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The discovery of strong extragalactic polarization using the Parkes Radio Telescope

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Abstract
By the end of 1961, interferometry to arc-minute precision in the East-West direction had resolved the compact source at the centre of Centaurus A into two unequal components spaced about 5′ in right ascension and with measured widths. Were they on the dark bar of the associated extragalactic nebula, NGC 5128, and perhaps indications of a toroidal source, or were they in the perpendicular direction and on their way out to feed the extended radio source Centaurus A? The 6′.7 pencil beam of the Parkes Radio Telescope, employed in an unusual scanning mode, was capable of just separating the peaks and resolving the ambiguity in declination. In 1962 April, I carried out the first observations of linear polarization in Centaurus A using the Parkes antenna, and these were soon followed by other observations made by Brian Cooper and Marcus Price and then by Frank Gardner and John Whiteoak. Because the research papers reporting these pioneering observations were not published in chronological order and the dates of the observations and submission of the manuscripts are not mentioned in them there has been considerable confusion surrounding the discovery history of Centaurus A polarization at Parkes, and this has been compounded by a misleading contemporary newspaper report, uninformed folklore, and conflicting recollections printed 30 years after the event. This paper clarifies the situation by presenting a first-hand account of the original observations and associated publications.

Keywords: *Centaurus A, extragalactic nebulae, Parkes Radio Telescope, polarization*

1 INTRODUCTION

There was a time when astrophysicists did not feel the need for magnetic fields to account for celestial phenomena. Even solar physicists, despite the discovery of kilogauss fields in sunspots, did not call upon magnetic fields to interpret chromospheric and coronal structure. When Alfvén published his masterful *Cosmical Electrodynamics* in 1950 a new dimension was introduced into astrophysics, but there was still little inclination on the part of astronomers to embrace radiophysics, let alone radio engineering. By 1962, the year to which this paper refers, today's awareness of the pervasiveness of magnetic fields in the universe was not yet shared by textbooks. Traces of polarization had been detected in the light of stars, but this was explained optically by reflection and scattering of initially unpolarized radiation by interstellar dust.

By 1953 Ginzburg, Pikel'ner, and Shklovsky had separately studied the theory of how energetic electrons might be influenced by magnetic fields on a galactic scale, and arrived at the idea of synchrotron emission of radiation. The following year Dombrovsky and Vashakidze observed that the light of the Crab Nebula was polarized, just as Shklovsky had predicted, and the prediction was confirmed soon afterwards in the USA, France, and Holland. In 1955 Hanbury Brown, Palmer, and Thompson tried to detect radio-frequency polarization, and Westerhout was also unsuccessful in 1956. But in this same year, Mayer, McCullough, and Sloanaker used a meticulous observational technique that allowed the parallactic angle to vary as the Crab Nebula was tracked by the 15-m antenna at the Naval Research Laboratory (henceforth NRL) in Washington, and they found substantial plane polarization at a wavelength of 3.15 cm. By the following year they had installed a motorized rotatable feed horn in the antenna, and were able to convincingly establish the polarization at ~10%.

Taken together, the optical and radio observations supported the proposed synchrotron mechanism of magnetic field interaction and established, within a few years from the time of Alfvén's vision, that magnetic fields were present on a vast scale in the Galaxy; they would henceforth play an essential role in astrophysics.

The even vaster realm of extragalactic space was then addressed at the NRL with the excellent instrumental arrangements and careful calibration procedures developed for the pencil-beam observations of the Crab Nebula. During 1961 Cygnus A, which had previously been investigated without success, was re-observed with improved equipment and methodology and was found to have 8% polarization at 3.15 cm. Mayer *et al.* (1962a) submitted their report to the *Astrophysical Journal* on 1962 January 22, and it was published in March.

Meanwhile, in Australia, Twiss, Carter, and Little discovered something that was to influence the first use of the Parkes 64-m Radio Telescope for polarization measurement. Tracking with different sets of four-dish interferometers that formed part of the 21-cm Chris Cross at Fleurs with a view to improving on the signal-to-noise ratio obtainable from a simple scan, they noticed that by the time the spacing reached 464λ the compact source situated between the two extended lobes of Centaurus A had structure of its own. Extrapolating visibility amplitudes and phases out to 1000λ they found that two regions each 2′.5 wide spaced 5′ East-West would fit the interferometer data (Twiss *et al.*, 1960), and this was later proven to be about right. The declinations were not determined, but the right ascensions straddled the nominal RA position adopted.

I was present during the Fleurs observations, and by the time the paper by Twiss *et al.* was published one of the authors, Sydney radio astronomer Alec Little, was at Stanford completing an M.S. degree. By using his wide-band parametric amplifier at 9 cm (Little, 1961) to improve the sensitivity, we were able to make direct fan-beam scans of Centaurus A with the East-West arm of the Stanford cross (Bracewell and Swarup, 1961) and verify the interpretation reached by the Fleurs observers. With a baseline of 1255λ at 9.1 cm and an East-West beamwidth of 2′.3, a good profile was obtained, and a final manuscript on this work was presented at the 1961 May 15-20 Symposium on Radio Astronomy held at Green Bank and eventually published in *Proceedings of the National Academy of Science* (Little *et al.*, 1964). The preceding component of Centaurus A was found to be unresolved (width <1′) while the following component had a substantial width of 2′.6. The spacing in RA was 5′.1. Since it was not feasible to rotate all 16 feedhorns, these results referred only to East-West polarization.

Concurrently in 1960-1961 an ambitious programme of interferometry was under way at the Owens Valley Radio Observatory to observe 180 different sources. No doubt stimulated by the reports that Cygnus A, and now Centaurus A, were double, Moffet and Maltby (1961) reported that nine of their sources, including Centaurus A, fitted a model with two equal centres of emission. And by 1961 August 19 Maltby (1961) could report enough detail in declination for Centaurus A to challenge the earlier suggestion by Mills (1953) that the central source could be elongated along the dark bar that crossed NGC 5128. Maltby (op. cit.) showed two equal racetrack-shaped sources in position angle 46 ± 2°, each with an axis ratio of about 2:1, the long axes parallel to each other in position angle 17°. The awkwardness of tracking for four hours with a north-south interferometer aimed at the southern horizon must account both for the racetrack-type elongation and the two-fold rotational symmetry of the half-intensity contours (implying that a constant fringe phase was accepted). None of the shape parameters was later confirmed, but the spacing and orientation, roughly perpendicular to the dark bar, would prove to be correct.

A radiating toroid enclosing the dust lane and seen edge-on could give the appearance of two sources but would have to present a width less than 10″ to be compatible with the Stanford scan. This deduction was presented at the 1961 Greenbank Symposium by Little *et al.* (1964) and the 1961 June 18-21 meeting of the American Astronomical Society (Little and Bracewell, 1961) as a basis for preferring two more or less globular volumes on their way outward along a line perpendicular to the dark band to join the components of the extended source.

2. THE PARKES OBSERVATIONS OF 1962 APRIL

When I visited the Radiophysics Laboratory in Sydney early in 1962 I had a rough picture, based on the various Australian and US observations, of the layout of the central components of Centaurus A. I was also keenly aware of the handicaps of working with a southern source at 43° S from a northern latitude of 37°. A direct map with a pencil beam and controllable polarization would clarify the situation so I asked my old mentor and Chief of the Division of Radiophysics, Taffy Bowen, for observing time on the 64-m Parkes Radio Telescope.

This was granted,[1] and on 1962 April 14 I went up to Parkes to observe, but on the understanding (as was the practice at National Observatories in America) that technically I would be collaborating with one of the Radiophysics research staff, in this case Brian Cooper.[2] My three days of observations of Centaurus A at Parkes were on April 15, 16, and 17. The 10-cm receiver readied by Tom Cousins was in the receiver room at the time. The circumstances were not entirely favourable because the beamwidth of 6′.7 was not as good as the 2′.3 I had been working with at Stanford when two peaks were recorded with an East-West spacing of only 5′.1 (Figure 1). Before my arrival at Parkes, this 6′.7 beam had already been scanned over the central source but no structure had been seen. This is what you would expect when scanning at different declinations with a 6′.7 beam over point sources spaced 5′.1 in RA – you only get one peak on any one scan, even though there are two sources – but if you looked closely you would see the peak shifted a little bit in RA between scans. However, by scanning diagonally one could separate two sources disposed on a NE-SW line because they would be 7′ apart. No such separation would be noted for a NW-SE disposition. Diagonal scanning with both drive motors running was therefore employed with a view to being able to see double peaks on the record, and to be able to get right on to each peak by eye without relying on dead reckoning. Calibration errors of about one minute in dish pointing were expected at the time but the character of the errors was not known to me.

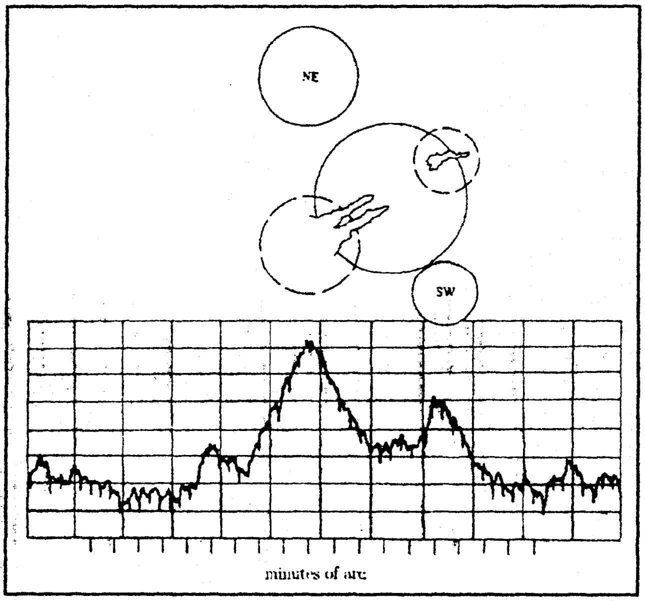

Figure 1. Stanford observations had shown that the NE and SW components of Centaurus A were unequal in size; the chart record, above, showing a single scan with a 2′.3 fan beam was made on 1961 March 14 (Little *et al.*, 1964). Observations at Parkes made with a 6′7 beam at 10 cm, undertaken to distinguish between the alternatives (full and dashed circles respectively), were successful. They established the NE-SW configuration, the one preferred in 1961 May (ibid., and Little and Bracewell, 1961). The alternative configuration is shown by two dashed circles lying on the dark belt in the same right ascension. At the same time, the unprecedented high degree of polarization of 15% was found in the NE component.

From the console I could drive the dish first downward from NE to SW, then stop the declination drive, wait a moment while the antenna continued westward, reverse the HA drive to take out the backlash, before restarting the declination going upward with both drives running and with a controlled shift in RA. The resulting scan pattern looked something like a set of hysteresis curves for iron and the peaks recorded were clearly seen to be quite unequal both in amplitude and diameter. This sort of manual mapping was repeated for four feed position angles spaced about 45°; maps for 115° and 25° were prepared for publication after 115° had been selected as giving maximum variation on the following source.

It was found that the NE component exhibited 15% plane polarization at a position angle of 115°, at that time an unprecedented degree of extragalactic polarization, while no polarization was noticed on the SW component (Figure 2). This was the first detection of linear polarization using the Parkes telescope, and although not world shattering perhaps, in view of the long history of astronomical polarization, it was memorable. The somewhat tricky observation established that the compact components were on the route leading to the outer extended lobes.

Immediately after I left Parkes, an American, Marcus Price, spent Easter weekend at the Radio Telescope, and his chatty account in *Serendipitous Discoveries in Radio Astronomy* (Price, 1983) exposes some of the trials and tribulations experienced by astronomy graduate students in those days and illustrates the workings of the Radiophysics 'hierarchy'. After installing the 21-cm receiver, Marcus found about 7% polarization in the emission from the two components which of course were not resolved in the 14′ beam, but he noted that "Poor old Ron got his feed angle wrong, because indeed at 21 centimeters the position angle of the linear polarization in Centaurus is exactly 90° different than it is at 11 centimeters." (Price, 1983:303). This discrepancy led to a comprehensive multi-wavelength programme (Cooper and Price, 1962) that would establish the existence of Faraday rotation and hence of magnetic fields within the Galaxy, as had been proposed by Alfvén in 1937.

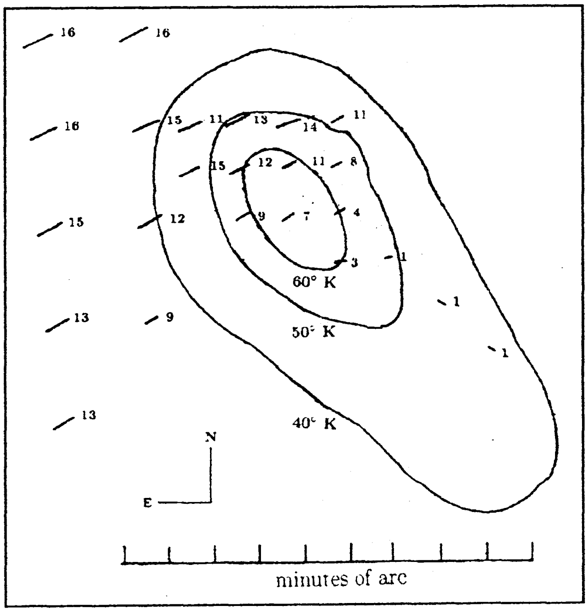

Figure 2. This data presentation from a preliminary draft gives an impression of the pencil-beam response to two components and shows some polarization directions and magnitudes.

Soon after Price's Easter adventure, Radiophysics staff members Frank Gardner and John Whiteoak exploited the 20-cm cooled parametric amplifier developed by Gardner and Milne, and quickly surveyed 15 sources for polarization, including several of the double sources previously reported by Moffet and Maltby (1961).

3 THE CONVOLUTED PUBLICATION SAGA

The telescope operators on my Parkes shift were George Henderson and L Fellows, who were mentioned in the manuscript draft that I wrote upon returning to Sydney, as was Tom Cousins. I listed the authors as myself and Brian Cooper, in accordance with my understanding with Taffy Bowen. Following the custom at Radiophysics, I handed the draft, including mention of permission to use the dish, to Bowen, and it came back with a page of his handwriting that superseded my introductory paragraph. I copied this out in a legible hand, added some extras, and gave it to the office for typing.[3] I will refer to this as Paper I, as it was the first written reporting observations of Centaurus A polarization using the Parkes Radio Telescope.

After returning to Stanford I received a letter from Brian Cooper saying that Mayer had observed some polarization in Centaurus A with the NRL's 15-m antenna, which I found impressive given that the centre of Centaurus A rises only 9° above the Washington horizon. I wrote to Connie Mayer on 1962 August 20, mentioned that my Parkes observations were about to appear in print, and included the precise optical position for NGC 5128 (13h 22m 31.6s ± 0.3, –42° 45′ ± 0.05, 1950) that I had circulated on 1962 May 21 and later published (see Little and Bracewell, 1966).[4]

Then I attended a meeting in Newhaven, Connecticut between 1962 August 26 and 29 at which Mayer reported polarization results for the Crab Nebula, Cygnus A, and Centaurus A. Six months had been devoted to the Crab and Cygnus A observations in 1961, as reported on 1962 January 22 (see Mayer *et al.*, 1962a), while the Centaurus polarization results were brand new. The Newhaven paper was published in 1962 November (Mayer *et al.*, 1962b). The NRL's developed observing technique was then applied to a series of other sources at wavelengths of 3.15, 3.47, and 9.45 cm, and the results were reported in the major paper of 1964 January (Mayer *et al.*, 1964) where Centaurus A was shown to exhibit 13.5% polarization at 3.15 cm and 7.2% at 9.45 cm. In none of these studies was the beamwidth narrow enough to resolve sources with double structure; hence the results refer to the composite source as a whole and not to the components.

Since the great Paris Symposium of 1958 it was usual for many of the world's radio astronomers to maintain close personal contact both through travel and correspondence, and not infrequently news from A reached B via a traveller from C who passed through both A and B. Presumably, this was how word of Mayer's Centaurus A polarization observations reached Sydney a week or two before the Newhaven conference.

While these US developments were in train I was eagerly anticipating the publication of my Parkes paper. Instead it was Gardner and Whiteoak's paper that first appeared in print, even though it was the third Centaurus A polarization study carried out at Parkes in 1962 and the third paper written (Paper III). This important paper (Gardner and Whiteoak, 1962), which exemplified the power of the new 64-m Radio Telescope, was received by *Physical Review Letters* on 1962 July 11, and was published in the September 1 issue.

Strangely, Cooper and Price's paper, reporting the second Centaurus A polarization study carried out at Parkes in 1962 (Paper II), was the second paper published, appearing in the September 15 issue of *Nature* (Cooper and Price, 1962). Two weeks later my own long-awaited paper finally appeared in the 1962 September 29 issue of *Nature,* with its figure of 15% polarization (Bracewell *et al*, 1962). Immediately I noticed that Tom Cousins had been promoted to co-authorship, and although this was irregular – in the sense of never happening to a paper I wrote before or since – it did not strike me as out of keeping with the hierarchical structure that I was familiar with after a dozen years or so at Radiophysics. Besides, Tom had made the crystal mixer that was used! What did surprise me though was a 'Note added in Proof' stating that C.H. Mayer had "... detected a similar degree of polarisation." at 3.15 cm. Clearly, submission or publication of our paper had been delayed for reasons that at the time were not apparent, notwithstanding the fact that the Australian Scientific Liaison Office in London used to read the proofs of papers submitted to *Nature* in order to minimize the delay. In a letter to me, co-author Brian Cooper (1962), said that he could not understand why the NRL result should have caused any delay, but Haynes *et al.* (1966: 251-252) later laid the blame squarely with John Bolton: "... Bolton, furious at this unscheduled use of the telescope, intervened to delay submission of the paper... [and] Bolton, ever the *éminence grise*, arranged that this paper should appear in *Nature* two weeks before the report of Bracewell's earlier observation."

If this is a realistic account of Bolton's role (and it is the only such mention that I have seen or heard), then it is ironic that Bolton should rate these observations so highly, for when asked what he considered was the greatest discovery made with the Parkes Radio Telescope, he immediately identified the occultation of 3C273, but was quick to add: "I would place, certainly on an equal footing, the discovery of polarisation in the extragalactic radio sources as one of the really fundamental discoveries." (see Bhathal, 1996: 113). The Parkes telescope saw 'first light' in 1961 October, was opened on 1961 October 31, and detected strong polarization on 1962 April 15. The occultation of 3C273, the first accredited quasar, was observed by Cyril Hazard, a visitor from the Physics Department at Sydney University, on 1962 August 5.

4 UNINFORMED FOLKLORE AND CONFLICTING RECOLLECTIONS

Obviously, the chronological reversal of the publication order of Papers I, II and III was a surprise to me but I thought the dates of observation and submission would speak for themselves. However, in 1996 I noticed that none of the papers included the dates of the observations; nor did the two papers published in *Nature* state the dates upon which they were received. As the discovery paper was the last of the three to appear in print, although written up and submitted promptly, there has been some confusion on the part of subsequent authors as to the true sequence of events. Yet the priority of the initial observations is clearly confirmed by the dates, and acknowledgments to Brian Cooper, Tom Cousins, Les Fellows, G. Henderson and Jim Roberts, recorded in the Parkes Visitor's Book. This was the first entry by a visiting observer in the Book, and it reads:

> 1962 April 14-18. I came as a guest investigator to study the central source of Centaurus A, which had been resolved into two components by Alec Little of the Radiophysics Laboratory. He used the 2'.6 fan beam of my aerial at Stanford, Calif. Centaurus A furnishes a wonderful opportunity for understanding the evolution of a radio galaxy. I measured polarization parameters over the field, finding a degree of polarization much higher than has been observed hitherto in galactic or extragalactic sources. It is a great privilege to use this magnificent

instrument and to have had the assistance of Geo. Henderson and L. Fellows, who drove the telescope, and Tom Cousins, who operated the 10 cm receiver. To Brian Cooper and Jim Roberts my thanks for advice and guidance.

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Undoubtedly, a contributory factor in this later confusion was an article that appeared in the *Sydney Morning Herald* on 1962 September 15, which reported that

> Two C.S.I.R.O. scientists, using the new radio-telescope at Parkes, have discovered what they believe is a possible clue to the origin of the universe. They have discovered the existence of magnetic fields in outer space... The two scientists who made the discovery are Mr Brian Cooper, of Sydney, and Mr Marcus Price, an American, both of C.S.I.R.O.'s Radio-physics Division ... The scientists discovered that radio waves were 'linearly polarised' – the electrical vibrations lay in a definite plane. When the scientists changed the frequencies on which they were receiving signals, they found the plane had rotated.

This article did not mention Paper I, which was about to appear in print, or even Paper III, which had already been published. On 1962 September 18 Alec Little sent me a clipping of the article knowing I would find it of interest, and in his accompanying letter noted: "Apparently your discovery is being turned to good advantage, but it is a pity that you didn't get a mention!"

With the passage of time and dimming of memories, even some of the authors of the 1962 papers have shared in the confusion. For example, John Whiteoak (1994:76), a co-author of Paper III, states in *Parkes. Thirty Years of Radio Astronomy*: "I am a little hazy as to what actually happened at Parkes, but the word filtered back to Sydney that, at some stage during the visit, Ron had rotated the feed system and found that the radio emission of the southern radio galaxy Centaurus-A was polarised ..." Likewise, Marcus Price, a co-author of Paper II, says in *Serendipitous Discoveries in Radio Astronomy*: "... the Australians, with help from an ex-patriot [*sic*], namely Ron Bracewell, were measuring and reporting the polarization of Centaurus A." (Price, 1983:302). Robertson's (1992:223) account in *Beyond Southern Skies. Radio Astronomy and the Parkes Telescope* says: "The Parkes observations by Ron Bracewell, Brian Cooper and Tom Cousins detected 13% polarisation at 10 cm from one of the two compact central sources of Centaurus A."

A more realistic account of the actual sequence of events has been published by Haynes *et al.* (1996:251):

> In April 1962, Brian Cooper and his technical officer, Tom Cousins, had just installed a 10-cm receiver and retired for a well-earned rest, when Ron Bracewell of Stanford University, Palo Alto, and a former staff member of the Radiophysics Laboratory, who happened to be visiting Parkes and who knew of the as-yet unpublished paper from Mayer's group, noticed that the new polarisation equipment was in place. Pointing the telescope to Centaurus A, he rotated the feed antenna and immediately found that the radiation from the source was indeed polarised. Describing his observations in the visitors' book, he quickly prepared a note to *Nature* with himself, Cooper and Cousins as authors ...

Yet this version reveals no awareness of the purpose of my visit to Parkes, or of the official scheduling by Bowen. However, it is right about who made the observations and prepared the manuscript of Paper I (even if the list of original authors is wrong).

5 CONCLUDING REMARKS

The first observations that resolved the two central components of Centaurus A while providing polarization readings were made with the Parkes Radio Telescopes at 10 cm between 1962 April 15 and 17. The 15-m NRL antenna never managed to resolve the central component of Centaurus A, nor did the Parkes observations reported in Papers II and III – and the polarizations reported were necessarily composite because the beamwidths exceeded the 7′ component separation.

Because the three different suites of observations that were made at Parkes in 1962 were not published in the logical chronological order and a contemporary newspaper report and later reminiscences have added further confusion, there has been considerable uncertainty surrounding the 1962 observations of Centaurus A, but this account documents the actual sequence of events.

The polarization studies of 1962 initiated a whole new research focus at Parkes, and in due course suitable receivers at short wavelengths enabled the 64-m Radio Telescope to return to fine-structure polarimetry, while the VLA and AT were designed from the start with polarimetry in mind. Further developments of the extra dimension added by polarimetry to both extragalactic and galactic studies continued in subsequent years, and are still under way, with more discoveries to come. Intergalactic Faraday rotation must exhibit a dependence on the cosine angle between the source direction and the direction of the Sun's velocity relative to the cosmic background radiation, an effect waiting to be convincingly discerned.

Looking back, it is hard to recall that astrophysics once did without magnetism, accelerated beams of high-energy particles, and, for that matter, radio waves.

6 ACKNOWLEDGEMENTS

I should like to thank Woody Sullivan (University of Washington, USA) for kindly providing a copy of the relevant page of the Parkes Visitors' Book, and Wayne Orchiston for comments that benefited the manuscript.

7 NOTES

1. I should mention that shortly before my observing run, Taffy Bowen kindly flew me up to the Parkes Radio Telescope to look around, and on the way home I was allowed to fly the plane over the Blue Mountains and to take a look at the Fleurs field station from a rather unusual angle.
2. As with many other novices who joined Radiophysics, I was turned over to Brian when I arrived in 1942, and he gave me things to do – such as making a speech-controlled pulse-width modulator for the E1210B magnetron (one of which had arrived from England), to see if we could communicate speech at 10 cm (see RP182, 1943 March). We set up a link between the National Standards Laboratory tower and Kensington Racecourse (where the University of New South Wales now stands) and although I thought this was a pretty exciting achievement Brian told me in 1996 April that in his opinion the speech quality was a little garbled. Another assignment was to characterize a specimen of the great 701A modulator tetrode, a magnificent bottle that is now a collector's item (see TI49/2, 1943 March). Yet another project related to a lighthouse triode that had arrived from the USA. This had been designed to operate in one coaxial line inside another, and by building it instead into a pair of cylindrical cavity resonators sharing a common plane wall it was induced to produce 70 mW at 21 cm (see RP261, 1945 September).
3. I still have these manuscript drafts and a carbon copy of the resulting typescript in my files.
4. It was needed for absolute purposes because of the minute-of-arc accuracy achieved, and has probably not been improved upon. The two radio components are at significantly different distances from the optical position (see Little and Bracewell, 1966).

8 REFERENCES

Bhathal, R., 1996. *Australian Astronomer.* Australian Academy of Science, Canberra.

Bracewell, R.N., Cooper, B.F.C. and Cousins, T.E., 1962. Polarisation in the central component of Centaurus A. *Nature*, **195**:1289-1290. [Paper I]

Bracewell, R.N., and Swarup, G., 1961. The Stanford microwave spectroheliograph antenna, a microsteradian pencil beam antenna. *Transactions IRE on Antennas and Propagation*, **AP-9**:59-67.

Cooper, B.F.C., 1962. Letter to R. Bracewell, dated September 19. Original in Bracewell Collection.

Cooper, B.F.C. and Price, R.M., 1962. Faraday rotation effects associated with the radio source Centaurus A. *Nature*, **195**:1084-1085. [Paper II]

Gardner, F.F. and Whiteoak, J.B. 1962. Polarisation of 20-cm wavelength radiation for radio sources. *Physical Review Letters*, **9**: 197-199. [Paper III]

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

Little, A.G., 1961. A wide band single diode parametric amplifier using filter techniques. *Proceedings of the Institution of Radio Engineers*, **49**:821-822.

Little, A.G., 1962. Letter to R. Bracewell, dated September 18. Original in Bracewell Collection.

Little A.G. and Bracewell, R.N., 1961. The central component of Centaurus A. *Astronomical Journal*, **66**:290-291.

Little, A.G. and Bracewell, R.N., 1966. The central component of Centaurus A. *Australian Journal of Physics*, **19**:421-426.

Little, A.G., Cudaback D.D. and Bracewell, R.N., 1964. Structure of the central component of Centaurus A. *Proceedings of the National Academy of Science*, **52**:690-691.

Maltby, P., 1961. Central component of the radio source Centaurus A. *Nature*, **191**:793-794.

Mayer, C.H., McCullough, T.P. and Sloanaker, R.M., 1962a. Evidence for polarized 3.15 cm radiation from the radio galaxy Cygnus A. *Astrophysical Journal*, **135**:656-658.

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

Mayer, C.H., McCullough T.P. and Sloanaker, R.M., 1964. Linear polarization of the centimeter radiation of discrete sources. *Astrophysical Journal*, **139**:248-268.

Mills, B.Y., 1953. The radio brightness distributions over four discrete sources of cosmic noise. *Australian Journal of Physics*, **6**:452-470.

Moffet, A.T. and P. Maltby, 1961. Distribution of brightness in extragalactic radio sources. *Nature*, **191**:453-454.

Price, M., 1983. The first years at Parkes. In K. Kellermann and B. Sheets (eds.) *Serendipitous Discoveries in Radio Astronomy*. National Radio Astronomy Observatory, Green Bank. Pp. 300-306.

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

Twiss, R.Q., Carter, A.W.L. and Little, A.G., 1960. Brightness distribution over some strong radio sources at 1427 Mc/s. *The Observatory*, **80**:153-159.

Whiteoak, J., 1994. Early polarisation research at Parkes. In D.E. Goddard and D.K. Milne (eds.). *Parkes. Thirty Years of Radio Astronomy*. CSIRO Publishing, Melbourne. Pp. 75-80.

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