sun rose, the fringes suddenly appeared (note that 'radio sunrise' came earlier than optical sunrise) and then gradually faded away an hour later as the Sun moved above the antenna beam. Note the greater ratio of fringe maximum to minimum for the top observations, indicating that the radiation originated from a smaller region of the Sun. The very fast variations and intense signals recorded at 0600 on 7 February indicate a solar outburst. Note the closer spacing of the fringes for the Collaroy observations, taken from a higher elevation above the sea (after McCready, Pawsey and Payne-Scott, 1947).

In a paper submitted to the *Proceedings of the Royal Society* in July 1946,[5] McCready, Pawsey and Payne-Scott (1947) reported the above results and much more. They expanded on their first results in *Nature* and now characterized the solar radiation as consisting of two components: (1) a slowly changing type that could vary by a factor of 200 in intensity over many days, and (2) intense bursts, lasting from less than a second up to a minute, that could be tens of times more powerful than the general level on a given day. These results were so unexpected that they worried at length that the ionosphere might somehow induce the bursts, but various arguments, principally the fact that separate sites observed the bursts at the same time (to within a second), convinced them that this indeed was an extraterrestrial "and presumably solar" phenomenon. As in their previous letter to *Nature*, they pointed out that the equivalent brightness temperatures for these bursts were extraordinarily high, as much as 3×10^9 K.

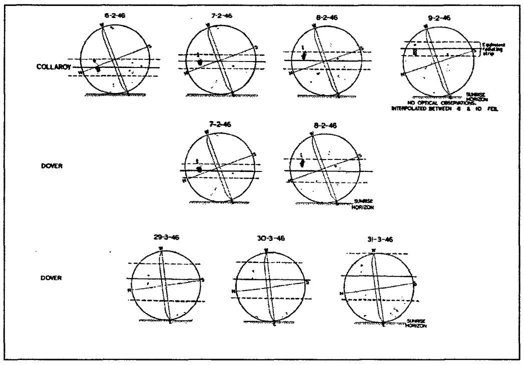

Figure 8: Sketches of optical sunspots visible on the days corresponding to Figure 7. The top two rows are dominated by the great sunspot group, while the March observations show much less activity. 'N-S' indicates the rotation axis of the Sun. The three horizontal lines on each sketch indicate the center and estimated width of the 'equivalent radiating strip' causing the radio fringes (after McCready, Pawsey and Payne-Scott, 1947).

This seminal paper also explained many basics of the sea-cliff interferometer, considering effects such as refraction (the worst uncertainty), the Earth's curvature, tides, and imperfect reflection from a choppy sea. As mentioned above, many of these effects had already been worked out during the War; for instance, in a 1943 RP report by J.C. Jaeger. But Pawsey's group also introduced a vital *new* principle, namely that their interferometer was sensitive to a single Fourier component (in spatial frequency) of the brightness distribution across the Sun, and that in principle a complete Fourier synthesis could be achieved if one had enough observations with interferometers of different effective baselines:

> Since an indefinite number of distributions have identical Fourier components at one [spatial] frequency, measurement of the phase and amplitude of the variation of intensity at one place at dawn cannot in general be used to determine the distribution over the sun without further information. It is possible in principle to determine the actual form of the distribution in a complex case by Fourier synthesis using information derived from a large number of components. In the interference method suggested here ... different Fourier components may be obtained by varying the cliff height *h* or the wave-length λ. Variation of λ is inadvisable, as over the necessary wide range the distribution of radiation may be a function of λ. Variation of *h* would be feasible but clumsy. A different interference method may be more practicable. (McCready, Pawsey and Payne Scott, 1947: 367-368).

Much of the subsequent technical development of radio astronomy was to be concerned with this method of making high-resolution cuts across sources, and eventually complete maps. By the early 1950s their suggested type of Fourier synthesis was indeed central to much of radio astronomy. But the last two sentences of the above quotation were prophetic, for it was not sea-cliff interferometry, but the more tractable and flexible conventional interferometry with separate, movable antennas, that made such mapping a reality.

3.3 The Million-degree Corona

Sometime toward the middle of 1946, Pawsey extracted another jewel from his wealth of data. He noticed that his large set of daily values of the 200 MHz solar flux density had a peculiar distribution (Figure 9), with a sharp lower limit corresponding to an equivalent brightness temperature for the solar disk of about 1×10^6 K. This was drawn from the same data presented earlier, but looked at in a new way: first, with a histogram of values (~150 values over seven months) rather than a plot against time, and second, using single-day values rather than three-day averages. Pawsey had earlier argued that three-day averages were necessary because the solar bursts frequently vitiated daily observations, but now he saw that this averaging had also tended to mask the marked lower limit of intensity, since about two-thirds of all days exhibited enhanced levels.

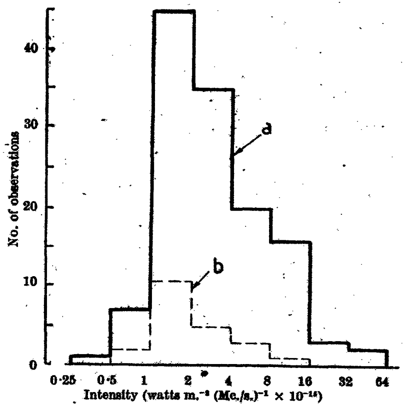

Figure 9: Histograms of daily 200 MHz solar intensity: (a) October 1945 to March 1946, observed by Air Force personnel, and (b) March-May 1946, RP staff. Note the marked lower limit, corresponding to an effective (brightness) temperature for the solar disk of ~1 x10^6 K (after Pawsey, 1946).

At this same time David F. Martyn (1906–1970), the leading ionospheric theorist in Australia (then at the Commonwealth Solar Observatory, Mt. Stromlo) and a key figure in wartime RP (Section 3.4), became very interested in this hot new field and introduced a theory that could explain a million-degree base level for the solar radiation. He learned, undoubtedly from discussions with Allen and Richard v.d.R. Woolley, the Observatory's Director, that recent studies of ionization states and spectral-line widths strongly suggested that the solar corona had a temperature of about 1×10^6 K. *Why* the corona was so hot was not at all understood, but the evidence was there. Martyn realized he could apply standard techniques in ionospheric theory to calculate the expected radio emission from the Sun. Once he had adopted likely values for the electron densities in the corona, he found that the corona was opaque at Pawsey's kind of frequencies. The observed radio waves were therefore emanating not at all from the 6000 K optical surface (photosphere) of the Sun, but from well above the photosphere out in the million-degree corona. When the Sun was quiet, this coronal thermal emission constituted the entire solar signal; when active, the coronal emission was dwarfed. Furthermore, at shorter wavelengths, the observed emission would come from deeper in the corona, and eventually even from the chromosphere. This powerful idea thus explained why the measured brightness temperature of the quiet Sun always seemed greater than 6000 K and sharply increased at longer wavelengths. It also meant that one could now study the corona without the inconvenience of having to chase down a total eclipse or resort to a coronagraph. As it turned out, in the Soviet Union a few months earlier Vitaly L. Ginzburg had indedependently made similar calculations while considering the possibility of reflecting radar off the Sun; and the basic ideas were again independently presented, yet a third time, in the Russian literature in a late 1946 paper by Iosif S. Shklovsky. But Martyn had access to better confirming data and was positioned more in the mainstream of postwar radio astronomy. His paper, in *Nature* for 2 November 1946, had far more influence.

The above description of Pawsey's and Martyn's work seems fairly well established, but there is controversy over whether Martyn first predicted the million-degree corona and then suggested that Pawsey seek it in his data, or whether Pawsey first found it empirically and so instigated Martyn's working on the problem. The archival evidence unfortunately does not speak with certainty. It does show that Pawsey and Martyn were planning a joint publication on this subject in July and August of 1946, but that Martyn then backed out since he and Woolley had decided to do their own theoretical study. Pawsey then persuaded Martyn to change his mind, but in the end Martyn (1946) sent off his own note to *Nature* early in September, apparently without Pawsey's knowledge. Pawsey got wind of this, however, and within a week convinced Martyn to agree that Pawsey (1946b) should send in his own short note and suggest to *Nature*'s editor that it follow Martyn's.[6] The collaboration had clearly gone sour, resulting in two adjacent notes: Martyn's did not mention Pawsey's base-level data at all (citing only Reber's and Southworth's measures of the solar intensity), while Pawsey's acknowledged his indebtedness to Martyn for "… pointing out to me the probable existence of high-level thermal radiation."

Within a few months, however, arguments developed over who had priority over 'the million-degree corona'. In January Bowen (1947a) wrote to Martyn because of "… your insistence on the importance of the written as against the spoken word." Bowen cited a year-old press release, which referred to the RP work as indicating that the usual 'apparent temperature' of the Sun was a million degrees, as clearly antedating Martyn's note in *Nature*, and said that RP knew about million-degree radiation from the Sun long before Martyn came along. Further direct evidence lies in 1948 letters commenting on a draft of a radio astronomy review then being written by Appleton for the International Union of Radio Science (URSI). Martyn (1948) wrote:

> There is a natural tendency now to look on my theory as one designed to explain the observed facts, which followed rapidly upon its heels. In point of fact it was developed (see the internal evidence in Pawsey's *Nature* letter) before the facts were known. It is a theory of prediction rather than explanation, and perhaps has correspondingly greater weight because of that.

And Pawsey (1948d) separately wrote:

> The actual sequence of events ... was as follows: (a) observation of considerably high and very variable effective temperatures, 10^6-10^8 degrees on 200Mc/s – J.L.P. and colleagues. (b) Suggestion of high-temperature coronal thermal emission – D.F.M. and colleagues. (c) Successful search for 10^6 degree base level on 200 Mc/s – J.L.P. (d) Detailed theory – D.F.M.

Pawsey (1948c) also wrote from overseas to Bowen about this time:

> I think Martyn might get a mention in [Appleton's] section on the discovery of thermal radiation. I am all for a quiet life and the theory was a vital part of the discovery.

From this evidence it would appear most likely that Pawsey's own recounting of events best tells the story, although it should be noted that he was at times self-effacing. It is clear that Martyn's withdrawal from collaboration and lack of any mention of Pawsey's base-level work upset the RP staff. But this notwithstanding, it seems that Martyn was indeed the one who brought in the previous astronomical evidence of a million-degree corona and who pointed out that the million-degree 'effective' or 'apparent' temperatures cited by the RP group could actually represent *thermal* emission from the solar atmosphere. Pawsey and his colleagues had calculated these temperatures, but thought of them only in a formal sense. In fact, to them these incredibly high values were at first prima facie evidence of *non*-thermal phenomena.

3.4 Mt. Stromlo

It is remarkable that the Commonwealth Solar Observatory at Mt. Stromlo worked so closely with RP right from the start—such active collaboration between astronomers and active radio investigators occurred no where else in the world in the first few years after the War.[7] Since 1930, however, the Observatory had been doing a small amount of RRB-funded ionospheric research (in particular by Arthur J. Higgs, who after the War became RP's Technical Secretary). Moreover, during the War, Cla Allen had worked on the effects of sudden solar disturbances on ionospheric conditions and optimum communications frequencies. As we have seen, Allen from as early as October 1945 was feeding optical solar data to RP and indeed over the years his ties with RP remained strong (Smerd, 1978: 92A). Since the Commonwealth Solar Observatory was already in the solar-monitoring business at optical wavelengths and RP did not want to maintain a strict daily patrol, the idea soon developed of RP installing a radio system at Mt. Stromlo. From April 1946 onward Allen oversaw regular 200 MHz solar monitoring with a steerable array of four Yagi antennas (similar to the 2-Yagi antennas shown in Figure 6). In early 1949 he used the same array to make a complete map of the Galactic background radiation (Allen and Gum, 1950).

In addition to Allen, Martyn worked on extraterrestrial noise as a sideline to his ionospheric research.

Besides his important work on the million-degree corona, he also pointed out in his 1946 *Nature* note that at wavelengths of 60 cm or less the quiet Sun should appear brighter at its edges than in the center. This prediction of 'limb brightening' turned out to be qualitatively correct, although it took more than five years before observations of sufficient detail seemed to settle the question.

This radio activity could not have flourished without the encouragement of the Observatory's Director and Commonwealth Astronomer, Richard Woolley (1906–1986). Woolley was a stellar and dynamical theorist, an Englishman who had come to Australia to take over the Commonwealth Solar Observatory in 1939, and who would return to Britain in 1955 as Astronomer Royal. He had a personal interest in the radio work; for instance, he authored an early paper on the theory of Galactic noise and others on solar models incorporating radio data. In late 1946 Woolley suggested that Bolton should check for radio emission from the nebulosity near the bright star Fomalhaut, and in 1947, after Martyn had speculated that the Cygnus source (Section 4) might be a distant comet, Woolley searched for such an object. Moreover, relations between Woolley and RP were cordial enough that Bowen first checked with Woolley before sending off the first RP paper on the Cygnus source. Woolley also was elected in 1948 as the first Chairman of the International Astronomical Union's new Commission 40 on Radio Astronomy, and shortly thereafter became Vice-Chairman of Australia's national URSI organization.

Yet despite these fruitful exchanges of ideas, data, and know-how between the astronomers and the radio physicists, tension also existed between Woolley and Martyn on the one hand and Bowen and Pawsey on the other. Much of this stemmed from Martyn and his status as an 'exiled' RP staff member, seconded to the Observatory from Sydney. Martyn had been removed as RP Chief late in 1941 after two years of continual problems—despite his scientific excellence, he did not have the managerial skills or temperament needed to run a large organization developing new technology under the threat of Japanese attack. By 1941 his relations with the military, with industry, and with his own staff were abysmal. On top of this, in early 1941 he was viewed as a security risk because of his liaison with a German woman who had recently emigrated to Australia (Schedvin, 1987: 253-259). With this background, one can understand that his postwar relations with RP often went less than smoothly.

Woolley, too, appears to have developed an ambiguous relationship with RP in particular and with radio astronomy in general. For instance, in a major address on the solar corona, he mentioned Allen's and Martyn's work, but none of RP's results (Woolley 1947). In another talk the same year on "Opportunities for astrophysical work in Australia", radio was not mentioned once, although this may have resulted from his definition of *astrophysical* (Woolley, 1946b). Several interviewees from RP and from Mt. Stromlo have testified to Woolley's lack of support for radio astronomy. Even as late as 1954, when asked about radio astronomy after a popular talk, Woolley apparently replied that in a gathering of 'real' astronomers it was not considered decent to mention radio astronomy (see Bok, 1971; Bowen, 1973, 1984; de Vaucouleurs, 1976; Kerr, 1971, 1987; Mills, 1954; Stanley, 1974; Wild, 1987). On the other hand Woolley was part of a proposal for an independent department of radio astronomy at Mt. Stromlo. The matter culminated in 1951-1952, after the departure of Allen to take up a professorship in England. Professor Mark L. Oliphant (head of physical sciences at the new Australian National University in Canberra) and Woolley made a major thrust to acquire a large radio telescope, but were beaten down by White at CSIRO headquarters and by Bowen and Pawsey (Robertson, 1992: 107-113).

4 RADIO STARS

In August 1946 Bowen, then visiting England, excitedly sent Pawsey a reprint of the recent letter in *Nature* by Stanley Hey, John Parsons and James Phillips (1946) of the Army Operational Research Group. While mapping the general distribution of Galactic noise, they had accidentally discovered that the noise from one particular spot in the constellation of Cygnus fluctuated in intensity on a time scale of minutes. Although they could measure with their beam only that the fluctuating region was less than two degrees in size, they argued that such rapid changes must originate in a small number of discrete sources, perhaps only one. These sources were taken to be stars, by analogy with the Sun and its radio bursts. Pawsey jumped on this. As he wrote (within a few days of receiving Bowen's letter):

> ... we immediately made some confirmatory measurements on 60 and 75 Mc/s, obtaining similar fluctuations, of the same form as the "bursts" observed in solar noise. We have no hint of the source of this surprising phenomenon. (Pawsey, 1946a).

This early success, however, was apparently followed by a period of conflicting observations, during which the reality of the Cygnus fluctuations came into question. In the end Pawsey's group gave up, no longer knowing what to make of Hey's claim (Bolton, 1976: 3-4T; Stanley, 1974: 4-5T).

Cygnus investigations thus lay dormant for several months until resumed by John Bolton (1922–1993), who had joined the RP staff as its second postwar recruit in September 1946 (see Kellermann, 1996). Bolton (Figure 3) was a Yorkshireman who had studied undergraduate physics at Cambridge before joining the Royal Navy, where he first developed radar and then served as a radar officer before demobilization in Sydney Harbour. Assigned to the solar noise problem at Dover Heights, Bolton built two 60 MHz Yagi aerials to follow up on Martyn's earlier detection of circular polarization, and was soon joined by technician O. Bruce Slee, a former Air Force radar mechanic who also had just started at RP.[8] But the Sun was not co-operating with much activity, and so Bolton decided to check for radio emission at the positions of various well-known astronomical objects, as listed for instance in the venerable *Norton's Star Atlas*. His inattention to solar monitoring, however, got him in trouble:

> After a week or two our efforts were cut short by an unheralded visit from Pawsey, who noted that

> the aerials were not looking at the sun. Suffice it to say that he was not amused and we were both ordered back to the Lab for reassignment. (Bolton, 1982: 349-350).

Notwithstanding this setback, a few months later Bolton managed to resume at Dover Heights, where he was joined by electrical engineer Gordon J. Stanley (1921–2001), a New Zealander who had come to RP upon leaving the infantry three years before (Kellermann et al., 2005). This time the goal was to follow up recent studies by Payne-Scott and Donald E. Yabsley on simultaneous solar burst observations at widely spaced frequencies. On 8 March 1947 the Sun obliged with a remarkable burst exhibiting delays of a few minutes between signals arriving first at 200 MHz, then 100 MHz, and finally 60 MHz. The behavior of this and earlier bursts was taken to arise from emission at various critical frequencies as successively higher coronal layers were excited; with a model of electron densities in the corona, it was even possible to infer a speed of ~600 km/s for the ejected material (Payne-Scott, Yabsley and Bolton, 1947). Here indeed was a dramatic confirmation of Martyn's model of different coronal levels effectively emitting different radio frequencies.

Bolton again grew tired of solar monitoring, however, and together with Stanley returned to the Cygnus phenomenon in June 1947 (see Bolton, 1982). The antenna was nothing more than a pair of 100 MHz Yagis (shown in Figure 6) connected to a converted radar receiver and operated as a sea-cliff interferometer. This allowed a three-week reconnaissance of the southern sky, during which they at last reliably found the Cygnus source, as well as hints of two weaker ones (Bolton, 1947). They spent several months checking out the Cygnus source, and by the end of the year submitted papers to *Nature* and the very first issue of the *Australian Journal of Scientific Research* (Bolton and Stanley 1948a, 1948b). Cygnus usually gave a workably strong set of fringes as it rose (Figure 10), and this directly implied that the radiation emanated from a very small, single region of the sky. But the source never rose more than 15° above the northern Sydney horizon and observations were continually harassed by the strong intensity fluctuations that had led to Hey's discovery in the first place. By analogy to the Sun, Bolton and Stanley's analysis split the signal into a constant component (which they estimated as 6000 Jy) and a variable component that added (never subtracted) amounts that fluctuated over times of 0.1-1 minutes. Through auxiliary observations made with other Yagis they found a maximum in the spectrum of the constant component at ~100 MHz, whereas the variable component's intensity increased sharply as frequency was lowered.

The heart of their study was concerned with the size and position of the source. Size came from the solar technique worked out before, namely from measuring the ratio of fringe maximum to minimum. As the 'equivalent radiating strip' became broader, the fringes would wash out in a predictable manner. But Cygnus gave difficulties with (1) subtracting off a considerable baseline slope caused by strong Galactic noise in the vicinity, (2) isolating the constant component from the variable, and (3) determining a proper upper limit for the fringe minimum, for it appeared that the best records in fact showed minima that were not distinguishable from zero (Figure 10). They estimated that the maximum-to-minimum ratio was at least 50, implying that the source size was <8′ (about one-eighth of the lobe separation). Hey's group had inferred that the Cygnus fluctuations must arise from a discrete source or collection of sources, perhaps scattered over two degrees of sky, but here was strong evidence for a single, small source. In fact they thought the source even smaller than their published limit:

> Careful examination of the records suggests a much smaller source size than stated above [8′]. Further experiments using improved receiver stability and greater aerial height will probably substantiate the authors' belief that the source is effectively a "point." (Bolton and Stanley, 1948b: 64).

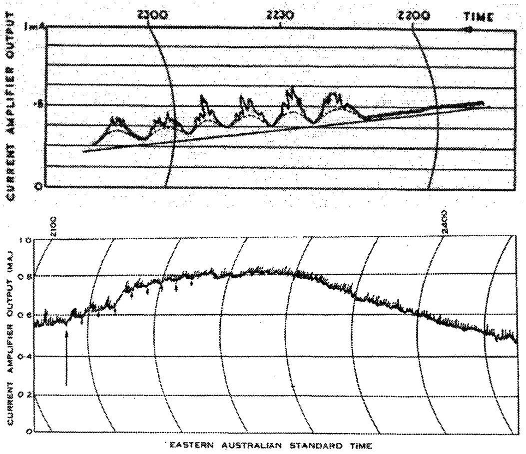

Figure 10: Sea-cliff interference patterns obtained at 100 MHz at Dover Heights for Cygnus-A in June 1947 (top) and for Taurus-A in November 1947 (bottom, discovery recording). Note the ionospheric scintillations superimposed on the Cygnus fringes and the sloping baselines from Galactic background radiation. For the Taurus-A record, the rising point and probable minima of the weak fringes are shown by arrows. Vertical lines on this record are due to interference from a timing mechanism (after Bolton and Stanley 1948b; 1949).

With a source size in hand, they moved on to the even trickier task of a position. This involved analyzing the timing and spacing of fringes in terms of sky geometry and radio wave propagation. One had to find the sidereal time when the source was highest in the sky (culmination) and the length of the arc travelled by the source between rising and culmination. But Bolton and Stanley were forced to tie together observations at three different cliffs around Sydney[9] in order to secure reliable data; furthermore, the necessary corrections for refraction were large and, as it turned out, uncertain. In the end, the derived position was 19h 58m 47s ± 10s, +41° 47′ ± 7′. With this first well-defined position for the enigmatic Cygnus source (Hey's group had been able to give its position only to within 5°), their next step was of course to consult the optical catalogs and photographs. But this was disappointing:

> Reference to star catalogues, in particular the Henry Draper Catalogue, shows that the source is in a region of the galaxy distinguished by the absence of bright stars and objects such as

> nebulae, double and variable stars, i.e., the radio noise received from this region is out of all proportion to the optical radiation ... The determined position lies in a less crowded area of the Milky Way and the only obvious stellar objects close to the stated limits of accuracy are two seventh magnitude stars. (Bolton and Stanley, 1948b: 68).

They did, however, request that Woolley take a special photograph of that portion of the sky, and this appeared as a plate in their paper, along with a tracing-paper overlay indicating their source position and error box. It certainly appeared a nondescript patch of sky (but we should note that this initial position for Cygnus-A was a full degree north of the correct position and so there was no chance of finding an optical counterpart, and even positions obtained years later to accuracies of a few arc minutes at first did not disclose an optical identification).

Given that there was no optical counterpart, could one nevertheless put any constraints on the distance to the object? Since they had been observing the source for three months, the changing position of the orbiting Earth might have caused an apparent shift in position if the object were nearby. But they had detected no shift greater than 2.5′ (corresponding to their 10sec accuracy in timing the sudden appearance of the source at rising), and this meant the source was at least ten times the 50 light-hour distance to Pluto, that is, well outside the Solar System. But *how* far outside? Bolton and Stanley could only suggest that the farthest imaginable would be if somehow the radio object were a star with total power output similar to that of the Sun, but all channeled into the radio spectrum. That distance worked out to 3,000 light years. But no matter what the distance, the cause of the radio radiation was not at all understood. They could only say it had to be a non-thermal mechanism, for the measured effective (brightness) temperature was $>4 \times 10^6$ K.

Just as Bolton and Stanley were writing up these results, they received an interesting communication from Pawsey (1947), who was then on the first leg of an around-the-world tour. He had visited Mt. Wilson Observatory in Pasadena and there found Rudolph Minkowski and Seth B. Nicholson "intensely interested" in the Cygnus results and willing to undertake observations directed toward finding an optical counterpart. Pawsey then described optical objects that Minkowski had showed him near the Cygnus position, mentioning that in the process they had had to convert Bolton's derived position to account for "... the change of axes due to 'precession of the equinoxes'."[10] Pawsey's letter (ibid.) ended with a raft of suggestions from Minkowski for possible places to look for radio noise:

> The Magellanic Clouds [are] the nearest external galaxies, abnormal with much dust and blue stars ... If we are interested in interstellar dust, etc. the "Crab Nebula", NGC 1952, is a good sample. If white dwarfs are of interest, the companion of Sirius is a convenient sample. The Orion region is a region of emission nebulae. [But] I do not think these ideas get us very far. I should recommend the method of empirical searching; our tools are not too fine to prevent this.

With the Cygnus case temporarily closed, Bolton and Stanley, assisted by Slee, indeed set out in November 1947 to search the sky in Pawsey's 'empirical' fashion. Stanley and Slee had made significant improvements to their receiver's short-term stability, in particular through constructing power supplies able to provide voltages stable to a part in a few thousand. Even weak fringes could now be reliably detected. They methodically took records at different points along the eastern horizon, and were delighted when fringes for several sources appeared over the next few months. As it became clear that the sky had a lot more to offer than just the Cygnus source, Bolton introduced a nomenclature still used today: in the tradition of Bayer's notation for stars, the strongest source in a constellation would be called A, the next B, etc. And so their second source became Taurus-A, one-sixth as strong as Cygnus-A, followed by Coma Berenices-A at a similar level. The uncertainties of this work can be appreciated by noting that Taurus-A appeared nicely on one November night (Figure 10), but it took another three months for confirmation of its existence and measurement of a position good enough to assign a constellation.

By February 1948 Bolton, Stanley and Slee had surveyed about half of the southern sky (man-made interference made daytime observations nearly worthless), and had good cases for six new discrete sources. Bolton (1948) sent a short note to *Nature* announcing that a new class of astronomical object existed: Cygnus-A was not unique, either in its existence or in its lack of association with "... outstanding stellar objects". Upper limits on the new sources' sizes were no better than 15-60′, but Bolton was becoming convinced that all these discrete sources were truly stellar, "... distinct 'radio-types' for which a place might have to be found in the sequence of stellar evolution." (Bolton, 1948: 141). Since even the most powerful solar-style bursts would not do the trick, he appealed to either pre-Main Sequence, collapsing, cool objects or to old, hot objects related to planetary nebulae.[11] He felt, too, that a large portion of the general Galactic noise probably originated from the aggregate effect of solar-burst type emissions.

After this survey Bolton chose to improve his source positions, in particular to eliminate systematic errors, by observing source *setting* as well as rising. High westward- and northward-facing cliffs were needed and so Bolton and Stanley headed off to New Zealand in the southern winter of 1948 (Orchiston, 1994). As Bolton (1976: 8T) recalled:

> [Just before the New Zealand trip] ... I remember Taffy Bowen asking me what I really thought of the positions of my sources, and I said, "Well, they're the best I can do at the moment, but I'd like to be the first to correct them." And indeed the corrections were absolutely massive when they came in.

The 300 m sea cliffs at Pakiri Hill and Piha (see Figure 11) led to superior observations which put an even tighter limit on Cygnus-A's size (<1.5′), and, together with simultaneous observations by Slee in Sydney, provided strong evidence that most of the intensity fluctuations originated in the Earth's atmosphere, not in the source itself. Many new sources also turned up and it became apparent that incorrect refraction corrections and other problems had thrown most previous positions 5° to 10° off. Some even changed names as when Coma Berenices-A migrated into Virgo! But Cygnus-A was still vexing, as neither its new position (shifted about 1° south from earlier) nor its old one agreed with that measured by Martin Ryle at Cambridge (privately communicated in June 1948). For a while it seemed that the source might actually be moving, but after six months of sorting out, both Hemispheres admitted earlier errors and came to agree on a common position.

The beautiful outcome of the new positions of $\sim 10'$ accuracy was that for the first time optical counterparts could be tentatively suggested (Bolton, Stanley and Slee, 1949). And these were no ordinary objects. Taurus-A was associated with the Crab Nebula, the expanding shell of a supernova known to have exploded 900 years before (Bolton and Stanley, 1949); Centaurus-A was found to coincide well with one of the brightest and strangest nebulosities in the sky, so peculiar that astronomers were not even sure whether or not it was part of our Galaxy; and Virgo-A's position correlated with that of a bright elliptical galaxy six *million* light years away. These associations quickened interest in the study of discrete sources and caused several optical astronomers, among them Minkowski, to take serious note.

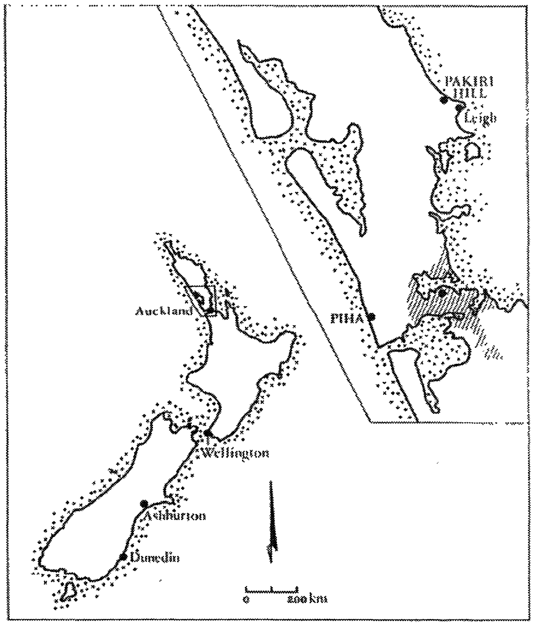

Figure 11: Locations of Pakiri Hill and Piha, near the city of Auckland (hatching), New Zealand (after Orchiston, 1994).

5 OVERVIEW OF RP'S FIRST DECADE

5.1 The Isolation Factor

Almost any analysis of things Australian must consider the geographical isolation of Australia from the other centers of Western culture. Geoffrey Blainey (1968) speaks of "... the tyranny of distance...", that is, the overwhelming importance of distance, isolation, and transport in molding the general history of Australia. In the sciences also, isolation has played a major role. Although the vestiges of a subservient colonial relationship between British and Australian radio science created an asymmetry in status and power that was independent of the distance from London, many problems of Australian science during the postwar years were notably exacerbated by the antipodal separation.

The early RP years are rife with examples of things that would have gone differently if RP had not been located 10,000 miles from its sister institutions, but instead 100 miles, or even 1,000. The best airline connections to Europe required a gruelling three days (or a civilized week) and more common passage by ship took about four weeks; moreover, the cost of a ship's berth amounted to one or two months' pay for an RP staff member. The inability to have frequent contact with colleagues from other institutions, the long interval before learning about research conducted elsewhere, the delays in publishing Australian results in the prestigious overseas journals, and the lack of foreign readership of Australian journals—these circumstances constantly bedeviled the RP staff (and Australian science in general). One counterforce was the maintenance of Australian Scientific Research Liaison Offices in London, Washington, and Ottawa. These had been originally set up during the War to coordinate radar research, and served as scientific embassies to increase the flow of information to and fro. But a far better solution was to send an RP researcher on an extended 'jaunt' through North America and Europe. In the six years after the War, the primary overseas stays or trips of importance for the development of Australian radio astronomy were undertaken by Bowen (in 1946), Ronald N. Bracewell (1946-1949), Pawsey (1947-1948), Westfold (1949-1951), Bolton (1950) (see Bolton, 1982: 353) and Kerr (1950-1951). The RP correspondence files relating to these trips are particularly good sources for understanding the influence of the isolation factor on RP's work. What emerges is that such trips served five primary purposes: (1) intelligence (in the military and political sense of the term), (2) education, (3) publicity, (4) establishment of personal contacts, and (5) fund-raising for large antennas, which first paid off with American grants in the mid-1950s towards what became the Parkes Radio Telescope.

The first purpose of the overseas trips was simply to find out what was going on. The RP visitor to an overseas laboratory typically sent back a detailed report of recent and ongoing research, and this report (as evidenced by multitudinous initials on the original documents) was widely circulated back home. Pawsey and Bowen, in particular, were masters at picking up what was being done elsewhere and analyzing its effects on RP's current research program and future plans. To give but two examples: in August 1946 Bowen (1946b) cabled back that British work on the Sun was ahead of RP's at observing frequencies less than 200 MHz and that therefore RP should concentrate on higher frequencies. And in April 1950 Bolton sent word home that the solar work by Hey's group lagged Wild's by at least eighteen months.

A second purpose of the overseas trips was education. Sometimes this was in the formal sense, as when Bracewell took a Ph.D. at Cambridge and Westfold one at Oxford, and Kerr a Master's degree at Harvard; but more often it was simply the wealth of knowledge to be garnered from overseas contacts. The background of the RP staff was of course far weaker in astronomy than in radio physics, and thus it was the visits to observatories that were particularly valuable. As Kerr (1971: 19T) recalled:

> Bolton and also Pawsey did some touring at that time and learned something of what generally were the interesting problems in astronomy, acquiring some of the attitude of astronomers toward astronomy, instead of just the electrical engineers' and physicists' attitudes.

On the other hand, Mills (1976: 20T) points out that the paucity of astronomers in Australia may have helped more than it hindered:

> Our isolation did help us develop with an independent outlook. We had no famous [astronomer] names to tell us what we should believe, and to some extent we just went ahead following our noses.

Overseas voyagers also served to spread the word about RP research—Pawsey called them "... ambassadors for Australian science". The RP archives are full of instances where Bowen and Pawsey sent reprints, complained about Australian work being neglected in reviews overseas, and urged people to subscribe to the *Australian Journal of Scientific Research*, started by CSIR in 1948 and a further sign of the growing independence of Australian science from British hegemony. RP sent thirty full papers to this journal in its first four years, but only eight to British journals (plus eight letters to *Nature*).[12] Although this corpus probably lent more stature to the journal than did any other single field, it took years to foster a world readership, even among radio astronomers. For example, Jodrell Bank did not subscribe until 1950; before then, the only copies they could locate were in London.

Direct word-of-mouth, when possible, was of course also important. After attending a 1948 URSI meeting in Stockholm, Pawsey (1948b) wrote back, "Martyn and I, to put the matter rather bluntly, attempted to put Australia on the map, and I think were fairly successful." And Bracewell (1980: 131A) recalls that while he was at the Cavendish as a postgraduate student, Ryle's group thought Sydney work way behind, but when he returned to RP he found that they thought the same of the Cambridge work—each side was simply acting on dated information. Preprints were not common in those days, and in any case were sent by sea mail (as were journals, even *Nature*), taking two to three months for the passage.[13] Bracewell (1948) also remembers wanting to act as a link between the two groups: "Being young and idealistic, I felt that I should try to close the gap, that a freer flow of information was a blow struck against entropy, as well as my duty." As he wrote to Bowen in early 1948:

> Publication [of Australian work] is slow and the diffusion of advance news by word of mouth does not occur. It results that ideas of priority are fixed before Australian work filters through. This is the case with solar noise. The attitude in the Cavendish Lab. is that nothing much of value is done elsewhere ... [Since] I am in an effective position for informal dissemination of news from Radiophysics, I recommend for your consideration the transmission of this news. (ibid.).

Despite his request, it appears that Bracewell himself remained little better informed than others in Cambridge. Upon his return to Australia in late 1949, he wrote back to Ryle:

> There is a lot of good work going on, and the people are very keen. Very little pre-publication news seemed to filter through to me in the Cavendish from Australia ... Do not hesitate to let me know if ... I can make enquiries which you may think can be better done informally through me. There is a lot of interest in your work – I have had to ward off quite a barrage of minor queries about your set-up since arriving. (Bracewell, 1950).

This induced Bracewell over succeeding years to send three short papers to *Observatory* for the purpose of advertising RP's work.

One of the grandest opportunities for interchange and to advertise RP's work was the URSI General Assembly that met in Sydney in August 1952. This was a feather in the hat not only for Australian radio research, but for all of Australian science, as it marked the first time that *any* international scientific union had met outside Europe or North America. In 1948 URSI had created a new Commission V on Extraterrestrial Radio Noise with Martyn as its first President and Pawsey as Secretary. Martyn in particular engineered the General Assembly coming to Sydney and masterminded the organization and funding. Sir Edward Appleton (Figure 1) was the patriarch among the fifty foreigners in attendance, of whom about a third were active in radio astronomy (Figure 3). At last the RP staff could associate faces with names like Jean-Louis Steinberg from France, Robert Hanbury Brown from Jodrell Bank, F. Graham Smith from Cambridge, C. Alexander Muller from Holland, and H. I. 'Doc' Ewen from the United States. RP of course put on its best show for the guests with a detailed, glossy *Research Activities* booklet and tours of several of the field stations. The home team was greatly stimulated, and the visitors went away impressed.

5.2 The Field Stations

The RP radio astronomy work took place at individual field stations, some as far as 30-50 miles from home base on the grounds of Sydney University (Figure 4). These sites provided sufficient land and isolation for observations free from man-made electrical interference. But why not just one or two sites well removed from Sydney? Many small sites also provided freedom from a second type of 'manmade interference': the RP staff simply preferred to spend most of their time alone at the field stations, not in a central laboratory, and management too found this a productive style of operation. By the late 1940s RP's research in radio astronomy was divided into many teams of two or three: leaders and sites about 1948-1950 were Piddington and Minnett (University grounds), Kerr and Shain (Hornsby), Bolton (Dover Heights), Wild (Penrith), Mills (Badgerys Creek), Payne-Scott and Christiansen (Potts Hill), and Lehany (Georges Heights). Orchiston and Slee (2005) discuss in detail these field stations and their major research programmes over their lifetimes. Christiansen (1984: 113-114) has evoked the atmosphere of these stations:

> Each morning people set off in open trucks to the field stations where their equipment, mainly salvaged and modified from radar installations, had been installed in ex-army and navy huts ... The atmosphere was completely informal and egalitarian, with dirty jobs shared by all. Thermionic valves were in frequent need of replacement and old and well-used coaxial connectors were a constant source of trouble ... During this period there was no place for observers who were incapable of repairing and maintaining the equipment. One constantly expected trouble.

Although groups had little day-to-day contact, Pawsey's skill as roving monitor and coordinator gave cohesion to RP's radio noise work. This was achieved first through meetings every two to four weeks of his 'Propagation' Committee (which changed to 'Radio Astronomy' in 1949). These meetings provided a forum for progress reports, discussion of astronomical results and technical problems, floating of new ideas, coordination of experiments, and arguments about priorities. They also served to counter the danger that isolated groups would develop too narrow scientific or organizational perspectives. Several interviewees commented on the value of these sessions; for instance, Christiansen (1976: 19-20T) reported:

> Despite the fact that we were independent groups, we used to have these sessions, sort of what Americans call 'bull sessions', thinking of every conceivable sort of aerial ... A really good one would last all day. Joe Pawsey was one to stimulate that.

Pawsey's second device for holding the radio noise research together was to frequently visit the field stations to see for himself what was happening and to give advice. As Wild (1972: 5) recollects:

> On some days he would arrive unexpectedly at one's field station, usually at lunch time (accompanyied by a type of sticky cake known as the lamington, which he found irresistible), or else infuriatingly near knock-off time. During all such visits one had to watch him like a hawk because he was a compulsive knob-twiddler. Some experimenters even claimed to have built into their equipment prominent functionless knobs as decoys, especially for Pawsey's benefit ... [But] when one ran into problems, half-an-hour's discussion with Joe tended to be both soothing and rewarding.

These visits, however, sometimes led to Pawsey seeing things he did not like:

> Pawsey was in direct linkage with the little isolateed groups. He'd try and make sure they didn't clash. And he stopped us working at times when Jack [Piddington] had had some idea and we'd started in a new direction ... For instance, one day he found me [working on a radio analogue to a Fabry-Perot interferometer] and I was stopped. He said there are other people already there, and they've got a prior claim. (Minnett, 1978: 29-30T).

But although Pawsey usually assigned exclusive turf to each small group, he sometimes encouraged two groups to plow ahead on the same problem if he felt their approaches differed enough. For example, Mills and Bolton for many years both observed discrete sources, albeit with different types of interferometers:

> Bolton's group and mine each felt rather strongly that our own technique was the best. Although we saw each other sometimes, Bolton lived out at Dover Heights and didn't come into the Lab very often and I spent most of my time out at Badgerys Creek. So we didn't actually have very much contact, and there were quite a few arguments about interpretation of the results. (Mills, 1976: 26-27T).

5.3 Management of Radio Noise Research

Bowen turned over scientific leadership for radio noise investigations to Pawsey, who was the Division's number-two man from the start (although the office of Assistant Chief was not created until 1951). Pawsey thus had a free hand in running the radio noise side of things while Bowen took on the general administrative burden and concentrated on the rest of RP's program, taking a particular interest in the rain and cloud physics research to which he himself made several contributions. Bowen, however, minimized the number of his collaborations and so through 1951 published only seven papers. His career had seen more than its share of scientific directors (such as Appleton, Watson-Watt, and Martyn) who claimed credit for too much of what happened in their laboratory:

> When I became Chief, I was going to be quite certain of one thing … I was not going to jump in and claim credit when somebody else did the work ... My previous experience of some pretty hard cases was that the best way to get first class work out of people was to give them the credit. (Bowen, 1973: 27-28T).

Along this line, Bolton (1978: 118T) recalled:

> Bowen was on our side in terms of letting people have their head—giving you a pat on the back when you did well and commiserating with you when something failed.

Bowen's philosophy also was expressed in a 1948 letter to Pawsey after the latter had been overseas for eight months:

> It is true that those of us who have had a fair amount of experience can give a lot of help in choosing problems for the younger people, keeping their sights on the target and helping them snatch the odd pearl out of the tangled mass, but I am quite sure that what we are suffering from in the Lab. is not that there is too little of this help but too much. With few exceptions our youngsters have not learnt to stand on their own feet and go for a line of their own ... The boys in the Radio Astronomy Group are feeling your absence quite keenly, but I am taking the view that their present gropings are part of their education. (Bowen, 1948).

Bowen and Pawsey's leadership styles very much fitted in with Rivett's philosophy discussed earlier: get the best people possible, give them the needed resources, and then let them run free. But there were bounds to this freedom, as we have seen, leading to a creative tension between tight control of the Laboratory's work, as it had necessarily operated during the War, and the kind of individual freedom one might find in a university department. This delicate balance is well illustrated by the juxtaposition of allowing workers to be scattered all over the countryside, while still keeping close tabs on what they did. Other strong limits existed. For example, most scientific correspondence was routed through either Pawsey or Bowen. More significantly, RP maintained a system of rigid internal reviews of all proposed publications, involving one or more of Bowen, Pawsey, and Arthur Higgs (Technical Secretary). The RP archives are replete with internal memoranda shuttling drafts back and forth between authors and management (and sometimes anonymous third-party RP referees), often to the frustration of the authors. But once a paper surmounted this first hurdle, a journal's referees usually seemed easy by comparison. The extent of Pawsey's influence on the radio noise papers can be gauged by the fact that half of them from the 1946-1951 era specifically acknowledge his assistance with either preparation of the paper itself or the project in general. Yet he, like Bowen, published only seven papers through 1951.[14]

Bowen and Pawsey agreed on the basic policies needed to run RP, but their differing temperaments led to differing contributions to RP's success in radio astronomy:

> [Pawsey's scientific style] … set the tone completely … but he was a very, very unworldly fellow ... Bowen was the man who got the money, the tough businessman, while Joe was the rather academic scientist. And it was an excellent combination. (Christiansen, 1976: 22T).

Bowen knew how to deal with the CSIRO hierarchy, how to pull off the necessary balance of applied and fundamental research, how to use his connections to source funding, and how to manage RP as a whole. On the other hand, interview testimony of numerous RP staff members indicates that Pawsey by nature was not suited for such things. For instance, he abhorred (and avoided) making managerial decisions that he knew would cause upset.

Pawsey played a vital role, however, as scientific father figure and mentor. He was about ten years older than most of the radio noise researchers, who averaged only about thirty years of age, and he quickly gained their respect and confidence. The words of his protégés speak for themselves:

> He had the ability to develop the latent powers in other people. All of the people who came out of that group—Christiansen, Mills, Wild, and so on—I also count myself in it—were made independent and skillful in their subject, experienced and self-reliant, quite largely because of Pawsey's way of drawing people out. He was not the kind of research leader who'd insist on claiming everything himself. But he fed in the ideas that other people developed—he was a teacher as much as anything. In the written record you don't find his name on many papers, but he was the inspiration behind an awful lot. (Kerr, 1971: 41-42T).
>
> There were, and are, few scientific groups of comparable size where the head of the group had such a detailed knowledge of the work of each member and where every paper was criticised in detail by him. Yet this ... did not lead to any authoritarian regime. Pawsey's criticisms were usually accepted not only because they were sound but because they were so clearly and intelligibly expressed that acceptance was inevitable. (Christiansen and Mills, 1964: 139).

Pawsey's style of science grew out of his training under Ratcliffe in the Cavendish Laboratory of Ernest Rutherford. He inherently loved the simple, inexpensive experiment and distrusted anything coming from complex setups. He also had an innate distrust of theory and mathematics (Westfold, 1978: 97B), complemented by a faith in experimentation. As he himself wrote in 1948 (regarding the possibility of solar bursts at frequencies less than a few hundred hertz):

> My present guess is that the theory is wrong in general, and consequently I do not advise any time-consuming observations which are based on the theory. On the contrary, the observation of low-frequency noise is a fundamental scientific observation which is of value independent of the theory. Positive or negative results are of use. Hence this investigation is in order, and it is up to the experimenters to decide how far they go. (Pawsey, 1948a).

The experimental style that Pawsey inculcated was particularly striking to H.I. 'Doc' Ewen (1979: 42T), accustomed to much larger American budgets, when he visited Sydney for the 1952 URSI meeting:

> Their equipment was shoestring stuff, but there were a lot of cute tricks ... They didn't waste much time with hardware where it wasn't all that important, [or with] trying to make it look pretty. But wherever a part was critical to the operation of a device, they spent a lot of time thinking about it.

And from the other perspective, Christiansen (1976: 31-32T) recalls how Ewen reacted upon seeing his 21 cm hydrogen line receiver:

> Ewen came out and said he had to see how these damn Australians did in three weeks what took other people eighteen months to do. And when he saw our gear, lying all over the room and on the floor, he just about passed out.

Pawsey's scientific style was distinctive and exemplary:

> He had an enormous enthusiasm. It was always a delightful experience to bring to Pawsey some new idea or some interesting new observation. His immediate reaction would be one of intense interest, followed by suspicion as he looked for some mistake or misinterpretation, or what he called 'the inherent cussedness of nature'. Finally, if convinced that all was well, his face would shine with boyish pleasure ... He never forced his opinions on a younger colleague; if the matter was open to doubt he was willing to leave it to experiment. He was, in fact, the arch-empiricist. "Suck it and see" was one of his favourite expressions ... He did not in general accept theoretical predictions as a guide to experiment; he preferred to investigate the questions that arose from previous experiments. "Following his nose" was how he described this process. (Christiansen and Mills, 1964: 139).
>
> Pawsey had a childlike simplicity about him, a childlike curiosity. He was not a sophisticated man in the least. I find this is a talent that a lot of people who are truly great have in common—retaining a feeling that science is not a business, that it's a game ... If Joe had been a businessman, you would have called him a sucker, but [for science] I think that's actually an important characteristic. (Stanley, 1974: 25-26T).

> I think you could say Pawsey was a very simple soul ... But he could floor a speaker: there'd be a fellow turning up a great piece of astrophysics and Joe would get up at the end and say quite innocently, and it *was* innocent, "I can't reconcile this with Ohm's Law." It would absolutely torpedo the speaker. (Christiansen, 1976: 21T).
>
> Pawsey did not have much of a mathematical background – he once asked me what [statistical] 'variance' meant – but he thought in physical terms ... He once proposed what he called the Sausage Theorem: "If the error bars on a set of visibility measurements fit inside a certain sausage, then the calculated source distribution [from the Fourier transform of the visibilities] runs down the middle of another sausage." Pawsey very reasonably wanted to know how fat this other sausage was and my job was to find out. It is a very good question. (Bracewell, 1984: 171).

Finally, a dissenting view has been given by Francis F. Gardner (1986), an RP ionospheric colleague of Pawsey's during these years:

> The impression of Joe as a naive, unworldly type is misleading. To some extent this was a pose, which contributed to his ability to 'draw people out' ... Nor was he opposed to theory ... In discussions he was able to grasp immediately what was said to him, even if poorly expressed, and he also was able to concentrate one's attention on the problem under consideration. Occasionally he would suggest solutions to some degree with tongue-in-cheek. His suggestions might not be appropriate, but enabled others to see the solutions.

5.4 Why was RP So Successful?

When an institution is created for one specific mission and then, because of changed circumstances, tries to adapt to a different role, the results are often less than satisfactory. RP's shift from war to peace, however, was a striking counter to this. Through skillful leadership, scientific expertise, and good fortune (for instance, how might the fledgling solar noise efforts have gone if the 'sunspot group of the century' had not shown up in February 1946?), RP put Australia at the forefront of radio astronomy over the postwar decade. By the early 1950s, RP was also clearly CSIRO's scientific leader (Schedvin, 1987: 360). In fact, in no other natural science did such international stature come to Australia during these years—perhaps the closest was the immunology research led by F. MacFarlane Burnet at Melbourne's Walter and Eliza Hall Institute of Medical Research, or the neurophysiology led by J.C. Eccles (see Courtice, 1988). Many of the factors important in this achievement have already been discussed, but others deserve mention.

One was the sheer size of the radio noise group, far larger than other institutions in the field—with so many projects going on simultaneously, one is much more likely to have at least one winner at any given time. The radio physicists were also supported by invaluable assistance from the large staff of technicians for electrical and mechanical work. A mild climate also conferred distinct advantages for research involveing outdoor construction and experimentation (Bolton, 1978: 107T). We can dismiss, however, one possible factor for the Australians' success, namely that they had the southern sky to themselves and therefore had no competition and only needed to mimic northern observers. Although for over a century Australia had been a fertile outpost for research precisely because of its unique flora and fauna and non-European skies, the evidence of this chapter shows that for radio astronomy this notion is patently untenable. After all, the same Sun is shared between north and south. In fact, Bolton took the view that any new setup should work the reachable northern sky first so as to beat the northerners—the southern regions would always be there later (Kerr, 1987; cf. Piddington, 1959). Witness the trouble Bolton made for himself by observing the notably northern source Cygnus-A as it barely scraped his horizon, although overhead in England.

5.5 Transforming Radio Physicists into Radio Astronomers

As work on radio noise developed in the Radiophysics Laboratory over the years, there was a gradual integration of the research into astronomy proper and the transformation of radio physicists into radio astronomers. Even from the beginning, Pawsey recognized that this new radio technique was fundamentally altering *astronomical* knowledge. As he stated during a talk to an August 1946 meeting in Adelaide:

> This [solar noise] work is a new branch of astronomy ... New observational tools [in astronomy and astrophysics] have an unusual importance. The last outstanding development in solar instruments was probably the spectroheliograph (developed at the turn of the century). Consequently it is reasonable to expect that the discovery of this radiation will come to be recognised as one of the fundamental advances in astrophysics. (Pawsey, 1946c).

Yet although the RP staff realized that they were essentially doing astronomy, albeit of a wholly different type and not well understood by astronomers, their astronomical education proceeded in a checkered manner. Whereas Bolton (1978: 30, 36-37T) chose to plow methodically through volume upon volume of the *Astrophysical Journal* during long observing nights, most just picked up what they deemed necessary as they went along. Books such as George Gamow's *The Birth and Death of the Sun* were read and Bolton undertook a partial translation of Max Waldmeier's 1941 treatise on the Sun. The exposure to Mt. Stromlo, including occasional joint colloquia, was also important. But RP had nary an astronomer on its staff and its orientation during the first postwar years was as often toward the techniques as the astronomy:

> We were simply radio people trying to provide another tool for detecting what these astronomers said was likely to be there ... We didn't consider ourselves to be astronomers—our primary interest was in the equipment. In fact we'd just left a wartime situation and we knew that our success in radar stemmed from having people who were very well trained in the techniques. (Hindman, 1978: 98B).

By the early 1950s, however, overseas trips, increasing contacts with astronomers, and a gradual accumulation of astronomical knowledge had caused a clearer picture to emerge of how the radio work fitted into astronomy as a whole (cf. Jarrell, 2005).

5.6 The 1950s as a Watershed

The 1950s represent a watershed from several perspectives. For the first time research on solar noise was overtaken in quantity by that on 'cosmic' (non-solar) noise—the percentage of solar papers dropped from ~70% before 1951 to ~40% during 1952-1954. At this time also, Pawsey and Bracewell (1955) wrote a masterful monograph, *Radio Astronomy* (mostly written in 1952). It formed a capstone to the first stage of the field's development and was to remain the definitive textbook for a decade. And of course the 1952 URSI meeting also happened at this juncture.

A key change during the early 1950s was the shift from a large number of relatively small experiments to a smaller number of projects on a large scale. This was the start of the transition from 'Little Science' to 'Big Science'—or, as Wild (1965) has pungently described it, moving from trailers "... with a characteristic smell ..." to air-conditioned buildings. Progress in the science now demanded huge antennas and arrays, and many of these were beyond the capacity of RP to produce in-house. For example, in 1951 *outside* bids for antennas were sought for the first time for 50 ft and 80ft dishes ("Tentative specifications ...", 1951). In 1953 RP funded its last major antenna from its own resources: the 1500 ft Mills Cross array at Fleurs for £2,500 (Mills, 1953). More costly ventures did not come easily, however, for the Government and CSIRO were not willing to support large capital projects (Bolton, 1978: 56T; Bowen, 1978: 44T). Eventually, however, the first one emerged in the form of a 'Giant Radio Telescope' whose cost and planning dominated the second half of the 1950s (see below).

6 THE SECOND DECADE AND BEYOND

This section gives a very brief overview of the period beyond 1955, focusing on the major instruments that were built and the personnel changes that led to an entirely different Radiophysics Division.

6.1 A Giant Radio Telescope and a Solar Ring

Nascent thoughts about a 'Giant Radio Telescope' (GRT) and its funding began as early as 1948. Bowen at that time tried to convince the Royal Australian Air Force to build a huge radar antenna that could do radio astronomy on a part-time basis. Several designs were studied over the next few years, some as large as 500 ft in dimension, but the funding never materialized. By 1951 the search for funds shifted to non-military sources and eventually the key money came from American foundations, starting in 1954 when the Carnegie Foundation made a major grant for a giant dish. But such a facility would represent a wholly different philosophy from that of RP's small field stations and their concomitant research groups, since it would command such a high fraction of RP's resources that it necessarily had to be all things to all people. In 1961 RP consummated the transition to 'Big Science' with the commissioning of a 210 ft parabolic antenna at Parkes, 260 km west of Sydney. For complete details of the fund-raising, design, construction, and research programme of the Parkes Radio Telescope, see Robertson (1992). Today, after forty-four years and many upgrades, 'The Dish' remains amazingly productive; it is still the largest stand-alone radio telescope in the Southern Hemisphere, and the only one ever to be the star of a feature film (in 2000).

The other major RP instrument of this period was the pet project of Wild, who later became Division Chief and then Chief Executive of all of CSIRO. In the early 1960s the US Ford Foundation funded the Culgoora Radioheliograph, a 3-km-diameter circle of 96 low-frequency dishes that could produce a detailed, second-by-second 'movie' of the changeable Sun, ultimately at three different frequencies. Over the period 1967-1984 it was the premiere solar radio telescope in the world, and it was only closed down in order to make way for the Australia Telescope Compact Array (see Section 6.3, below).

6.2 Dissension and Exodus

The decision to build the Parkes dish had far more than scientific consequences, for it created dissension among the maturing RP group leaders (most of whom were then in their early 40s). Pawsey had had great success in scientifically rearing his junior colleagues, but RP was not like a university department with its steady stream of students—the RP 'students' had no where to go in the first decade, and there were no positions for new ones. Already, in 1951, Pawsey was saying that the outstanding defect in the radio astronomy group was its lack of the 'research student' type with which he worked so well. Through the 1950s the various group leaders became strong-willed, confident individuals, arguing their own particular visions of how radio astronomy at RP should be done. Major disputes centered on two questions: (a) Should the focus continue on small technique-oriented groups or shift to a single major facility?, and (b) Which types of antennas would pay off best? Regarding the latter, the cost of major projects was now such that only roughly every decade or so could one be afforded.

The first major figure to leave Pawsey's group was Bolton, who in 1953 switched to cloud physics (after denial of funding for a new type of interferometer) and then in 1955 (assisted by Stanley) founded a new radio observatory at the California Institute of Technology (Kellermann et al., 2005; Stanley, 1994: 511-513). In 1960, however, Bolton returned (without Stanley) to become Director of the new Parkes Radio Telescope. Also about this time, Bowen and Pawsey began to work less well as a team and developed significant differences, in particular over the choice of a big dish and how to run it. This led to Pawsey accepting a position to direct the fledgling National Radio Astronomy Observatory in Green Bank, West Virginia, USA, but he died of a brain tumor in 1962 (at age 54) before he could assume his duties. Others who permanently departed in the second decade were Stanley (to Caltech), Bracewell (to Stanford), and Kerr (to the University of Maryland).

Christiansen was also lured away about this time to the University of Sydney (he called the Parkes dish "... the last of the windjammers."), where he continued to develop aperture synthesis techniques at the Fleurs field station (Orchiston and Slee, 2005), culminating in the Fleurs Synthesis Telescope, which made continuum maps over the period 1973-1988. Likewise, Mills, after his proposal to RP for a giant (Mills) Cross antenna was passed by (in favor of the Culgoora Radioheliograph), also moved in 1960 to the University of Sydney and built his cross at Molonglo (once again with US funding, this time from the Government's National Science Foundation). It was completed in 1967, and in its first decade catalogued more than 10,000 radio sources at 408 MHz; in 1981 it was transformed into the Molonglo Synthesis Tele-scope (MOST).

6.3 The Australia Telescope

During the 1970s, Australian radio astronomy remained strong, but did not keep up with the major facilities being constructed overseas (e.g., the Westerbork Synthesis Radio Telescope (12 dishes) in the Netherlands, a 100 meter fully-steerable dish in Germany, and the Very Large Array, a 27-dish synthesis array in the US). On the other hand, the pace and scale of worldwide astronomy meant that Australian astronomers (of all stripes, not just radio) wanting any new major facilities needed to act in unison in order to secure funding from the Government. The radio astronomy community had already been supportive of various major optical projects with its expertise and personnel. For example, Bowen and Minnett had contributed to the design of the Anglo-Australian (optical) Telescope at Siding Spring, and Robert Hanbury Brown (a transplant from Jodrell Bank in England) established a specialized optical observatory at Narrabri for measuring stellar diameters (employing his intensity interferometer principle).

Thus in the years around 1980 a (mostly) united front of astronomers sought and eventually secured major funding from the Government for a synthesis array of dishes (final cost was about A$50 million). This eventually became known as the Australia Telescope (AT) when it was accepted as an official Australian Bicentennial Project, which dictated that it had to officially open in 1988—although the first synthesized map (using just three antennas) was not produced until the following year. The AT was centered on a set of six 22-m dishes located at the site of the Culgoora Radioheliograph, near Narrabri, New South Wales. With precision surfaces that could operate at wavelengths as short as 3 mm, it did much to restore Australia's prestige in radio astronomy. A new CSIRO Division, the Australia Telescope National Facility, was set up to operate this major new resource. The inaugural Director was Ronald Ekers, who had trained under Bolton in the 1960s but now came home after two decades overseas.

Australia would never again be as dominant in radio astronomy as it had been in the decade after World War II when the field was brand new, but with the Australia Telescope it was now again fully competitive.

7 NOTES

1. Citations of the form '1971: 7T' refer to page 7 of the transcript of my 1971 interview. The form '1971: 32A' refers to side A of Tape 32 of my (untranscribed) 1971 interview, and 'B' to side B.
2. The data of Figure 2 come primarily from annual reports and lists of publications issued by the Division of Radiophysics (File D2, RPS).
3. If we assume a brightness temperature of the Sun (at solar minimum at 10 cm wavelength) of 35,000 K, then Pawsey and Payne-Scott would have detected an antenna temperature with their 4-ft dish of ~150-200 K, well above their sensitivity to relative changes of ~20-30 K. This type of dish and microwave receiver was in fact very similar to that employed by George Southworth in 1942-1943. Minnett (1986) has speculated, from his memory of the room used, that in March the Sun was not easily observable from any window. Although there is no written record of anyone at RP trying for the Sun before the end of the War, Frank Kerr (1971: 7T, 1976: 53T) recalled a brief attempt he made at a wavelength of 1.5 m with a small antenna. He also recalled that the first RP solar observations were motivated by overseas reported detections of the Sun, and not by the 'Norfolk Island Effect' as I have concluded. Piddington and Martyn also made a brief attempt to observe the Sun in 1939 (Piddington, 1978: 1-4T).
4. I use the term *sea-cliff interferometer*, although at the time the arrangement was called either a *sea interferometer* or a *cliff interferometer*.
5. The introduction to this paper (McCready, Pawsey, and Payne-Scott, 1947) provides an especially good example of how historical information is usually lost in the formalism of a scientific paper. In this case it appears to have happened because of referee's comments rather than in the initial writing. The submitted manuscript was Report No. RPR 24 (for some reason with a different author order: Pawsey, Payne-Scott and McCready), dated 16 June 1946, and contained historically-interesting material about what the Sydney group knew from overseas reports and when they knew it. The finally-published version, however, was modified in several places to merely recite who published what and what they said. In particular, the phrase "In a prior letter, not available here until our initial work was completed, Appleton (1945) ..." was changed to simply "Appleton (1945) ...".
6. Correspondence between Pawsey, Martyn, Woolley and Bowen, July to September 1946, is all contained in the in RP file B51/14.
7. The only minor exception was neighboring New Zealand. Both Alexander's group (which Unwin subsequently inherited) and the Burbidge-Kreilsheimer-Maxwell group at the University of Auckland—where Maxwell was doing M.Sc. research on solar radio emission—worked closely with Ivan Thomsen, the Director of Carter Observatory. At the time, Carter Observatory specialized in optical solar work, and Thomsen (1948) eventually published a paper in *Nature* on the correlation between solar radio emission and optical features.
8. Although Slee did not join RP until November 1946, he had made an independent discovery of the radio Sun while operating a radar set near Darwin in late 1945-early 1946, a discovery which he duly reported to RP (Briton, 1946 Slee, 1946; Sullivan, 1988: 342). Orchiston and Slee (2002) recently reported in detail on these observations, and placed them in the public domain. Slee (1994) has published his memories of the years 1946-1954 at Dover Heights, and Orchiston (2004, 2005b) gives detailed overviews of Slee's career.

9. Because Dover Heights was not suitable to follow Cygnus-A's entire track low across the northern sky, Bolton and Stanley used two other sites in the vicinity of Collaroy, namely Long Reef and West Head (Figure 4 shows Collaroy).

10. The phenomenon of precession of co-ordinates, covered at the start of any basic astronomy text, had apparently not been previously known to Pawsey. It also almost slipped the attention of Bolton and Stanley (1948b) when they constructed their photographic overlay (see Stanley, 1974: 7-7T).

11. It was only fitting that an ailing Australian star should radiate its Swan song in the form of Cygnus-type radio noise.

12. One of the factors in the founding of the Australian journal was the well-founded suspicion that letters and research papers sent to British journals in many cases were not being treated fairly, either through premature dissemination of their contents or through delays in publication (Kerr, 1987: 8).

13. A check of accession dates for *Nature* in the Sydney University Library (which was used by RP) revealed that each weekly issue was received fully 5 to 11 weeks after its date of issue. This situation continued until 1954, when the delay became only one week, presumably because of airmail delivery. I thank J. Threlfall for this information.

14. RP researcher Donald Yabsley (1986) has pointed out a typical example of Pawsey's keeping his name off publications. With regard to the paper by Payne-Scott, Yabsley and Bolton (1947), Pawsey contributed much to the project and to the paper, and originally he was intending to be a co-author. But in the end he withdrew his name because he felt that three authors were quite enough for a letter to *Nature*.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

The following abbreviations are is used:

RP = CSIRO Division of Radiophysics
RPA = CSIRO Division of Radiophysics Archives

Alexander, E., 1945. Report on the investigation of the "Norfolk Island effect". R.D. 1/518, Radio Development Lab., D.S.I.R., Wellington, New Zealand.

Alexander, F.E.S., 1946. The Sun's radio energy. *Radio & Electronics*, 1, 16-17, 20.

Allen, C.W. and Gum, C.S., 1950. Survey of Galactic radio-noise at 200 Mc/s. *Australian Journal of Scientific Research*, A3, 224-233.

Bhathal, R., 1996. *Australian Astronomers: Achievements at the Frontiers of Astronomy*. Canberra, National Library of Australia.

Blainey, G., 1968. *The Tyranny of Distance: How Distance Shaped Australia's History*. Melbourne, Macmillan.

Bok, B., 1971. Taped interview with W. Sullivan.

Bolton, J.G., 1947. Summary of Cygnus Results – 4th-25th June, 1947. Undated 1-page report, in File A1/3/1a (RPA).

Bolton, J.G., 1948. Discrete sources of Galactic radio frequency noise. *Nature*, 162, 141-142.

Bolton, J.G., 1950. Letter to E.G. Bowen, dated 14 April. In File F1/4/BOL/1 (RPA).

Bolton, J.G., 1982. Radio astronomy at Dover Heights. *Proceedings of the Astronomical Society of Australia*, 4, 349-358.

Bolton, J.G. and Stanley, G.J., 1948a. Variable source of radio frequency radiation in the constellation of Cygnus. *Nature*, 161, 312-313.

Bolton, J.G. and Stanley, G.J., 1948b. Observations on the variable source of cosmic radio frequency radiation in the constellation of Cygnus. *Australian Journal of Scientific Research*, A1, 58-69.

Bolton, J.G. and Stanley, G.J., 1949. The position and probable identification of the source of Galactic radio-frequency radiation Taurus-A. *Australian Journal of Scientific Research*, A2, 139-148.

Bolton, J.G., Stanley, G.J. and Slee, O.B., 1949. Positions of three discrete sources of Galactic radio-frequency radiation. *Nature*, 164, 101-102.

Bowen, E.G., 1945a. *Future Programme of the Division of Radiophysics*. Report dated 2 July, in File D1/1 (Copy in RPA).

Bowen, E.G., 1945b. Letter to F.G.W. White, dated 1 August. In File A1/3/1a (RPA).

Bowen, E.G., 1946a. Letter to Sir Edward Appleton, dated 23 January. In File A1/3/1a (RPA).

Bowen, E.G., 1946b. Letter to J.L. Pawsey, dated 23 August. In File A1/3/1a (RPA).

Bowen, E.G., 1947a. Letter to D.F. Martyn, dated 28 January. In File A1/3/1a (RPA).

Bowen, E.G. (ed.), 1947b. *A Textbook of Radar*. Sydney, Angus and Robertson.

Bowen, E.G., 1948. Letter to J.L. Pawsey, dated 17 June. (#4). In File F1/4/PAW/1 (RPA).

Bowen, E.G., 1973. Taped interview with W. Sullivan.

Bowen, E.G., 1984. Taped interview with W. Sullivan.

Bowen, E.G., 1987. *Radar Days*. Bristol, Adam Hilger.

Bracewell, R.N., 1948. Letter to E.G. Bowen, dated 19 January. In File F1/4/BRA (RPA).

Bracewell, R.N., 1950. Letter to M. Ryle, dated 6 January. In Box 1/1, RYL.

Bracewell, R.N., 1984. Early work on imaging theory in radio astronomy. In Sullivan, 1984a, 167-190.

Briton, J.N., 1946. Letter to O.B. Slee, dated 18 March. In File A1/3/1a (RPA).

Christiansen, W.N., 1984. The first decade of solar radio astronomy in Australia. In Sullivan, 1984a, 113-131.

Christiansen, W.N. and Hindman, J.V., 1952. A preliminary survey of 1420 Mc/s line emission from Galactic hydrogen. *Australian Journal of Scientific Research*, A5, 437-455.

Christiansen, W.N., and Mills, B.Y., 1964. Biographical memoir of Joseph Lade Pawsey. *Australian Physicist*, 1, 137-141.

Collis, B., 2002. *Fields of Discovery: Australia's CSIRO*. Crows Nest, Allen & Unwin.

Courtice, F.C., 1988. Research in the medical sciences: the road to national independence. In Home, 277-307.

de Vaucouleurs, G., 1976. Taped interview with W. Sullivan.

Edge, D.O. and Mulkay, M.J., 1976. *Astronomy Transformed: The Emergence of Radio Astronomy in Britain*. New York, John Wiley.

Gardner, F.F., 1986. Letter to W. Sullivan, dated 12 November.

Gillmor, C.S., 1991. Ionospheric and radio physics in Australian science since the early days. In Home, R.W. and Kohlstedt, S.G. (eds.). *International Science and National Scientific Identity*. Dordrecht, Kluwer. Pp. 181-204.

Goddard, D.E. and Haynes, R.F. (eds.), 1994. Pioneering a New Astronomy: Papers in Memory of John G. Bolton. *Australian Journal of Physics*, 47(5), 495-680.

Goddard, D.E. and Milne, D.K. (eds.), 1994. *Parkes: Thirty Years of Radio Astronomy*. Melbourne, CSIRO Publishing.

Haynes, R., Haynes, R., Malin, D. and McGee, R., 1996. *Explorers of the Southern Sky: A History of Australian Astronomy*. Cambridge, Cambridge University Press.

Hey, J.S., 1973. *The Evolution of Radio Astronomy*. London, Elek Science.

Hey, J.S., Parsons, S.J. and Phillips, J.W., 1946. Fluctuations in cosmic radiation at radio-frequencies. *Nature*, 158, 234.

Home, R.W. (ed.), 1988. *Australian Science in the Making*. Cambridge, Cambridge University Press.

Home, R., 11982-83. Origins of the Australian physics community. *Historical Studies*, 29, 383-400.

Home, R., 2005. Rainmaking in CSIRO: the science and politics of climate modification. In Sherratt, T. et al. (eds.). *A Change in the Weather: Climate and Culture in Australia*. Canberra, National Museum of Australia Press. Pp. 66-79.

Jaeger, J.C., 1943. *Theory of the Vertical Field Patterns for R.D.F. Stations*. RP Report, No. RP174 (copy in RPA).

Jarrell, R., 2005. "Radio astronomy, whatever that may be." The marginalization of early radio astronomy. In Orchiston, W. (ed.). *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth*. Dordrecht, Springer. Pp. 191-202.

Kellermann, K.I., 1996. John Gatenby Bolton (1922–1993). *Publications of the Astronomical Society of the Pacific*, 108, 729-737.

Kellermann, K.I., Orchiston, W., and Slee, B., 2005. Gordon James Stanley and the early development of radio astronomy in Australia and the United States. *Publications of the Astronomical Society of Australia*, 22, 1-11.

Kerr, F.J., 1971. Taped interview with W. Sullivan.

Kerr, F.J., 1976. Taped interview with W. Sullivan.

Kerr, F.J., 1987. Letter to W. Sullivan, dated 6 April.

Lovell, A.C.B., 1964. Joseph Lade Pawsey 1908–1962. *Biographical Memoirs of Fellows of the Royal Society*, 10, 229-243.

Martyn, D.F., 1946. Temperature radiation from the quiet sun in the radio spectrum. *Nature*, 158, 632-633.

Martyn, D.F., 1948. Letter to Sir Edward Appleton, dated 27 October. In Appleton Papers, Edinburgh University.

McCready, L.L., Pawsey, J.L., and Payne-Scott, R., 1947. Solar radiation at radio frequencies and its relation to sunspots. *Proceedings of the Royal* Society, A190, 357-375.

Mills, B.Y., 1953. Large aerial for meter wavelengths. Report, in File A1/3/10 (RPA).

Mills, B.Y., 1954. Letter to J.L. Pawsey, dated 27 August. In File F1/4/PAW/3 (RPA).

Minnett, H.C., 1986. Letter to W. Sullivan, dated 22 October.

Minnett, H.C., and Robertson, Sir Rutherford, 1996. Frederick William George White 1905–1994. *Historical Records of Australian Science*, 11, 239-258.

Orchiston, W., 1994. John Bolton, discrete sources, and the New Zealand field-trip of 1948. *Australian Journal of Physics*, 47, 541-547.

Orchiston, W., 2004. From the solar corona to clusters of galaxies: The radio astronomy of Bruce Slee. *Publications of the Astronomical Society of Australia*, 21, 23-71.

Orchiston, W., 2005a. Dr. Elizabeth Alexander: first female radio astronomer. In Orchiston, W. (ed.). *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth.* Dordrecht, Springer. Pp. 71-92.

Orchiston, W., 2005b. Sixty years in radio astronomy: a tribute to Bruce Slee. *Journal of Astronomical History and Heritage*, 8, 3-10.

Orchiston, W., and Slee, B., 2002. The Australasian discovery of solar radio emission. *AAO Newsletter*, 101, 25-27.

Orchiston, W. and Slee, B. 2005. The Radiophysics field stations and the early development of radio astronomy. In Orchiston, W. (ed.). *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth.* Dordrecht, Springer. Pp. 119-168.

Orchiston, W., Sullivan, W.T. and Chapman, J., 2006. *The Foundations of Australian Radio Astronomy*. New York, Springer.

Pawsey, J.L., 1945. Letter to C.W. Allen, dated 15 October. In File A1/3/1a (RPA).

Pawsey, J.L., 1946a. Letter to R. Woolley, dated 11 September. In File B51/14 (RPA).

Pawsey, J.L., 1946b. Observation of million degree thermal radiation from the sun at a wavelength of 1.5 metres. *Nature*, 158, 633-634.

Pawsey, J.L., 1946c. Solar radiation at radio frequencies and its relationship to sunspots: interpretation of results. Paper presented on 19 August at the ANZAAS Meeting. Copy in FileA1/3/1a (RPA).

Pawsey, J.L., 1947. Letter to J. Bolton and G. Stanley, dated 11 November. In File A1/3/1a (RPA).

Pawsey, J.L., 1948a. Letter to E.G. Bowen, dated 13 February. In FileA1/3/1a (RPA).

Pawsey, J.L., 1948b. Letter to E.G. Bowen, dated 12 August. In File F1/4/PAW/1 (RPA),

Pawsey, J.L., 1948c. Letter to E.G. Bowen, dated 15 August. In File F1/4/PAW/1 (RPA).

Pawsey, J.L., 1948d. Letter to Sir Edward Appleton, dated 8 September. In File F1/4/PAW/1 (RPA).

Pawsey, J.L., 1951. Letter to M. Oliphant, dated10 September. In File A1/3/1n (RPA).

Pawsey, J.L., 1961. Australian radio astronomy. *Australian Scientist*, 1, 181-186.

Pawsey, J.L. and Bracewell, R.N., 1955. *Radio Astronomy*. Oxford, Oxford University Press.

Pawsey, J.L. and Payne-Scott, R., 1944. *Measurements of the Noise Level Picked up by an S-band Aerial*. Report, No. R.P. 209 (dated 11 April. Confidential). (Copy in RPA).

Pawsey, J.L., Payne-Scott, R. and McCready, L.L., 1946. Radio-frequency energy from the sun. *Nature*, 157, 158-159.

Payne-Scott, R., Yabsley, D.E. and Bolton, J.G., 1947. Relative times of arrival of bursts of solar noise on different radio frequencies. *Nature*, 160, 256-257.

Piddington, J.H., 1959. Proposed early investigations using 210 ft radio telescope. Planning document, dated 16 September. In File A1/3/11/17 (RPA).

Piddington, J.H., 1978. Taped interview with W. Sullivan.

Reber, G., 1940. Cosmic static. *Proceedings of the Institute of Radio Engineers*, 28, 68-70.

Robertson, P., 1992. *Beyond Southern Skies: Radio Astronomy and the Parkes Telescope*. Cambridge, Cambridge University Press.

Schedvin, C.B., 1987. *Shaping Science and Industry: A History of Australia's Council for Scientific and Industrial Research, 1926-49*. Sydney, Allen and Unwin.

Slee, O.B., 1946. Letter to Radiophysics Division, CSIRO, dated 4 March. In File A1/3/1a (RPA).

Slee, O.B., 1994. Some memories of the Dover Heights field station, 1946-1954. *Australian Journal of Physics*, 47, 517-534.

Stanley, G.J., 1974. Taped interview with W. Sullivan.

Stanley, G.J., 1994. Recollections of John G. Bolton at Dover Heights and Caltech. *Australian Journal of Physics*, 47, 507-516.

Sullivan, W.T., 1982. *Classics in Radio Astronomy*. Dordrecht, Reidel.

Sullivan , W.T. (ed.), 1984a. *The Early Years of Radio Astronomy: Reflections Fifty Years after Jansky*. Cambridge, Cambridge University Press.

Sullivan, W.T., 1984b. Early radio astronomy. In Gingerich, O. (ed.). *Astrophysics and Twentieth-Century Astronomy to 1950*. Cambridge, Cambridge University Press. Pp. 190-198.

Sullivan, W.T., 1988. Early years of Australian radio astronomy. In Home, 308-344.

Sullivan, W.T., 1990. The entry of radio astronomy into cosmology: radio stars and Martin Ryle's 2C survey. In Bertotti, R. et al. (eds.) *Modern Cosmology in Retrospect*. Cambridge, Cambridge University Press. Pp. 309-330.

Tentative specifications for 80-foot and 50-foot radio astronomy aerials. Document dated 8 August 1951, in File A1/3/1h (RPA).

Thomsen, I.L., 1948. Solar radio emissions and sunspots. *Nature*, 161, 134-136.

Wild, J.P., 1965. Origin and growth of radio astronomy in CSIRO. Lecture delivered to CSIRO Division of Plant Industry. Copy in File D/12/1/5 (RPA).

Wild, J.P., 1972. The beginnings of radio astronomy in Australia. *Records of the Australian Academy of Science*, 2(3), 52-61.

Wild, J.P., 1987. The beginnings of radio astronomy in Australia. *Proceedings of the Astronomical Society of Australia*, 7, 95-102.

Woolley, R., 1947. Opportunities for astronomical work in Australia. [Section A Presidential Address.] In Ross, A.G. (ed.). *Report of the 26th Meeting of ANZAAS, Perth 1947.* Canberra, Government Printer. Pp. 64-80.

Yabsley, D., 1986. Letter to W. Sullivan, dated 10 October.

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THE IMPACT OF F.F. GARDNER ON OUR EARLY RESEARCH WITH THE PARKES RADIO TELESCOPE

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Abstract: Frank Gardner, who died in 2002, aged 78, was one of the driving forces in the early years of the Parkes Radio Telescope, and it is hard to separate Frank from any of the early discoveries. An inventive receiver engineer who turned radio astronomer with the commissioning of the Parkes Telescope, Frank was a pioneer in radio polarization and spectral line observations. The present authors both benefited greatly from their association with him. In this paper we outline those early scientific discoveries and tell some of the tales that reveal his character.

Keywords: Frank Gardner, polarization and spectral line studies, Parkes Radio Telescope

1 'FF' GARDNER, RADIO ASTRONOMER EXTRAORDINAIRE

Dr Francis Fredrick Gardner (Figure 1) was born in Sydney in 1924 and died in 2002. He graduated from the University of Sydney in Science in 1943 and with First Class Honours in Electrical Engineering in 1945. Quiet and unassuming, he worked on ionospheric research at the Cavendish Laboratory from 1947 to 1949 graduating with a Ph.D. from Cambridge University. Returning to Australia, he joined the CSIRO's Division of Radiophysics in 1950, and continued in ionospheric research until 1957 when he turned his attention to developing low-noise amplifiers for the Parkes Radio Telescope. From 1962 until his retirement in 1989, and for a few years afterwards, Frank Gardner (henceforth 'FF', as he was affectionately known) carried out research with the Parkes Radio Telescope that produced cutting-edge results in fields as diverse as the polarization of radio emission and interstellar chemistry.

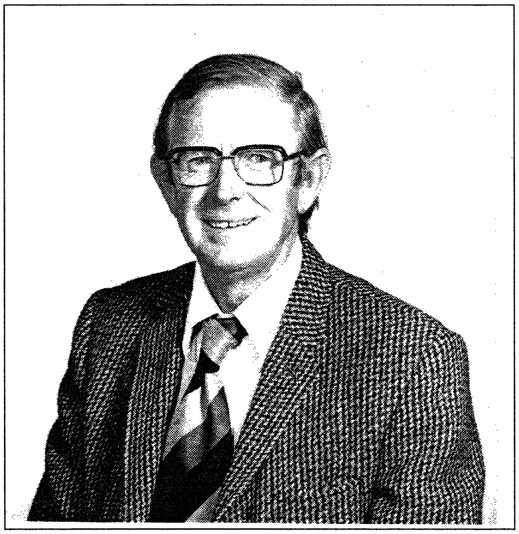

Figure 1: Dr Frank Gardner (courtesy: ATNF Historic Photographic Archive).

2 THE EARLY YEARS AT RADIOPHYSICS

The first author (DKM) first met FF in 1951. The latter needed someone to climb the antenna mast at CSIRO's Camden field station and attach further wires, dipoles or other equipment. DKM asked FF to make sure that the transmitter was switched off and he stuttered "y-y-yes, it's off", so DKM climbed the dizzy heights and nearly fell off when the first tingle hit him! "Who *is* this idiot …?" he thought. He did not realise that FF was simply displaying his keen sense of humour!

DKM joined FF in 1958 when he and Gib Bogle were developing a maser receiver for the Parkes Radio Telescope (see Milne et al., 1994: Figure 1), and they worked closely together for the next four years. They built an operational maser, one of the world's first, and tested it briefly on the 11-m radio telescope at Potts Hill (see Figure 2). However, they realized that handling liquid helium at Parkes was going to be beyond them at that time, and so they abandoned the project in favour of a 20-cm nitrogen-cooled parametric amplifier (see Gardner and Milne, 1963). At that stage, this was only the fourth receiver built specifically for the Parkes Radio Telescope (see Brooks and Sinclair, 1994: Table 1). During this period DKM came to respect FF as a brilliant engineer, and he learnt much from their association. In retrospect, he feels that FF may also have benefited on the practical side from his presence.

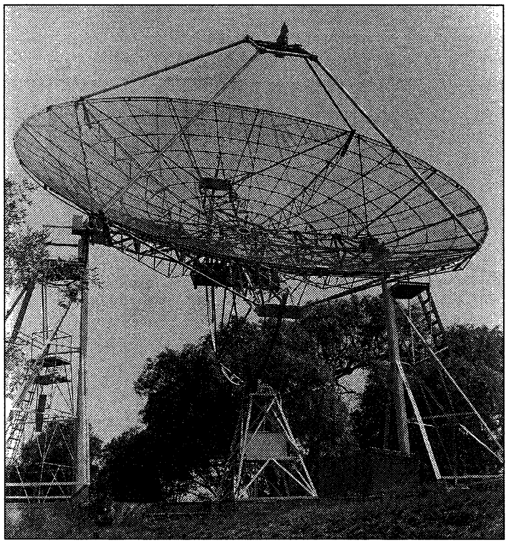

Figure 2: The 11-m transit radio telescope at Potts Hill field station (courtesy: ATNF Historic Photographic Archive).

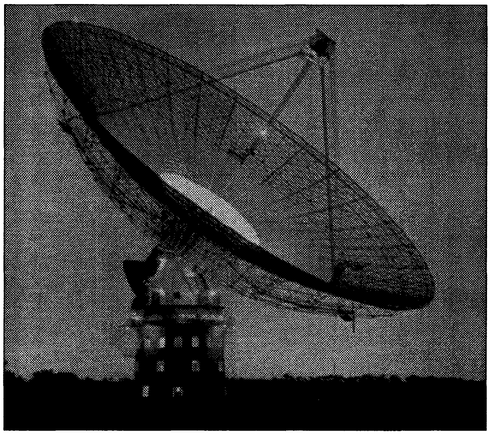

Figure 3: The 64-m Parkes Radio Telescope (courtesy ATNF Historic Photographic Archive).

FF was sometimes referred to as 'Bushranger Gardner' after his notorious nineteenth century namesake, and DKM saw his opportunism in action around 1960. The Radiophysics Laboratory had only one signal generator, which Norm Labrum had been using for several days. So, one morning when DKM met FF on the train two stations down from where he and Labrum normally embarked, FF said, "Grab the sig gen as soon as we get to the Lab." DKM protested that Labrum was still using it, to which FF replied: "No, he won't be in for another half hour; he missed the train!" Later, when FF and DKM were working at Parkes, Dick McGee had a locked cupboard in which he kept his personal 'goodies' like attenuaters, matched terminations, cables and cable gender changers. The first thing FF always did upon arriving at the Radio Telescope was to find McGee's 'well-hidden' key and help himself to anything he needed! It is no wonder that he was sometimes referred to as 'Fearless Frank' rather than 'FF'.

One of the authors (JBW) also tells the tale of how FF returned to Sydney halfway through an observing run with his 'personal' cold load reference in his pocket and without informing his observing collaborator, JBW, of the removal of this piece of equipment from the observing system. This left JBW observing with a less effective skyhorn as a reference, and wondering why the system performance had deteriorated suddenly (see Whiteoak, 1994: 78, 80)!

3 OBSERVATIONS WITH THE PARKES RADIO TELESCOPE

Once observations started in earnest with the Parkes Radio Telescope (Figure 3), like other research staff, FF was more or less forced to become a 'radio astronomer'. However, he took very quickly to the art of 'observing' with the Radio Telescope and its associated activities. The authors believe that his love of chocolate may have played a part in his rapid transformation into an avid observer. In the early days at Parkes chocolate was included in the supper basket, and pity the poor observer who replaced FF at midnight or 1 a.m. for the 'grave-yard shift' only to be met by empty wrappers and a totally contented radio astronomer—complete with chocolate-coated grin!

One of the authors (JBW) generally took the late shift, and recalls another interesting feature of the shared observing. FF regarded very seriously the changeover time, and expected the second shift observer to always be on time. Even if the second observer was as much as a few seconds late he would invariably be met by FF, rushing down the stairs on his way back to the observers' quarters.

Be that as it may, FF's first research program at Parkes was with John Bolton, and involved surveying the sky simultaneously at wavelegths of 75-cm and 20-cm and at declinations ranging from from –20° to –60°. About 2,000 discrete sources were detected (Bolton, Gardner, and Mackey 1964).

When the source survey was completed, FF joined forces with JBW to investigate linear polarization (see Whiteoak, 1994). By the late 1950s it had been accepted that the non-thermal component of Galactic and extragalactic radio emission was caused by synchrotron emission. It was therefore expected to display a fairly high degree of linear polarization, but initial attempts to detect this polarization were unsuccessful. However, in the early months of 1962 linear polarization was detected at 3-cm for the radio galaxy Cygnus-A and the Crab Nebula supernova remnant (SNR) (Mayer, McCullough and Sloanaker, 1962). Then, later in 1962, polarization of the extended Galactic Plane radio emission was reported by workers in Holland (Westerhout et al., 1962) and England (Wielebinski and Shakeshaft, 1962). Before the Parkes Radio Telescope was operational, preliminary planning of future research projects included a search for linear polarization (which at that stage had not been detected). Thus, an important task for the fledgling Parkes Radio Telescope became the investigation of the polarization of discrete sources and the extended Galactic radio emission.

The first Parkes polarization measurements were made by FF, Jim Roberts and JBW in March 1962 with a dual 20/75-cm wavelength system. Both receivers were crystal mixers, fed from two pairs of orthogonal dipoles, and the receiver outputs were fed to a two-pen chart recorder. This system had only a short tenure, with the installation of the Gardner-Milne 20-cm parametric amplifier in April 1962. In December, an 11-cm paramplifier, developed by Brian Cooper's team, was also available for use (see Brooks and Sinclair, 1994: Table 1). The much improved sensitivity of these two receivers, coupled with the advantages of an alt-azimuth mounted radio telescope, made polarization measurements relatively easy, and polarization observations at Parkes began in earnest.

In their initial observations, FF and JBW looked at the brightest radio sources and concentrated more on the 75-cm wavelength, but they did not detect any polarization. In retrospect, they could not have made a worse start since at that wavelength the brightest sources proved to be the least polarized, and depolarization increases markedly with wavelength. Matters improved when they reduced their 20-cm data and detected linear polarization from seven discrete sources, including the radio galaxy 3C270 (8% polarized) and the very extended SNR Vela-X—which exhibited a high degree of polarization in several directions (see Gardner and Whiteoak, 1962; 1963).

It would be churlish to omit an incident that occurred shortly before Easter 1962. A 10-cm receiver had just been installed on the Radio Telescope and was being tested by Brian Cooper. Ron Bracewell was visiting Parkes at this time and took advantage of some spare telescope time to pre-empt the scheduled observations of the brightest radio galaxy, Centaurus-A, and discover a remarkably high degree of polarization from this galaxy (see Bracewell, 2002; Bracewell, et al., 1962). This object became the subject of further *ad hoc* observations when Marc Price used unscheduled time over Easter to observe the polarization at several wavelengths and towards three directions in the Galaxy. He found that at each position the polarization angle varied as wavelength squared. This variation is consistent with the Faraday Rotation of polarized radiation in a magneto-ionic environment, and Price had discovered Faraday Rotation in the interstellar medium (Cooper and Price, 1962). The Faraday Rotation was similar at each position, suggesting that the magnetic field distribution was widespread and uniform either in our Galaxy or in Centaurus-A.

The origin of the Faraday Rotation was the next question to be addressed, and FF and JBW embarked on a project to determine the 'rotation measure'—a rather unimaginative term that they coined as a measure of the Faraday Rotation in terms of radians per metre squared—for a sample of polarized extragalactic radio sources. The initial investigation showed a marked decrease in rotation measure with Galactic latitude, being highest near the plane of the Galaxy (Figure 4). This was consistent with the Faraday Rotation taking place in the interstellar medium within our Galaxy. It was expected that the Rotation would be enhanced in directions along spiral arms, where the magnetic field would be along the line of sight, but this effect was not well established in these early data (Gardner, 1964).

As already mentioned, polarization of the Galactic background emission had already been detected by radio astronomers in Europe, and similar observations were now commenced by JBW, FF, and Roberts at Parkes. Scans across the Galactic Plane were made at different feed angles, switching the receiver against a cold load. The technique was fairly insensitive, and the project was abandoned in late 1962 when JBW left to work in the USA. Research on the background polarization was taken up again in 1963 by Don Mathewson and DKM. Beginning initially as a continuum and polarization survey of the Magellanic Clouds, the program became a full-sky survey when the observers followed strong polarized emission extending in all directions well away from the Clouds and showed that it was consistent with a magnetic field aligned along the local spiral arm of our Galaxy (Mathewson and Milne, 1964).

By this time an observational method had evolved whereby the antenna feed at the focus of the radio telescope was rotated through 360° in a direction towards the polarized emission, then in an adjacent reference direction devoid of polarization. The receiver output was recorded on a chart, and markers registered every ten degrees of feed rotation. Each rotation produced a 'wonky' sinusoid signal—'wonky' because instrumental effects during the rotation contributed modulations with periods of both 180° and 360°. It took a little under 2.5 minutes to rotate the feed a full turn forward and reverse, so by rotating at positions with right ascension advanced by two minutes each observation, the observations were performed at similar hour angles (that is, similar elevations in the sky) and suffered similar instrumental rotational effects. An unpolarized reference position was also observed and the polarization intensity and feed angle of maximum intensity were extracted for each position by subtracting the off-source rotations; using tracing paper and pencil. Finally, because the Parkes Radio Telescope had an alt-azimuth mount, the feed angles had to be tranformed to position angles on the sky using computed parallactic angles. This method proved to be quite satisfactory and was really only superseded by scans at selected feed angles once two-channel receivers with polarization switching or polarization correlation were installed.

During 1962 DKM helped FF observe, in the process learning the vagaries of polarization measurements, and then became involved with producing the Parkes 20/75-cm radio source catalogue extending from declination –60° to the South Celestial Pole, working with Marc Price (see Price and Milne, 1965). But DKM wanted a project that he could call his own, and FF suggested that he follow up the Gardner-Whiteoak discovery of strong polarization in Vela-X. DKM began observations in November 1962; this object offered a challenge because of its relatively large size (~5°) and because its identification as a supernova remnant was questionable. From this time on, SNRs became DKM's main field of research (see Milne, 1994).

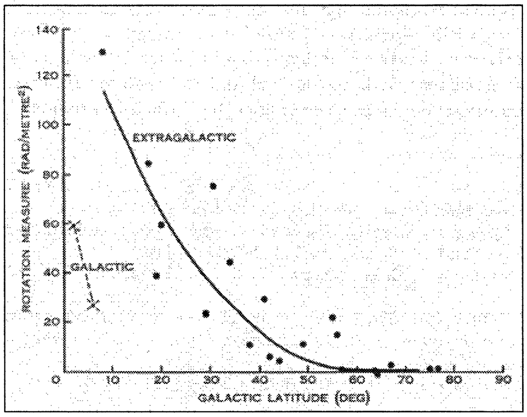

Figure 4: Plot of rotation measure vs Galatic latitude for Galactic and extragalactic sources (after Gardner,1964: 144).

DKM's next observational contact with FF was when the latter laid a map on the desk showing a double-arc source and asked: "Is this one of your SNRs?" DKM's response was to immediately ask FF where it was located in the sky, since FF—in typical Gardner fashion—was very cagey and had not even put any co-ordinates on the map. After some banter FF wrote "14^h 59^m, –41°" somewhere on the map, and DKM immediately said, "It's got to be the A.D. 1006 remnant." And indeed it was (see Figure 5). This object (Gardner and Milne, 1965) was only the fourth SNR to be identified with its progenitor supernova (see Stephenson and Green, 2002), and the Parkes measurements showed the associated magnetic field to be radial, as would be expected for a young expanding SN shell.

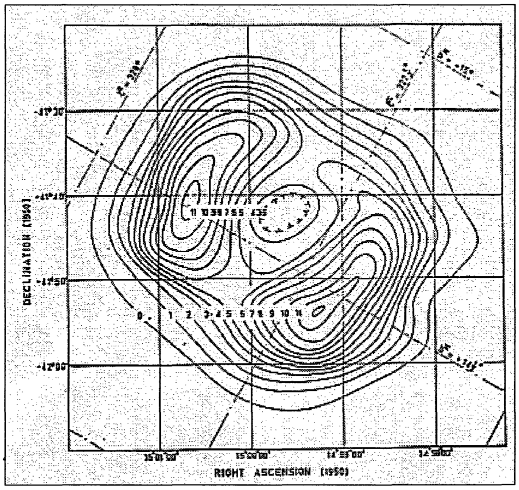

Figure 5: The first radio isophote map of the 1006 SNR (after Gardner and Milne, 1965).

When the first radio spectral lines from an interstellar molecule (the hydroxyl radical, OH, with lines at 1665 and 1667 MHz) were finally detected by US radio astronomers in 1963, FF realised the importance of the result as a probe of interstellar molecular clouds, and decided to diversify his research interests. He and several colleagues rapidly improvised a receiving system and confirmed the existence of the lines using Parkes observations of the dense molecular clouds near the centre of our Galaxy (Bolton et al., 1964a, 1964b; Robinson et al., 1964). Further observations of the clouds yielded the two weaker lines (at 1612 and 1720 MHz) of the OH ground-state quartet (Gardner et al., 1964). FF participated in the initial OH project long enough to collaborate in observations of other molecular clouds which showed that anomalous relative intensities of the four OH lines were due to disturbed populations of energy levels associated with the line production, rather than to other causes (McGee et al., 1965).

In April 1968 a 6-cm receiver on loan from the US National Radio Astronomy Observatory (NRAO) was installed at Parkes, and FF invited DKM to join him, Peter Mezger and Tom Wilson in surveying recombination lines in HII regions (Wilson et al., 1970). DKM recalls that FF had to talk him into joining the collaboration, the argument being that DKM could take over for further study all the objects that showed no recombination lines and hence were possibly SNRs. Mainly through this work, DKM was able to considerably increase the number of known SNRs.

The US receiver had been loaned to the Division of Radiophysics specifically for the Parkes recombination line survey, but a communication from an NRAO radio astronomer—who shall remain nameless—advised that the Radiophysics scientists could do whatever they liked with the receiver. This was in 1969, when NRAO radio astronomers had just detected the first spectral lines from interstellar formaldehyde in molecular clouds, at a wavelength of 6-cm. FF immediately realized the potential of the Greenbank receiver for this type of research, and he tuned the system to the formaldehyde frequency. He and JBW then began a love affair with interstellar chemistry that was to continue with the Parkes Radio Telescope and overseas instruments until FF's retirement in the late 1980s.

There was a twist to the initial Parkes observations, however, in that FF and JBW noted that the spectral line was so strong towards some molecular clouds (Figure 6) that it should also be possible to detect the 6-cm transition of the ^{13}C isotopomer (see Whiteoak and Gardner, 1969). The ^{13}C/^{12}C isotope abundance ratio is a rather important quantity in the study of Galactic nucleosynthesis. The observers planned a new observing run, but word of this intention somehow reached the USA and the Radiophysics Laboratory was instructed to immediately return the receiver to the NRAO! Not to be outdone, FF planned an impromptu observing run with an old Radiophysics 6-cm receiver. However, this project was also suddenly vetoed a few days before it was to due to commence, and it was not until 1971 that the ^{13}C isotopomer was observed at Parkes (Whiteoak and Gardner 1972). By this time, it had been well and truly detected at the NRAO.

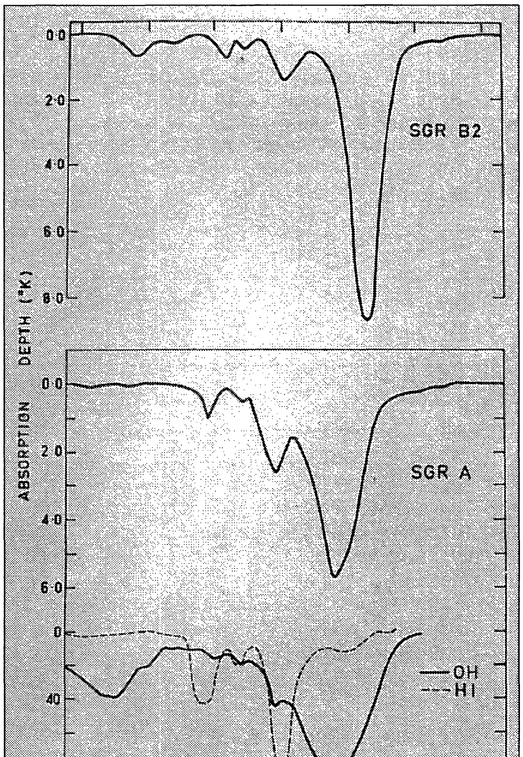

Figure 6: Formaldehyde absorption profiles for Sgr A and Sgr B (after Whiteoak and Gardner, 1969: 283).

A new two-channel 6-cm receiver, built by Brian Cooper's group, was installed at Parkes in late 1970, and a 3.4-cm receiver the following year (Brooks and Sinclair, 1994). At last FF, DKM and JBW had systems operating at frequencies close enough (in wavelength^2) to eliminate the ambiguities in large rotation measures, and by rapidly switching between dual orthogonally-polarized channels they were able to scan in polarization. DKM was then joined by John Dickel in an SNR partnership that has persisted to the present day. By the late 1960s, FF and JBW had amassed quite a large sample of rotation measures derived from the polarized radio emission of discrete radio sources (see Whiteoak, 1994). However, the distribution of the rotation measure over the sky was complex, and it was not possible at that stage to identify patterns that could be interpreted in terms of the magnetic field structure of our Galaxy. Accordingly, the two astronomers discontinued their polarization studies and concentrated on their astro-chemistry research (e.g. see Robinson, 1994).

4 CONCLUSION

Frank Gardner was always modest, quiet and unassuming (except for his tennis and table tennis styles which had to be classified as 'sneaky'!). He was endowed with dry humour and a sense of fun that made working with him anything but boring. These characteristics were enhanced by by an uncanny 'feel' for microwave engineering, plus a fundamental knowledge of and interest in organic chemistry that was rare within the Australian radio astronomical community. As a result, he played a major rôle in contributing to the list of research successes during the early days of the Parkes Radio Telescope.

5 ACKNOWLEDGEMENTS

We are grateful to the ATNF for providing Figures 1-3.

6 REFERENCES

Bolton, J.G., Gardne, F.F., and Mackey, M.B., 1964. The Parkes catalogue of radio sources, declination zone –20° to –60°. *Australian Journal of Physics*, 17, 340-372.

Bolton, J.G., Gardner, F.F., McGee, R.X., and Robinson, B.J., 1964a. Distributions and motions of OH near the Galactic Centre. *Nature*, 204, 30-31.

Bolton, J.G., van Damme, K.J., Gardner, F.F., and Robinson, B.J., 1964b. Observations of OH absorption in the radio spectrum of the Galactic Centre. *Nature*, 201, 279.

Bracewell, R, 2002. The discovery of strong extragalactic polarization using the Parkes Radio Telescope. *Journal of Astronomical History and Heritage*, 5, 107-114.

Bracewell, R.N., Cooper, B.F.C., and Cousins, T.E., 1962. Polarization in the central component of Centaurus A. *Nature*, 195, 1289-1290.

Brooks, J., and Sinclair, M., 1994. Receivers, electronics and people—past and present. In Goddard and Milne, 47-56.

Cooper, B.F.C., and Price, R.M., 1962. Faraday Rotation effects associated with the radio source Centaurus A. *Nature*, 195, 1084-1085.

Gardner, F.F., 1964. Radio polarization effects in the Galaxy. In Kerr, F.J., and Rogers, A.W. (eds.). *The Galaxy and the Magellanic Clouds, IAU/URSI Symposium 20, Can-berra, 1963*. Canberra, Australian Academy of Science. Pp. 143-147.

Gardner, F.F., and Milne, D.K., 1963. A 1410 Mc/s continuum radiometer. *Proceedings of the Institute of Radio Engineers of Australia*, 24, 127.

Gardner, F.F., and Milne, D.K., 1965. The supernova of A.D. 1006. *Astronomical Journal*, 70, 754.

Gardner, F.F.,and Whiteoak, J.B., 1962. Polarization of 20-cm wavelength radiation from radio sources. *Physical Review Letters*, 9, 197-199.

Gardner, F.F.,and Whiteoak, J.B., 1963. Polarization of radio sources and Faraday Rotation effects in the Galaxy. *Nature*, 197, 1162-1164.

Gardner, F.F., Robinson, B.J., Bolton, J.G., and van Damme, K.J., 1964. Detection of the interstellar OH lines at 1612 and 1720 MHz. *Physical Review Letters*, 13, 3-5.

Goddard, D.E., and Milne, D.K. (eds.), 1994. *Parkes: Thirty Years of Radio Astronomy*. Melbourne, CSIRO Publications.

Mathewson, D.S., and Milne, D.K., 1964. A pattern in the large-scale distribution of Galactic polarized radio emission. *Nature*, 203, 1273-1274.

Mayer, C.H., McCullough, T.P., and Sloanaker, R.M., 1962. Polarization of the radio emission of Taurus A, Cygnus A, and Centaurus A [abstract]. *Astronomical Journal*, 67, 581.

McGee, R.X., Robinson, B.J., Gardner, F.F., and Bolton, J.G., 1965. Anomalous intensity ratios of the interstellar lines of OH in absorption and emission. *Nature*, 208, 1193-1195.

Milne, D.K., 1994. Three decades of supernova remnant polarization, 1962–1992. In Goddard and Milne, 81-84.

Milne, D., Sinclair, M., and Robertson, P., 1994. When I look back—a forum. In Goddard and Milne, 85-95.

Price, R.M., and Milne, D.K., 1965. The Parkes catalogue of radio sources, declination zone –60° to –90°. *Australian Journal of Physics*, 18, 329-347.

Robinson, B., 1994. Spectral line astronomy at Parkes. In Goddard and Milne, 106-118.

Robinson, B.J., Gardner, F.F., van Damme, K.J., and Bolton, J.G., 1964. An intense concentration of OH near the Galactic Centre. *Nature*, 202, 989-991.

Stephenson, F.R., and Green, D.A., 2002. *Historical Supernovae and their Remnants*. Oxford, Oxford University Press.

Westerhout, G., Seeger, C.L., Brouw, W.N., and Tinbergen, J., 1962. Polarization of the Galactic 75-cm radiation. *Bulletin of the Astronomical Institute of the Netherlands*, 16, 187-212.

Whiteoak, J., 1994. Early polarization research at Parkes. In Goddard and Milne, 75-80.

Whiteoak, J.B., and Gardner, F.F., 1969. Radio observations of interstellar formaldehyde. *Proceedings of the Astronomical Society of Australia*, 1, 282-283.

Whiteoak, J.B., and Gardner, F.F., 1972. The C^{13} isotope of formaldehyde in Sgr A and Sgr B. *Astrophysical Letters*, 11, 15-20.

Wielebinski, R., and Shakeshaft, J.R., 1962. Faraday Rotation of polarized Galactic radio emission. *Nature*, 195, 982-983.

Wilson, T.L., Mezger, P.G., Gardner, F.F., and Milne, D.K.. 1970. A survey of H 109 recombination line emission in Galactic HII regions of the southern sky. *Astronomy & Astrophysics*, 6, 364-384.

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MAGNITUDE SYSTEMS IN OLD STAR CATALOGUES

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Abstract: The current system of stellar magnitudes originally introduced by Hipparchus was strictly defined by Norman Pogson in 1856. He based his system on Ptolemy's star catalogue, the *Almagest*, recorded in about AD137, and defined the magnitude-intensity relationship on a logarithmic scale.

Stellar magnitudes observed with the naked eye recorded in seven old star catalogues were analyzed in order to examine the visual magnitude systems. Although psychophysicists have proposed that human visual sensitivity follows a power-law scale, it is shown here that the degree of agreement is far better for a logarithmic scale than for a power-law scale. It is also found that light ratios in each star catalogue are nearly equal to 2.512, if the brightest (1st magnitude) and the faintest (6th magnitude and dimmer) stars are excluded from the study. This means that the visual magnitudes in the old star catalogues agree fully with Pogson's logarithmic scale.

Keywords: stars, historical star catalogues, stellar magnitude system, visual magnitude estimates, astronomical photometry

1 INTRODUCTION

The concept of magnitudes was introduced by Hipparchus in the second century BC (Werner and Schmeidler, 1986; Zissell, 1998). Hipparchus compiled his catalogue of 850 stars with ecliptic coordinates and visual magnitudes. This work was triggered by the discovery and the observation of a nova (not yet explained) in the constellation Scorpius in 134BC. He started to record the coordinates and magnitudes of fixed stars in order to aid discoveries of such objects, and to record the brightness of each star. He defined the brightest twenty stars as 1st magnitude, Polaris and stars of the Great Dipper in Ursa Major as 2nd magnitude, and stars at the observable limit of the naked eye as 6th magnitude. The work of Hipparchus was lost over the years, but Hipparchus' magnitude system came down through subsequent star catalogues such as the *Almagest*. The observational data in the *Almagest* are found to be partly dependent on those of Hipparchus (Duke, 2002; cf. Evans, 1987; Rawlins, 1982).

In the nineteenth century, astronomers tried to define the magnitude system more precisely and quantitatively, based on simple arbitrary visual estimates. Because of the advent of visual photometry, some refinements have been necessary to extend the magnitude scale to fainter objects (see Peirce, 1878). Sir William and Sir John Herschel tried to deduce the form of the magnitude-intensity relationship, and Sir John concluded that a logarithmic law was preferable to a power law and that the light ratio, R, corresponded to 2.551. However, they did not have access to the intensive photometric measurements required in order to relate the visual magnitude scale to stellar intensities. Stenheil made photometric observations in 1836, deduced a logarithmic form for the magnitude-intensity relation, and calculated a value of $R = 2.831$. In the 1850s, Fechner (1860) and Weber explained the logarithmic law on the basis of physiological principles. Applying the laws of the visual senses to stellar magnitudes, Fechner derived a logarithmic relation. This finding was supported by other researchers who investigated the magnitude-intensity relationship (e.g. see Young, 1990).

In 1856, Pogson used the data in Ptolemy's star catalogue, the *Almagest*, to propose adopting a light ratio $R = 2.512$ for two stars that differ in brightness by one magnitude, and he defined the magnitude as

$$m = -(1/\log R)\log I \qquad (1)$$

In the case of $R = 2.512$, this formula could be transformed into

$$m = -2.5 \log I \qquad (2)$$

This definition is well-known as the Pogson scale, and it is still used in stellar photometry.

In the 1960s, psychophysicists demonstrated that the human eye's response to light follows a power law (e.g. Stevens, 1961; 1975), and on this basis visual magnitude estimates should also follow a power law (Schulman & Cox, 1997). On the other hand, astrophysicist, Hearnshaw (1996; 1999), examined the *Almagest*, and he showed that the magnitudes listed there agreed with a logarithmic scale, and that the light ratio (R) was 3.42, far larger than the value derived by Pogson.

In order to determine whether visual magnitude estimates fit a logarithmic or a power law, we intend to investigate the magnitude systems in a number of old star catalogues, using data in *Sky Catalogue 2000.0* (Hirshfeld et al., 1991) for 'modern' stellar magnitudes (henceforth referred to as V magnitudes). The following old star catalogues contain stellar magnitudes estimated by eye and graded from 1 to 6 on the basis of the Hipparchus system:

1. The *Almagest* (Ptolemy, AD127–141)
2. *Kitāb Ṣuwar al-Kawākib* (al-Ṣūfī, 986)
3. *Ulugh Beg's Catalogue of Stars* (1437)
4. *Astronomiae Instauratae Progymnasmata* (Brahe, 1602)
5. *Uranometria* (Bayer, 1603)
6. *Historia Coelestis Britannica* (Flamsteed, 1725)
7. *Uranometria Nova* (Argelander, 1843)

A detailed discussion of these seven catalogues is included in Fujiwara et al. (2004).

In this paper, we present the results of our study of magnitude systems in these old star catalogues. The characteristics of each of the catalogues are discussed in Section 2, below, and the magnitude data and associated analyses are found in Section 3. We graphically present and compare the historical magnitude data with logarithmic and power-law scales in Section 4.1, and light ratios (*R*) are described in Section 4.2. Conclusions are presented in Section 5.

2 CHARACTERISTICS OF THE OLD STAR CATALOGUES

The *Almagest* provides one of the earliest quantitative studies on the brightness of the stars, and was written by Ptolemy (or Claudius Ptolemaeus) in the second century AD (Schmidt, 1994; Zinner, 1926). It comprises thirteen books, and books VII and VIII discuss the fixed stars. It was necessary to establish the coordinates of the stars near the ecliptic in order to observe the positions of the planets. These two books contain a catalogue of 1,022 stars, complete with magnitudes and ecliptic latitudes and longitudes, and the stars are arranged according the classical forty-eight constellations of antiquity. In our study, we only investigate the stars listed in books VII and VIII, and although Ptolemy's original catalogue has not survived, there are numerous manuscript copies dating from the ninth to sixteenth centuries AD. Extensive philological studies of the *Almagest* were conducted by Kunitzsh (1986) and Toomer (1998), and we used the star catalogues in these two works and extracted visual magnitudes for 1,022 stars. Ptolemy's own recorded observations expended from AD127 to 141, and the mean epoch of his catalogue is about AD137.

Kitāb Ṣuwar al-Kawākib (henceforth '*Ṣuwar al-Kawākib*'), which means book on the constellations of the fixed stars, was written in Arabic in the tenth century AD by Abu'l-Ḥusayn 'Abd al-Raḥmān ibn 'Umar al-Ṣūfī (903-986). Al-Ṣūfī is best known for his observations and descriptions of the fixed stars. In this work, he presents the results of his own observations, noting where they differ from or add to data in Ptolemy's star catalogue. In al-Ṣūfī's book—as in the *Almagest*—the forty-eight Ptolemaic constellations are presented in direction order: first the boreal constellations, then the twelve constellations on the ecliptic, and finally the austral constellations. In the table of stars, he lists the magnitude and celestial latitude and longitude of each star. The epoch of this star catalogue is AD964. For each star, he adopts a precession correction of 1° in 66 years, and simply adds a constant of 12° 42′ to Ptolemy's longitudes. However, it is important to stress that the magnitudes represent the results of his own observations. This catalogue represents the only significant independent work on stellar magnitudes between classical times and the Middle Ages; most other medieval astronomers merely reproduced data from Ptolemy's star catalogue. Since the art of printing had yet to be developed, our most serious concern was that scribal errors may have crept into the various manuscripts. Consequently, we examined various manuscripts and other literature relevant to al-Ṣūfī work (e.g. al-Bīrūnī, 1030; Schjellerup, 1874), but we ended up relying mainly upon *Ṣuwar al-Kawākib* (al-Ṣūfī, 986), which was published in Hyderabad in 1954.

At Samarkand, in AD1420, Ulugh Beg (1394-1449) founded a *madrasa*, or institution of higher learning, in which astronomy was the most important subject. A major outcome of the scientific work of Ulugh Beg and his school was the mathematical tables called the *Zīj* of Ulugh Beg or the *Zīj-i Gurgāni* ('Guragon'the title of Genghis Khan's son-in-law, was sometimes also used by Ulugh Beg). This work was originally written in the Tadzhil language, and includes calendrical calculations, planetary tables and a star catalogue that is based on astronomical observations made at Samarkand in about AD1437. Knobel (1917) accessed all contemporary Persian manuscripts available in Great Britain, and published the *Zīj-i Gurgāni* as "Ulugh Beg's Catalogue of Stars". For the purposes of this study, we used the French edition (which also contains some English passages).

Tycho Brahe (1546-1601), the well-known Danish astronomer, observed a supernova in Cassiopeia (the so-called 'Tycho's Nova') from 11 November 1572 until March 1574 (see Stephenson and Green, 2002: 91-95), and recorded his observations in two books (Brahe, 1573; 1602). The latter work, *Astronomiae Instauratae Progymnasmata,* was published posthumously, and in it Brahe included solar and lunar theories and a catalogue with the positions and magnitudes of 777 fixed stars. The data in this catalogue are based upon Tycho's own observations (Dreyer, 1890), and are of high precision. For example, stellar positions were determined to within one minute of arc. In our study, we used a reprinted edition of the *Astronomiae Instauratae Progymnasmata.*

The German astronomer, Johann Bayer (1572-1625), introduced a new system of naming fixed stars in his *Uranometria*, which was published in 1603. In Ptolemy's much earlier *Almagest* there are forty-eight constellations, and stars are usually identified by number and elaborate descriptions. For example, α UMi was described as "The star at the end of the tail of the Little Bear." This was a cumbersome method, and did not always direct each observer to the same star! Bayer decided to reform the system by unambiguously and succinctly identifying every star visible to the naked eye. In each constellation, he assigned Greek letters to the naked eye stars, in approximate order of magnitude, and continued on using the Latin alphabet when necessary (see Figure 1). Bayer's nomenclature is still widely used today. In the *Uranometria*, Bayer adds twelve southern constellations to Ptolemy's original forty-eight, and he depicts the positions and magnitudes of about 1,200 individual stars (with magnitudes for the southern stars drawn from data provided by Dutch explorers). For our study, we used Bayer's reprinted edition, which includes the twelve southern constellations.

John Flamsteed (1646-1719) was the first Astronomer Royal at the Royal Observatory, Greenwich, where he carried out 20,000 observations of almost 3,000 stars. His accumulating observational data were presented in the *Historia Coelestis*, which was published in 1712, and in the *Historia Coelestis Britannica*, which appeared posthumously in 1725. This latter work comprises three volumes, and the third and final volume contains his star catalogue (the earlier volumes 1 and 2 contain planetary data). The catalogue contains magnitude estimates, plus equatorial and ecliptic positions; the mean epoch is AD1689. We used the original copy of the *Historia Coelestis Britannica* held in the Paris Observatory for our study.

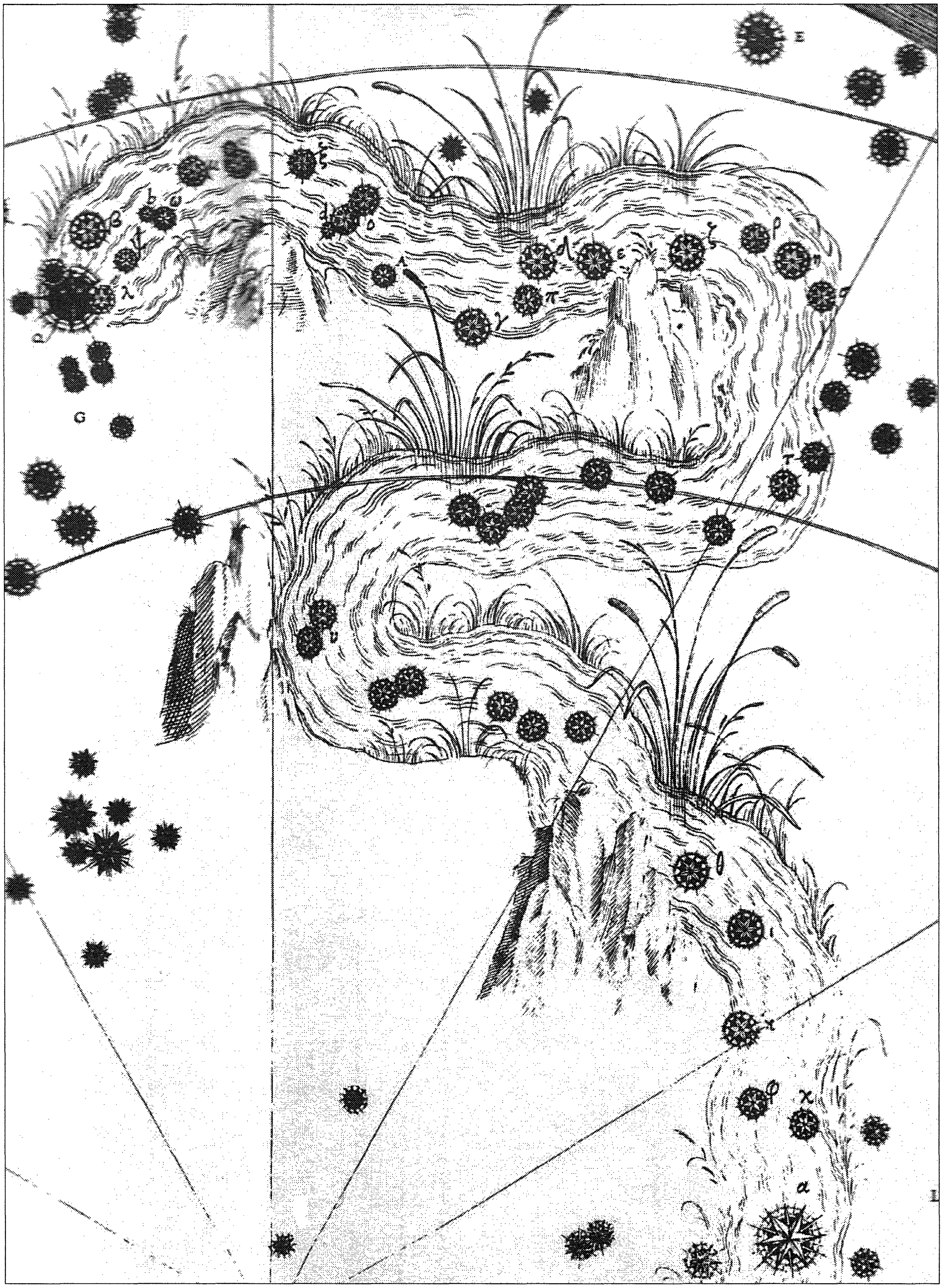

Figure 1: Map of the constellation of Eridanus in *Uranometria* (Bayer, 1603), showing stars labeled with all twenty-four Greek letters, plus four letters drawn from the Latin alphabet.

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Finally, in 1843 the Prussian astronomer Friedrich Wilhelm August Argelander (1799–1875) published his *Uranometria Nova*, which contained the equatorial coordinates and magnitudes of 3,256 stars that he observed with the naked eye from Bonn. Argelander was not so concerned about stellar positions; the main feature of his work was that he recorded *all* stars visible to the naked eye, settled on a nomenclature that has survived through to the present day, and clearly delineated the boundaries of the various constellations. We accessed one of Argelander's original 1843 published catalogues for this study.

3 DATA AND ANALYSIS

Before we could use the data contained in the old catalogues we had to examine the characteristics of each, and apply corrections to the published magnitudes. This was especially relevant in the case of Ulugh Beg's catalogue, which some scholars believe was copied from al-Ṣūfī's earlier work (e.g. see Knobel, 1917). To the contrary, our investigations revealed that although he was possibly influenced by al-Ṣūfī's efforts, Ulugh Beg did not directly duplicate his catalogue. Consequently, we were able to demonstrate the independence of all seven early catalogues, and the consistency of their magnitude data (see Fujiwara et al., 2004).

In the old star catalogues, magnitude classes were recorded by numbers (1–6) and plus or minus signs which indicated 'a little brighter than' or 'a little dimmer than', respectively. To quantify these magnitude descriptions, we subtracted or added 0.33 according to the plus or minus sign respectively. For example, we assigned 2.67 for 3+, and 3.33 for 3–.

We also had to omit unsuitable stars. Firstly, there were bright stars in *Sky Catalogue 2000.0* with $V < 1$, such as α CMa (Sirius) or α Boo (Arcturus), because when the various old catalogues were recorded there was no concept of a zero or a minus magnitude. Secondly, we eliminated stars that we could not readily identify. For example, Bayer recorded the six stars, π^1, π^2, π^3, π^4, π^5 and π^6 Ori as just the one star, π Ori, so we were unable to assign individual magnitudes to each of the components. As for the constellation 'Argo', it was divided by Lacaille into the constellations of Puppis, Vela, and Carina during the eighteenth century, so we simply omitted them from our analysis. We also had to leave out double and multiple stars with separation distances >1′ (the limit of the resolving power of the naked eye) that were recorded as single objects. For example, the angular separation of α^1 Cap and α^2 Cap is 7′ so if a catalogue recorded it as a single α Cap it was rejected. For close double stars (with separations of <1′) we accepted the combined single magnitudes listed in the old catalogues, and compared these estimates with the combined V magnitudes. Finally, we omitted known variable stars where $\Delta m_V > 0.5$, namely, ε Aur, δ Cep, μ Cep, o Cet (Mira), χ Cyg, β Lyr, β Per (Algol), ζ Phe and λ Tau. For further details see Fujiwara et al., 2004.

After this culling process, we ended up with a sample of 2,124 naked-eye stars (see Table 1). In this table, the catalogues are listed in column 1, with the numbers referring to those given here in Section 1; the observational epoch (rather than the publication date) of each catalogue is shown in column 2; and the total number of stars (n) in each is listed in column 3.

Table 1: Catalogue, observational epoch and number of sampled stars.

Catalogue	Epoch (AD)	n
1	137	910
2	964	911
3	1437	889
4	1572	658
5	1603	949
6	1689	1003
7	1843	1946

Atmospheric extinction is an important subject, and needs to be taken into consideration. We computed the mean differences, $m - V$, and standard deviation, σ, for each star catalogue, binned by declination. The mean difference, $m - V$, corresponds to the possible extinction, and since it was always smaller than σ we decided not to make any corrections to the magnitude data in the seven catalogues.

We then proceeded to compare the stellar magnitudes in the seven old star catalogues with the Pogson magnitude system. First we investigated the magnitude data in the old catalogues on the basis of a logarithmic magnitude scale (Figure 2). In this figure, the magnitudes of the stars as recorded in each star catalogue are shown as dotted lines that are equivalent to the Pogson scale, whereas the solid lines indicate linear regressions. Then we plotted the same magnitude data on a power-law scale (Figure 3). In these plots, a 'pure' power-law function, i.e.

$$\log m = aV + b \quad \Leftrightarrow$$

$$m = 10^{aV+b} = 10^b(10^V)^a = 10^b(I/I_0)^{-2.5a} \qquad (3)$$

is drawn as a straight line, whereas a 'shifted' power-law formula, such as the function suggested by Schulman and Cox (1997),

$$m = 5.5556(2.512^{(-0.5)(6-V)}) + 0.4444, \qquad (4)$$

is indicated by a curved line. Because a shifted power-law function proved inadequate, we chose to use a pure power-law function for our study. Details of these two power-law functions are given in Appendix 1.

4 RESULTS AND DISCUSSION

4.1 Logarithmic versus Power Law Scales

In this study, we compared the magnitude systems based on a logarithmic scale with that of a power-law scale. As shown in Figure 2, on a logarithmic scale the magnitude data recorded in old catalogues correspond exactly with the Pogson logarithmic scale (the dotted line). Our regression fits (the solid lines) for each catalogue are almost identical to the dotted lines.

On the other hand, Figure 3 indicates that the function suggested by Schulman and Cox (the dotted lines) in no way fits the magnitude data in the old star catalogues. Relative to the power-law regressions shown by the solid lines, at dimmer magnitudes (i.e. m = 3–6), the regressed functions do fit the magnitude data, but at brighter magnitudes (m = 1–3) they deviate notably. This indicates that the power-law regressions do not fit the data.

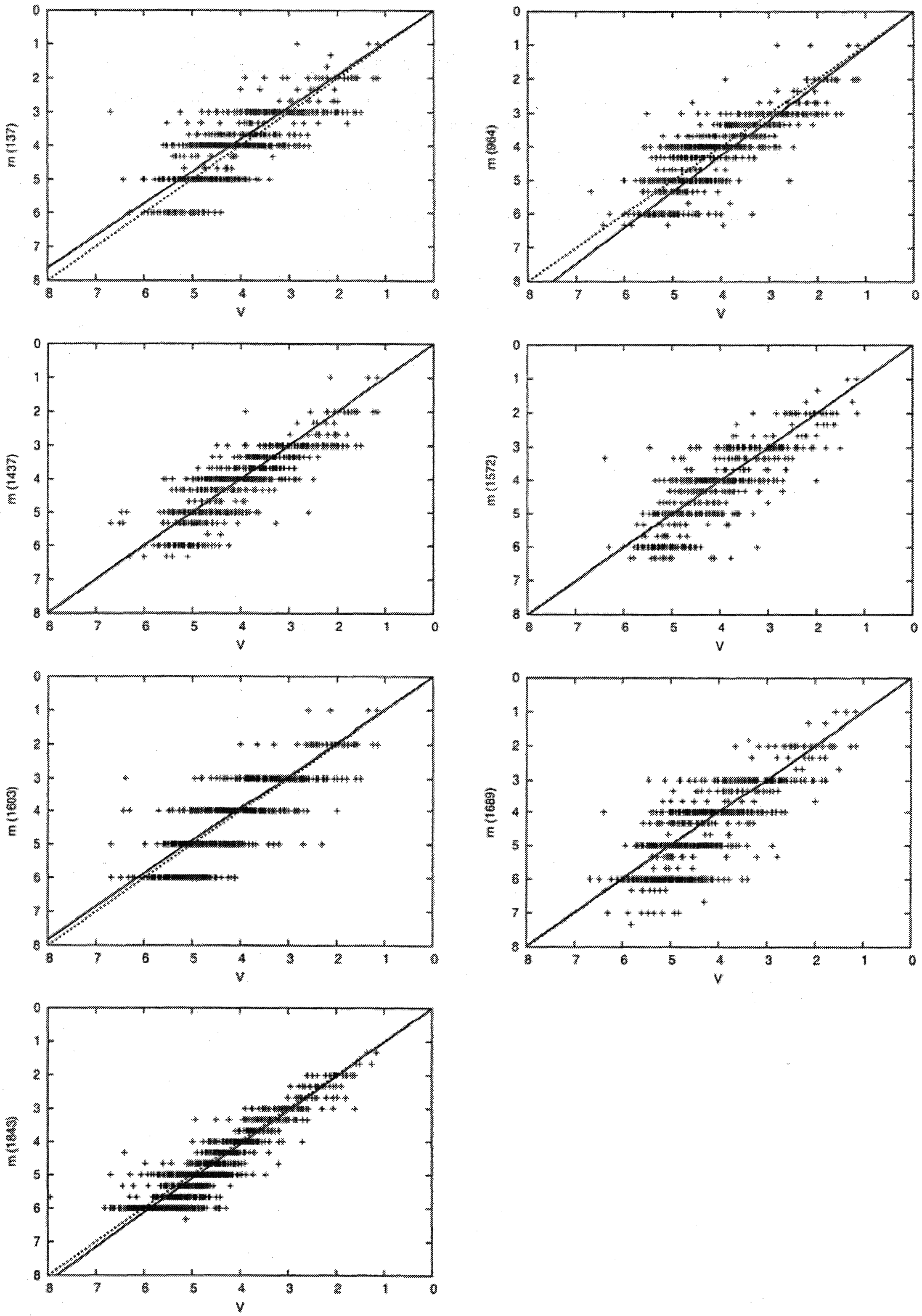

Figure 2: Magnitude systems on the logarithmic scale, where m(137) refers to the *Almagest* magnitudes, m(1437) to Ulugh Beg's catalogue, and so on, while V magnitudes are those listed in the *Star Catalogue 2000.0*. The dotted lines indicate Pogson's scale and the solid lines are the linear regressions.

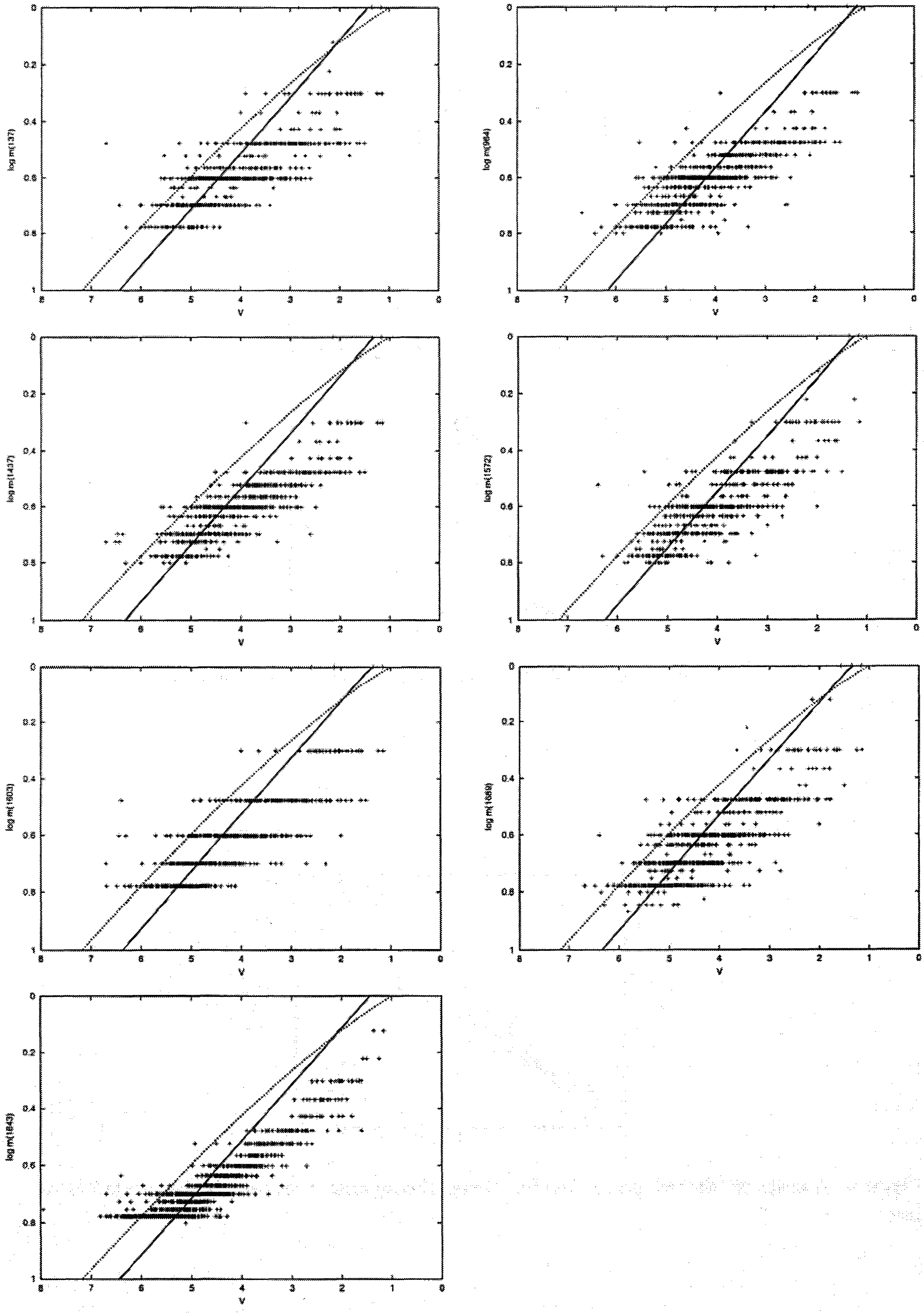

Figure 3: Magnitude systems on the power law scale. The dotted lines indicate the Schulman-Cox function and the solid lines are the power-law regressions.

In order to investigate which scale the magnitude data in the old star catalogues best fit, we carried out chi-squared (χ^2) tests. Table 2 contains the reduced chi-squares; column 1 lists the catalogues, while the reduced logarithmic and power-law chi-squares are shown in column 2 and 3 respectively. If a regressed function fits the data, the chi-squared value should be small. As shown in this Table, all of the logarithmic chi-squared values are small, indicating that the linear regressions are correct. In comparison, the power-law chi-squares values are large, which indicates that the power-law regressions do not fit the data. This indicates that the magnitudes in all of the old star catalogues do not follow a power-law but they do conform to a logarithmic scale.

Table 2: Reduced chi-square in old star catalogues on logarithmic and power-law scale.

Catalogue	χ^2 (logarithmic)	χ^2 (power-law)
1	0.3627	1.1396
2	0.2720	0.4851
3	0.2853	1.0845
4	0.3740	1.0179
5	0.4296	1.2828
6	0.3885	1.0976
7	0.1419	0.9286

4.2 Examination of the Light Ratio (*R*)

In Section 4.1, the magnitude systems were found to fit a logarithmic scale. Subsequently, we examined light ratios (R) of magnitude systems in the old star catalogues. In Table 3, we calculate R for each star catalogue using the linear regressions shown in Figure 2. Each R in the old star catalogues approximates Pogson's $R = 2.512$.

In calculating the value of R some data points had to be excluded, as discussed in Section 3. Firstly, values of V for stars recorded as 1st magnitude in the old star catalogues were reduced to fainter magnitudes, given that stars with $V < 1$ were omitted from our study. In addition, the average V of stars recorded as magnitude 6 was increased toward the brighter magnitude. Considering the present ranges of each magnitude, 3rd magnitude includes stars of 2.5-3.4 and 6th magnitude stars of 5.5-6.4. However, ancient observers defined the limit of naked eye visibility as magnitude 6, so their records rarely contain stars of $V > 6.0$. In the old star catalogues, only those stars with values of V = 5.5-6.0 magnitude stars were estimated as magnitude 6; observers recorded only the brightest stars in the range of the 6th magnitude. In the *Historia Coelestis Britannica*, Flamsteed (1689) recorded stars of the 7th magnitude, which he did not define at the time. The magnitudes of these stars were therefore considered to be imprecise, and they were not included in our study.

Table 3: The light ratio (*R*) in old star catalogues.

Catalogue	*R*
1	2.615
2	2.360
3	2.505
4	2.495
5	2.554
6	2.509
7	2.451

In Figure 4, we compare distributions of dispersion ($m_{137} - V$) in the *Almagest* for stars of 3rd and 6th magnitude. The distribution of 3rd magnitude stars is symmetry around $V = 3.0$, while the 6th magnitude curve is asymmetry and appears to be truncated at the fainter end of the distribution. Near the observable limit ($V = 6.0$), recorded and non-recorded stars should be represented on a 50:50 basis (the so-called 'Malmquist bias'). Consequently, there should be more stars of magnitude 6, and the peak in the distribution of 6th magnitude stars should be at 6.0. As shown in Figure 4, distributions of 6th and 3rd magnitude stars have a common shape for the brighter part ($\Delta m > 0$) of the histograms. On the other hand, for $\Delta m \leq 0$ the distribution of 6th magnitude stars is almost suppressed, and the peak is moved to the brighter part. Meanwhile, Table 4 indicates that the standard deviation (σ) of the 6th magnitude stars in the *Almagest* is much smaller than other values listed, which supports the view that some of the 6th magnitude stars are missing. This is probably due to the observable limit of the naked eye, and the 6th magnitude in the old star catalogues should correspond to the same class in Pogson's system. As well as 6th magnitude stars, the distribution of the 5th magnitude stars should also be truncated, but most of this distribution is within the range $V < 6.0$, and does not effect the results (for detailed values of σ see Table 3 in Fujiwara *et. al.*, 2004).

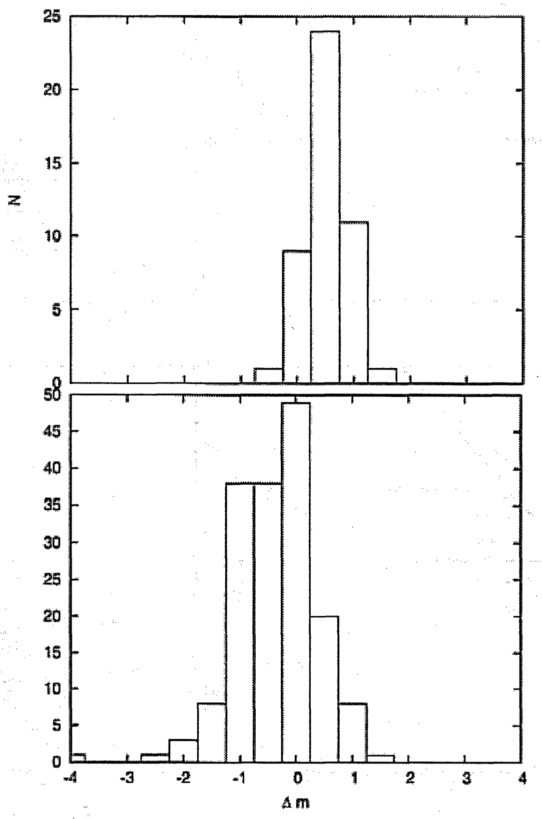

Figure 4: Differences in the distributions of dispersions between 6th magnitude stars (upper) and 3rd magnitude stars (lower).

Table 4: Standard deviation (σ) for each recorded magnitude in the *Almagest*.

Magnitude	σ
1st	0.91
2nd	0.66
3rd	0.73
4th	0.56
5th	0.51
6th	0.39

Relative to the magnitude system in the *Almagest*, Hearnshaw (1996) gave a logarithmic light ratio of R = 3.26, and later he revised this to R = 3.42 (Hearnshaw, 1999). Both values deviate from the Pogson system. Using all magnitudes recorded in the *Almagest*, we confirmed that R corresponds with Hearnshaw's findings. However, we suggest that the difference between Pogson's and Hearnshaw's values should be ascribed to marginal magnitudes, namely the brightest (1st magnitude) stars and the dimmest (6th and 7th magnitude) stars. In order to determine the real system of magnitude, we omitted the inaccurate 1st and 6th magnitude stars when investigating the linear regressions. As shown in Figure 2 and in Table 3, the magnitude systems in the old star catalogues, including the *Almagest*, do fit Pogson's scale of $R = 2.512$. We also note that the linear regressions in Figure 2 and values of R in Table 3 differ for stars in the al-Ṣūfī and Ulugh Beg catalogues, supporting the view that they represent from two quite independent observational datasets.

5 CONCLUSIONS

We show that there is agreement between the magnitude scales in the seven old star catalogues and the current system suggested by Pogson, and that the magnitudes in the old star catalogues fit a logarithmic scale. This is in spite of the suggestion by psychophysicists—based on visual sensitivity—that it should reflect a power law. Possibly our finding relates to the definition of the magnitudes in the old catalogues. As noted in Section 1, 1st, 2nd and 6th magnitudes were defined by Hipparchus. If the brightness of the stars of 1st magnitude in ~2.5 times greater than that of 2nd magnitude stars, and 100 times greater than stars of 6th magnitude, then the logarithmic function is a natural consequence. It is no surprise, then, that stars in the old catalogues do not follow a power law when their magnitudes are plotted against V magnitudes in the *Sky Catalogue 2000.0* (as in Figure 3).

It was also found that 6th magnitude stars in the old star catalogues exhibited a Malmquist bias, suggesting that stars in this magnitude range should not be used in determining the current magnitude system. Likewise, 1st magnitude stars also introduce a bias. When these two magnitude classes were omitted, the linear regressions presented here show that magnitudes of stars in the seven old catalogues are consistent with the light ratio of $R = 2.512$ suggested originally by Pogson.

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□ REFERENCES

al-Bīrūnī, 1030. *Al-Qānūn al-Mas'ūdī. Volume 3*. Reprint, 1956, Hyderabad, Dāiratu'l-Ma'ārif-il-'Oṣmānia.

al-Ṣūfī, 986. *Ṣuwar al-Kawākib*. Edited by M. Nizāamu'd-Din, 1954, Hyderabad, Dāiratu'l-Ma'ārif-il-'Oṣmānia.

al-Ṣūfī, 986. *Ṣuwar al-Kawākib*. Facsimile edition, Edited by Fuat Sezgin, 1986, Frankfurt am Main, Publications of the Institute for the History of Arabic-Islamic Science.

Argelander,W.A., 1843. *Uranometria Nova*. Berlin, Verlag von Simon Schropp.

Bayer, J., 1603. *Uranometria*. Reprint, 1987, London, British Library.

Brahe, T., 1573. *De Nova et Nullius aevi Memoria Prius Visa Stella*. Facsimile edition, 1901, Copenhagen.

Brahe, T., 1602. *Astronomiae Instauratae Progymnasmata*. Reprint, 1969, Bruxelles, Impression Anastaltique.

Dreyer, J.L.E., 1890. *Tycho Brahe: A Picture of Scientific Life and Work in the Sixteenth Century*. Edinburgh, Adam and Charles Black.

Duke, D.W., 2002. Associations between the ancient star catalogues. *Archive for the History of Exact Sciences*, 56, 435-450.

Evans, J., 1987. On the origin of the Ptolemaic star catalogue. *Journal for the History of Astronomy*, 18, 155-172, 233-278.

Fechner, G.T., 1860. *Elemente der Psychophysik*, Leipzig, Breitkopf und Härtel

Flamsteed, J., 1725. *Historia Coelestis Britannica. Tome III*. London.

Fujiwara, T., Yamaoka, H., and Miyoshi, S.J., 2004. Survey of long-term variability of stars I. Reliability of magnitudes in old star catalogues. *Astronomy and Astrophysics*, 416, 641-646.

Hearnshaw, J.B., 1996. *The Measurement of Starlight*. Cambridge, Cambridge University Press.

Hearnshaw, J.B., 1999. An analysis of Almagest magnitudes for the study of stellar evolution. *New Astronomy Reviews*, 43, 403-410.

Hirshfeld, A., Sinnott, R.W., and Ochsenbein, F., 1991. *Sky Catalogue 2000.0. Volume 1*. (Second edition). Cambridge, Cambridge University Press and Sky Publishing Corporation.

Knobel, E.B., 1917. *Ulugh Beg's Catalogue of Stars (1437)*. Washington, Carnegie Institution of Washington (Publication No. 250).

Kunitzsch, P., 1989. *The Arabs and the Stars*. London, Variorum Reprints.

Peirce, C.S., 1878. Photometric researches made in the years 1872-1875. *Annals of Harvard College Observatory*, 9(1), 1-184.

Pogson, N R., 1856. Magnitudes of thirty-six of the minor planets for the first day of each month of the year 1857. *Monthly Notices of the Royal Astronomical Society*, 17, 12-15.

Ptolemäus, C., 1986-1991 *Der Sternkatalog des Almagest Die Arabisch-mittelalterliche Tradition Teil I-III (AD 2c.)*. Wiesbaden, Otto Herrassowitz (German translation, edited by P. Kunitzsch).

Rawlins, D., 1982. An investigation of the ancient star catalog. *Publications of the Astronomical Society of the Pacific*, 94, 359-373.

Schjellerup, H.C.F.C., 1874. *Description des Étoiles Fixes* Reprint, 1987, Frankfurt am Main, Institut für Geschichte der Arabisch-Islamischen Wissenschaften.

Schmidt, H., 1994. The visual magnitudes of stars in the Almagest of Ptolemeus and in later catalogues. *Astronomy and Astrophysics*, 106, 581-585.

Schulman, E., and Cox, C.V., 1997. Misconceptions about astronomical magnitudes. *American Journal of Physics*, 65, 1003-1007.

Stephenson, F.R., and Green, D.A., 2002. *Historical Supernovae and their Remnants*. Oxford, Oxford University Press.

Stevens, S.S., 1961. To honor Fechner and repeal his law. *Science*, 133, 80-86.

Stevens, S.S., 1975. *Pyschophysics*. New York, John Wiley.

Toomer, G.J., 1998. *Ptolemy's Almagest (AD 2c.)*. English translation and annotated by G.J. Toomer, Princeton, Princeton University Press.

Werner, H., and Schmeidler, F., 1986. *Synopsis der Nomenklatur der Fixsterne,* Wissenschaftliche Verlagsgesellschaft, Stuttgart.

Young, A.T., 1990. How we perceive star brightnesses. *Sky and Telescope*, 79, 311-313.

Zinner, E., 1926. Helligkeitsverzeichnis von 2373 sternen bis zur Grösse 5.50. *Veröffentichungen der Remeis-Sternwarte zu Bamberg*, 2, 1-160.

Zissell, R.E., 1998. Evolution of the "real" visual magnitude system. *Journal of the American Association of Variable Star Observers*, 26, 151-161.

APPENDIX 1: A 'PURE' AND 'SHIFTED' POWER-LAW FUNCTION

A power-law response for visual sensitivity can be formulated in two ways. Firstly, if the zero point of the visual magnitude, m, is corresponding to the unit of the intensity, I, the relationship should be written as

$$m = BI^A \quad \Leftrightarrow \quad \log m = aV + b, \qquad (5)$$

where a is positive and A is negative. We call this a 'pure' power-law function, and it has two free parameters.

On the other hand, the zero point of m can be chosen arbitrarily. Thus,

$$m = BI^A + C \quad \Leftrightarrow \quad \log\,(m - c) = aV + b, \qquad (6)$$

also represents a power-law response, and we call this a 'shifted' power law. It has three free parameters, but if $m = 1$ at $V = 1$ and $m = 6$ at $V = 6$ are required, the freedom is reduced to one (i.e., the function is determined by a given a). The function of Schulman and Cox (SC) can be obtained from Equation (6) by setting a at 0.2.

The discussion in Schulman and Cox (1997) indicates that a should be positive, and they set the value at 0.2. As can be seen in Figure 3, however, the data can only be represented by a concave line in this plot, while the function of SC is a convex line. The boundary between a concave and a convex line is $a = 0.1556 = (\log 6)/5$, where c becomes zero (the pure power law, which in this Figure is represented by a straight line).

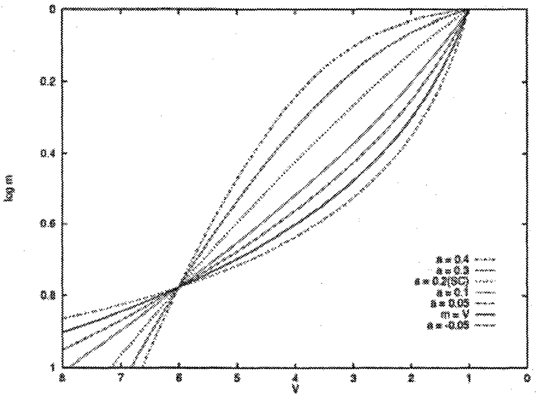

Figure 5: A series of 'shifted' power-law functions. The logarithmmic function (solid line) is also plotted.

Figure 5 shows a series of 'shifted' power-law functions with some values of a. When $a \rightarrow +0$ or $a \rightarrow -0$, the logarithmic function ($m = V$) is an asymptote. Both $a \rightarrow +0$ and $a \rightarrow -0$ in Equation 5, however, lead to a singular function (there is no solution for $a = 0$), and the best fit is not far from the logarithmic function (cf. Figure 2). Thus the 'shifted' power-law formula is inadequate as a fitting function. This is the primary reason we opted for a 'pure' power law in our study.

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'POPULAR' JOURNALS AND COMMUNITY IN AMERICAN ASTRONOMY, 1882-1951

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Abstract: Popularization fulfils several important roles beyond those recognized in the culturally-dominant view. Apart from its intended purpose of diffusing scientific knowledge among various audiences, popularization serves practitioners, especially when exercised in the format of a disciplinary 'trade' journal.

'Trade' journals inform researchers about developments occurring in areas of knowledge production beyond their immediate specialties. Such journals offer routine assessments and reviews of current investigations, innovations, and issues facing researchers and educators alike. These outlets attract new recruits into the profession, through encouragement of research methods and the explication of lingering problems. Most importantly, they serve to shape, direct, and influence peer-level dialogues and decisions upon future courses of action, including the research process itself.

In an inversion of the culturally-dominant view of popularization, such trade journals comprise an essential, if little-recognized, component of disciplinary professionalization.

Keywords: popularization, *Sidereal Messenger*, *Popular Astronomy*, William W. Payne, Carleton College, American Astronomical Society, trade journals

1 INTRODUCTION

In the late nineteenth century, three leading astronomical journals were founded, edited and privately published by William W. Payne (1837–1928; Figure 1), founder of the Department of Astronomy and later Director of the Goodsell Observatory at Carleton College in Northfield, Minnesota. Payne's three journals, *The Sidereal Messenger* (1882-1891), *Astronomy and Astro-Physics* (co-edited with George Ellery Hale), and *Popular Astronomy* (1893-1951), brought national and international recognition to the liberal arts College through the mid-twentieth century.

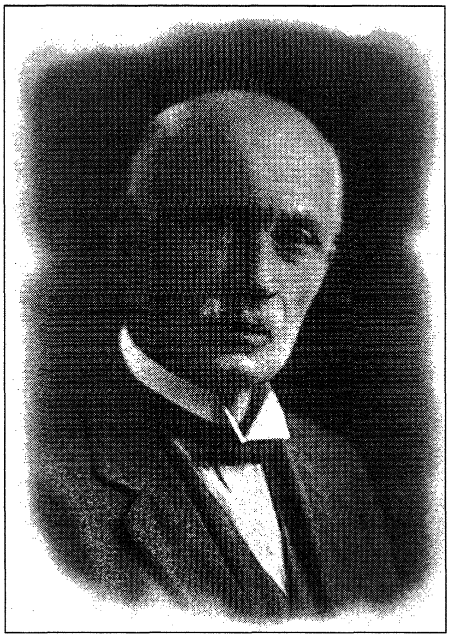

Figure 1: William W. Payne, founding Editor and publisher of *Popular Astronomy*, 1893-1910 (Reproduced from *Popular Astronomy*, 36, f.267 (1928). Courtesy, Carleton College Archives).

When launched in 1882, Payne's *Sidereal Messenger* was the only astronomical journal issued in the United States, whether popular or research-oriented. Benjamin Apthorp Gould's *Astronomical Journal*, which was founded in 1849 and suspended in 1861, was only revived in 1886 (Hermann, 1971). Nor was a national association of professional astronomers (the American Astronomical Society, or AAS) to be established until 1899. Before that occasion, many of the nation's astronomers belonged to a 'Section' within the larger, antecedent American Association for the Advancement of Science (AAAS).

Payne's journals appeared during a time of rapid disciplinary and institutional growth that included significant changes in research practices (i.e. the emergence of observational astrophysics). But they did not merely chronicle those developments. In the coming decades, they were to become an integral part of the American astronomical community, whose subsequent rise to a position of world leadership was likewise achieved during the period from 1860 to 1940 (see Lankford, 1997).

Payne's *Sidereal Messenger* and its principal successor, *Popular Astronomy*, became the discipline's first 'trade' journals. Long before its publication ceased in December 1951, *Popular Astronomy* had become the unofficial journal of the AAS. Associated with Carleton College for fifty-nine years, *Popular Astronomy* was published without interruption through the Great Depression and the Second World War. Nonetheless, its post-war survival was not guaranteed, and it ceased production just six months after the unexpected death of its final editor.

2 THE CULTURALLY-DOMINANT VIEW OF POPULARIZATION

In what has been termed the 'culturally-dominant' view, sociologist Stephen Hilgartner (1990: 519) has argued that the process of popularization is, "... at best, 'appropriate simplification'—a necessary (albeit low status) educational activity of simplifying science for the non-specialist ... [while at worst it may encompass] the distortion of science by such outsiders as journalists, and by a public that misunderstands much of what it reads."

The dominant view of popularization rests upon an overly simplistic, dichotomous model of science communication (Nelkin, 1987; Shinn and Whitley, 1985), which contrasts the development of genuine scientific knowledge with the dissemination of simplified accounts for the public. This dichotomy not only demarcates the intellectual properties of 'genuine' from 'popularized' science, but also reinforces the political authority of scientists against "... challenges by outsiders...[including] policy makers, journalists, [and] technical practitioners ...", along with scholars from other disciplines and the public (Hilgartner, 1990: 530, 533).

A selective body of literature has examined the growth and influence of popular accounts of American science, extending from the early Republican period to the mid-twentieth century and beyond (e.g. see Greene, 1958; Kuritz, 1981; LaFollette, 1990; Lewenstein, 1992; Whalen and Tobin, 1980; Zochert, 1974). Such studies have documented changing audience perceptions, assumptions and expectations concerning scientific knowledge and its practitioners. Far less attention, however, has been paid to the contents and significance of disciplinary 'trade' journals that served more specialized (and lower-circulation) audiences. Nonetheless, these journals provided a "... major route of communication among scientists." (K. Figlio, quoted in Whalen and Tobin, 1980: 202, f.n. 2).

3 PAYNE AND ASTRONOMY EDUCATION AT CARLETON COLLEGE

Born at Somerset, Michigan, in 1837, William Wallace Payne earned Bachelor's (1863) and Master's (1864) degrees from Hillsdale (Michigan) College, with proficiencies in mathematics and foreign languages (Hillsdale College, 1863).[1] While a teacher in local township schools, Payne studied law and received his LL.B. degree from the Chicago Law School in 1866. He then relocated to Mantorville, Minnesota, and formed a law partnership with Robert Taylor, but became discontented with the practice. He then returned to teaching and launched his first journal, the *Minnesota Teacher and Journal of Education* (ca. 1867-1871), which in other hands was later transformed into the *Western Journal of Education* (Fath, 1928; Greene, 1988).

In 1871, Carleton College President, James W. Strong, hired Payne as a Professor of Mathematics and Natural Philosophy at its Northfield campus in Minnesota. Remarkably, Payne soon undertook the construction of an astronomical observatory, although the Congregationalist College, founded in 1866, consisted of but three buildings (Headley and Jarchow, 1966; Leonard, 1904). By 1878, a small wooden observatory was completed, which housed a clock, a 7.6-cm (3-in) transit instrument, and a 20.3-cm (8-in) Clark refracting telescope. Time signals derived from astronomical observations were first relayed by telegraph from the unfinished structure in 1877. This service, which grew into the largest of its kind in the northwest, eventually provided time for more than twelve thousand miles of railroad lines.

During the 1880s, astronomy was the most vital and important of the College's various academic programs. In 1880, Payne offered an "... advanced course of study in Pure Mathematics and Practical Astronomy ..." (President's Annual Report, 1880: 11) that attracted his first students. In 1882, "... original astronomical work [included] ... double star observations ... daily sketches and observations of sunspots ... [and] comet observing and [orbital] computations." (President's Annual Report, 1882: 15). Payne secured additional funding to purchase a larger transit instrument, and then set his sights on a new and larger observatory (President's Annual Report, 1883), the construction of which was begun in 1886. Four years later, funds were secured for the installation of a 41-cm (16-in) refracting telescope—then the sixth-largest in the nation and the twelfth-largest in the world. The new brick observatory (Figure 2) was named after the College's founder, Deacon Charles Moorehouse Goodsell (Greene, 1988; Payne, 1891). In 1894, Payne received an honorary Ph.D. from Hillsdale College, and Carleton College awarded him an Sc.D. at its Golden Anniversary in 1916.

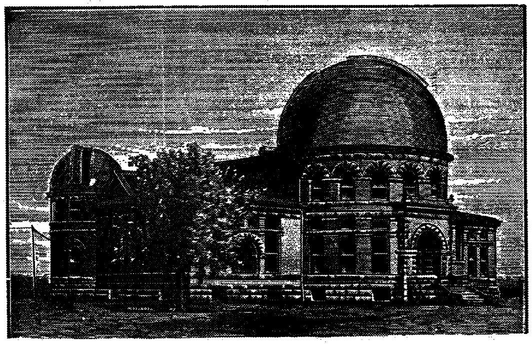

Figure 2: Goodsell Observatory, Carleton College, Northfield, Minnesota (after Payne, 1891, 84; reproduced with permission of the Editors, Astronomical Society of the Pacific).

4 *THE SIDEREAL MESSENGER* (1882-1891)

In 1882, Payne launched the first of three journals that were to spread Carleton's name throughout the astronomical community, both at home and abroad. His institution was one of many that partook in the wave of post-bellum observatory construction that swept across the United States (see Bell, 2002). A host of factors, including the generation of surplus capital, improved means of transportation, and rapid settlement of the western frontier, contributed to the growth of institutions of higher education and the spread of research programs relating to the physical and biological sciences.

Within the discipline of astronomy, the employment of celestial photography, the rise of astrophysics, and a number of other technological and scientific developments significantly aided the observatory movement. In the western states, astronomers were more widely separated, but they generally enjoyed superior observing conditions to those experienced by their eastern counterparts. Yet, not a single popular or research-oriented astronomical journal addressed the needs of the professional astronomers or collegiate/ secondary instructors.

It was possibly a summer's experience in observatory practice acquired at the Cincinnati Observatory (under Director Ormond Stone) that sparked Payne's desire to publish an identically-named journal to the one that was issued between 1846 and 1848 at Cincinnati by Ormsby MacKnight Mitchel (McCormmach, 1966; Shoemaker, 1991). However, Payne neither mentioned the prior existence of, nor his desire to emulate, Mitchel's earlier *Sidereal Messenger*. Across a gap of thirty-four years, tremendous cultural and scientific differences separated Mitchel's and Payne's journals. Substantial growth of the nation's astronomical community, along with attendant changes in the size and distribution of America's population, were readily apparent. In turn, the level of cultural authority and support for science had dramatically improved (Bruce, 1987). These factors and others suggested that a greater chance of success awaited Payne's venture into astronomical journalism. Yet, one similarity united the two men's efforts: each editor strove to direct his journal's contents toward both scientific and popular audiences.

Payne's *Sidereal Messenger* (along with *Popular Astronomy*) came to be adopted by the American astronomical community for reasons that were neither fully articulated, nor perhaps anticipated, by its founder. Having no pretensions whatsoever as research-grade publications, Payne's journals nonetheless followed an established pattern among contemporary periodicals that were created for the diffusion of scientific knowledge among colleagues, instructors, and the general public alike.

Historians Matthew Whalen and Mary Tobin have identified three 'general science periodicals' (*The American Naturalist, Popular Science Monthly*, and *Science*—all published during the era before they were transformed into branches of the Science Press by James McKeen Cattell) as representative of a particular genre. Each journal, they noted, "... originated under the auspices of a private, self-appointed editorship acting in the name of a scientific community ... who saw a need for conveying both a sense of and a meaning for the mission of science to the public and to their colleagues." (Whalen and Tobin, 1980: 198; c.f. Whalen, 1981: 15-16). With substitution of the word 'astronomy' for 'science' in the preceding sentence, no better, nor more succinct, description might be fashioned, to characterize the actions and approach of Payne and his publication of *The Sidereal Messenger*.

The *Messenger* was never conceived as a purely 'popular science' journal, nor was it directed toward a general readership. Upon completing its third year of publication, Payne (1884: 304) reiterated that his objective was not to maximize the number of subscriptions; by contrast, he had deliberately "... failed to interest hundreds of people ..." who might otherwise have become subscribers had the journal's contents been presented as "... chiefly popular and unscientific." He viewed his intended audience as an amalgam of readers, encompassing "... teachers of astronomy, in colleges and high schools ... student[s] of astronomy ... persons ... in every vocation of life, that have a love for the elements of this great science ... [and the] amateur observer." (Payne, 1882-1883: 20-21, 298). Under the third rubric, Payne may be categorized as a noted 'translator' or 'cultural transcriber' of scientific information, whose likes have included a host of scientists, journalists, and administrators (see Whalen, 1981: 15, 23).

Payne (1882-1883: 19) also made it clear that his publication had none of the pretensions of a research journal. *The Sidereal Messenger* was "... in no sense a rival for the place or patronage of such periodicals as the [*Astronomische*] *Nachrichten* ...", which were devoted to the needs of the 'practical astronomer'. He intended his journal to serve "... other public interests ... besides those that are mainly theoretical or professional." (Payne, 1882-1883: 20). The *Messenger*'s avowed purpose was "... to select that which is best, new or useful, from the mass of work that is going on ... and present the same in a terse or plain way, avoiding the use of technical terms, and the details of research as much as possible." (ibid.). Payne (ibid.) believed that such information could benefit astronomy educators, who often lacked "... the means of knowing the kind or extent of work carried on in observatories in this country and abroad." This knowledge provided an essential supplement to most textbooks, which Payne (1882-1883: 20) judged to be "... quite erroneous ..." In defending the *Messenger*'s contents, Payne (1884: 304) argued that "... an astronomical journal, to be worthy of the name, must maintain a scientific character worthy of the attention and support of the leading workers ... in this or any other country."

Among those helping to advance the scientific enterprise through the conduct of systematic observations of the heavens were avocational individuals termed 'amateur astronomers'. As historian, Thomas R. Williams (2000: 13), points out, a "... substantial record of scientific effort and achievement [can be found] among U.S. amateur astronomers in the later decades of the nineteenth century." Successful observers (of the calibre of Sherburne Wesley Burnham and Edward Emerson Barnard), who first earned distinctions as amateurs, were sometimes "... absorbed into the emerging discipline and found employment as professional astronomers." (Williams, 2000: 10). It was also toward scientifically-minded amateurs and students alike that the *Messenger* was pitched. Subscribers were promised ten numbers per year, each consisting of at least 24 pages, for a subscription price (including postage) of $2. Payne's premiere volume well exceeded that forecast (it totalled 314 pages!), prompting the Editor to remark that the "... amount of excellent matter coming to hand ... [along with] substantial aid and encouragement ..." he received, had proven "... as unexpected as it has been gratifying." (Payne, 1882-1883: 298).

However, the number of Payne's subscribers cannot be determined today, as the circulation figures themselves were never divulged, not even to Carleton's President.[2] Probable reasons for this silence can only be surmised. *The Sidereal Messenger* was seen as Payne's "... own responsibility, and is to be maintained ... without any expense to the College." (President's Annual Report, 1882: 14). As a privately-run business venture, its publication therefore lay exclusively in Payne's hands, with the implication that circulation figures were none of the College's business. Nonetheless, Payne must have reached an agreement with his administration over the *Messenger*'s indirect costs because by 1890 about one-third of his time as Observatory Director was devoted to the journal's production and distribution (see President's Annual Report, 1890: 12). At this time, Payne reported that the *Messenger* was "... still self-sustaining although the average cost per number ... [was] ... more than one hundred dollars." (ibid.). These expenses were partially offset by the College's growing reputation, which resulted from the *Messenger*'s success. On page 10 in the President's Annual Report for 1883 it was stated that the journal is "... patronized by the leading astronomers in America and in Europe ... [and has] done much to bring the Observatory and the College into wide and favourable notice."

After four years of publication, Payne reported that the journal was self-supporting, and each monthly issue of one thousand copies was profitable (President's Annual Report, 1886: 20). By 1889, the *Messenger*'s annual subscription price was raised to $3, while monthly issues were increased from thirty-two to forty-eight pages (President's Annual Report, 1889: 12), and by 1891, the journal's circulation had again "... materially increased ...", and foreign subscriptions proved "... unexpectedly large ..." (President's Annual Report, 1891: 8), perhaps because of the expanded coverage given to astrophysical topics. Payne's reluctance to disclose circulation figures lasted through the sale of *Popular Astronomy* to the College in 1910.

4.1 Disciplinary Growth at Carleton College

One of Payne's chief ambitions in launching *The Sidereal Messenger* was to secure copies of foreign journals and observatory publications on an exchange basis, and bring "... to the Observatory every important astronomical publication in the world, and reports from all observatories in all countries." (President's Annual Report, 1887: 14). This successful strategy allowed Payne to acquire a substantial astronomical library at his small and isolated institution—when the costs of procuring such subscriptions otherwise lay beyond the College's fiscal means—and to grow the collection from some 1,130 items in 1884 (President's Annual Report, 1884: 14) to more than 1,740 by 1891 (President's Annual Report, 1891: 7). Over four hundred volumes in the initial collection were on loan to the Observatory, while a similar number belonged to Payne personally. Gifts and purchases accounted for the remainder of the library's original collection. The library was an invaluable resource for the College's advanced students and encouraged the type and amount of original astronomical work that could be pursued,[3] while incoming journals and reports obtained by exchange offered Payne a steady supply of astronomical news from domestic and foreign sources, thereby fostering production of the *Messenger* and in turn expanding the number of subscribers.

Even the revival of Gould's *Astronomical Journal* in 1886 had no detrimental impact on the *Messenger*. If anything, its reappearance enhanced the latter's mission while raising the status of American astronomy. The monthly size of Payne's journal was increased to 48 pages by 1888, and its circulation likely increased as well. By 1891, Volume 10 of the *Messenger* had grown to 524 pages. Nor was a contest waged among American astronomers over the relative merits of subscribing to Payne's or Gould's journal. The success of both popular and research venues indicates that each style of communication had become a necessary component within the burgeoning astronomical community. Meanwhile, Payne's efforts to recruit advanced students led to the creation of a temporary 'school' of mathematics and practical astronomy, and this produced six Carleton Ph.D.s before the practice was discontinued after his retirement (Headley and Jarchow, 1966: 215).[4]

The Sidereal Messenger was created in an era before science journalism became recognized as a profession (for instance, the 'Science Service', a syndicated network created by Edwin W. Scripps, was only set up in 1921—see Nelkin, 1987: 86-91), and its feature articles were contributed by a network of American and international astronomers; many were likely commissioned by the Editor. Two important aspects regarding these submissions must be emphasized. First, by having respected astronomers contribute to its pages, the accuracy of its science content was assured. Second, potential authors knew that their works would be read and judged by colleagues, and not simply presented to the public. This latter factor imparted a degree of responsibility to the writing task that might otherwise have been lacking, and served to minimize the amount of sensationalism allowed. The monthly format adopted by Payne remained largely unchanged throughout the *Messenger*'s history, and it was essentially duplicated in the creation of *Popular Astronomy*.

4.2 Format of *The Sidereal Messenger*

A detailed, quantitative portrait of the *Messenger*'s contents lies beyond the scope of this study. Instead, a synopsis of its principal types of reports is sketched below. Included were: (a) review papers, intended to provide concise summaries of research in both the 'old' and 'new' astronomies; (b) descriptions of new instrumentation and techniques, including spectral analysis, photographic photometry, and the measurement of stellar parallaxes; (c) laboratory results, such as Michelson and Morley's experimental failure to detect the Earth's motion through the ether; (d) leading essays, derived from addresses of AAAS officers, or speeches delivered at observatory dedications; (e) professional meeting reports, featuring coverage of newly-founded regional (Astronomical Society of the Pacific) or international (British Astronomical Association) gatherings of astronomers; (f) pedagogical issues concerning the prescribed teaching of astronomical concepts; (g) recent and forthcoming celestial events, especially observations of solar and lunar eclipses, comets, asteroids, and double stars, along with their orbital elements and ephemerides; (h) historical contributions, comprising essays on individuals or institutions of chiefly American or European heritages; (i) obituary notices; (j) news and awards of the profession; (k) projects and guidelines for amateur astronomers; and (l) book reviews.

The above characteristics exhibit the major attributes of a disciplinary 'trade' journal serving a professional clientele. The diversity of subjects and viewpoints represented in *The Sidereal Messenger*'s pages reveal the rapidly evolving interests and expertise of the American astronomical community. Without question, both European and American astronomers became the *Messenger*'s principal subscribers, and were to remain its successor's greatest avenue of support.

5 *ASTRONOMY AND ASTRO-PHYSICS* (1892-1894): A FAILED MERGER

As evinced by *The Sidereal Messenger*'s final volume (1891), astrophysical topics had begun to acquire a prominent following among American and European researchers (e.g. Anonymous, 1891; Huggins, 1891; Keeler, 1891). That same year marked the entry of perhaps the most influential American astronomer of his generation onto the astrophysical scene—twenty-three year old George Ellery Hale (Osterbrock, 1993; 1997; Wright, 1994).

Hale acutely sensed the need for a professional journal devoted exclusively to astrophysical research, but he could not raise sufficient funds to undertake its production alone. His principal competition was none other than *The Sidereal Messenger*, which, though "... far from satisfactory as a research journal ... dominated the astronomy field." (Osterbrock, 1995: 3; cf. Osterbrock, 1984). Payne suggested that the two journals should be united, with Hale and his associates responsible for the astrophysical contents. A completely new journal, called *Astronomy and Astro-Physics*, would be created, and the *Messenger* would cease publication. *Astronomy and Astro-Physics* was nonetheless owned and published by Payne at Northfield. Subscriptions were $4 per year for ten numbers (as before), with 80 pages per issue promised. As the successor to the *Messenger*, the first volume of *Astronomy and Astro-Physics* was numbered 11, and it attracted some 520 paid subscribers, 100 of whom were from outside the United States (Osterbrock, 1995: 3).

As the journal entered its second year, Payne (1893: 90) noted optimistically that its subscription list had "... increased ... more than twenty percent ...", a result which was seen as "... most encouraging." But this bubble was about to burst, for the number of subscribers—and in particular amateurs—began to drop away in the second year. It was not simply the technical nature of astrophysics that accounted for this loss, for many of the papers that appeared under 'General Astronomy' were also highly mathematical (e.g. Coakley, 1892). Payne reported to Carleton's President that "... our publication has grown too expensive and too technical for the great number of interested readers and students ..." who formerly subscribed to the *Messenger*. He thus announced the possibility of issuing "... another publication wholly popular in character ... prepared expressly for amateur astronomers, teachers, students, and popular readers." (President's Annual Report, 1893: 12). It was to be called *Popular Astronomy*, and the contents would be "... in no sense professional, except to be accurate in statement of fact, and principle without being technical in terms ...", while employing the best writers "... that can be procured for compensation." Ten numbers, each of 48 pages, were promised (Payne, 1893: 377).

After three years, Hale had mustered enough support to break away from Payne and transfer his operation to the University of Chicago, which is where *The Astrophysical Journal* was issued, starting in 1895 (Osterbrock, 1984; 1995). Though scarcely concealing his feelings of regret, Payne (1894: 871) declared that this decision evidently reflected "... that which is best for astronomy in general." To President Strong, however, Payne confided that the real cause of the sale of *Astronomy and Astro-Physics* lay in the fact that its publication had become so cumbersome "... that its managing editor [himself] could not well meet its constantly increasing responsibilities ... [and] discharge other college duties faithfully." (President's Annual Report, 1895: 2). *Popular Astronomy*, he noted, had already acquired a "... larger circulation than either of its predecessors ...", with one-eighth of the subscribers located in sixteen countries other than the U.S.A. (ibid.).

6 *POPULAR ASTRONOMY* (1893-1951)

During its first three years, *Popular Astronomy* was edited by Payne and Charlotte R. Willard, head of Carleton College's time service (Willard, 1893-1894). Willard conducted the monthly column, 'The Face of the Sky', where celestial data were furnished by Herbert C. Wilson (1858–1940), an alumnus of the College (1879) who earned a Ph.D. in astronomy at the University of Cincinnati (1886) and was hired as an Assistant Professor in 1887 (Gingrich, 1940a). Willard then married Arakel G. Sivaslian, a Turkish-born student who in 1893 had received the first Ph.D. in astronomy awarded by Carleton College. They moved to Turkey where Sivaslian served as Professor of Mathematics and Astronomy at Anatolia College (Headley and Jarchow, 1966: 215; Leonard, 1904: 237). After Willard's departure, Wilson became the Associate Editor of *Popular Astronomy*. Payne (1893-1894: 45) hoped that, like *The Sidereal Messenger*, this journal would "... bring the scholars and the popular readers of astronomy nearer together in common interest." Astrophysics was not neglected and a civil attitude was maintained toward Hale's new venue, as when Payne (1894-1895: 283) noted that "*The Astro-Physical* [sic] *Journal* ... makes an excellent beginning ..." The awarding of the Janssen Prize to Hale for his invention of the spectroheliograph was likewise reported (Anonymous, 1894-1895).

6.1 Pedagogy and Community

In December 1892, Payne was chosen to represent the discipline of astronomy on a subcommittee of physics, chemistry, and astronomy educators chaired by Johns Hopkins University chemist Ira Remsen, which reported to Harvard University President, Charles Eliot (Anonymous, 1893). Payne's appointment likely arose from his prominence as Editor of *The Sidereal Messenger*, along with his recognized classroom experience and pedagogical interests. Eliot chaired the National Educational Association's Committee on Secondary School Studies, popularly known as the 'Committee of Ten' (Krug, 1964). At its conclusion, the Physics, Chemistry, and Astronomy Subcommittee recommended that secondary-level astronomy instruction should be reduced from a college prerequisite to an elective subject, with physics and chemistry elevated to front rank. However, no explicit rational for this decision was offered (Bishop, 1977; 1979).

In the national fervor which arose over publication of the Committee of Ten's *Report* (1893), pedagogical issues acquired a much higher profile in the pages of *Popular Astronomy* than they had received in *The Sidereal Messenger*, and this is reflected in Krug's (1964: 66) claim that "... from 1894 to 1905 almost every treatment of matters educational was referred to, compared with, or distinguished from the report of the Committee of Ten." Thus, essayists defended or criticized a variety of instructional strategies, ranging from the textbook-recitation approach to an increasing emphasis on laboratory teaching methods. Uniting many of these disparate themes, however, was the almost-universal acceptance of the mental discipline model of pedagogy and its rationale of support for astronomy education in the nation's secondary schools and colleges. But in the years after 1900, astronomy education underwent a dramatic decline following collapse of the mental discipline model, and it was largely eliminated from the American secondary curriculum until advent of the space age (see Marché, 2002).

For those subscribers involved in the instruction of students (and these included a growing percentage of astronomers), *Popular Astronomy* offered the most widely-accessible, disciplinary forum on that subject. Over the next two decades, the journal's pages were increasingly devoted to potential solutions by which a revival of astronomy education might be accomplished. One of the most vocal proponents of that task was Smith College Observatory Director, Mary Byrd, who was awarded a Ph.D. from Carleton College in 1904. Byrd examined many aspects of this issue, and wrote prolifically to try and bridge apparent gaps in the pedagogical literature (e.g. see Byrd, 1903-1907; 1913).

6.2 Popularization and Other Scholarly Tools

Throughout his editorship of Carleton's astronomical journals, Payne recognized the need for a regular review of current astronomy that effectively combed the expanding literature of the field. Back in 1887, he had published a paper by Princeton University astronomer, Charles Augustus Young, titled "Ten years' progress in astronomy, 1876-1886" (Young, 1887). Payne (1904a: 8) argued that by "... sifting this continual harvest ..." of books and journals, leading problems of the discipline could be brought, in condensed form, before a ready readership. Such a task, he realised, required the "... aid of many specialists." When initially unsuccessful at finding anyone willing to accept this challenge, Payne (1904b) presented results from his own modest literature survey, and he subsequently was successful in commissioning one such review, by British astronomer Edward Walter Maunder, although this was to be the last report of its kind to appear under Payne's tenure (Maunder, 1907).

Payne's desire to publish such information for English-language readers may have been inspired by the appearance of the German-language *Astronomischer Jahresbericht* (AJB), a Berlin publication that Walter Freidrich Wislicenus initiated in 1899.[5] Along with printed summaries of general and historical works, the *Jahresbericht* reported on developments in astronomy and astrophysics, as well as geodesy and nautical astronomy. The *Jahresbericht* also contained exten-sive bibliographies of astronomical subjects, plus an index of researchers. Payne had also commissioned a six-month bibliography, which was published in *The Sidereal Messenger* and reflected the prominence of astrophysical topics (Winlock, 1891).

Scholarly tools such as annual reviews, bibliographies, and even 'trade' journals themselves, arose in order to foster and improve the levels of communication and research within larger academic specialties or disciplines. All reflected the attainment of particular stages of professional development, through which a representative community inevitably passed as a function of its evolving size and maturity. These tools become indispensable aids for the maintenance and support of that community's further development. Viewed from this perspective, Payne's attempts to proffer such wholesale information to subscribers foreshadowed the future institutionalization of these tools among the discipline. In 1963, long after Payne's death and the demise of *Popular Astronomy*, the series, *Annual Review of Astronomy and Astrophysics*, was launched by Annual Reviews, Inc.

6.3 *Popular Astronomy* and the American Astronomical Society

Founding of the American Astronomical Society (AAS) in 1899 (under the original name, the Astronomical and Astrophysical Society of America, or AASA) has been traced to the written suggestion from U.S. Naval Observatory Director and AAAS Past-President, Simon Newcomb, to George Ellery Hale, and the new society was unofficially begun at the gathering of astronomers convened for the dedication of the Yerkes Observatory on 21 October 1897 (Berendzen, 1974; Osterbrock, 1999). Yet, two earlier regional societies, namely the Astronomical Society of the Pacific (founded in 1889) and the Astronomical and Physical Society of Toronto (founded in 1890 but reincorporated as the Royal Astronomical Society of Canada in 1902), preceded the establishment of this viable, national society (Jarrell, 1988; Osterbrock, 1978).[6] Newcomb (see Moyer, 1992) was elected the AASA's first President, and his "... graceful, somewhat florid, backward-looking ...." keynote address at the Yerkes Observatory dedication (Osterbrock, 1999: 11) was printed in *Popular Astronomy* (Newcomb, 1897-1898).

Throughout Newcomb's tenure as President (1899-1905), the AASA remained relatively small (never exceeding 160 members), and this allowed the Society to retain its 'club-like nature'. Historian, David H. DeVorkin (1999b: 22), has argued that Newcomb managed his office "... without much flair ...", instead directing his principal attention towards "... reforming the Naval Observatory." Names of persons present, titles of papers presented, officers elected and a brief summary of the Society's first official meeting on 6-8 September 1899 appeared in *Popular Astronomy* (Anonymous, 1899), but little else was reported there in the early years.

The youthful Society had no journal of its own, so its first official proceedings were not published until the occasion of its tenth anniversary (AASA, 1910). The discipline's leading research journals, the *Astronomical Journal* and the *Astrophysical Journal*, each predated the Society's founding, and both were independently edited and retained by institutional homes for decades to come. No regular publication of AASA meeting abstracts was advanced under Newcomb, but occasional summaries of papers were printed in *Science*. The Society's fourth meeting (1902-1903), held in conjunction with the AAAS, was attended by Herbert C. Wilson, and his report included the titles and selective notes regarding the thirty-six submitted papers (Anonymous, 1903).

Harvard College Observatory Director, Edward Charles Pickering, was elected the Society's second President in 1905. At Harvard, he had organized the "... world's largest spectroscopic, photographic, and photometric programs in astronomy." (DeVorkin, 1999b: 20), and under his guidance the Society "... began to create [research] committees to deal with the professionalization of their science." (DeVorkin, 1999b: 24). In turn, the Society's relationship with *Popular Astronomy* was to be significantly strengthened through two separate initiatives crafted by Wilson (which are described below), and these brought lasting benefits to Society members and raised the number of journal subscribers.

6.4 Sale of *Popular Astronomy* to Carleton College

As his seventieth year approached, Payne anticipated retirement from active duties at the College. In a letter to the Board of Trustees dated 11 September 1908 Payne tendered his resignation, to take effect 1 October 1908. Efforts by Executive Committee members to dissuade him from his decision failed, and they noted that "... his mind was made up and his purpose unchanged." (Board of Trustee Minutes, 1908: 33). But they did arrange for him to receive an annual allowance of $1,150, which was secured from the Carnegie Foundation for the Advancement of Teaching (see Page, 1908; Payne, 1908a, 1908b). Nonetheless, Payne remained the owner, editor, and publisher of *Popular Astronomy*, a post he might have retained for an indefinite period of time (Anonymous, 1909: 181).

Payne's plans were soon changed, however, when a directive from President Theodore Roosevelt was issued that the U.S. National Bureau of Standards conduct routine tests on the accuracy of all portable watches. In a replay of his Carleton appointment, Payne was hired in May 1909 to establish an astronomical observatory and time service for the Elgin National Watch Company in Illinois. The Elgin Observatory commenced operations in 1910 and Payne's engagement as Director was extended indefinitely. Payne eventually retired on 1 November 1926, but this time on full pay for life and with the title of Director Emeritus (Neidigh, n.d.: 3; Payne, 1927).

Payne's acceptance of the Illinois appointment finally severed his relationship with the longest-running astronomical journal he had founded, edited, and published. As a result, the "... purchase of *Popular Astronomy* from Professor Payne ..." was referred to the College's Board of Trustees, whereupon an undisclosed settlement price was negotiated (see Board of Trustees Minutes, 1909: 49). Though a highly unusual move for the College to make, Carleton's administration stressed the recognition of their institution achieved through Payne's editorship of the three journals. But as we shall see, under Wilson's tenure, that momentum was further cultivated in ways not attempted during the 'Payne era'.

In a final gesture that capped the significance of his published contributions, Payne supervised the assembly of a complete index to the twenty nine volumes he had edited through 1908. Publication of the index was funded by a $100 gift via Edward Pickering from the International Science Fund of Harvard College Observatory and a $200 donation from G.R. Agassiz of Boston (*General Index* ..., 1909). Thus did *Popular Astronomy* finally pass out of Payne's hands, after completion of the May 1910 issue (Payne, 1910). Thereafter, its annual cover sheet carried the tribute, 'Founded by W.W. Payne'.

7 WILSON, *POPULAR ASTRONOMY*, AND THE AAS

With the June 1910 issue, Herbert Couper Wilson (Figure 3) became Editor of *Popular Astronomy*. Two Assistant Editors were added: Ralph Elmer Wilson, who was Herbert Wilson's son, and Curvin H. Gingrich (1880–1951), who was hired in 1909 as an instructor to replace Payne. Ralph Wilson retained his post for little more than two years, while Gingrich remained at Carleton for the duration of his career and succeeded Herbert Wilson as the Editor of *Popular Astronomy* in 1926.

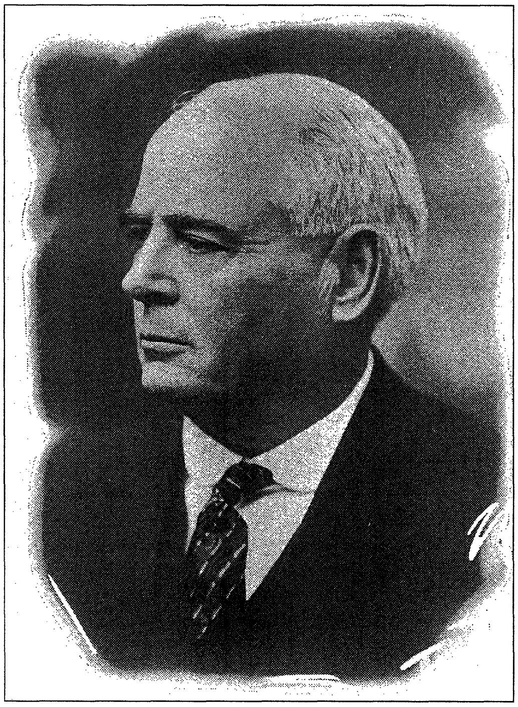

Figure 3: Herbert C. Wilson, second Editor of *Popular Astronomy*, 1910-1926 (Reproduced from *Popular Astronomy*, 48, f.231 (1940). Courtesy, Carleton College Archives).

Figure 4: Thirty-fourth meeting, American Astronomical Society (AAS), hosted 8-10 September 1925 at Goodsell Observatory (Reproduced from *Popular Astronomy*, 33, Plate XXX (1925). Courtesy, Carleton College Archives).

In coming years, Wilson spearheaded two significant editorial initiatives that enabled *Popular Astronomy* to assume a more integral role within the American astronomical community. The first of these was his decision (after the Society's sixteenth meeting in December 1913) to publish the abstracts of all papers delivered at AAS meetings, thereby ending the previously haphazard means by which these reports were publicized (Anonymous, 1914). Though unofficial in nature, abstracts printed by Wilson often appeared years in advance of their official publication in the Society's proceedings, thereby aiding a more rapid announcement of authors' works beyond the confines of meeting halls. After this trend became established, stronger incentives existed for professional astronomers and institutions to become regular subscribers.

By this means, the journal's visibility and legitimacy within the astronomical community were significantly enhanced. Wilson's first initiative went a long way toward making *Popular Astronomy* the unofficial journal of the AAS. For a period of seventeen years (1914 to 1930), until the practice was suspended (almost certainly for economic reasons), *Popular Astronomy* became the principal repository for rapid-style AAS communications. The final appearance of meeting abstracts accompanied a report on the Society's forty-fourth meeting (Anonymous, 1930-1931), and subsequently they were published in the *Astronomical Journal* (which was acquired by the Society in 1941), starting with Volume 51 (1944-1946). This policy remained in effect until the *Bulletin of the American Astronomical Society* was created in 1969, with the explicit purpose of "... publish[ing] abstracts of papers presented at meetings of the Society and its Divisions." (Schwarzschild, 1969: 1).

A second initiative crafted by Wilson significantly strengthened relations between the Observatory, the Northfield community and the wider astronomical establishment. This was his consolidation of the Society's official publications at Northfield after 1915. As previously noted, the Society's first volume of official proceedings was not issued until observance of its decennial anniversary in 1909. Containing the "Organization, Membership, and Abstracts of Papers, 1897-1909", it was published at Ann Arbor, Michigan (AASA, 1910), by Society Secretary, William J. Hussey, the volume's co-editor with Pickering. A second volume was issued by the same press in 1915.

Before Pickering's death in 1919, however, Wilson secured the Society's permission to allow its proceedings to be issued under his direction by the Northfield News, publishers of *Popular Astronomy*.[7] This action confirms and extends David DeVorkin's (1999b: 20) assessment that, during this era, the Society "... remained very much an eastern and midwestern power block, centered on Pickering and his circle." Starting with Volume 3 (AAS, 1918), which bore the amended title, *Publications of the American Astronomical Society*, all volumes issued through 10 (AAS, 1946), edited by Dean Benjamin McLaughlin and Curvin H. Gingrich, were published at Northfield. Publication dates reveal the sluggishness and irregularities in this process: Volume 4 was published in 1923, Volume 5 in 1927, Volume 6 (1931), Volume 7 (1933), Volume 8 (1936), Volume 9 (1939) and Volume 10 (1946). Thus, for twenty-eight years, the Society's official *Publications*, and its unofficial journal, *Popular Astronomy*, were edited and published under the auspices of Carleton College.

One of the high points of Wilson's career occurred shortly before his retirement, when in 1925 the Goodsell Observatory hosted the 34th meeting of the AAS (Figure 4; Anonymous, 1925). Carleton 1892 alumnus, Anne Sewell Young, who was Director of the Mt. Holyoke College Observatory and a Councillor to the Society, attended the meeting, but Payne was notable for his absence. Had the former Director and journal editor been in attendance, he might have taken pride in seeing the institution he founded welcome the nation's leading society of professional astronomers, including several other Carleton alumni. While Payne's roles were not formally acknowledged in the proceedings, the host institution did owe an enormous debt of gratitude to him for establishing its Department of Mathematics and Astronomy and its observatories, and for the three astronomical journals that he had founded, edited, and published. Carleton's hosting of the AAS meeting offered symbolic recognition of Payne's lasting influence upon the American astronomical community (and beyond).

8 GINGRICH, *POPULAR ASTRONOMY*, AND THE AAS

Following Wilson's retirement in June 1926, Curvin Henry Gingrich (Figure 5) succeeded him as Editor of *Popular Astronomy* (Greene, 1988; Leonard, 1951). A graduate of Dickinson College in Carlisle, Pennsylvania, Gingrich had earned his Ph.D. from the University of Chicago in 1912. He received editorial help from Carleton alumnus Edward Arthur Fath (1880–1959; class of 1902), who became a second Associate Editor of the journal in October 1920, when he was hired to teach at Carleton. Fath had earned a Ph.D. from the University of California in 1909, and pursued research in photoelectric photometry. He eventually succeeded Wilson as Director of the Goodsell Observatory, and was the author of a standard astronomical textbook (Fath, 1926) that passed through several editions. Fath ceased his editorial responsibilities at the end of 1938 (even though he did not retire from the College until 1950), and his vacancy was never filled by another Carleton astronomer. As a result, the first important break occurred in the Department's cycle of involvement with the journal—a factor that was to have important repercussions, and led to the eventual demise of the publication.

Upon assuming the editorship, Gingrich (n.d.: 1) presented a tentative program for *Popular Astronomy* to Carleton President Donald J. Cowling, arguing that the periodical occupied "... a position almost unique among magazines in this country and in the world." Carleton's publication was "... virtually the official organ of the American Astronomical Society ..." on account of its prompt publication of "... abstracts of all papers read before the society ... and periodical reports of observatories." (ibid.). Without exaggeration, Gingrich (ibid.) could claim that the journal's contents offered "... a body of material not only of interest to all astronomers, but potentially indispensable to those desiring to keep pace with astronomical development."

Gingrich steered the journal for the next twenty five years, through its most difficult period, which encompassed both the Great Depression and the Second World War. But despite enormous social and economic changes that lay ahead, *Popular Astronomy* retained an almost identical format and received the continued support of his administration. Pre-war subscriptions to the journal reached a peak of 1,200, including some 200 foreign subscribers (Greene, 1988: 20), approximately twice the concurrent AAS membership.

In the wake of Fath's departure as Associate Editor and with war looming, Gingrich (1942c) announced that ten astronomers, "... representatives of various fields and of different sections of the country ...", had consented to serve as 'collaborators'. They were Leon Campbell, Alice H. Farnsworth, Edward A. Fath, Alfred H. Joy, Dean B. McLaughlin, Charles P. Olivier, John H. Pitman, Charles H. Smiley, Robert J. Trumpler and George van Biesbroeck (Gingrich, 1941), and their names appeared for the first time on the masthead of Volume 50 (1942). Gingrich's initiative, which aimed to keep the journal alive in coming years, reflected the greatest extension of its editorial responsibilities beyond the confines of Carleton's campus. It likewise represented the strongest measure of voluntary support that the journal received from the American astronomical community. By instituting this co-operative measure, Gingrich (1942c: 1) hoped that "... the position of *Popular Astronomy* will be strengthened and its sphere of usefulness extended." By the time the periodical closed in 1951, the number of collaborators had grown to twelve, nine of whom had maintained their association from 1942.

Figure 5: Curvin H. Gingrich, third (and final) Editor of *Popular Astronomy*, 1926-1951 (Reproduced from *Popular Astronomy*, 59, f.343 (1951). Courtesy, Carleton College Archives).

9 OTTO STRUVE AND THE AAS

It might come as a surprise to learn that a steady stream of contributions to *Popular Astronomy* emanated from no less a figure than Otto Struve (1897–1963), then Director of the University of Chicago's Yerkes Observatory and Managing Editor of the *Astrophysical Journal* from 1932 to 1947. During his tenure at Yerkes, Struve managed to build that institution into one the nation's top astronomical research facilities (Osterbrock, 1997). So, why did a leading research astronomer, Observatory Director, and Editor of the discipline's most prestigious scientific journal, devote considerable attention to the welfare of a 'popular' astronomical magazine?

The answer is that Struve had long recognized *Popular Astronomy* as a strategic communications link within the AAS, whose importance was not diminished during periods of national hardship and emergency. Thus, it was for the sake of preserving the integrity of the Society, and the astronomical community as a whole, that Struve came to exercise his considerable influence and support for the Carleton journal.

Gingrich and Struve held a number of professional traits in common, the principal one being that both were Editors of the most widely-read and -respected journals in their field. Struve (1933) wrote to Gingrich, "I realize from my own experience that an editor's job is not an easy one, especially at a time like the one in which we are living." A close working relationship developed between these men, borne of mutual respect and commitments of unstinting service to their discipline and institutions. Even though their respective facilities shared distinctly unequal levels of prestige, Struve seemingly displayed a high regard for Gingrich's efforts and provided considerable support for the latter's publications, which did not go unacknowledged. It is not clear whether Gingrich engaged in a similar correspondence with Benjamin Boss, the Editor of *The Astronomical Journal* from 1912 to 1941, or with his successor, Yale University's Dirk Brouwer.

Along with furnishing abundant news from the astronomical community, Struve composed a number of feature articles for Gingrich on the status of particular fields or problems within contemporary astronomical research. Such review articles accomplished multiple purposes, then as now. They offered to non-specialists an opportunity to be brought up to date on research extending beyond one's own area of expertise. Investigative techniques were summarized, while future directions of research could possibly be foreseen. In Struve's case, these reports surveyed results in stellar astronomy or spectroscopy, along with current work on the interstellar medium (Struve, 1935; 1937). He also occasionally refereed material submitted to Gingrich (see Gingrich, 1939; Struve, 1939).

After receiving a paper titled "The problem with Phi Persei" from Struve (1941), Gingrich (1940b) responded that "... we are always pleased to receive a paper from you and shall plan to publish it at the earliest opportunity." An address delivered by Struve before the Cincinnati Astronomical Society on "The story of Pleione" (Struve, 1943b) was likewise submited to *Popular Astronomy*, and Gingrich (1943a) replied that he thoroughly appreciated Struve's interest. A very different type of article emerged from Struve's pen when he submitted an essay on "Astronomy faces the war" (Struve, 1942). His analysis offered, in Gingrich's (1942a) opinion, "... exactly the kind of article which we need." Gingrich (ibid.) again thanked Struve for his "... continued helpful attitude toward our publication."

In the following year, Gingrich (1943b) wrote to Struve about his plan to publish a series of review papers "... summarizing the progress made in the several fields [of astronomy] up to the present time." Gingrich's nominal purpose was to commemorate the principal developments that had transpired during the fifty-year history of *Popular Astronomy*. But Gingrich (1942c) was also mindful of the effect of the Second World War on astronomy, and he wrote: "... the world has now come upon a time when, to the best of our knowledge, the astronomical journals, except those in England and America, have practically ceased to exist." To prevent his own publication from suffering an identical fate, Gingrich was forced to shift the balance of coverage from newer to older research, in order to ensure that full-length issues appeared on a regular basis and his subscribers were satisfied. Struve (1943a) responded that he "... shall be very glad to cooperate in the plan which you have outlined." However, Struve's original piece, entitled "Fifty years of progress in astronomy" (Struve, 1943c), evolved into something more ambitious than anticipated and ended up as the introductory paper for Gingrich's series. A still more comprehensive outcome of the war-time efforts by Struve and Gingrich to synthesize a half-century of astronomical knowledge was later realized with the publication of Struve and Zebergs' (1962) widely-utilized compilation, *Astronomy of the Twentieth Century.*

10 THE FIFTIETH ANNIVERSARY CELEBRATION OF *POPULAR ASTRONOMY*, 1943

The fiftieth anniversary of *Popular Astronomy* was celebrated amidst the depths of the Second World War. Gingrich (1943c) prepared an account of the journal's founding by Payne and its subsequent production under Wilson and himself. In reviewing the 500 published issues, he remarked (with evident surprise) that "... one naturally expects conditions at the end of a fifty-year interval to be different from those at the beginning ... [yet] the form, size, and general appearance of this [500th] issue are strikingly similar to those features [contained] in the first issue." Such a testimonial affirmed that the periodical's format was satisfactorily envisioned by Payne and had achieved stability under his guidance. *Popular Astronomy*, although maintained by differing editorial hands, had withstood the test of time, despite enormous changes in the nature and content of astronomical research over the same fifty-year period. Gingrich (1942d) reiterated that the journal's steadfast mission rested on the continued presentation of new facts, "... in order to keep those who are interested abreast with current developments and discoveries." This was surely the task of any disciplinary trade journal.

In a letter to Struve written on 23 November 1942, Gingrich (1942b) announced that the journal's golden anniversary issue will contain "... a series of brief statements from those who have been acquainted with this magazine through the years." True to his promise, this special issue contained forty-five contributions solicited from astronomers worldwide (Struve being one of them). While Gingrich's selection naturally reflected favorably on *Popular Astronomy*, many respondents nonetheless spoke of the journal's significant contributions to the American astronomical community. MIT astronomer, Harlan True Stetson, expressed the opinion that "... this periodical has made an important contribution to the rise of astronomy in the United States, and it well deserves the recognition and esteem in which it has been held throughout the astronomical world." (Gingrich, 1943c: 8). Lick Observatory Director (and Editor of the *Publications of the Astronomical Society of the Pacific*), Robert Grant Aitken, argued that the journal's uninterrupted appearance represented no small achievement (Gingrich, 1943c: 10), while Mount Wilson Observatory Director, Walter Sydney Adams, expressed his belief that the journal had "... filled a most useful place in astronomical literature, combining articles of technical merit with those in simpler language." (Gingrich, 1943c: 15). *Popular Astronomy*'s role as an invaluable organ for disseminating results by certain groups of professional and amateur astronomers was commented upon by Harvard College Observatory Director, Harlow Shapley, who felt that such contributions "... cannot be over-emphasized." (Gingrich, 1943c: 16).

One of the most reflective reactions came from Otto Struve, who—perhaps more optimistically than realistically—argued that a close friendship had long existed between *Popular Astronomy* and *The Astrophysical Journal*, both of which had sprung from Payne and Hale's failed *Astronomy and Astro-Physics*. Struve thus declared that "*The Astrophysical Journal* takes pleasure in extending cordial greetings to her older sister upon her fiftieth anniversary." (Gingrich, 1943c: 64). But in a departure from other authors, Struve ventured that *Popular Astronomy* offered "... what no other journal now provides: the dissemination of astronomical information ... [in order] to elevate the minds of people from the immediate problems confronting them to the contemplation of the wonders of the universe." (Gingrich, 1943c: 64-65).

As the fiftieth anniversary of Yerkes Observatory drew near, and with it Struve's impending resignation as Observatory Director and Managing Editor of *The Astrophysical Journal*, he composed what was arguably his 'swan song', and furnished *Popular Astronomy* with his most elaborate contribution, titled, "The story of an observatory" (Struve, 1947b). Struve (1947a) specifically asked for this essay to appear before his resignation on 1 July 1947, and Gingrich (1947) acceded to this request. Historian, Donald Osterbrock (1997: 289), has argued that Struve's account, "... like [those of] most directors writing about their institutions ... [had aimed] not so much to make sure all the facts were absolutely correct as to give a positive picture of the current situation, and in that [Struve] succeeded admirably." Later, in mid-1950, Struve became Chairman of the Astronomy Department at the University of California-Berkeley.

11 TRANSFER OF *POPULAR ASTRONOMY* TO THE AAS?

One of Struve's last and potentially most significant interactions with Gingrich and *Popular Astronomy* concerned a proposal that likely stemmed from the former's election as AAS President in 1946. As early as 1941, Struve had recommended that ownership of *The Astrophysical Journal* be transferred to the AAS, a decision that was postponed until 1972 (Abt, 1999). In the spring of 1950, however, Struve approached Gingrich about the possibility of transferring production of *Popular Astronomy* from Carleton College to the AAS, thereby transforming it into an official organ of the Society (see Gould, 1950). Struve was almost certainly aware that Gingrich was also approaching retirement age and that no immediate successor stood in line to assume his editorial post. Struve's proposal revealed his personal estimate of the publication's value to the AAS membership, along with the seriousness of purpose that he associated with the journal's continued production. Struve even recommended an expansion of its offerings so as to attract more teachers of astronomy.

Struve's proposal was forwarded to Carleton's President, Laurence M. Gould, who then wrote to Gingrich: fearing the loss of reputation to the College that would accompany such a change, he opined, "... we do not want to transfer *Popular Astronomy* to the [American] Astronomical Society or to any other society." (Gould, 1950). Struve's suggestion possibly forced Gingrich to confront his administration as to the degree of continued support that it could be expected to provide. Gould (ibid.) assured Gingrich that Carleton "... has every expectation of continuing to support *Popular Astronomy*." But in light of the unexpected events that transpired, had Struve's suggestion been adopted, the rapid demise of *Popular Astronomy*, in little more than eighteen months time, might have been forestalled.

12 THE END OF *POPULAR ASTRONOMY*, 1951

With the close of Carleton's 1950-1951 academic year, Gingrich completed twenty five years of service as Editor of *Popular Astronomy* and more than forty years as an instructor. Having reached the age of 70 (like Payne before him), he had planned to retire, but continue indefinitely as the journal's Editor. Those plans, however, and the fate of *Popular Astronomy*, were abruptly severed when Gingrich suffered a fatal heart attack on 17 June 1951, after an illness of only one week (Leonard, 1951). The sudden vacuum created by Gingrich's death was exacerbated by the absence of an Associate Editor to co-ordinate the multitude of responsibilities. The burden of questions surrounding the journal's operation fell upon Ralph L. Henry, Editor of the College's publications, and Carleton's President, Gould. At first there was no indication that the journal would come to an end, and the initial task was to produce the year's remaining issues, which rested upon a dozen or so collaborators.

But subscription renewals and other business details brought matters to a head, as did the lack of copy for further issues, and Henry (1951a) advised Carleton's Business Manager, Bruce Pollock, that "... there can hardly be any issues of the magazine after December." Further actions taken by the Board of

Trustees also blocked a potential avenue for salvaging the journal, by rendering it "... impossible for us to approach a new board of editors who could get manuscripts for us." (ibid.). On 15 November 1951, Henry (1951b) had the dubious distinction of informing people closely associated with *Popular Astronomy* that the College was to suspend publication with the December (1951) issue.

An eleventh-hour bid to keep the journal afloat surfaced from Charles Anthony Federer Jr., founding Editor of *Sky and Telescope* and *Popular Astronomy*'s principal competitor as a mass-market astronomical periodical. But rather than attempting to gain control of *Popular Astronomy* by himself, Federer made a strong pitch to have the journal's publication resumed by the Rensselaer Polytechnic Institute of Troy, New York (Gould, 1951; Henry, 1951c). However, these negotiations broke down and the sale never materialized. Instead, Federer acquired some 333 prepaid subscriptions to *Popular Astronomy*, which were subsequently fulfilled by *Sky and* Telescope (Pollock, 1952). Thus, the venerable *Popular Astronomy*, which was launched fifty-nine years earlier by Payne and survived the Great Depression and the Second World War, abruptly ceased publication just six months after Gingrich's death. So far as is known, neither Struve nor the AAS attempted to rescue *Popular Astronomy* during this interval.

13 EPILOGUE

One of the most intriguing (if contrafactual and unanswerable) questions to be pondered concerns the potential fate of *Popular Astronomy* had Gingrich not died without an editorial successor in place and had the journal's production remained at Northfield. Might *Popular Astronomy* have survived to witness the advent of the space age, or beyond? Subscription records argue in support of this contention. While wartime subscriptions dropped to just below 1,000, they rebounded sharply to 1,410 by June 1950 (Gingrich, 1950). At this same date, AAS memberships reached ~700, or approximately half the number of journal subscribers. Without question, Carleton's journal had acquired a strong contingent of loyal followers who showed no signs of cancelling their subscriptions.

Nonetheless, portentous changes in the form of 'Big Science' began to affect the American scientific community and the AAS during the post-war years (Capshew and Rader, 1992). The late 1950s (and beyond) witnessed an enormous influx of astronomers, physicists and aerospace engineers into the Society as the space age unfolded. Applications of former military technologies, starting with the V2 rocket program, co-ordination of the International Geophysical Year (1957-1958), *Sputnik* and creation of the National Aeronautics and Space Administration (NASA) heralded the opening of the electromagnetic spectrum to wavelengths previously inaccessible by ground-based astronomical instruments (e.g. see DeVorkin, 1992; Launius, Logsdon, and Smith, 2000; Leverington, 2000; McDougall, 1985; and Sullivan, 1961). Concurrently, the establishment of multi-institutional consortia (like AURA), funded chiefly by the National Science Foundation, led to the creation of the first national observatories (Edmondson, 1997; McCray, 2004). The impact of Government patronage on post-war U.S. science policy revealed to AAS leaders that "... the structure and scale of pre-war astronomy in America held little relevance for the future." (DeVorkin, 1999c: 120). The era of 'Big Science' soon overshadowed and rendered obsolete many pre-war instructional programs and institutions.

Former Carleton College Archivist, Mark Greene, has argued that it was perhaps for the best that *Popular Astronomy* ceased publication when it did. He suggests that the journal had outlived its usefulness and become an 'anachronism', analogous to the College's Goodsell Observatory and Astronomy Department which had nurtured its existence for nearly sixty years but had themselves "... clearly and inevitably lost [their] national significance." (Greene, 1988: 21). Greene notes that it took Carleton College four years to secure a replacement for Fath, but he does not indicate why. Perhaps it was because there was a widespread perception that any new Carleton appointee would be expected to revive *Popular Astronomy*. If that were the case, then the journal's reputation had become a liability that frustrated hiring committees until its final demise had become a certainty.

Had *Popular Astronomy* continued publication at Northfield, its production and distribution likely would have outstripped the human and financial resources available within the College and the Northfield community. Memberships in the AAS soared into the thousands after 1960. Out of necessity, *Popular Astronomy* then would have become an official journal of the AAS and its production transferred elsewhere (as Struve had once advocated), or else it would have ceased publication altogether. Such was the fate of *The Astronomical Journal* and *The Astrophysical Journal*, both of which were eventually acquired and managed by the AAS. The era had most likely reached an end when a monthly disciplinary trade journal could be produced almost single-handedly by a lone editor who also retained instructional and administrative duties at a liberal arts college and relied on assistance from a local newspaper company to get the publication printed.

In 1975, Carleton's Goodsell Observatory was listed on the National Register of Historic Places as a site where important contributions were made to Minnesota astronomy education and the 'scientific literary field' encompassed by Payne's journals (Greene, 1988: 24). This award is perhaps the only recognition of its kind ever bestowed upon a scientific journal that embraced the adjective 'popular' within its title.

14 CONCLUSIONS

This case study has demonstrated an *inversion* of the culturally-dominant view of scientific popularization. By serving practitioners within a scientific discipline, the two principal journals founded, edited and published at Carleton College by William W. Payne, namely *The Sidereal Messenger* and *Popular Astronomy*, became the American astronomical community's first 'trade' journals. Their most steadfast clientele was the era's professional astronomers, many of whom later belonged to the American Astronomical Society (AAS). These periodicals routinely helped to shape, direct and influence communications and decision-making processes among disciplinary leaders and others involved in policy developments. Trade journals and other scholarly tools such as annual reviews and bibliographies comprise an essential—if sometimes overlooked—component of disciplinary professionalization, and complement the establishment of professional societies and the creation of research-grade journals.

Trade journals inform researchers and practitioners about developments that occur in areas of knowledge production beyond their immediate specialties. These journals offer routine assessments and reviews of current investigations, innovations and issues facing practitioners and educators alike. More succinctly, trade journals foster as well as chronicle disciplinary actions within a profession, especially during periods of transition, such as during the rise of late-nineteenth-century astrophysics. These outlets serve to attract new recruits to the profession, through the encouragement of research objectives and the explication of lingering problems and issues within their fields.

The Sidereal Messenger and *Popular Astronomy* brought national and international recognition to Carleton College. By contrast, *Astronomy and Astro-Physics* symbolized the short-lived failure to unite the features of a research-grade publication and a trade journal into a single compendium. In the early twentieth century, *Popular Astronomy* began to function as the AAS's unofficial journal, when rapid publication of meeting abstracts and the Society's official proceedings were consolidated at Northfield (Minnesota) under Herbert C. Wilson.

Thanks to Curvin H. Gingrich's concerted efforts, *Popular Astronomy* was guided through the Great Depression and the Second World War, but the very existence of the journal proved contingent upon his continued survival. After he died suddenly in 1951 the journal folded, ending a fifty-nine year association with Carleton College. Only one year earlier, the College administration had politely but firmly refused Otto Struve's request that they relinquish control of the journal to the AAS. But even if Gingrich had not died suddenly, it is unclear for how long the College would have maintained its support for this publication in the light of post-war scientific developments characterized as 'Big Science'.

15 ACKNOWLEDGEMENTS

I am indebted for the helpful assistance provided over the years by Eric Hillemann and Susan Garwood-DeLong from Carleton College Archives for permiting me to examine and copy the President's Annual Reports, Board of Trustees Minutes and other files pertaining to the history of its Astronomy Department, journals and personnel. Judith L. Bausch, Librarian at the Yerkes Observatory, granted similar privileges regarding its Papers of the Director. Dr. Jerome A. Fallon, Hillsdale College's retired Archivist, graciously supplied copies of the College's 1863 catalogue and list of the school's graduates. Liz Marston, Elgin Area Historical Society and Gail Borden Public Library, furnished a copy of Ray S. Neidigh's publication on the history of the Elgin Observatory. Thomas R. Williams (Rice University) read an earlier draft of this paper and offered valuable suggestions for strengthening its core arguments. A condensation of these results was presented before the Sixth Biennial History of Astronomy Workshop, University of Notre Dame, in 2003 June. I am also grateful to the Woodman Astronomical Library, Department of Astronomy, University of Wisconsin-Madison, for providing unfettered access to its collection of historical journals. Without the help of these individuals and institutions, this investigation could not have been undertaken or completed.

16 NOTES

1. Payne is listed as one of eleven male and three female graduates of the 'College Course' who received their diplomas in June 1863 (Hillsdale College, 1863). A biographical file on Payne is held at the Carleton College Archives in Northfield, Minnesota.
2. All subscription records and an extensive correspondence were apparently discarded after Payne's resignation. Towards the close of his second year of publication, Payne admitted that his circulation, "... though not large ... [was] very general and slowly, but steadily growing." (President's Annual Reports, 1884: 9).
3. Payne noted that this subscription exchange strategy "... ought to and does make the Observatory library a place to be sought above all others for the latest and best information on the themes of Astronomy." (President's Annual Reports, 1887: 14).
4. The six graduates were: Arakel G. Sivaslian (1893), DeLisle Stewart (1895), Anna D. Lewis (1896), Edwin C. Norton (1896), Mary E. Byrd (1904), and Florence E. Harpham (1909).
5. More than a century earlier, however, the *Astronomisches Jarhbuch* had been issued by the Royal Academy of Sciences in Berlin. It began in 1776, under the direction of Johann H. Lambert.
6. Jarrell (1988: 79) has written that, "... despite its name ... [the APST] behaved like a national organization, akin to the earlier version of the RAS in Britain." From the start, APST members "... forged links with professionals everywhere." (Jarrell, 1988: 80).
7. Unfortunately, Wilson's correspondence was not preserved at Carleton College; consequently, documentation of this initiative has not been traced. Neither Pickering's correspondence nor AAS records has been examined for corroborative evidence. Each volume of the Society's *Publications* retained its own editor(s).

17 REFERENCES

The following abbreviations are used:

AAS = American Astronomical Society
AASA = Astronomical & Astrophysical Society of America
CCA = Carleton College Archives, Northfield, Minnesota
YOA = Yerkes Observatory Archives, Williams Bay, Wisconsin

AAS, 1918. *Publications of the American Astronomical Society*, 3.
AAS, 1946. *Publications of the American Astronomical Society*, 10.
AASA, 1910. *Publications of the Astronomical and Astrophysical Society of America*, 1.
Abt, H.A., 1999. The American Astronomical Society and *The Astrophysical Journal*. In DeVorkin, 1999a, 176-184.

Anonymous, 1891. The Smithsonian Astro-Physical Observatory. *The Sidereal Messenger*, 10, 271-273.

Anonymous, 1893. Astronomy, Physics and Chemistry in Primary and High Schools. *Astronomy and Astro-Physics*, 12, 91.

Anonymous, 1894-1895. Professor George E. Hale awarded the Janssen Prize. *Popular Astronomy*, 2, 331.

Anonymous, 1899. Astronomical and Astrophysical Society of America. *Popular Astronomy*, 7, 444-446.

Anonymous, 1903. The Astronomical and Astrophysical Society of America. *Popular Astronomy*, 11, 104-109.

Anonymous, 1909. New director for Goodsell Observatory. *Popular Astronomy*, 17, 181.

Anonymous, 1914. Astronomical and Astrophysical Society of America: report of the sixteenth meeting. *Popular Astronomy*, 22, 129-149.

Anonymous, 1925. Thirty-fourth meeting of the American Astronomical Society. *Popular Astronomy*, 33, 533-538, 588-600.

Anonymous, 1930-1931. Forty-fourth meeting of the American Astronomical Society. *Popular Astronomy*, 38, 519-522, 593-601; 39, 14-23.

Bell, T.E., 2002. The roles of lesser-known American telescope makers in 19-th century American observatories. *Journal of the Antique Telescope Society*, 23, 9-18.

Berendzen, R., 1974. Origins of the American Astronomical Society. *Physics Today*, 27, 32-39 (December issue).

Bishop, J.E., 1977. United States astronomy education: past, present, and future. *Science Education*, 61, 295-305.

Bishop, J.E., 1979. The Committee of Ten. *Sky and Telescope*, 57, 212-214 (March issue).

Board of Trustees Minutes, 1908 December 23, pp. 33-35. In CCA.

Board of Trustees Minutes, 1909 May 20, p. 49. In CCA.

Bruce, R.V., 1987. *The Launching of Modern American Science, 1846-1876*. Ithaca, Cornell University Press.

Byrd, M.E., 1903-1907. Astronomy in the high school. *Popular Astronomy*, 11, 550-552; 12, 24-27, 199-202; 13, 545-549; 15, 227-237.

Byrd, M.E., 1913. Astronomy and the normal school. *Popular Astronomy*, 21, 2-4.

Capshew, J.H., and Rader, K.A., 1992. Big science: Price to the present. *Osiris*, 2nd series, 7, 3-25.

Coakley, G.W., 1892. Tidal theory of the forms of comets. *Astronomy and Astro-Physics*, 11, 177-189.

DeVorkin, D.H., 1992. *Science With a Vengeance: How the Military Created the U.S. Space Sciences after World War II*. New York, Springer-Verlag.

DeVorkin, D.H. (ed.), 1999a. *The American Astronomical Society's First Century*. Washington, American Astronomical Society.

DeVorkin, D.H., 1999b. The Pickering Years. In DeVorkin, 1999a, 20-36.

DeVorkin, D.H., 1999c. The post-war Society: responding to new patterns of patronage. In DeVorkin, 1999a, 107-121.

Edmondson, F.K., 1997. *AURA and Its U.S. National Observatories*. Cambridge, Cambridge University Press.

Fath, E.A., 1926. *The Elements of Astronomy*. New York, McGraw-Hill.

Fath, E.A., 1928. William Wallace Payne. *Popular Astronomy*, 36, 267-270.

General Index to Sidereal Messenger, Vol. 1-10, Astronomy and Astro-Physics, Vol. 1-3, [and] Popular Astronomy, Vol. 1-16. Northfield (Minnesota), Northfield News (1909).

Gingrich, C.H., n.d. [ca 1926]. Undated report, "POPULAR ASTRONOMY", submitted to President Cowling. In CCA: Gingrich file.

Gingrich, C.H., 1939. Letter to O. Struve, dated December 6. In YOA: Box 179, Folder 6.

Gingrich, C.H., 1940a. Herbert Couper Wilson, 1858-1940. *Popular Astronomy*, 48, 231-240.

Gingrich, C.H., 1940b. Letter to O. Struve, dated September 19. In YOA: Box 187, Folder 3.

Gingrich, C.H., 1941. Letter to D.J. Cowling, dated October 22. In CCA: Gingrich file.

Gingrich, C.H., 1942a. Letter to O. Struve, dated September 21. In YOA: Box 202, Folder 3.

Gingrich, C.H., 1942b. Letter to O. Struve, dated November 23. In YOA: Box 202, Folder 3.

Gingrich, C.H., 1942c. Volume Fifty. *Popular Astronomy*, 50, 1.

Gingrich, C.H., 1942d. Volume Fifty concluded. *Popular Astronomy*, 50, 523.

Gingrich, C.H., 1943a. Letter to O. Struve, dated February 25. In YOA: Box 208, Folder 3.

Gingrich, C.H., 1943b. Letter to O. Struve, dated March 24. In YOA: Box 208, Folder 3.

Gingrich, C.H., 1943c. *Popular Astronomy*: the first fifty years. *Popular Astronomy*, 51, 1-18, 63-67.

Gingrich, C.H., 1947. Letter to O. Struve, dated March 27. In YOA: Box 232, Folder 2.

Gingrich, C.H., 1950. 'Copy for President Gould of letter to the Collaborating Board', dated December 19. In CCA: Gingrich file.

Gould, L.M., 1950. Letter to C.H. Gingrich, dated May 24. In CCA: Gingrich file.

Gould, L.M., 1951. Letter to R.L. Henry, dated December 7. In CCA: *Popular Astronomy* file.

Greene, J.C., 1958. Science and the public in the age of Jefferson. *Isis*, 49, 13-25.

Greene, M., 1988. *A Science Not Earthbound: A Brief History of Astronomy at Carleton College*. Northfield (Minnesota), Carleton College.

Headley, L.A., and Jarchow, M.E., 1966. *Carleton: The First Century*. Northfield (Minnesota), Carleton College.

Henry, R.L., 1951a. Letter to B. Pollock, dated October 18. In CCA: *Popular Astronomy* file.

Henry, R.L., 1951b. 'To Persons Closely Associated with Popular Astronomy,' dated November 15. In CCA: *Popular Astronomy* file.

Henry, R.L., 1951c. Letter to C.A. Federer Jr., dated December 11. In CCA: *Popular Astronomy* file.

Hermann, D.B., 1971. B. A. Gould and his *Astronomical Journal*. *Journal for the History of Astronomy*, 2, 98-108.

Hilgartner, S., 1990. The dominant view of popularization: conceptual problems, political uses. *Social Studies of Science*, 20, 519-539.

Hillsdale College, 1863. *Eighth Annual Catalogue of the Officers and Students of Hillsdale College, Hillsdale, Michigan*. Chicago, Evening Journal Book and Job Print.

Huggins, W., 1891. On Wolf and Rayet's bright-line stars in Cygnus. *The Sidereal Messenger*, 10, 49-65.

Jarrell, R.A., 1988. *The Cold Light of Dawn: A History of Canadian Astronomy*. Toronto, University of Toronto Press.

Keeler, J.E., 1891. Elementary principles governing the efficiency of spectroscopes for astronomical purposes. *The Sidereal Messenger*, 10, 433-453.

Krug, E.A., 1964. *The Shaping of the American High School*. New York, Harper and Row.

Kuritz, H., 1981. The popularization of science in nineteenth-century America. *History of Education Quarterly*, 21(3), 259-274.

LaFollette, M.C., 1990. *Making Science Our Own: Public Images of Science, 1910-1955*. Chicago, University of Chicago Press.

Lankford, J., 1997. *American Astronomy: Community, Careers, and Power, 1859-1940*. Chicago, University of Chicago Press.

Launius, R.D., Logsdon, J.M., and Smith, R.W. (eds.), 2000. *Reconsidering Sputnik: Forty Years Since the Soviet Satellite*. Amsterdam, Harwood Academic Publishers.

Leonard, D.L., 1904. *The History of Carleton College*. Chicago, Fleming H. Revell.

Leonard, F.C., 1951. Curvin Henry Gingrich. *Popular Astronomy*, 59, 343-347.

Leverington, D., 2000. *New Cosmic Horizons: Space Astronomy from the V2 to the Hubble Space Telescope.* Cambridge, Cambridge University Press.

Lewenstein, B.V., 1992. The meaning of "public understanding of science" in the United States after World War II. *Public Understanding of Science*, 1, 45-68.

Marché, J.D., II, 2002. Mental discipline, curricular reform, and the decline of U.S. astronomy education, 1893-1920. *Astronomy Education Review*, 1, 58-75.

Maunder, E.W., 1907. Progress of astronomy in 1906. *Popular Astronomy*, 15, 1-12.

McCormmach, R., 1966. Ormsby MacKnight Mitchel's *Sidereal Messenger*, 1846-1848. *Proceedings of the American Philosophical Society*, 110, 35-47.

McCray, W.P., 2004. *Giant Telescopes: Astronomical Ambition and the Promise of Technology.* Cambridge (Mass.), Harvard University Press.

McDougall, W.A., 1985. ... *The Heavens and the Earth: A Political History of the Space Age.* New York, Basic Books.

Moyer, A.E., 1992. *A Scientist's Voice in American Culture: Simon Newcomb and the Rhetoric of Scientific Method.* Berkeley, University of California Press.

Neidigh, R.S., n.d. *The Elgin Observatory Story, 1909-1960.* Fredericksburg (Texas), Printing Press.

Nelkin, D., 1987. *Selling Science: How the Press Covers Science and Technology.* New York, Freeman.

Newcomb, S., 1897-1898. The aspects of American astronomy. *Popular Astronomy*, 5, 351-367.

Osterbrock, D.E., 1978. Edward S. Holden — the founder of the A.S.P. and the early days of the California-Wisconsin astronomical connection. *Mercury*, 7, 106-110 (September-October issue).

Osterbrock, D.E., 1984. *James E. Keeler: Pioneer American Astrophysicist and the Early Development of American Astrophysics.* Cambridge, Cambridge University Press.

Osterbrock, D.E., 1993. *Pauper and Prince: Ritchey, Hale, and Big American Telescopes.* Tucson, University of Arizona Press.

Osterbrock, D.E., 1995. Founded in 1895 by George E. Hale and James E. Keeler: the *Astrophysical Journal* centennial. *The Astrophysical Journal*, 438, 1-7.

Osterbrock, D.E., 1997. *Yerkes Observatory, 1892-1950: The Birth, Near Death, and Resurrection of a Scientific Research Institution.* Chicago, University of Chicago Press.

Osterbrock, D.E., 1999. AAS meetings before there was an AAS: the pre-history of the Society. In DeVorkin, 1994a, 3-19.

Page, H.W., 1908. Letter to W.H. Laird, dated December 3. In CCA: William H. Sallmon File.

Payne, W.W., 1882-1883. Editorial remarks. *Sidereal Messenger*, 1, 19, 20, 21, 298.

Payne, W.W., 1884. Editorial remarks. *Sidereal Messenger*, 3, 304.

Payne, W.W., 1891. Carleton College Observatory. *Publications of the Astronomical Society of the Pacific*, 3, 85-87.

Payne, W.W., 1893. Editorial remarks. *Astronomy and Astro-Physics*, 12, 90, 377.

Payne, W.W., 1893-1894. Editorial remarks. *Popular Astronomy*, 1, 45.

Payne, W.W., 1894. Editorial remarks. *Astronomy and Astro-Physics*, 13, 871.

Payne, W.W., 1894-1895. Editorial remarks. *Popular Astronomy*, 2, 283.

Payne, W W., 1904a. The wider field for this magazine. *Popular Astronomy*, 12, 5-8.

Payne, W.W., 1904b. Recent astronomical research. *Popular Astronomy*, 12, 89-94.

Payne, W.W., 1908a. Letter to W.H. Laird, dated July 20. In CCA: William H. Sallmon File.

Payne, W.W., 1908b. Letter to W.H. Laird, dated October 26. In CCA: William H. Sallmon File.

Payne, W.W., 1910. Change of management of *Popular Astronomy*. *Popular Astronomy*, 18, 314.

Payne, W.W., 1927. Elgin Observatory. *Popular Astronomy*, 35, 1-10.

Pollock, B., 1952. Letter to a Mr. Feyerharm, dated February 28. In CCA: *Popular Astronomy* file.

President's Annual Reports, 1880. In CCA: Series 42, Box 1, Folder 1/8.

President's Annual Reports, 1882. In CCA: Series 42, Box 1, Folder 1/10.

President's Annual Reports, 1883. Unnumbered page labelled 'Gifts to the Observatory'. In CCA: Series 42, Box 1, Folder 1/11.

President's Annual Reports, 1884. In CCA: Series 42, Box 1, Folder 1/12.

President's Annual Reports, 1886. In CCA: Series 42, Box 1, Folder 1/14.

President's Annual Reports, 1887. In CCA: Series 42, Box 1, Folder 1/15.

President's Annual Reports, 1889. In CCA: Series 42, Box 1, Folder 1/17.

President's Annual Reports, 1890. In CCA: Series 42, Box 1, Folder 1/18.

President's Annual Reports, 1891. In CCA: Series 42, Box 1, Folder 1/19.

President's Annual Reports, 1893. In CCA: Series 42, Box 1, Folder 1/21.

President's Annual Reports, 1895. In CCA: Series 42, Box 2, Folder 2/2.

Schwarzschild, M., 1969. Introduction. *Bulletin of the American Astronomical Society*, 1, 1.

Shinn, T., and Whitley, R. (eds.), 1985. *Expository Science: Forms and Functions of Popularisation* [Sociology of the Sciences Yearbook, Volume 9]. Dordrecht, Reidel.

Shoemaker, P.S., 1991. Stellar impact: Ormsby MacKnight Mitchel and astronomy in antebellum America. Ph.D. thesis, University of Wisconsin-Madison.

Struve, O., 1933. Letter to C.H. Gingrich, dated October 20. In YOA: Box 144, Folder 3, Papers of the Director.

Struve, O., 1935. Some new trends in stellar spectroscopy. *Popular Astronomy*, 43, 483-496, 559-568, 628-639.

Struve, O., 1937. Recent progress in the study of reflection nebulae. *Popular Astronomy*, 45, 9-23.

Struve, O., 1939. Letter to C.H. Gingrich, dated December 9. In YOA: Box 179, Folder 6.

Struve, O., 1941. The problem with Phi Persei. *Popular Astronomy*, 49, 129-139.

Struve, O., 1942. Astronomy faces the war. *Popular Astronomy*, 50, 465-472.

Struve, O., 1943a. Letter to Gingrich, C.H., dated March 25. In YOA: Box 208, Folder 3.

Struve, O., 1943b. The story of Pleione. *Popular Astronomy*, 51, 233-244.

Struve, O., 1943c. Fifty years of progress in astronomy. *Popular Astronomy*, 51, 469- 481.

Struve, O., 1947a. Letter to C.H. Gingrich, dated March 25. In YOA: Box 232, Folder 2.

Struve, O., 1947b. The story of an observatory: the fiftieth anniversary of the Yerkes Observatory. *Popular Astronomy*, 55, 227-244, 283-294.

Struve, O., and Zebergs, V., 1962. *Astronomy of the 20th Century.* New York, Macmillan.

Sullivan, W., 1961. *Assault on the Unknown: The International Geophysical Year.* New York, McGraw-Hill.

Whalen, M.D., 1981. Science, the public, and American culture: a preface to the study of popular science. *Journal of American Culture*, 4(4), 14-26.

Whalen, M.D., and Tobin, M.F., 1980. Periodicals and the popularization of science in America, 1860-1910. *Journal of American Culture*, 3(1), 195-203.

Willard, C.R., 1893-1894. Time and time signals. *Popular Astronomy*, 1, 60-62.

Williams, T.R., 2000. Getting Organized: A History of Amateur Astronomy in the United States. Ph.D. thesis, Rice University.

Winlock, W.C., 1891. A brief bibliography of astronomical literature for the year 1890, January to June. *The Sidereal Messenger*, 10, 83-89.

Wright, H., 1994. *Explorer of the Universe: A Biography of George Ellery Hale*. New York, American Institute of Physics (originally published in 1966 by E. P. Dutton, New York).

Young, C.A., 1887. Ten years' progress in astronomy, 1876-1886. *The Sidereal Messenger*, 6, 4-41.

Zochert, D., 1974. Science and the common man in ante-bellum America. *Isis*, 65, 448-473.

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THE IAU HISTORIC RADIO ASTRONOMY WORKING GROUP. 2: PROGRESS REPORT

This Progress Report follows the inaugural report of the Working Group (WG), which appeared in the April 2004 *ICHA Newsletter* and was published in the June 2004 issue of the *Journal of Astronomical History and Heritage* (see Orchiston *et al.*, 2004, below).

1 Role of the WG

This WG was formed at the 2003 General Assembly of the IAU as a joint initiative of Commissions 40 (Radio Astronomy) and 41 (History of Astronomy), in order to:

- assemble a master list of surviving historically-significant radio telescopes and associated instrumentation found worldwide;
- document the technical specifications and scientific achievements of these instruments;
- maintain an on-going bibliography of publications on the history of radio astronomy; and
- monitor other developments relating to the history of radio astronomy (including deaths of pioneering radio astronomers).

2 New Committee Members

Since the last report was prepared we have added two further members to the Committee of the WG. As Chair of the WG, I am delighted to offer a warm welcome to Richard Wielebinski from the Max Planck Institute for Radioastronomy, representing Germany, and Jasper Wall (University of British Columbia), who represents Canada.

3 Further Publications on the History of Radio Astronomy

Balick, B., 2005. The discovery of Sagittarius A*. In Orchiston, 2005b, 183-190.

Beekman, G., 1999. Een verjaardag zonder jarige. *Zenit*, 26(4), 154-157.

Cohen, M., 2005. Dark matter and the Owens Valley Radio Observatory. In Orchiston, 2005b, 169-182.

Davies, R.D., 2003. Fred Hoyle and Manchester. *Astrophysics and Space Science*, 285, 309-319.

Gordon, M.A., 2005. *Recollections of "Tucson Operations". The Millimeter-Wave Observatory of the National Radio Astronomy Observatory*. Dordrecht, Springer. Pp. xvii+221.

Gunn, A., 2005. Jodrell Bank and the meteor velocity controversy. In Orchiston, 2005b, 107-118.

Holpp, W, 2004. The century of radar. From Christian Hülsmeyer to Shuttle Radar Topography Mission. See: www.100-jahre-radar.de

Jarrell, R., 2005. "Radio astronomy, whatever that may be." The marginalization of early radio astronomy. In Orchiston, 2005b, 191-202.

Kellermann, K.I., 2004. Grote Reber (1911-2002). *Publications of the Astronomical Society of the Pacific*, 116, 703-711.

Kellermann, K.I., 2005. Grote Reber (1911-2002): a radio astronomy pioneer. In Orchiston, 2005b, 43-70.

Kellermann, K.I., Orchiston, W., and Slee, B., 2005. Gordon James Stanley and the early development of radio astronomy in Australia and the United States. *Publications of the Astronomical Society of Australia*, 22, 1-11.

Lovell, B., and Davis, J., 2003. Robert Hanbury Brown. *Biographical Memoirs of Fellows of the Royal Society*, 49, 83-106.

Orchiston, W., 2004. The 1948 solar eclipse and the genesis of radio astronomy in Victoria. *Journal of Astronomical History and Heritage*, 7, 118-121.

Orchiston, W., 2005a. Dr Elizabeth Alexander: first female radio astronomer. In Orchiston, 2005b, 71-92.

Orchiston, W. (ed.), 2005b. *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth. A Meeting to Honor Woody Sullivan on His 60th Birthday.* Dordrecht, Springer. Pp. xvi + 328.

Orchiston, W., and Slee, B., 2005a. The Radiophysics field stations and the early development of radio astronomy. In Orchiston, 2005b, 119-168.

Orchiston, W., and Slee, B., 2005b. Shame about Shain! Early Australian radio astronomy at Hornsby Valley. *ATNF News*, 55, 14-16.

Orchiston, W., Davies, R., Denisse, J.-F., Kellermann, K., Morimoto, M., Slysh, S., Swarup, G., and van Woerden, H., 2004. The IAU Historic Radio Astronomy Working Group. 1: Progress report. *Journal of Astronomical History and Heritage*, 7, 53-56.

Raimond,, E., and Genee, R. (eds.), 1996. *The Westerbork Observatory. Continuing Adventure in Radio Astronomy.* Dordrecht, Kluwer Academic Publishers (Astronomy and Space Science Library, Volume 207). Pp. x+266.

Strom, R., 2005. Radio astronomy in Holland before 1960: just a bit more than HI. In Orchiston, 2005b, 93-106.

Swarup, G., 1986. The story of the Ooty Radio Telescope. In Cowsik, R. (ed.). *Cosmic Pathways.* New Delhi, Tata McGraw-Hill. Pp. 349-360.

Van Loon, B., and Hin, A., 2004. Scanning our past from the Netherlands: early Galactic radio astronomy at Kootwijk, and some consequential developments. *Proceedings of the IEEE*, 92, 1004-1006.

Van Woerden, H., 2000. Vijftig Jaar Toponderzoek. *Zenit*, 27(5), 196-200.

Wakker, B.P., de Boer, K.S., and Van Woerden, H., 2004. History of HVC research – an overview. In Van Woerden, H., Wakker, B.P., Schwarz, U.J. and de Boer, K.S. (eds.). *High-Velocity Clouds.* Dordrecht, Kluwer Acadmeic Publishers. Pp. 1-24.

Wielebinski, R., 2003. The new era of large paraboloid antennas: the life of Prof. Otto Hachenberg. *Advances in Radio Science*, 1, 321-324.

4 Up-Coming Publications

(1) Conference Proceedings: An interesting new book for historians of radio astronomy is:

> Orchiston, W. (ed.), 2005. *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth. A Meeting to Honor Woody Sullivan on His 60th Birthday.* Dordrecht, Springer. Pp. xvi + 328.

This contains papers on the history of radio or radar astronomy by Bruce Balick, Marshall Cohen, Alastair Gunn, Rich Jarrell, Ken Kellermann, Wayne Orchiston, Wayne Orchiston & Bruce Slee, and Richard Strom (see the reference list above), which collectively account for 53% of the text of the book. Other papers in the book relate to astrobiology (2 papers), the history of space astronomy (3), the history of gamma ray astronomy (1), transits of Venus (1), and sundials (2 papers). *The New Astronomy* is in the process of being published, and copies can be ordered from Springer or through your local bookseller.

(2) JAH^2: The next three issues of the *Journal of Astronomical History and Heritage* (June 2005, December 2005 and June 2006) will feature a series of research papers on the history of radio astronomy. Altogether, there will be about a dozen different papers, most deriving from the history of radio astronomy sessions at the 2003 IAU General Assembly. Authors of these papers include Ron Bracewell, Bruce McAdam, Doug Milne, John Murray, Wayne Orchiston, Bruce Slee, Richard Strom, Woody Sullivan, Hugo van Woerden and John Whiteoak. For additional details, or offers of further papers, please e-mail Wayne Orchiston at the following new address: Wayne.Orchiston@jcu.edu.au

5 Recent Meetings

(1) JENAM-2003: From 27 to 30 August 2003 a symposium on "Radio Astronomy at 70: From Karl Jansky to Microjansky" was held in Budapest, Hungary. Although the bulk of the papers were on contemporary radio astronomy, the first session of the conference was devoted to historical issues and three papers were presented:

- Graham-Smith, F. "Early years of radio astronomy in Europe."
- Burke, B. "Early years of radio astronomy in the US."
- Gunn, A. "Jodrell Bank and the pursuit of cosmic rays."

These papers, and others presented at the Conference will appear in the following proceedings, which are currently in press:

> Gurvits, L., and Frey, S. (eds.), 2005. *Radio Astronomy at 70: From Karl Jansky MicroJansky*. EDP Sciences, in press.

For further information on this conference or the proceedings, contact Leonid Gurvits (lgurvits@jive. nl).

(2) Woodfest: In June 2004 a meeting spanning astrobiology, the history of astronomy and sundials was held at the University of Washington, Seattle, to celebrate Woody Sullivan's 60th birthday. Many of the history of astronomy papers related to radio and radar astronomy (see those by Balick, Cohen, Gunn, Jarrell, Kellermann, Orchiston, Orchiston & Slee, and Strom in the foregoing list of references). For further details of this conference e-mail Wayne Orchiston.

(3) ICOA-5: In October 2004 the Fifth International Conference on Oriental Astronomy was held in Chiang Mai, Thailand, and Richard Strom and Richard Stephenson organized a special session on "Supernovae: Historical Records and Observations". Among the papers presented were:

- Dickel, J.R. "Current observations of the remnants of Kepler's SN of 1604 and other historical supernova remnants."
- Orchiston, W., and Slee, B. "Early Australian observations of historical supernova remnants at radio wavelengths."

These papers will appear in the following proceedings, which are currently in preparation:

> Chen, K.-Y., Orchiston, W., Soonthornthum, B., and Strom, R. (eds.), 2005. *Proceedings of the Fifth International Conference on Oriental Astronomy*. Chiang Mai, University of Chiang Mai Press.

6 Up-coming Meetings

(1) Cambridge, England, 2005: The Historical Astronomy Division (HAD) of the American Astronomical Society will meet 4-8 September, 2005 (Sunday-Thursday) at the Umney Theatre, Robinson College, University of Cambridge.

This will be a joint meeting with the Division of Planetary Sciences (DPS) of the AAS. The HAD program will include nine, 90-min. sessions of papers. One or two of these sessions will be on the history of radio astronomy, and are being organised by Professor Woody Sullivan.

A Sunday evening reception will open the meeting; HAD papers will be on Monday, Tuesday, and Wednesday; with the conference DPS/HAD banquet on Wednesday; and on Thursday a final plenary session will be followed by tours of Cambridge sites relevant to the Conference.

Housing will be at St John's College and Robinson College. The Conference registration fees are $290 (full Conference) or $145 (one day) for members of DPS, AAS, or RAS, until June 30; see the Conference web site (http://www.dps2005.org/) for non-member & student/emeritus rates, and for accommodation charges. The deadline for advance registration, reservation of accommodation, and submission of abstracts is 1 July 2005. For general Conference details see the DPS web site or e-mail Peter Abrahams (had2005@europa.com).

Meanwhile, if you would like to present a paper on historic radio astronomy, please e-mail Woody Sullivan (woody@astro.washington.edu) as soon as possible for further details. Note that this Conference is open to non-AAS members.

(2) Prague, Czech Republic, 2006: The Twenty-Sixth General Assembly of the IAU will be held in Prague during 14-25 August 2006, and we are hoping to hold between two and four quarter-day meetings of the Historic Radio Astronomy Working Group. These will provide an opportunity for those interested in the history of radio astronomy to discuss their latest research, with emphasis on the development of radio astronomy in Europe, and the status of radio astronomy worldwide fifty years ago when 'big science' first began to impact on radio astronomy. For general information about the General Assembly consult the following web site: http://www.astronomy2006.com, and further information about the WG meetings contact Wayne Orchiston@jcu.edu.au

7 Research by Working Group Members

Ron Bracewell (Stanford University) has been researching the history of radio astronomy at Stanford as part of his efforts to ensure the preservation of the early radio telescopes at Site 515 (see below), and he is also preparing a paper for publication in the *Journal of Astronomical History and Heritage*.

Miller Goss (National Radio Astronomy Observatory, USA) and *Dick McGee* (ex-Australia Telescope National Facility) continued their biographical study of Ruby Payne-Scott, one of the world's first female radio astronomers. During WWII, Payne-Scott worked on radar developments whilst employed by the Commonwealth Scientific and Industrial Research Organization's (CSIRO) Division of Radiophysics in Sydney, and following the war carried out pioneering research on solar radio astronomy. She left Radiophysics in 1951 in order to start a family. Following Miller and Dick's paper at the IAU General Assembly in Sydney, the Australian Broadcasting Commission (ABC) took a special interest in Ruby Payne-Scott. She featured in the 'Science Show' on 14 February 2004, which included interviews with both Miller and Dick, and Miller was also interviewed on the ABC television program, 'Rewind Moments', which was screened on 7 February 2005.

Alastair Gunn (Jodrell Bank, University of Manchester) continued his research into the early development of radar (meteor) astronomy and radio astronomy at Jodrell Bank, and he and *Rod Davies* began a review of surviving historically-significant radio telescopes and associated equipment at this site.

Ken Kellermann (National Radio Astronomy Observatory, USA) is editing an English language version of the 1985 book, *History of Radio Astronomy in USSR*, which Denise Gabuzda is currently translating. This new English edition will be published by Springer. *Slava Slysh* (Lebedev Physical Institute. Moscow) says that this book "... contains some less known details of the early days of radio astronomy in USSR ...", and he hopes the new edition will be updated and enlarged.

Ken Kellermann also reports that the National Radio Astronomy Observatory Archives actively seeks out, collects, organizes, and preserves institutional records and personal papers of enduring value which document NRAO's historical development, institute-ional history, instrument construction, and ongoing activities, including its participation in multi-institutional collaborations. As the national facility for radio astronomy, it also includes materials on the history and development of radio astronomy in the United States, particularly if such materials are in danger of being lost or discarded by other institutions or individuals. During 2004, the Web pages chronicling Nan Dieter Conklin's career as the first woman in US radio astronomy were completed; Grote Reber's correspondence and papers currently at NRAO were indexed and a finding aid was published on the Web; the papers of John Findlay are being indexed; and an inventory of both the Findlay and NRAO Director's Office files was completed. A Web page presenting Doc Ewen's informal recollections of events in US radio astronomy history is in process, while the papers of John Kraus will be sent to the NRAO Archives, where they will be processed and made available to researchers. The NRAO Archives is located at the NRAO headquarters in Charlottesville, Virginia. The web page can be found at http://www.nrao.edu/archives/, and includes links to NRAO Archives resources and to the NRAO Archives Policy.

A biographical study of the late Gordon Stanley—and the key role he played in the early development of radio astronomy in Australia and California—was carried out by *Ken Kellermann*, *Wayne Orchiston* (Anglo-Australian Observatory) and *Bruce Slee* (Australia Telescope National Facility), and was published in an Australian astronomical journal.

Wayne Orchiston (Australia Telescope National Facility), *Woody Sullivan* (University of Washington) and *Jessica Chapman* (Australia Telescope National Facility) have been collaborating on a book titled *The Foundations of Australian Radio Astronomy*, which will be published by Springer (New York) in 2006. This well-illustrated volume makes excellent use of the ATNF's unique collection of historical photographs of Australian radio telescopes and associated equipment, radio astronomers, and field stations. The book focuses on the nine field stations and twenty or so remote sites located in and near Sydney that were maintained by the CSIRO's Division of Radiophysics between 1945 and 1961.

In addition, *Wayne Orchiston* (Anglo-Australian Observatory) and *Bruce Slee* conducted further historical research on the Division of Radiophysics field stations and prepared a major review paper on these and a number of short papers on individual field stations. Wayne also prepared a bibliography on the history of radio astronomy in Australia, and he assembled a national master-list of surviving historically-significant Australian radio telescopes.

Meanwhile, *Bruce Slee* began reviewing the range of non-solar research carried out between 1968 and 1988 with the Culgoora Circular Array (aka Culgoora Radioheliograph). He also participated in the ABC's television program, 'Rewind Moments', about Ruby Payne-Scott (with whom he used to work back in the 1940s).

Govind Swarup (National Centre for Radio Astron -omy, India) reports that Dr Indira Chaudhary, an historian, is recording oral history interviews with radio astronomers at the Centre. "She has already interviewed me five times," he said, "and plans another five sessions. That material may get ... put into a written semi-edited version in a year or so." In the course of the next year Govind plans to begin researching the history of the Giant Metre Wave Radio Telescope near Pune, with a view to writing this up.

Woody Sullivan (University of Washington) reports that he "... remains frustrated that his detailed treatment of the early (through 1953) history of worldwide radio and radar astronomy remains at the 80-90% completion point, where it has been 'stuck' for the past decade. But the good news is that he has a sabbatical year beginning in January 2006, and the first item on the 'to-do' list is to finish this book!" Woody also remarks: "It has been satisfying to see that recent visitors to Seattle have been making good use of his huge archive of materials on early (pre-1965) radio astronomy. These were Ken Kellermann, Miller Goss, and in particular, Wayne Orchiston, who spent two months in late 2003 expressly to study portions of this material, especially dealing with Australia."

Hugo Van Woerden (Kapteyn Astronomical Institute, University of Groningen, The Netherlands) and *Richard Strom* (ASTRON, The Netherlands) have been researching the history of Dutch Wurzburg dishes and the Dwingeloo Radio Telescope. During the 1950s, as many as eight different Wurzburg-Riese radar antennas from WWII were being used in The Netherlands for radio astronomical research. Parts of six of these have survived, and currently two are in museums in Germany, and four are at a museum, a public observatory and a planetarium in The Netherlands. Hugo and Richard are also building up a bibliography on the history of radio astronomy in The Netherlands.

Richard Wielebinski (Max Planck Institute for Radioastronomy, Bonn) has been recording oral history interviews with German radio astronomers, and reviewing archival material on German radio astronomy in various repositories (in the process unearthing some wartime reports on radar by people who later were involved in radio astronomy). He has also begun developing a bibliography on the history of German radio astronomy, and is planning a digital picture gallery of various German radio telescopes.

8 The Preservation and Destruction of Historically-Significant Radio Telescopes

1) Stanford University: down a dirt road off Highway 280 in California is Site 515, where Ron Bracewell and other scientists from Stanford's Space, Telecommunications and Radioscience Laboratory (STAR Lab) established a major radio astronomy field station in 1956. The first instrument on this site was an array of 32 small parabolic antennas, each 10-ft in diameter, arranged in the form of a cross. From 1961 this array was used to generate daily microwave maps of the Sun, and for the next eleven years (i.e. one complete solar cycle) these were forwarded to the US Air Force and distributed around the world. Subsequently an interferometer comprising five 60-ft antennas was constructed, and this was used to study the angular diameters, temperatures and polarization of radio galaxies.

Towards the end of the 1970s the site was abandoned, and the radio telescopes and associated buildings began to deteriorate. In June 2004 Stanford University's fire inspector visited the site, finding weed-choked meadows, dilapidated buildings and rusting instruments. He declared Site 515 a fire hazard, and called for its clean-up.

Professor Channing Robertson, Senior Associate Dean in the School of Engineering subsequently called a halt to demolition of the antennas until 30 June 2005 in order to give the newly-formed Friends of the Bracewell Observatory (FoBO) time to mount a rescue effort. FoBO proposes to save and restore this site at no expense to Stanford University, and to upgrade the existing antennas so they can be used to track Stanford's SSDL CubeSat satellite. Between tracking missions, the facility will:

- Offer hands-on radio telescope facilities for the general public
- Be used for educational programs and mentoring in amateur radio astronomy
- Be available to amateur organizations, schools, and individuals for special projects

FoBO now has more than 60 volunteers, and pledges of funding which will allow the restoration of the first 60-ft antenna, its up-grade to satellite-tracking status, and initiation of the 'public program' bullet-pointed above. For further information, and offers of assistance, please contact Dr Bob Lash, Co-organizer Friends of the Bracewell Observatory (bob@bambi.net). See, also, the following web site, which includes some nice colour photographs of the dishes and control room: www.bambi.net/stanford_dishes/rescue.html

2) The Chris Cross: In stark contrast to the promising future for Site 515 in California is the fate of the historic Chris Cross radio telescope in Australia. This antenna comprised 64 parabolic antennas, each 19-ft in diameter, arranged in the form of a cross, and was erected at the Fleurs field station of the CSIRO's Division of Radiophysics in 1957. Initially, this cross-grating interferometer was used to generate daily solar isophote maps at 1420 MHz, but once the site was taken over by the University of Sydney's School of Electrical Engineering the array was converted into the Fleurs Synthesis Telescope (FST) with the addition of six 45-ft parabolas. With a 20 arcsecond beam, this array was used to study southern radio galaxies, SNRs and emission nebulae.

The FST was closed down in 1988 when the Australia Telescope Compact Array was comm.-issioned, and the Fleurs field station passed to the Engineering Faculty at the University of West-ern Sydney as a teaching facility. The FST dishes then began to deteriorate, and in 1990 a decision was made to preserve the large dishes and the 12 centrally-located Chris Cross dishes from the solar array. The remaining Chris Cross dishes were then offered to local astronomical societies, four were removed from the site, and the remaining ones were bulldozed. Undergraduate students were involved in cleaning and painting the surviving Chris Cross dishes, and on 22 November 1991 a ceremony was held at the site to commemorate their preservation.

In early 2005, CSIRO staff discovered that these surviving Chris Cross antennas had recently been destroyed. Apparently the dishes were beginning to rust, and a local farmer, concerned that children playing on them could be injured, requested they be bulldozed. The area is part of the University of Sydney's farm operations, and the site manager simply sanctioned this request—without even bothering to discuss this matter with any of the University's radio astronomers or other members of the IAU Historic Radio Astronomy WG employed by the Australia Telescope National Facility. As a result of this regrettable action, the world has lost a pioneering radio telescope that for more than three decades made important contributions to solar, Galactic and extragalactic radio astronomy. Currently, the rusting six large antennas remain, and efforts are being made to ensure that two of these are preserved.

9 Obituaries

Further to the obituaries listed in our initial report, it is with sadness that we announce the deaths of the following colleagues:

- Hendrik Christoffel (Henk) van de Hulst (born 19 November 1918, died 31 July 2000).
  Obituaries: Blaauw, A., 2002. *Proceedings of the American Philosophical Society*, 146, 419-423; Habing, H.J., 2001. *Astronomy & Geophysics*, 42(1), 1.33-1.35; Welther, B.L., 2000. *Bulletin of the American Astronomical Society*, 32, 1688-1689.
- Bob Duncan (born 1929, died 19 April 2004).
  Obituary: Sim, H., 2004. *ATNF News*, 53, 4-5.
- John D. Kraus (died 18 July 2004, aged 94).
  Obituary: see below.
- Brian Robinson (born 4 November 1930, died 22 July 2004).
  Obituary: Sim, H., and Orchiston, W., 2005. *ATNF News*, 54, 11-13.
- Christiaan Alexander (Lex) Muller (born 1923, died 8 August 2004).
  Obituaries: Van Woerden, H., Hin, A.C., Raimond, E., and Schipper, B.A.P., 2005. *Zenit*, 32 (1), 27-28; Van Woerden, H., Hin, A.C., Raimond, E., and Schipper, B.A.P., 2005. *Proceedings of the IEEE*, in press.
- Fred L. Whipple (born 5 November 1906, died 30 August 2004).
  Obituary: Yeomans, D.K., and Veverka, J., 2004. *Nature*, 432(7013), 31.
- Vladimir Kotelnikov (died 11 February 2005, aged 96).
  Obituary: see below.

Ken Kellermann kindly forwarded the following biographical details about *John Kraus*, which, although from an amateur radio source, do provide some information about his radio astronomical activities.

"Radio astronomer, antenna designer, cosmic explorer and author, John D. Kraus, W8JK, of Delaware, Ohio, died July 18. He was 94. While he enjoyed a worldwide reputation, Kraus is best known in Amateur Radio circles for his bi-directional wire beam antenna—often dubbed the '8JK array'. Other important Kraus designs include the corner reflector and helix antennas. The Michigan native was a pioneer of radio telescope design and the father of the 'Big Ear' radio telescope ...

A graduate of Michigan State University, he joined the faculty of the Ohio State University in 1946, serving as a Professor of Electrical Engineering and Astronomy, and founding and directing the OSU Radio Observatory. In that capacity, Kraus designed and oversaw construction of the 'Big Ear' on the campus of nearby Ohio Wesleyan University.

Kraus' classic textbook, *Antennas*, now in its second edition, has been an engineering school staple for decades and can be found in virtually every antenna engineer's library. Among his other titles are *Electromagnetics*, *Radio Astronomy*, *Big Ear*, *Big Ear Two* and *Our Cosmic Universe* ...

Kraus was a Fellow of the IEEE and a member of the National Academy of Engineering. In 1966, Dayton Hamvention honored Kraus as the recipient of its Special Achievement Award. In 2001, CQ added Kraus' name to the inaugural class of its Amateur Radio Hall of Fame.

In 1978, after the 'Big Ear' detected the still-unidentified "Wow!" signal that suggested the possibility of intelligent life elsewhere in the Universe, Kraus launched *Cosmic Search*, a magazine devoted to the search for extraterrestrial intelligence. The 'Big Ear' fell victim to development pressures and was torn down in 1998."

Nicholai Kardashev and Slava Slysh, kindly sent the following brief report on *Vladimir Kotelnikov*: "With deep regret we inform you that on Friday 11 February 2005, Vladimir Kotelnikov died. He was in his 97th year. Academician Kotelnikov was a creator of the Scientific Radioastronomical Council, one of the pioneers of planetary radar exploration, a founder of the statistical theory of radio reception, and an author of numerous scientific papers and books. He was awarded Lenin and State Prizes, twice obtained the title 'Hero of Socialist Labour', was decorated with the order 'For Merits of the Nation' of the first grade, and received many other national and foreign awards. He was an Honorary Member of the Scientific Council of Astronomy."

On behalf of our international colleagues, we express our condolences to the relatives and friends of these distinguished radio astronomers who have recently been taken from us.

Wayne Orchiston, Chair (Wayne.Orchiston@jcu.sedu.au)
Ron Bracewell (bracewell@star.stanford.edu)
Rod Davies (rdd@jb.man.ac.uk)
Jean-François Denisse (debarbat@danof.obspm.fr)
Miller Goss (mgoss@nrao.edu)
Alastair Gunn (agg@jb.man.ac.uk)
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Journal of Astronomical History and Heritage, 8(1), 70-71 (2005).

THE IAU TRANSITS OF VENUS WORKING GROUP. 4: PROGRESS REPORT

This Progress Report follows the previous report of the Working Group, which appeared in the April 2004 *ICHA Newsletter* and was published in the June 2004 issue of the *Journal of Astronomical History and Heritage* (see Orchiston *et al.*, 2004, below).

As we indicated in the 2004 report of the Working Group, various historic re-enactments, lectures, seminars, conferences and museum displays were arranged to link with the June 2004 transit. Sara Schechner's "Festival of the Transit of Venus" at Harvard University not only included an observing program and a museum display featuring instruments used by John Winthrop in 1761 and 1769 but also live performances of John Philip Sousa's "Transit of Venus March" by the Harvard Band and "The Venus Waltz" for banjo, by John Huth, Chairman of the Physics Department at Harvard. An exhibition titled "Chasing Venus: Observing the Transits of Venus, 1631–2004" at the National Museum of American History in Washington was mentioned in the previous Report. Associated with it was a series of five lunchtime public lectures spanning the 1639, 1769, 1874 and 1882 transits, presented by Wilbur Applebaum, David DeVorkin, Steven Dick, Richard Fisher and Jay Pasachoff. The 1 June 2004 symposium at the Museum Sterrenwacht Sonnenborgh in Utrecht (The Netherlands) mentioned in the previous Report featured papers by Hilmar Duerbeck, Jessica Ratcliff, Klaus Staubermann, Albert van Helden and Rob van Gent.

In the previous Report we reproduced a list of existing transit of Venus plaques compiled by Peter Broughton and various international colleagues, and reported on new plaques planned to mark observations of the 1761 and 1882 transits from St. John's (Newfoundland) and Wellington (South Africa), respectively. We have also learnt, through Paul Maley (Johnson Space Center Astronomical Society) and Brenda Corbin (U.S. Naval Observatory Library), of an historical marker that was dedicated at San Antonio, Texas, on 3 December 2004 to mark the site where Asaph Hall observed the 1882 transit of Venus. This historical marker was the brainchild of Paul Maley. He researched the 1882 expedition, located the site of the U.S. Naval Observatory transit station within the perimeter of Fort Sam Houston, and successfully lobbied for the military to approve and fund the historical marker. Maley was also successful in convincing the Texas Historical Commission to erect a separate monument 500 metres to the west, in order to commemorate observations of the transit made by the Belgian astronomer, Jean-Charles Houzeau.

Further to the lists of references that appeared in previous Reports of the Working Group, other transit of Venus references we have noted are:

Aughton, P., 2004. *The Transit of Venus: The Brief Brilliant Life of Jeremiah Horrocks, Father of British Astronomy*. London, Weidenfeld & Nicholson.

Bònoli, F., 2004. Il passaggio di Venere alla meridiana. *Giornale di Astronomia*, 30(3), 2-3.

Botez, E., 2004. Maximilian Hell and the northernmost transit of Venus expedition of 1769. *Journal of Astronomical Data*, 10(7), 165-174.

Brashear, R., 2005. The transits of Venus and new technologies: a time to reflect. In Orchiston, W. (ed.). *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth*. Dordrecht, Springer. Pp. 251-260.

Calanca, R., 2003. I transiti di Venere nella storia (1631-1882). *Giornale di Astronomia*, 29(4), 6-36.

Chinnici, I., 2003. Transito di Venere 1874: una spedizione Italiana in Bengala. *Giornale di Astronomia*, 29(4), 45-53.

Clark, B.A.J., and Orchiston, W., 2004. The Melbourne Observatory Dallmeyer photoheliograph and the 1874 transit of Venus. *Journal of Astronomical History and Heritage*, 7, 44-49.

Corbin, B.G., 2004. Archives of the U.S. Naval Observatory – recent projects. *Journal of Astronomical Data*, 10(7), 13-26.

Edwards, P.G., 2004. Charles Todd's observations of the transits of Venus. *Journal of Astronomical History and Heritage*, 7, 1-7.

Débarbat, S., 2004a. Astronomers Français et passage de Vénus sur le Soleil. *L'Astronomie*, 118(Mai), 268-273.

Débarbat, S., 2004b. Quand Crabtree observe le passage de Vénus. *L'Astronomie*, 118(Mai), 266-267.

Duerbeck, H.W., 2004a. Le passage de Vénus de 1882 observé depuis le Chili. *Ciet et Terre*, 120(2), 45-50.

Duerbeck, H.W., 2004b. The German transit of Venus expeditions of 1874 and 1882: organization, methods, stations, results. *Journal of Astronomical History and Heritage*, 7, 8-17.

Duerbeck, H.W., 2004c. Historische Venusdurchgänge – eine bibliographische nachlese. In Dick, W.R., and Hamel, J. (eds.). *Beiträge zur Astronomiegeschichte*, 7.

Duerbeck, H.W., 2004d. Zach, Gotha and the Venus transits of the 18th and 19th centuries. In Balázs, L.G., Brosche, P., Duerdeck, H.W., and Zsoldos, E. (eds.). *The European Scientist. Symposium on the Era and Work of Franz Xaver von Zach (1754–1832)*. Frankfurt, Harri Deutsch. Pp. 53-63.

Dumont, S., 2004. Les expéditions du XVIIIe siècle pour les passages de Vénus. *L'Astronomie*, 118 (Mai), 290-295.

Gualandi, A., and Poppi, F., 2003. Venere a Bologna! *Giornale di Astronomia*, 29(4), 37-44.

Hingley, P.D., and Launay, F., 2000. Passages de Vénus, 1874 et 1882. In *Dans le Champ des Étoiles: Les Photographes et le Ciel*. Paris. Pp. 119-120.

Jayawardhana, R., 2004. Chasing the shadow of Venus. *Astronomy*, 32(6), 32-37.

Kopper, M., 2004. Austria's scientific contribution to the observation of the 1874 transit of Venus. *Journal of Astronomical Data*, 10(7), 175-210.

Lauga, J., 2004. Les missions Françaises pour le passage de Vénus de 1874. *L'Astronomie*, 118(Mai), 296-305.

Launay, F., 2004. Le revolver photographique de Jules Janssen. *L'Astronomie*, 118(Mai), 306-308.

Launay, F., and Hingley, P., 2005. Jules Janssen's 'Revolver Photographique' and its British derivative, 'The Janssen Slide'. *Journal for the History of Astronomy*, 36, 57-79.

Lomb, N., 2004. *Transit of Venus. The Scientific Event that Led Captain Cook to Australia*. Sydney, Powerhouse Publishing.

Marlot, C., 2004. 6 Décembre 1882, une opportunité qui ne se représentera pas ... *L'Astronomie*, 118 (Mai), 309-313.

Marston, P., 2004. *Jeremiah Horrocks. Younger Genius & First Venus Transit Observer*. Preston, University of Central Lancashire.

Mourão, R.R. de F., 2004. *Transit of Venus: 1639–2012*. Brazil (in Portuguese).

Misch, A. & Sheehan, W., 2004a. A movie of the 1882 transit of Venus assembled from plates taken at Lick Observatory by David P. Todd. *Journal of Astronomical Data*, 10(4), 1-9.

Misch, A. & Sheehan, W., 2004b. A remarkable series of plates of the 1882 transit of Venus. *Journal of Astronomical Data*, 10(7), 211-218.

Orchiston, W., 2004. The nineteenth century transits of Venus: an Australian and New Zealand overview. *Journal of Astronomical Data*, 10(7), 219-308.

Orchiston, W., and Buchanan, A., 2004. 'The Grange', Tasmania: survival of a unique suite of 1874 transit of Venus relics. *Journal of Astronomical History and Heritage*, 7, 34-43.

Orchiston, W., Dick, S.J., Duerbeck, H.W., van Gent, R., Hughes, D., Koorts, W., and Pigatto, L., 2004. The IAU Transits of Venus Working Group. 3: progress report. *Journal of Astronomical History and Heritage*, 7, 50-52.

Parmeggiani, G., 2003. Astronomi in viaggio. *Giornale di Astronomia*, 29(4), 54-65.

Pigatto, L., and Zanini, V., 2004. The 1882 transit of Venus observed in Italian observatories. *Journal of Astronomical History and Heritage*, 7, 18-24.

Pigatto, L., Salmaso, M., and Zanini, V., 2004. The Lorenzoni-Tacchini correspondence at Padova Observatory archives: the "true" history of Italian astronomy of the second half of the nineteenth century. *Journal of Astronomical Data*, 10(7), 105-120.

Poppi, F., 2003. Il transito di Venere dell'8 Giugno 2004. *Giornale di Astronomia*, 29(4), 3-5.

Sheehan, W., and Misch, A., 2004. *Ménage à trois*: David Peck Todd, Mabel Loomis Todd, Austin Dickinson, and the 1882 transit of Venus. *Journal for the History of Astronomy*, 35, 123-134.

Sheehan, W., and Westfall, J., 2004. *The Transits of Venus*. Amherst, Prometheus Books.

Sicard, M., 1998. Passage de Vénus: le revolver photographique de Jules Janssen. *Études Photographiques*, 4, 44-63.

Sterken, C., and Duerbeck, H., 2004a. Jean-Charles Houzeau and the 1882 Belgian transit of Venus expeditions. *Journal of Astronomical Data*, 10(7), 309-330.

Sterken, C., and Duerbeck, H., 2004b. The 1882 Belgian transit of Venus expeditions to Texas and Chile—a reappraisal. *Journal of Astronomical History and Heritage*, 7, 25-33.

Sterken, C., and Duerbeck, H.W. (eds.), 2005. *Astronomical Heritages. Astronomical Archives and Historic Transits of Venus*. Brussel, published by C. Sterken.

Toulmonde, M., 2004. La parallaxe du Soleil. *L'Astronomie*, 118(Mai), 275-289.

Verdun, A., 2004. Die bestimmung der sonnenparallaxe aus den Venus-transits im 18 jahrhundert. *Orion*, issue 3 (no. 322), 4-20.

Zuidervaart, H., and van Gent, R.H., 2004. "A bare outpost of learned European culture on the edge of the jungles of Java." Johan Maurits Mohr (1715–1775) and the emergence of instrumental and institutional science in Dutch colonial Indonesia. *Isis*, 95, 1-33. [Includes observations of the 1761 and 1769 transits from present-day Jakarta.]

In the previous Report we mentioned the transit of Venus web site of the Scientific Instrument Commission (SIC) of the International Union for History and Philosophy of Science (Division of History of Science). In May 2004, Stephen Johnston reported (via HASTRO-L) that this is now up and running and can be accessed via

http://transits.mhs.ox.ac.uk

He provides the following information about this web site:

> "The core of the site is a browsable database of historical instruments and images from collections around the world. Institutions and individuals are invited to develop the site by contributing their own material.
>
> Currently the site displays material from:
>
> - Museo della Specola, Universita di Bologna
> - Collection of Historical Scientific Instruments, Harvard University
> - Museum of the History of Science, University of Oxford
> - National Museum of American History, Washington
> - Mathematisch-Physikalischer Salon, Dresden
> - UK Particle Physics and Astronomy Research Council
>
> To take part in this international collaboration, visit the Contributors section of the site. Material is submitted directly online for instant access on the web."

This site was developed for the SIC of the IUHPS/DHS by Stephen Johnston, Sara Schechner and Steven Turner.

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Astronomical Instruments and Archives from the Asia-Pacific Region. Edited by Wayne Orchiston, F. Richard Stephenson, Suzanne Débarbat, and Nha Il-Seong (Seoul, IAU Commission 41, 2004), 204 pp., ISBN 89-7141-656-4 (93440), hard cover, US$80.00, A4.

This is the *Proceedings* of an international conference held in Cheongju, Korea, in July 2002, and it contains many of the papers presented at the conference. Twenty-two of the twenty-nine papers given at the meeting and five of the poster papers are to be found between the covers of this volume. The conference was attended by representatives from twenty-one countries from which papers were given by eighteen.

Following introductory addresses, two commemorative lectures were given, and are published in the *Proceedings*, on "Korean observations of the supernova of AD 1604" by Richard Stephenson and "King Sejong's sundial, *Angbu Il-gui*" by Nha Il-Seong. Both papers are informative and lay a solid foundation for what may follow in the conference. The editors have divided the papers into the standard eight technical sections generally used for these types of Asian meetings; however the papers also appear to fall into 'factual' and 'speculative' categories. The former discuss the records of supernovae of AD1604 and AD1054, the location and condition of early astronomical instruments of the region, archives relating to the astronomical history of some countries, and the archives of modern photographic records (some 100,000 held by the CSIRO radio astronomy group). A good example of a speculative paper is Alex Gurshtein's "Relevant queries in respect of the archaic Chinese sky", where he suggests the gradual development of the Zodiac from the mythology of the sixth millennium BC.

There are two papers on recent astronomical instrumentation in the region. Alan Batten gives a history of the 72-inch Plaskett telescope in Victoria (Canada), where he summarizes its successes, modernization and rôle model for other instruments. Wayne Orchiston then "... discusses the design, observational programs and subsequent development of the Chris Cross [radio telescope at Fleurs, near Sydney, Australia], before focussing on the closure of the field station and preservation of the remaining elements of this historic radio telescope." The possibility of early Chinese observations of sun-grazing comets is the subject of a paper by Richard Strom in which he dismisses other suggestions for all but thirteen of the observations considered. The use of modern computer programs in reproducing and creating ancient star maps is an excellent blend of the old and the new, and Oh Gil-Sun's printouts of some old star charts are very well-depicted in his paper. The longest paper (just 12 pages), by Luisa Pigatto, relates the activities of the Jesuits in Peking during the seventeenth and eighteenth centuries and their rôle in reforming the Chinese calendar, more accurately determining the longitudes of major cities, updating ephemerides, and trying to introduce Catholicism into the country. There are about sixty colour photographs of the conference dispersed throughout the book.

I purposely wrote this review before I read the "Conference Summary" by Richard Strom, and this presents an excellent overview. Would I buy this book? Probably ... but I would strongly recommend it to the librarian of my institution.

John Perdrix

The European Scientist. Symposium on the Era and Work of Franz Xaver von Zach (1754–1832), edited by Lajos G. Balázs, Peter Brosche, Hilmar W. Duerbeck and Endre Zsoldos (Frankfurt am Main, Harri Deutsch), pp. 241 + [3], ISBN 3-8181-1748-5 (paperback), 19.80 Euros.

This delightful book is the proceedings of a symposium that was held in Budapest, Hungary, on 15-17 September 2004 to celebrate the 250th birthday of Franz Xaver von Zach. It is published in Dick and Duerbeck's invaluable Acta Historica Astronomiae series as Volume 24.

As might be expected given Zach's prominence in late eighteenth and early nineteenth century international astronomy, there are chapters on his contributions to astronomy (minor planets, transits of Venus, variable stars), his accomplishments in geodesy, his eventful four-year sojourn in England, his travels throughout Europe (when he "... weaved a web of personal relations to such eminent scientists as Volta, Laplace and Herschel.") and membership of scientific societies, his correspondence with Gauss and Amici, his involvement with the Bavarian Academy of Sciences, his scientific instruments, the three astronomical journals he launched (the contents of which are becoming available through the ADS), and his archival records (which Cunningham is systematic-ally publishing).

But *The European Scientist* ... does more than merely document the achievements of a notable astronomer, for it examines the astronomical 'scene' in Europe—and even Jesuit China—at this time, and also looks beyond astronomy. For example, there is a fascinating chapter on the role of the Piarist order in developing "the scientific way of thinking" in Hungary. The conference organizers should be commended for adopting this catholic approach (excuse the pun).

I found *The European Scientist* excellent value at just 19.80 Euros, and I recommend it as a good read.

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Empire and the Sun. Victorian Solar Eclipse Expeditions, by Alex Soojung-Kim Pang (Stanford, Stanford University Press), pp. [xiv] + 196, ISBN 0-8047-3926-9 (paperback), US$21:95; also available in cloth (US$55:00).

Mankind has long been fascinated by total solar eclipses, and even today there are avid amateur astronomers who are only too happy to brand themselves as 'eclipse-chasers'. However, the nineteenth century was the era *par excellence* of the scientific eclipse expeditions, before solar spectroscopy and later the coronagraph rendered such expensive and opportunistic scientific ventures largely—but not totally—obsolete.

As the subtitle suggests, Alex Pang's book is mainly about British solar eclipse expeditions that date to the second half of the nineteenth century. Some of these were private ventures, others were organised by the Royal Astronomical Society and/or the Royal Society, and towards the end of the century they were sponsored by the British Astronomical Association.

Although there are long chapters on "Planning Eclipse Expeditions", "The Experience of Fieldwork", "Drawing and Photographing the Corona" and "Astrophysics and Imperialism", this book is much more than a mere astronomical adventure. It also examines "... the rich interplay between science, culture and British imperial society ..." This is the reason that more than half of the 48 pages of Notes at the end of the book have nothing whatsoever to do with astronomy. For some this will be a distinct 'plus', but at times—and particularly when I was keen to indulge my passion for solar eclipses—I found it just a little frustrating. I also had trouble accepting RASMN *in lieu* of MNRAS (or simply MN).

Having said that, *Empire and the Sun* is a delightful book and is packed with lots of interesting astronomical information. I can thoroughly recommend it to those with an interest in nineteenth century astronomical history, astronomical expeditions or solar eclipses.

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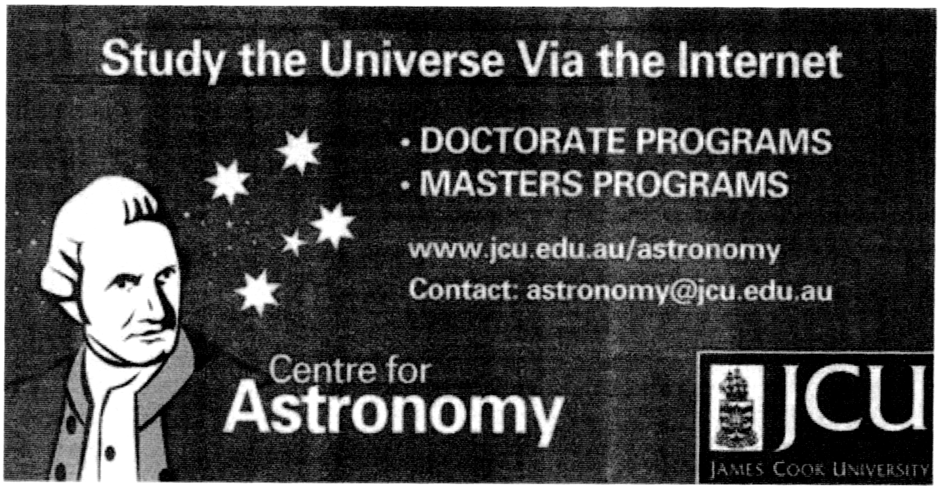

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