NRAO ONLINE 47

1961-2- Completion of the Giant Radio Telescope, 31 October 1961 Opening of the Parkes Telescope, Early Operation

Epigraph: W.F. Evans History of the Radiophysics Advisory Board (1970), p 231 on the Parkes telescope

> Sited as it is in the heart of New South Wales grazing country, this magnificent scientific instrument emerged to become, not only the envy of many research groups all over the world, but also an enduring source of pride to Australians from farm and factory alike. In a subtle way, it had constituted a visible symbol of Australia's intellectual "coming of age". It finally shattered the outworn image of the broad-hatted sheep-grazing Australian, which thoughtful Australians had been trying unsuccessfully to blur for some time.

Planning the first months of the GRT- the Parkes Telescope [1]

As 1961 began, John Bolton re-joined CSIRO in early January. On 24 February 1961, a meeting of the 210-foot Radio Telescope Committee (aka the GRT) was held with Bowen (chair), Minnett (secretary), Pawsey, Beard, Higgs, Bolton, Cooper, Day, Mathewson, McCready and McGee.[2] Pawsey had prepared a document two days earlier that set out a plan of action for the GRT; the construction was expected to be completed by August 1961. Pawsey described Phase 1 tests of the new aerial, consisting of determinations of the shape of the dish, pointing accuracy as a function of position, wind and temperature. An example was the determination of the "… directional patterns at various polarisations to access dish accuracy, the determination of the radio axis of the dish … The measurements will require a series of radio sources of known positions distributed over the coverage of the telescope."

The 22 February 1961 document described Phase 2: initial observations with existing receivers at 20 and 75 cm in the continuum and at 21 cm for the hydrogen line (HI). The major continuum research programmes proposed by Bolton were discussed: positions and spectra of 400 catalogued sources at 75 and 20 cm with the goal of optical identifications. Frank Kerr was to start galactic HI observations, concentrating on the galactic centre, while Dick McGee was to start a 21 cm line survey of both Clouds of Magellan. The planning for a promising programme of planetary research (Jupiter, Venus and Saturn) was to await the return during the next month of Jim Roberts from Caltech.

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[1] In 1955, the formal proposal was titled "A Proposal for a Giant Radio Telescope". But during 1961, the GRT name disappeared. At the opening on 31 October 1961 the official programme was titled "Inauguration of the Australian National Radio Astronomy Observatory and the Commissioning of the 210 Ft Radio Telescope". Soon the term "Parkes radio telescope" was in common use. In 2020 the common name is "Parkes Observatory".

[2] NAA, C3830, A1/1/7.

At the meeting of 24 February 1961, the status of GRT construction was described: "The access tower on the turret has been erected and all welding work on the turret and hub is complete … all the ribs have been bolted together in groups and painted ready for erection. The spiral purlins have been bent to shape and are being painted … It is now reported from London (by Frank Kerr) that the control desk (Askania) may be shipped on 15 March 1961- two weeks earlier than previously expected."

In the section concerning new spectroscopy, HI observations of external galaxies by Brian Robinson using the "Leiden receiver" (21 cm parametric amplifier) were discussed along with "high order 21 cm spectral lines", clearly the H 158α hydrogen recombination lines of ionized hydrogen from HII regions, a project of John Murray. [3]

In phase 2, John Bolton had prepared an observing scheme that occupied three months, planned to begin 1 October, 1961: (1) Jupiter observations of the intensity and polarisation at 10, 20 and 75 cm for three days, (2) "First radio star finding programme" (in 1961 Bolton still used the old terminology of "radio star") for 10 days, (3) Continuum and HI line survey of the Magellanic Clouds for 20 days, (4) Selected regions at right ascension 03 to 05 hours and declinations -20 to -35 degrees (the northern declination limit of the GRT was +27 degrees).

A discussion followed on the topic "operating arrangements at Parkes" with two possible models: (1) the users themselves would operate the telescope or (2) telescope "controllers" or operators would be present.

The minutes of the meeting continued:

(1) Bolton proposed that, in the initial stages, responsibility for operating the telescope should be taken by the small group of people who would become familiar with the instrument during the commissioning period. For the longer term, these people would train and "license" other suitable members of the research staff. Thus a typical research team might consist of a Research Officer, Experimental Officer and Technical Assistant, and they would operate the telescope during the 12-hour observing period on a rostered basis.
(2) The other scheme is that a number of men should be recruited and trained for the special job of operating the telescope. One of these "controllers"[4] would be attached to the observing team and would carry out the movements required by the observer in charge. The safety of the telescope would be the responsibility of the "controller". This system provides continuity of operating skill and safety procedure, whatever the observing team composition.

[3] Apparently, Murray's proposed observations were never carried out.
[4] A term used at Jodrell Bank; the word never caught on at Parkes.

> The first scheme has been used successfully with the somewhat simpler control system of the Caltech radio telescopes [at Owens Valley Radio Observatory]. The second is similar to that used at Jodrell Bank, and Dr Mathewson reported that the skill of the operators there allowed the astronomer to concentrate on the observations. Dr Bowen said this relation was similar to that between pilot and scientist in rain-physics experimental flights. The scheme finally adopted might well combine some of the features from each proposal[5].

The next meeting of the radio astronomy group (organised again by Pawsey) occurred on 10 March 1961 with the title "Radio Astronomy Group to Discuss (1) Technical Manpower Questions and (2) Technical Liaison in Laboratory". At this time, two groups from Fleurs were present: (1) the compound interferometer group of Krishnan, Harting, Payten and Palmer using the 60-foot Kennedy antenna with the Chris Cross, and (2) the radio link interferometer group of Peter Scheuer (visitor from the Cavendish Laboratory), Bruce Slee, Higgins and Fryar using the Mills Cross at Fleurs as the main element at 85.5 MHz. A major decision at this time was the setting of a firm time scale for the GRT receivers, e.g. the 75 receiver was to be ready by 1 September 1961.

Progress with the GRT construction -1961

On 15 February 1961, Bowen wrote White with a comprehensive report of the GRT status. A major problem was in the erroneous calculation of the desired amount of counterweight for the GRT.

> FFP have been secretive about it, but final instructions have now been given and the counterweight material is going in. When this is completed, the ribs, which were finished some time ago, can be lifted into place. [The amount of counterweight would remain a problem well into 1962.] There has been further fiddling around with the mesh panels ... Roberts has always been petulant and a bit shy about this one, and this is … having its effect on the fabrication.[6]

The main problem was with Askania and the ME (Master Equatorial) and the control desk; the delays were to extend for at least two months.[7]

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[5] The scheme finally adopted was a variation on proposal 1, with a member of the technical or maintenance personnel who became the "telescope driver" at night or during the weekend.

[6] In spite of the rapid progress made with the construction, Gilbert Roberts of FFP continued to irritate Bowen in 1961.

[7] NAA C3830 Z1/14/A Part 2. Also, Bowen told White that he hoped that Casey, Walter Bassett and himself could visit Parkes in mid-March 1961; the visit did occur on 13 March 1961, almost exactly a year after the visit described in ESM_30.2 and NRAO ONLINE 46. The 1961 visit is described in Chapter 31.

On 19 April 1961, Bowen provided a detailed update to Robert Morison, Director of Medical and Natural Sciences, Rockefeller Foundation on the status of the GRT[8]. This Foundation was the most recent and largest of the overseas benefactors.

> The erection of the structure on the site at Parkes has been progressing steadily for the past eight or nine months and a few days ago the last rib was lifted into place on the dish …The remaining structural work will be completed about mid-June and the electrical control gear shortly afterwards. Some of the precision components are … behind schedule but these should allow completion of the device in July or early August [too optimistic by two to three months]. For this [time scale] we have to thank the excellence of our contractors, the MAN Company, and our design engineers, Freeman, Fox and Partners.

Bowen then described the interest shown by US agencies in the progress of the GRT: NASA, Office of Naval Research and the Air Force's Lincoln Laboratory of the Massachusetts Institute of Technology. They were interested in the scientific use of a southern hemisphere instrument but "I suspect they are interested more … in the refinements which have been built into the device and in the economy with which it has been constructed … [W]e are anxious to give them all the assistance we can in return for the generous help we have always received from our friends in the USA".

Finally, the question of "open skies" was raised by Bowen in the letter to the Rockefeller Foundation; as had occurred earlier[9], the issue of "repayment of the debt" of the overseas support from the two US foundations for the GRT. "[W]e have informal requests from around a dozen radio astronomers [from around the world] for permission to work with us on the telescope … This makes us exceedingly happy and it is one of our objectives to throw the instrument open to any competent astronomer who has a worthwhile problem to tackle."[10]

CSIRO paid only lip-service to this commitment until 1988, when the Parkes radio telescope and the newly completed Australia Telescope Compact Array where combined into a single National Facility. These instruments were open to the best scientific proposals from all over the world. Prior to this period the facilities were operated by CSIRO for its own scientific staff. While collaboration with outside users was encouraged, there was no open access process. In the modern era, this "open skies policy" is supported by the international

[8] NAA, C3830, A1/3/11/3, Part 5. The first Rockefeller grant had been made in December 1955 followed by the second grant in December 1959.

[9] Discussed in 1955 by Bowen in correspondence with the Rockefeller Foundation.

[10] NAA C3830 Z1/14/A Part 2. In a letter to Sir Walter Bassett on 19 April 1961 (after the visit of the previous month), Bowen was proud of their achievements: "On the whole we seem to have a powerful combination of British design, German fabrication and Australian get up and go." Bowen also mentioned, as he had to the Rockefeller Foundation, the desirability of an "open skies" policy with respect to overseas visiting observers.

community of astronomers. Thus there is a sharing of facilities, providing all Australians with reciprocal access to many observational facilities worldwide.

On 16 November 1961, Bowen wrote Morison again with news of the opening of the 210 -foot telescope on 31 October 1961, including a number of photographs. Morison replied on 15 December 1961[11]:

> In light of our experience here, it is simply fantastic the way you have succeeded in meeting all of the specifications in the allotted time. *The New York Times* [see below- 5 December 1961] carried a very good story during the week of our Trustees' Meeting, and several of the Trustees commented with satisfaction on the modest part the Foundation played in making the project a success. The comments of some of those who know something about our American efforts in the same field were, I'm afraid, mingled with a certain degree of embarrassment. Please accept our warmest congratulations to you and the entire group that worked with you.

In April-May 1961, Bowen had an exchange of letters with Merle Tuve[12] concerning the Carnegie Corporation of New York grant. He had given an up to date report to the Carnegie Corporation of New York (Stephen Stackpole); the Corporation had provided the first overseas funds in 1954 that provided the essential kick-start to the GRT. "It has been a long haul and we are happy to see this phase of it drawing to a close. We would never have got so far without the encouragement and continued interest of our friends overseas."

On 20 July 1961[13], Pawsey sent a memo to all "Research Officers and Experimental Officers in Radio Astronomy Group" at RP. This was just before he departed on 26 July 1961 for his visit to the US and Europe for the IAU in Berkeley in August 1961 (Chapter 38), returning only just before the opening of the GRT at the end of October 1961[14]. Pawsey wrote:

> Last October (colloquium 4 October 1960) when arrangements for operating the Parkes radio telescope were discussed it was stated that there would be three basic sections in the radio astronomy group: GRT, Solar and Receivers under Bolton, Wild and Cooper, respectively. The time has now come to implement this arrangement and I now wish to allocate responsibility as shown on the attached page [an organogram].

[11] *ibid*
[12] NAA C3830 Z1/14/A Part 2. Tuve was a member of the scientific staff of the Carnegie Institution of Washington.
[13] NAA C3830 A1/1/1 Part 14
[14] On 19 July 1961, White and Bowen exchanged letters about Pawsey's reluctance to be present for the opening of the GRT in late October 1961. Pawsey was anxious to be present at this time in London for the presentation of the Hughes Medal of the Royal Society. He wrote to White on 21 July 1961, agreeing to be at the opening. As we discuss in Chapter 40, Fred Hoyle presented the Hughes Medal to Pawsey in November 1962 just before his death on 30 November 1962.

> As I stated last October I wish free interchange between observing and technical groups and, as a receiver, for example is completed, the appropriate individuals should transfer to Parkes. Such transfers should normally be arranged between heads of section. [15]
>
> I should also like to take this opportunity of informing you that Bolton and Wild have been promoted to the grade of Chief Research Officer. CRO's who are not actually Chiefs of Divisions are very rare in CSIRO and we heartily congratulate them on this recognition of their work.

On 23 November 1961, about a month after the GRT opening on 31 October 1961, the radio astronomy group had a meeting organised by Pawsey to discuss plans for the next months. Bolton began with a summary of the status of the GRT. A major point of the discussion was the status of the receivers for the telescope. Other groups at RP gave their reports, including Paul Wild on the "design study for equipment for metre-wavelength pictures of the sun" (the future Culgoora Radioheliograph). Scheuer and Slee reported on their 85.5 MHz long baseline interferometry plans. This was a survey initiated by Mills and Scheuer to settle the remaining disagreement between Sydney and Cambridge on the effect of source angular size on the source counts[16] – see further discussion in Chapters 35-36.

On 19 December 1961, a thoughtful report on the GRT appeared in the US newspaper *The Christian Science Monitor* written by Albert E. Norman. He provided an update on the radio telescope located

> within 15 miles of this quiet rural town [Parkes] where sheep graze among wheatfields … The Australian telescope has the advantage of being located on the level plain of the Goobang Valley, a region free from industrial radio "noise" generated by factory machinery and where temperature variations are not generally great.

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[15] Pawsey informed the staff that during Paul Wild's absence (at the IAU) Kevin Sheridan would be his deputy; Bolton was to coordinate the Parkes, receivers and data processing groups. The Parkes group included Bolton, Kerr, Roberts, Mathewson, Hill and McGee. The receiver group consisted of Cooper, Gardiner, Robinson, van Damme, Gruner and Mackey.

[16] About a 1000 radio sources were observed in the southern sky; the baselines ranged from 6 km to 32 km providing partial angular size information in the range to 3.5 arc min to 20 arc sec. A preliminary publication appeared in the 1993 issue of *Proceedings of the Institution of Radio Engineers Australia*, edited by Pawsey. "Apparatus for Investigating the Angular Structure of Radio Sources" by Scheuer, Slee and Fryar. P 185, vol 24 but the main survey results were never published.

Norman described the 1945-46 pioneering solar research of Pawsey and the discovery of "radio stars" by the CSIRO group of Bolton and Stanley in 1946 at Dover Heights. (A picture of Bolton at the new GRT was included, with no identification.)

> It was international admiration of the pioneering work of Australian astronomers in this field under the leadership of Dr. Edward G. Bowen … that lead the Carnegie Corporation to offer $250,000 toward an Australian radiotelescope. This was followed by donation of a similar sum from the Rockefeller Foundation and the balance needed to provide the $2 million came from private Australian donors [sic] and the Australian Government.

The precedence of the Jodrell Bank radio telescope was emphasised: "The Australian telescope owes a good deal to the British one since discoveries made after the instrument was begun revealed directions in which the Australian telescope would need to be improved if it was to exceed the performance of its British partner, the only two in the world of this type of such giant size." The article also foreshadowed an important contribution the GRT would play with the next decade in the Apollo programme of NASA: "It is expected that Australia's debt of gratitude for the very generous American gifts will be a little repaid when the United States begins launching a truly deep space probe such as the projected moon shot."[17]

This return to NASA was soon to be realised. Following the commissioning, Parkes was used in the Mariner space tracking mission as an extension of the NASA contract to use Parkes as part of the design study of NASA's deep space network of 64-metre antennas. Then, in the late 1960s, CSIRO agreed that the Parkes dish be used to support the Apollo mission. Most of the televised video of the first moon landing (Apollo 11 in July 1969), including Armstrong's and Aldrin's walk, was received by the Parkes telescope. At the time of the ill-fated Apollo 13 mission in April 1970, the Parkes played a role in the post-accident telemetry with the astronauts. Further contracts with NASA and later with ESA provided Parkes a significant role in the Voyager II, Giotto and Galileo space missions.

The complex interactions between FFP and NASA are described in Additional Note 1: "NASA and Freeman, Fox Partners Negotiations 1962".

31 October 1961- Opening of the Parkes Radio Telescope

[17] The *New York Times* article of 5 December by Harold M. Schmeck, Jr. was a brief account that appeared before *The Christian Science Monitor* report, "The only larger instrument of its kind in the world is the 240 [sic]-foot dish at Jodrell Bank in Britain. Nothing in the Southern Hemisphere approaches the Parkes telescope in size. Specialists believe that its design, more refined in important respects than that at Jodrell Bank, should give the Australian radio telescope capabilities unequaled, at present, anywhere in the world."

The opening of the telescope has been described in detail in Chapter 32 (main book) with a number of images (Fig. 32.1 to Fig. 32.11).   Here we show two additional images (Fig 2 and 3) and two repeated images (Fig. 1, Fig.4 and Fig. 5).

1962- First Full year of the Parkes Radio Telescope

As 1962 arrived, Bowen was honoured in the New Years' Honours' list: CBE, Commander of the British Empire. On 2 January 1962[18], Ralph Freeman (also a CBE) wrote a letter of congratulations and thanked Bowen for pictures of the opening at Parkes from 31 October 1961. The Parkes telescope was still having teething troubles, but progress was reported with the Master Equatorial (ME). Bowen gave White a thorough report of the status of the telescope on 2 February 1962; he had been on a visit to the US, Canada, Chile and London (January to March, 1962)[19]: The Bowen to White letter read:

> Many thanks for your nice note about the CBE. It feels good to be raised to these giddy heights.
>
> The NASA Grant is as good as fixed, but I will send you a cable when it is fixed. [The grant was to use the Parkes telescope as a test bed for the new 64 m NASA Deep Space Tracking instrument. Harry Minnett was at JPL in Pasadena from 15 to 28 February 1962 for discussions.][20] The Grant could easily have been for double that amount of money in the first year….. Our [Australian] stocks are certainly high at the moment. Poor old Rabi [President of AUI] is getting desperate about the 140 footer at Green Bank. They have spent $7M and expect to spend another $6M on the redesign…. Money is being poured into scientific work [in the US]- good and bad- as never before. The standard offer [yearly salary] for boys like Harry Minnett and Paul Wild is $15,000 and $20,000 per annum, and for the likes of you and I [sic], $30,000 and up. It is hard to believe, but true. You will probably have to talk hard to Bob Menzies [Prime Minister] and his boys about this or else the losses from the ranks are going to be heavy.[21]

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18 NAA C3830 Z1/14/A Part 2
19 NAA C3830 Z1/9 1962
20 Bolton (1994) has provided a three page summary of the Parkes role "Parkes and the Apollo Missions: (in the book by DE Goddard and DK Milne *Parkes: Thirty Years of Radio Astronomy*, page 134
21 On 2 February 1962, Bowen also described to White the status of the Ford Foundation request for funds for the "Paul Wild solar instrument". On 25 January 1962, Bowen had met Borgmann (a friend of Pawsey's, Chapter 38 and 40) and lunched with John McCloy (Assistant Secretary of War in WWII, High Commissioner for Germany in the post war, chair of the Ford Foundation, 1958-1965) as he continued the lobbying for the new Australian initiative. Bowen was optimistic that CSIRO would come in "for a half share. If we are lucky and tread the primrose path carefully enough, they may go the whole way." A major concern was the worry that the Foundation had to "resolve ... how the

A few months later (16 April 1962), Bowen again wrote White with a more detailed report about the scientific achievements of the Parkes telescope[22]:

> The telescope is performing like a dream and it is clear that, except for some of the Askania components, the performance is even better than we expected a few months ago. The research programme is running on a regular basis from about 6 pm to 4 am every night, most of the receivers and telescope maintenance being done during the day.
>
> The morale of the troops is sky high, which is in marked contrast to a year or so ago. They are all clamouring to get their programmes on the dish and this is being done in a very orderly fashion. [Bowen enclosed a summary of the programmes.]
>
> … [A] quick survey of the Magellanic region on 408 MHz is also attached. This was taken by Mathewson and Healy ... and illustrates the wonderful detail which shows up even on this low frequency. [Bowen asserted that the quality was much better than the old 3.5 metre observations with the original Mills Cross, with comparable resolution of 50 arc min.] Mathewson now has similar plots on 20 cm [15 arc min] and will shortly have them at 10 cm [8 arc min resolution]. It is really wonderful stuff.

On 27 February 1962[23], Bolton wrote to Bowen with a detailed report of the status at Parkes. Major problems with the power supply of the ME had been temporarily fixed by a new power supply suggested by John Shimmins of the RP staff at Parkes. The deformation of the dish from zenith to the 60 deg zenith angle limit (of the dish motion) was quite favourable with only 2 arc min pointing changes and a slight loss of gain (less than 20 per cent) at large zenith angles at 10 cm. Herr Putz from MAN was back installing the 20 tons of missing counterweight. The stability of the tracking was remarkable, about 7 arc sec. Additional good news was that total of eight of the "galactic group" were learning to drive the telescope (e.g. Frank Kerr, Jim Roberts, Don Mathewson and Dick McGee).

On 2 March 1962[24], Bowen wrote White a long letter from London with more news about the status of the joint project with JPL for a detailed evaluation of the new Parkes telescope as it related to planned NASA tracking instruments. As Hanbury-Brown, Minnett and White wrote in 1992 (*Biographical Memoirs of Fellows of the Royal Society*, vol 9, p 42):

[CSIRO project] relates to their other activities in the social and medical sciences which the Foundation had favoured so much in the past." Later in 1962 RP was successful (Chapters 38 and 40) as the Ford Foundation provided US $630,000 for the solar instrument. Pawsey had also played a major role in the negotiations with the Ford Foundation. Finally, in the letter Bowen also described giving a lecture at MIT to an audience of 1000 people on the topic of the new Parkes telescope.

[22] NAA C3830 Z1/7/B Part 2
[23] *Ibid*
[24] *Ibid*

> The Parkes Telescope also proved timely for the US space programme. Bowen received a NASA grant for Minnett to participate in studies at the Jet Propulsion Laboratory … for the design of a 210 ft instrument [in the end three of these were constructed] for communicating with very distant space probes. Many of the Parkes features, including the drive and control concepts, were adopted.

Minnett had two visits to Pasadena in 1962 as a consultant. "NASA was greatly impressed by the performance achieved in the Parkes radio telescope, compared with any US design … One aspect of the contract [with JPL] was the supply of engineering data to NASA on the performance of the Parkes antenna." (Thomas and Robinson, 2005, Minnet obituary in *Historical Records of Australian Science*, vol 16, p 199)

<u>Parkes Telescope Scientific Programmes, 1962</u>

As the new GRT began operation in 1962, the scientific programmes can be categorised in two groups: Projects that were anticipated based on the telescope specifications which had been achieved, and (2) a small but significant number of projects that had not been anticipated but arose unexpectedly due to unanticipated discoveries.

First, we will examine anticipated science. Immediately the new telescope made significant contributions due to advanced planning of the scientific staff throughout the 1950s. In 1962 the staff possessed a telescope that was easy to use and even surpassed many of the design specifications.

<u>Planned Observations</u>

As we have discussed in Chapter 29 (see NRAO ONLINE 45), Pawsey had summarised the types of observations to be done with the GRT in 1959:

> These observations will include hydrogen line observations of external galaxies and selected galactic objects, continuum surveys of the sky with special reference to discrete sources at about 10 and 20 cm and less exacting continuum surveys at longer (50 and 100 cm) wavelengths. In addition, observations concerned with items of current interest, e.g. polarisation, will form an important part of the programme which cannot well be predicted.

The polarisation observations produced immediate successes. Polarised radio emission had been detected in the Crab nebula in 1957[25] following the predictions of the new synchrotron radiation theory. In 1960 Pawsey had written[26]:

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[25] Mayer, C.H., McCullough, T.P. & Sloanaker, R.M. (1957), *Astrophys. J*, 126, 468

[26] Pawsey, J. L. and Harting, E. (1960). "An attempt to detect linear polarization in the galactic background radiation at 215 mc/s." *Australian Journal of Physics* 13, no. 4: 740-742.

> Current theories of the mode of origin of galactic radio-frequency radiation assume the main components to be due to "synchrotron" emission by relativistic electrons in interstellar magnetic fields. Such emission is almost completely linearly polarised at the point of origin. The received radiation could, however, be substantially depolarised owing to its origin in extended regions of inhomogeneous magnetic fields, or to effects associated with the rotation of the plane of polarisation in ionised regions with magnetic fields along the line of sight. The detection polarisation is a most important observation, which could substantiate the synchrotron emission hypothesis and provide direct evidence on magnetic fields in interstellar space.

The Parkes telescope was a circularly symmetric dish with the receiver mounted on-axis at the focus on a rotating platform. Thus measurements of polarisation were straight forward with minimal instrumental polarisation. During Easter 1962 Ron Bracewell, while visiting Sydney University on sabbatical leave from Stanford in California, observed the strong radio galaxy Centaurus A. He detected strong polarised signals at 20 cm immediately.[27] Mark Price, a Fulbright student from the US, based at Parkes at the time, has provided a lively account of this unexpected sequence of events[28]. The detection of linear polarisation in Centaurus A was rapidly followed by the first observation of Faraday rotation at radio wavelengths. Again, the ease of changing the observing frequency with the single dish was decisive. Frater, Goss and Wendt (2017, *Four Pillars of Radio Astronomy: Mills, Christiansen, Wild, Bracewell*, p. 142-143) have described the controversial role played by Bowen in the publication of these two papers in *Nature* later in 1962[29]. The wavelength squared dependence of the position angle of polarisation was easily detected in Centaurus A[30] and other sources[31]. One of Pawsey's key science drivers for the Parkes telescope had been the measurement of polarisation and the extension of these measurements to higher frequencies. This direct observation of Faraday rotation in Centaurus A was made in the months just before Pawsey died in late November 1962 (see Chapter 40) Pawsey told a number of colleagues at RPL that he was particularly proud of this major achievement at Parkes. In addition, Pawsey wrote to both G. Tape (5 September 1962) and I.I. Rabi (25 September 1962) of Associated Universities in the US (see Chapter 40) about his excitement. To Rabi he wrote (exactly two months before his death):

> [The new data from Parkes] seem to be almost certainly due to Faraday rotation in an ionised interstellar region between us and [Centaurus A] … The plane of polarisation rotates with changing frequency in the precise manner which would be

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[27] Bracewell, R.N., Cooper, B.F.C. & Cousins, T.E. (1962), *Nature* 195, 1289
[28] Price, M. (2012). In: *Parkes @ 50 Years Young*, eprint arXiv:1210.0986
[29] Also NRAO ONLINE 2 for the roe played by Bowen in delaying the Bracewell et al publication in *Nature*
[30] Cooper, B.F.G. & Price, R.M. (1962), *Nature* 195, 1084
[31] Gardner, F.F. & Whiteoak, J.B. (1963), *Nature* 197, 1162

> expected from passage of a wave through an ionised medium containing a magnetic field … This effect gives the first real chance of measuring magnetic fields in interstellar space, which I think is an overwhelmingly important objective in astronomy … This is one of the very good examples of a subject which requires study from both northern and southern hemispheres, so that work undertaken at Green Bank could be indeed complementary to that which is being done here.

By 1962 linear polarisation from Cygnus A had been detected[32] and polarisation had at last been measured in the Galactic plane[33]. This field of research prospered and was expanding rapidly. Parkes now dominated observations of polarisation and Faraday rotation in many different classes of radio sources: radio galaxies, diffuse Galactic emission, supernova remnants, pulsars, spectral lines, and the Galactic Faraday rotation. Whiteoak and Milne both provide excellent reviews of these early Parkes polarisation observations[34].

The radio continuum surveys were another, well planned and executed programme for which the Parkes telescope was ideally suited. A team now led by John Bolton was able to produce a catalogue of about 2000 southern sources. This was a low frequency survey compiled from 408-MHz scan records, but with sources confirmed or rejected by scans at 1410 MHz where the resolution and positional accuracy were superior. The source list resulting from the 408-MHz survey became the first version of the highly respected *Parkes Catalogue of Radio Sources*. The survey was published in four papers between 1964 and 1966 and a convenient version of the combined catalogue was put together by Jennifer Ekers (1969)[35].

The combination of the low frequency survey and higher frequency follow-up made it difficult to assign a finding frequency to this survey – effectively a frequency between 408 and 1410 MHz. Thus the surveys were not suited for statistical or cosmological studies ... However, the process had a fortunate side effect. A large number of previously unknown flat or inverted-spectrum sources were detected; these had been missed at low frequencies. A new industry of investigating different populations of extragalactic radio sources[36] was opened.

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[32] Mayer, C.H., McCullough, T.P. & Sloanaker, R.M. (1962), *Astron. J.*, 67, 581A
[33] Wielebinski, R. & Shakeshaft, J.R. (1962), *Nature* 195, 982
[34] *Parkes 30 Years of Radio Astronomy* (1994), Ed DE Goddard and DK Milne, CSIRO Australia has contributions from many of the key players who were still alive and provide lively first-hand discussions of the commissioning and early science results.
[35] Ekers, J ed. (1969) The Parkes Catalogue of Radio Sources Declination Zone +20˚ to -90˚, compiled by the Staff of the Division of Radiophysics, CSIRO. *Aust J. Phys. Astrophys.. Suppl. No* 7
[36] Wall, J and Savage, A. (1994) *Parkes 30 Years of Radio Astronomy* (1994), Ed DE Goddard and DK Milne, CSIRO Australia

The discovery of the peaked spectrum source PKS1934-63 highlights the unexpected value of the move to a higher frequency. This object was the first of the class of Gigahertz Peaked Spectra radio sources and provided the evidence for the synchrotron self-absorption model of radio sources[37]. This particular source became the primary calibrator for most Southern Hemisphere radio telescopes; with its inverted spectrum the radio source was too weak at low frequencies to have been included in previous catalogues such as the Mills, Slee and Hills survey at 85.5 MHz.

Another development, which had been planned by John Bolton, was the interferometer using the 60-foot Fleurs dish as one element along with the 210 foot telescope. Bolton was aware of the resolution limitations of the single dish and wanted to continue the highly successful projects using the two 90-foot dishes at Owen's Valley as an interferometer. By 1965 a unique, variable baseline interferometer using the 210-foot and the 60-foot dishes was operational. Radhakrishnan (1994)[38] provides an insightful description of this unusual instrument and has drawn attention to the fact that Ekers and Goss, both authors of this book, cut their teeth using this modest interferometer. The absolute phase stability of the exposed trailing cables was inadequate to determine the precision positions which were required, to identify extragalactic radio sources. The first detailed observations of the structure of the southern radio sources was carried out by Ekers in 1969[39]. Radhakrishnan, Goss and colleagues used this interferometer to determine the HI absorption profiles of weak extragalactic and galactic radiosources (Goss 1994)[40].

Surveys of atomic hydrogen gas (HI) had always been an obvious target for the big dishes due to the required brightness sensitivity and the observations at Parkes were very successful. The 12 arc min beam insured that the galactic HI features could be studied at a resolution of 10s of parsecs. Both the galaxy and our nearest neighbours, the Magellanic Clouds, provided high quality images. These surveys continued for the next decade and were particularly important because the centre of the Milky Way, Sgr A, passed overhead at Parkes. Then in 1972, Don Mathewson discovered the Magellanic Stream, an immense cloud of HI gas emanating from the Magellanic Clouds, arcing more than 120 degrees across the sky[41]. Another planned project involved the study of radio emission from the planets. Thermal emission from the planetary disks is stronger at higher frequencies due to the Rayleigh Jeans law. Kellermann detected Mercury, Venus, Mars, Saturn and Uranus at 11 cm in 1964 and 1965.[42]

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[37] Kellermann, K. (1966) Aust J. Physics 19, 195
[38] Radhakrishnan, V. (1994) *Parkes 30 Years of Radio Astronomy* (1994), Ed DE Goddard and DK Milne, CSIRO Australia
[39] Ekers, R.D. (1969) *Aus. J. Phys*. **6**, 3-87
[40] Goss, W.M. (1994) *Parkes 30 Years of Radio Astronomy* (1994), Ed DE Goddard and DK Milne, CSIRO Australia
[41] Matthewson, D. (1992) *ibid*
[42] Kellermann, K.I. (2012) In: *Parkes @ 50 Years Young*, eprint arXiv:1210.0986

Unexpected Science with the Parkes Telescope

The Parkes dish embarked on many productive but often routine observing programmes that had been anticipated by Pawsey and his team in the 1950s. The agility of this single dish led to many other unexpected and surprising results.

The most significant was the lunar occultation of the radio source 3C 273 in 1963. To measure lunar occultations it was essential that the telescope could be pointed to any position on the sky where an occultation was expected. Pawsey had invited Cyril Hazard from Manchester University, then working at the University of Sydney in Hanbury-Brown's intensity interferometer group, to make lunar occultation observations with the Parkes telescope. The timing of the occultation of 3C 273 provided a precise position at the sub-arc sec level, leading to a possible identification with a stellar object with a jet. A spectrum of the bright star like object was obtained by Maarten Schmidt using the Mt Palomar 200-foot telescope. The remarkable result was that the redshift was found to be z=0.158. (Schmidt 1963)[43]. Thus, the first quasar was discovered. Details of the occultation and events leading up to this discovery are described by Hazard et.al. (2018)[44]. Observations of quasars continued at Parkes for another two decades and PKS2200-330 held the record for the most distant objects in the universe for 25 years.

Soon after observations started with the Parkes dish, a new spectral line emitted by the OH radical in interstellar space was discovered by Sander Weinreb at 1667 MHz. The Parkes engineers were able to quickly retune an existing receiver to this new frequency and confirmed the existence of the absorption line. In addition they were able to detect the strong OH absorption in the galactic centre of the Milky Way.[45].

One of the greatest discoveries in astronomy during the 1960s was the pulsating radio sources (pulsars) which were found serendipitously at Cambridge by Jocelyn Bell in 1967. Parkes was quickly adapted to observe pulsars and within a month was able to take advantage of having long observing tracks to determine a more precise pulse period. The favoured model for the emission of the radio pulses was the lighthouse effect from a rotating neutron star containing a narrow radio beam. In December 1968, Radhakrishnan, Cooke, Komesaroff and Morris used the Parkes polarimetry to observe the position angle of the linear polarisation of the strong Vela pulsar during the pulse. They found a regular sweep of the position angle, providing direct evidence for the rotating neutron star model[46],

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[43] Schmidt, M. (1963). "3C 273: a star-like object with large red-shift." *Nature* 197, no. 4872: 1040-1040.

[44] Hazard, C., Jauncey, D., Goss, W. M., & Herald, D. (2018). The Sequence of Events that led to the 1963 Publications in Nature of 3C 273, the First Quasar and the First Extragalactic Radio Jet. *Publications of the Astronomical Society of Australia*, *35*.

[45] Robinson, B. (1994), in *Parkes 30 Years of Radio Astronomy* Ed DE Goddard and DK Milne, CSIRO Australia

[46] Radhakrishnan, V., Cooke, D. J., Komesaroff, M. M., & Morris, D. (1969). Evidence in support of a rotational model for the pulsar PSR 0833–45. *Nature*, *221*(5179), 443-446.

establishing the slightly oblique magnetic field model which has remained a key component of pulsar emission theory to this day. Later Radhakrishnan and Cooke (1969 *Astrophysical Letters*, vol 3, p 225) wrote: "Comparison of the polarization structure of PSR 0833-45 at different frequencies leads to the conclusion that pulsar radiation must emanate from the neighbourhood of magnetic poles."

Later Developments

Further advances in astronomy and new technology have enabled the Parkes radio telescope to maintain world class status for a period exceeding 50 years. The basic telescope structure has remained unchanged; however there have been a series of other changes which have resulted in renewed bursts of activity every decade or so since it began operation. In the 1970s the surface was upgraded to work at millimetre wavelengths, and this allowed Parkes to search for other molecular lines which were being found at higher frequencies, notably by the Green Bank 140' telescope. New technology has revolutionised the receivers first, by lowering receiver noise to levels not anticipated in the 1950s. Then, the receiver bandwidths have increased by two orders of magnitude. The data processing advanced with fast digital signal processing. Computing power has increased in both the areas of computer control and data analysis.

In 1967-1968 the technique of Very Long Baseline Interferometry was developed in Canada and the US and then in 1982 when VLBI observations were started in the South the Parkes telescope became the dominant element of the Southern hemisphere VLBI network.

In 1997 a revolutionary new 13 beam receiver was installed at the focus of the Parkes telescope. This multibeam receiver revolutionised searches for HI in galaxies and made it the most productive pulsar telescope in the world doubling the number of known pulsars. In 2007 this multibeam receiver on the Parkes telescope discovered a completely new and enigmatic class of radio source with bursts lasting only one thousandth of a second (FRBs) arising from the distant universe.

The decision to build a Giant Radio Telescope has certainly been vindicated. Many generations of astronomers have benefited from this legacy of the two radio astronomy pioneers: Bowen, the visionary entrepreneur and Pawsey, the science leader.

Why was the Parkes design so successful compared to contemporary radio telescopes?

The flexibility of the single large dish at Parkes insured that the instrument was adaptable to new, unexpected discoveries. During the 1960s, the rate of discoveries in this new field of radio astronomy reached a peak (Ekers, 2010, Fig.5).

The technical performance of the Parkes antenna was superior to the other big telescopes of that era such as Jodrell Bank and the Greenbank 140-foot[47]. The key difference in the antenna design, construction and commissioning was the integration of the broad range of disciplines involved. The *Parkes: 30 Years of Radio Astronomy* symposium included excellent reviews of the construction and commissioning of the GRT by those involved during the 1950s. Harry Minnett asserted that the skills of both the antenna and servo engineers had been combined effectively. Several participants at the symposium provided examples of astronomers and receiver builders collaborating in the early days of the Parkes telescope. In addition, close collaboration existed between the software personnel, receiver experts and astronomers, producing innovative science. These connections were necessary in the remote environment of Australia, where wide ranging industrial connections were lacking. This cooperation and integration of skills, part of Australian culture, made major contributions to the rapid success of the new Parkes telescope in the following decades.[48].

Additional Note 1: NASA and Freeman Fox and Partners, Negotiations 1962

Setting up the arrangements with JPL in early 1962 was a complex process. Bowen had planned that Mike Jeffery of FFP would also play a major role (in addition to Minnett) in the NASA collaboration as Jeffery would spend an additional year working with CSIRO. The proposal was that Jeffery would spend a substantial time at JPL working on the design studies as part of the "Australian" team. In the 2 March 1962 letter from Bowen to White (composed while in London), Bowen pointed out a major stumbling block:

> I tried very hard to pull FFP into the plans we are working up with NASA/JPL but Gilbert [Roberts] made himself so unpopular at Pasadena that JPL wouldn't have anything to do with him. It is a pity and I hope it does not lead to any future unpleasantness. I had a long talk [likely in person in London] with Ralph Freeman and he is satisfied that we in CSIRO have done all we can to keep the party clean. [49]

Two days later (4 March 1962[50]), Bowen elaborated on the troubled arrangement with FFP in regards to the JPL contract in a letter to Bolton at Parkes. Bolton was anxious that Jeffery not depart from Australia until after Bowen's return from overseas on 16 March 1962:

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[47] However it is interesting to note that the 140 foot telescope was scientifically more productive by the mid-1960s with its superior receivers and spectrometers and a large astronomy community in the US taking advantage of NRAO's open access policy.
[48] Ekers "Achievements and Challenges for Australian Science" Distinguished Lecture Series, Ian Clunies Ross Memorial Foundation (1993)
[49] The tortuous relationship between Roberts and RP had not ended with the opening of the Parkes telescope.
[50] *Ibid*

> [Bowen to Bolton]: In the meantime, have a good talk with Harry [Minnett] about future plans in the light of his Pasadena visit [15 to 28 February] and advise Mike [Jeffery] accordingly. (1) [Bowen reported again the break between JPL and Roberts]. [Freeman] sees no prospect of the breach being healed. (2) We can obviously use Mike for a year or two on various aspects of our programme using the NASA funds. (3) This might eventually lead to sending Mike to Pasadena for a substantial period. (4) In view of [Roberts's] attitude, I doubt whether we [CSIRO] can make arrangements with FFP to retain Mike [Jeffery] for a further period. However, a great deal depends on Mike himself. (i) If he wants to make a clean break, we can offer him a good prospect for several years and he has even better prospects in the US later. (ii) If he wants to retain a connection with FFP, perhaps he can negotiate leave better than we can.

The negotiations with FFP continued to be troubled. In a remarkable hand-written letter from Ralph Freeman to Bowen from 30 March 1962[51], Freeman thanked his host for a tour of the GRT a few days earlier. Freeman was on his way to the Auckland, NZ, Harbour Bridge Project (a FFP endeavour) and spent 30 hours in Australia. "It was a tremendous thrill to the see the GRT complete and in all its glory, and really moving." The letter indicated that there were also severe internal conflicts at FFP; Freeman and Gilbert Roberts did not see eye-to-eye at all, especially on the future role of Jeffery. "I have explained [in a letter sent to Roberts back in London] the importance … of acting as you [Bowen] and I discussed, and have stressed, that if we don't act thus, that MHJ [Jeffery] will accept your [offer to remain with CSIRO]." Freeman then proposed the salary arrangements that CSIRO would need to fulfil in order that FFP could allow Jeffery to remain in Australia for the following year. "But you will appreciate that these are only my suggestions and that I have not told London [the FFP office] that I am telling you these details. And I cannot guarantee that my plea for concurrence and your wishes will succeed. Gilbert [Roberts] is being very 'cute' at JPL at present, and it may be an unsurmountable obstacle. They [JPL] already asked for consultancy service in general and MHJ in particular, but he [Roberts] wouldn't play."[52]

Bowen replied to Freeman on 3 April 1962[53]; he had sent a letter to FFP in London with the proposed plan for Jeffery. "I have made specific reference to NASA and the activities we would like Mike to help us on, but otherwise not been too specific. I sincerely hope that we can come to an arrangement along these lines."

Within a few weeks, the negotiations completely floundered. On 29 April 1962, Roberts wrote a letter of rejection to White with a copy to Bowen (this letter has not been located in

[51] NAA C3830 Z1/14/A Part 2

[52] Freeman suggested that Roberts's obstinate behaviour could have been due to the bad timing as these discussions with JPL also occurred at a time that Eberhart Rechtin (Assistant Director of JPL and often called the "father of the Deep Space Network") had sent an "offensive cable" to Roberts.

[53] *Ibid*

the archive). White replied to Roberts on 14 May 1962, summarising the status as he viewed the rejection:

> Apparently Dr Bowen discussed with Mr Freeman, during the latter's visit to Australia in March, the possibility of FFP entering into a new form of arrangement by which we would retain the services of the company [FFP] for a further period of twelve months. At Mr Freeman's suggestion Dr Bowen made a proposal to FFP [on 3 April 1962]. I presume you have seen this letter. Dr Bowen has now received a reply dated 16th April, in which his proposal has been declined. I understand that Mr Jeffery[54] has already returned to the United Kingdom to your organization [FFP]. I presume that this closes the argument. [Again, no reply from Roberts to White has been located in the archive.]

[54] Later in his career Mike Jeffery worked on the 150 foot Algonquin NRC telescope in Canada. The experience gained with the Parkes telescope was invaluable with the higher precision Canadian telescope. In the late 1960s, Jeffery was recruited by Bowen to return to Australia where he became the successful (first) Project Manager for the Anglo-Australian Telescope in 1968 until his tragic death in a skiing accident in 1969. He was succeeded by Harry Minnett (Project Manager 1969-1970).

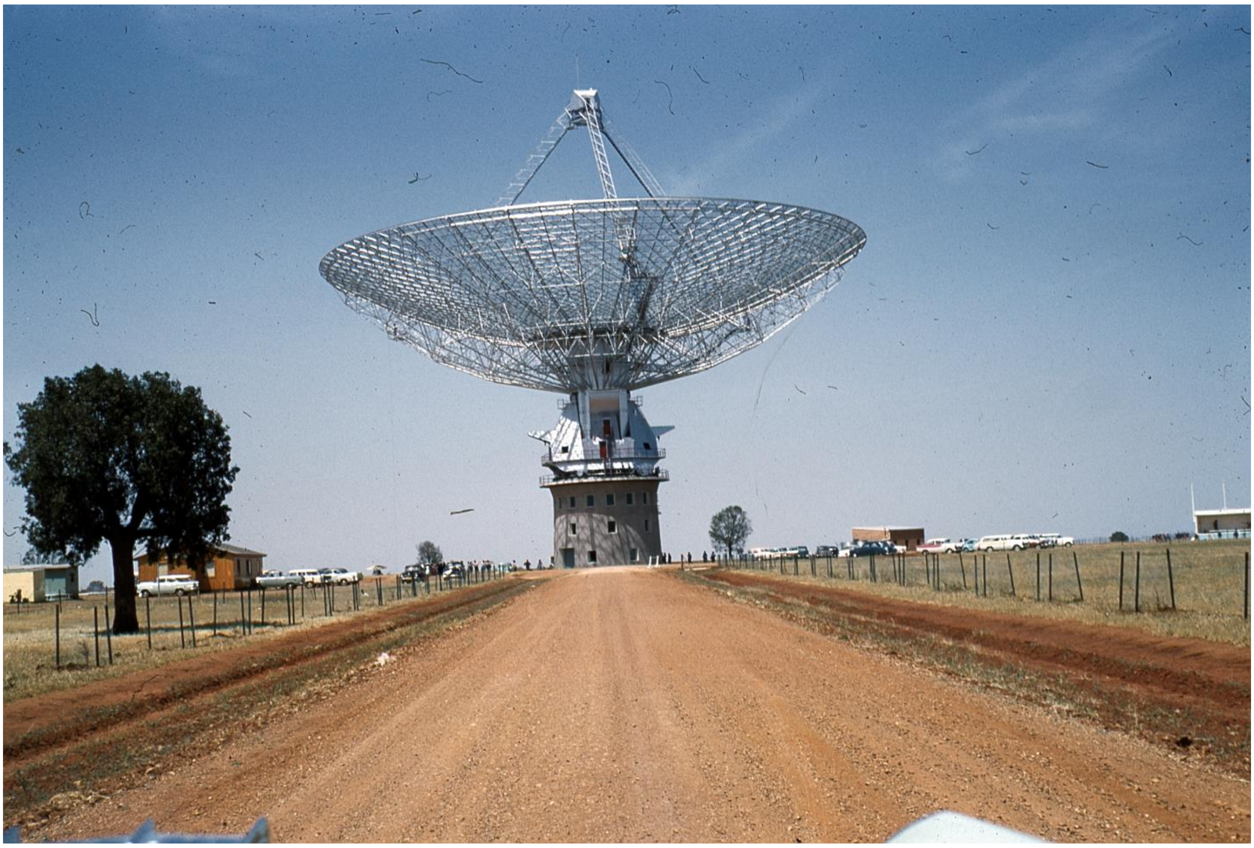

Fig 1. Pawsey's image on the day of the opening 31 October 1961. See Chapter 32, Fig, 32.5. The visitors' cars were being parked for the days' events. Credit: Joe and Lenore Pawsey Family Collection

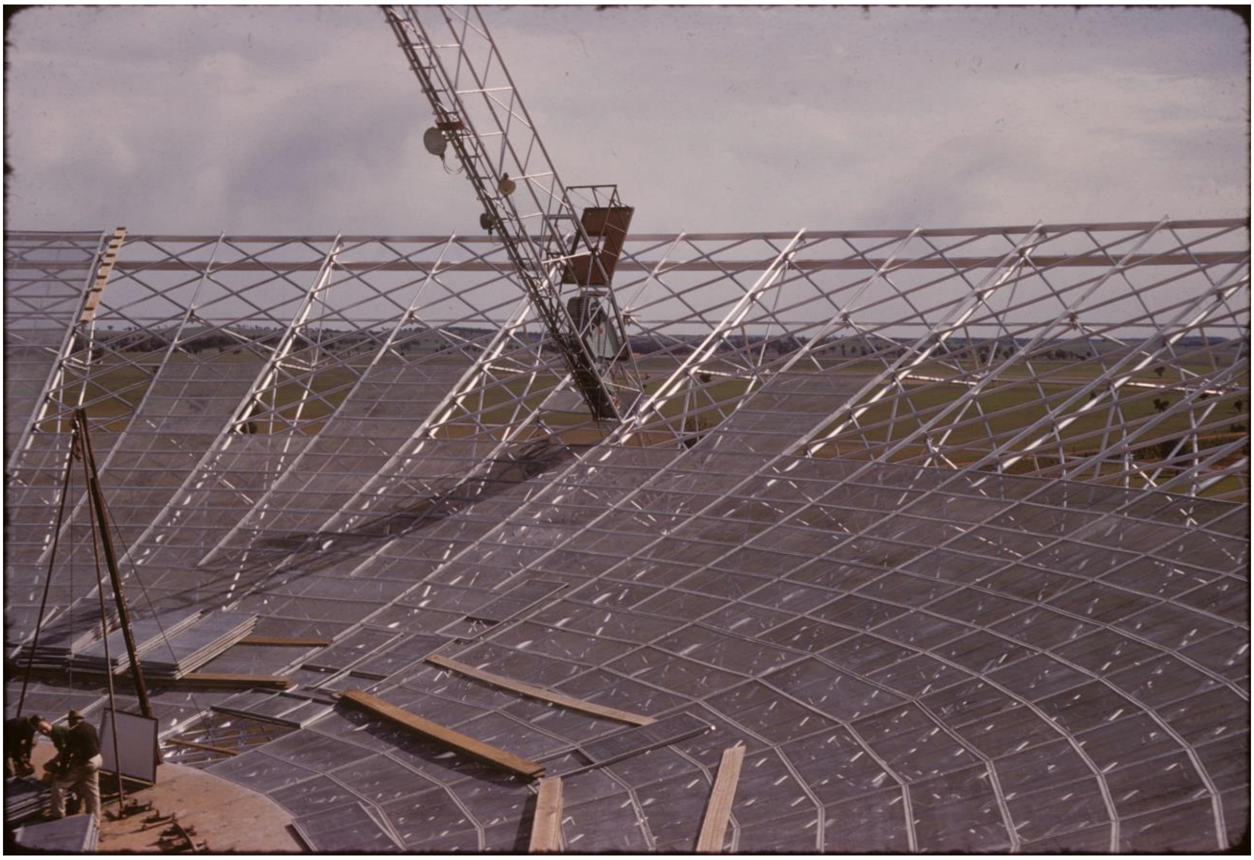

Fig 2. The status of the mesh of the Parkes telescope in mid-1961. The dish was nearing completion. George Day collection (permission from the Day family) provided by David Nash.

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Fig 3 From George Day collection (permission from the Day family) provided by David Nash. The invitees to the Parkes telescope opening arrive at the 210-foot telescope on 31 October 1961.

Fig. 4 Viscount De L ʻ Isle Governor-General of Australia. The Governor-General appears to “pop” up out of the dish on 31 October 1961. Bowen at the extreme right. Credit: CSIRO Radio Astronomy Image Archive B6607-8

Below – Ekers (2010) showing the evolution of major radio discoveries per decade from 1930 to 2000, for predicted and serendipitous discoveries.