NRAO ONLINE 41

1955- GBT Publicity Book, Rockefeller Grant, Pawsey - Barnes Wallis II

Epigraph

> The young science of radio astronomy is rapidly extending our knowledge of the universe around us. In all this work Australia has played a foremost part. The time has now been reached where the greatest advances in radio astronomy will come from the use of a very large radio telescope. Such an instrument is already under construction in England, and a strong case can be made out for building a second one in Australia. The Carnegie Corporation has made a very generous grant of $250,000 (about a quarter of the required sum) to C.S.I.R.O. for this purpose…[1]

Publicity Booklet- completion 1955

A major milestone was achieved in 1955 with the publication of the booklet "A Proposal for a Giant Radio Telescope" nominally written by Bowen and Pawsey. The author of most of the text was actually Frank Kerr, confirmed by the archive record and by Kerr's comments to W.T. Sullivan in the 1970s. After multiple drafts and a long publication process, the booklet was published in May 1955 with a wide-spread distribution throughout the world.[2]

The foreword is shown in Fig. 1 and the introductory page in Fig. 2.

An examination of the versions of the document shows the evolving opinions at RPL in the period of 1954-1955. In the Planning Committee-GRT minutes of 8 June 1954, it was noted that "Bowen [proposes] that someone should be asked to start drafting an extensive document covering: preamble, research programme, specification of requirements, the variety of possible structures [and] estimate of costs. Bracewell and Wild were suggested as possible authors". However, after a fortnight, Bowen reported to the next Planning Committee meeting that Kerr was to be the author. Already at this time, one section was complete. The time scale moved in a rapid manner, with a first draft available in late July 1954. By the time of the Planning Committee meeting of 17 August 1954, extensive comments were given to Kerr:

> ... it was decided to adhere to the original concept of a simple publication to cover the two classes of intended readers, i.e. potential benefactors and engineers. The large

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[1] *A Proposal for a Giant Radio Telescope* by Bowen and Pawsey, CSIRO 1955, Foreword

[2] The address list found in the National Archives (RPL 94 C3830, A1/3/11/6) is a who's who of international astronomy and radio science.

> body of detail which is included would not be understood by all readers, but serves a useful purpose by indicating that the proposal has been very carefully thought out.

Mills suggested that the document should provide more emphasis on the high frequency nature of the GRT in order to highlight the importance of a highly accurate aerial. "Bolton [working in the Cloud Physics group at this time] suggested extending the story of radio astronomy [in the document], and especially the Australian part of its development; also the inclusion of pictures of astronomical objects, aerials etc." The final version of 1955 followed Bolton's suggestions. In November, the text was ready and the publication of the booklet was organised by CSIRO Head Office. By December 1954, the page proofs were available. The distribution was discussed including potential donors, politicians, possible engineering contractors, interested scientists and newspapers. Over 500 of the "publicity booklets" were printed.[3] The booklet remains an invaluable tool in tracing the evolution of GRT planning in the 1950s.

Figs. 3 and 4 show two novel designs from the publicity booklet. The design in Fig. 3 shows the "swashplate"[4] design, a design that Bowen favoured: "I am personally attracted to the one entitled 'Jacks on turntable', but of course the details will be quite different from those shown."[5] The Fig. 4 design was a novel "hole in the ground" concept. The conventional design shown in Fig. 5 is similar to the final Freeman Fox design (see later chapters).

As 1955 began there was an impasse in further planning; Pawsey wrote Husband on 8 February 1955: "It seems we can do nothing until the financial position is clarified," [6] that is, additional funding was required. Then on 3 March 1955, Merle Tuve sent a disturbing letter to Bowen that led to serious re-appraisals by the RPL leadership:

> I have long wondered how you are faring in your efforts to raise additional money to make the Carnegie grant as fruitful as possible. Berkner [President of AUI] is pushing the idea of a "world's biggest" dish for this country [US]. [AUI and NRAO were planning large

[3] The evolution of the name of the booklet provides fascinating snapshots showing changing perceptions of the purpose of the document. For official use by RPL in 1954, the "descriptive document" evolved into the "publicity booklet". In the final version, "Specification of a Giant Radio Telescope for Which a Design Study is Required" on 23 November 1955, there were frequent references to simply the "booklet" – the "Proposal for a Giant Radio Telescope". Informally, in early 1955, the RPL management showed a hint of cynicism about the booklet with references to a "promotion" document, a "sales" document (Bowen to Barnes Wallis 30 March 1955), "propaganda" (from Pawsey to Charles Husband 8 February 1955) and a "glossy line-shoot" (attributed to Merle Tuve by Bowen 6 March 1955). NAA C3830, A1/3/11/3 Part 3.

[4] A swashplate consists of a disk attached to a shaft, c.f. a helicopter swashplate is a pair of plates, one rotating and one fixed, that are centered on the main rotor shaft of the helicopter.

[5] NAA C3830 A1/3/11/1 Part 3. Bowen to Barnes Wallis 30 March 1955.

[6] *op cit*, Pawsey to Husband

> reflectors of 300, 450 and 600 feet in diameter with an initial plan for a 130 foot diameter aerial.] I am on his Advisory Panel, and as Chairman of the NSF Panel for Radio Astronomy I participated (reluctantly) [in the AUI studies]. Combining this with our [DTM, Department of Terrestrial Magnetism, Carnegie Institution of Washington] own design and construction problems on the 60-84 foot dish ... I have often considered what might be fruitful for you to pursue there in Australia with respect to the big dish problem. I hope it is not amiss for me to make a suggestion ... I think if you have a 170 foot dish with a good drive you will be preeminent in the field for at least ten years ... I have a feeling you will be ahead of all the procession if you go ahead with the funds you have [US$250,000] in hand now and put up a dish such as Kennedy [the US antenna manufacturer in Massachusetts], preferably on a polar mount ... if I were obliged to make the choice I would rather have a 130 foot dish on a polar mount than to have a 200 foot dish on an alt-azimuth mount. It seems to me that an irrational ambition for the "biggest" is behind all of this discussion of 250 foot dish designs, and very little foundation rests on anything related to astronomy. It is kind of an engineer's paradise.[7]

Bowen and Pawsey were clearly worried by these comments. Within a few days (8 and 9 March 1955), a meeting of the Planning Committee-GRT was held with Pawsey in the chair. Bowen was not present. Mills, Kerr, Higgs and McCready attended the meeting. "... [The meetings] were called to discuss a letter from Tuve to Bowen, making the suggestion that we might be better off building a somewhat smaller aerial than 250 feet". The smaller (150-180 foot) diameter dish might be built for a cost of $500,000; the pointing accuracy might be 1 to 2 arc min. "For our point of view, the much lower cost is very appealing, as the higher amount may be difficult or impossible to raise. In any event, a smaller aerial could be built and operating much sooner than a 250 ft one." With Commonwealth matching funds, there was a possibility that, with the existing grant from the Carnegie Corporation of New York, the smaller aerial could be constructed. "An additional point raised in favour of a lower-cost aerial was there should be more possibility of making small auxiliary aerials. There would be little prospect of additional aerials after paying for a 250 foot aerial." There was then a discussion of the impact this reduced size antenna would have on astronomical programs. In the radio continuum, fewer radio sources would be detected than with the 250 foot aerial, but the smaller dish would still provide a substantial improvement over the number of sources detected by existing instruments in 1955. Certainly fewer normal galaxies would be observable in the continuum. The resolution of the smaller dish would still be sufficient to study the large scale HI structure of the Milky Way and even the Magellanic Clouds. Details of individual gas clouds in HI could still be determined but few extragalactic systems would be detected in HI emission, perhaps as few

[7]In retrospect, the doubts of Tuve were not confirmed. Within a few years, all major radio telescopes were alt-az.

as ten. (In the modern era with lower noise receivers and more sophisticated spectrometers, a 150 foot antenna would be able to detect numerous extragalactic systems in HI.) The summary consisted of a rather indecisive text:

> A 150 ft. aerial would be quite good enough for many types of investigations, a bit doubtful for some, but in these cases a 250 ft. dish might not be much better. In any case, a 150-footer in existence could do more than a 250-footer on paper. For these reasons, there was a general feeling in favour of reorienting the program towards the smaller dish.

Bowen wrote two letters on 10 March 1955 summarising his despondency; he seemed to have been convinced that there was little chance to build the GRT with a diameter of 250 ft. To Sir Ian Clunies Ross, Chairman of CSIRO, he wrote: "... [Y]ou will recall ... that Tuve was one of the people principally concerned with the grant from the Carnegie Corporation. His suggestion is that we not go for a 250 ft dish but limit ourselves to 150-180 feet. This is a possibility we have always had in mind but had kept in the background for reasons which I think you will appreciate". Also in the US, AUI was going to build the largest radio telescope in the world, "come what may, and we just can't compete".[8] Also a new major rationale for building the GRT, the discovery of the HI 21 cm line in 1951, was relevant, as Bowen wrote to Ross:

> The best scientific returns will come from hydrogen line studies on 1420 Mc/s and the lower frequency observations are likely to be much less useful. There are extreme, or even unsurmountable, difficulties in building a 250 ft. dish to the tolerances necessary for [HI] line operation and we have always thought in terms of making the central 150 feet suitable for [HI] line operation, the remainder being good for lower frequencies. Very little would be lost, therefore, by building a 150 or 180 ft. dish to [HI] line tolerances.[9]

A more dispirited letter followed on 10 March 1955 to Merle Tuve, whose original letter of 3 March 1955 was the origin of the re-evaluation in Sydney. Bowen was appreciative:

> We are very taken by your suggestion that we go for a dish of intermediate size ... Might I also say how grateful we are for your generous way in which you always keep us in mind and for being so ready to make helpful suggestions. I have become despondent in the last few months about the possibility of making progress here along the lines we originally considered. There are a number of reasons for this, all of which make sad

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[8] The large dish at Green Bank would only be completed in 2000, the fully steerable 100 metre Green Bank Telescope operational in 2003 by NRAO.

[9] NAA, C3830 A1/3/11/3 Part 3. In addition Bowen suggested to Clunies Ross that the Australians might share development costs with the Americans (DTM and AUI) for a 180 ft. aerial.

> reading. In the first place, the response outside [RPL] to the possibility of constructing a large radio telescope has not been good. The attitude of people in industry and in financial circles is that this is the responsibility of the Government: meanwhile the Government is quite apathetic. Even in research circles there has been a disappointing tendency to say that **sheep are more important and that radio astronomy is all right for other countries, Finally, purely from the point of view of constructing a large device I have been surprised to find how scared the rugged Australians are of going one better than anyone else in the world. [10] [our emphasis]**

Bowen then pointed out that he did not agree with Tuve that a polar axis mount was required, though later he would change his mind.

Pawsey was also pessimistic about the fund raising for the GRT. In a letter to Barnes Wallis on 17 March 1955 Pawsey wrote :

> We have felt that it is necessary to have the money in sight before getting at all heavily involved in design problems and we do not yet have any more than the original Carnegie promise of $250,000 ... It looks as if the Australian Government is not anxious to put up the main part of the remainder, and plans to raise the balance by private subscriptions have been made but are not very promising. However, it is always darkest before the dawn.[11]

In the next months of 1955 several events occurred that alleviated Bowen's and Pawsey's concerns. On 14 April, Barnes Wallis wrote Bowen, anticipating meeting Bowen for the first time in the UK in June-July 1955.[12] The up-beat letter stated that his proposed design for the GRT would meet the "compromise" design for a dish even larger than 250 ft {Barnes Wallis to Bowen):

> it would help me if you could give me some indication of how <u>much</u> larger you would like the dish to be <u>if you could have it</u>? [Wallis's emphasis] I expect your reaction will be that this cost is the deciding factor. Against this I think we shall find that the cost is greatly influenced by the structural design and that, for a given cost, the size will depend on the efficiency of the design ... I believe that we can adopt methods of construction [based on his experience with building large rigid airships] which will be cheaper than any in your book [the "publicity booklet"].

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[10] *op. cit*. Robertson (1992) has also used this quote. Clearly Bowen was quite depressed by the meagre response for public donations to the Radio Astronomy Trust.

[11] NAA, C3830 A1/3/11/1 Part 3.

[12] NAA, C3830 A1/3/11/1 Part 3. Barnes Wallis had been contacted by Pawsey in 1954, the first personal contact with RP staff.

On 19 April 1955, the Prime Minister of Australia, Robert Menzies, wrote R.O. Casey, the Minister of Foreign Affairs and the Minister in Charge for CSIRO, that the Commonwealth Government would match all private contributions for the GRT on a "pound for pound" basis: "... one-half of the cost of the project must be in sight from private sources before any Commonwealth grant becomes payable".[13] This commitment was hardly a surprise for the CSIRO since indications had been given earlier that matching funds might well be available. Later the CSIRO Secretary for General Administration (F.G. Nicholls) wrote Pawsey on 23 May 1955 that the Prime Minister would give a press conference in the second week of June; also he planned to submit an article about the GRT in the Australian newspapers (of course, written by his staff). In addition the Prime Minister would make a statement about the matching funds in the Parliament:

> In particular the Minister is anxious to say something to the press ... about the possible practical outcome of the work with the radio telescope. He seems to have given up on the idea of tracing [sic, likely tracking] flying saucers but anything ... that might have some practical bearing will be useful. We can, of course, use the Lord Kelvin touch (what is the use of a new born babe?) and talk about fundamental research on the ionosphere which gave us radar, but any new angles will be helpful.[14]

Clearly the most decisive factor in calming Bowen's anxiety was the meeting that Bowen had with the Rockefeller Foundation[15] in New York in late May 1955. Bowen wrote Clunies Ross on 26 May 1955 (reported in a letter to Fred White on 7 June) with the wonderful news that the prospects for funding were "optimistic". On 10 June 1955, Warren Weaver (Vice-President for Natural and Medical Sciences, Rockefeller Foundation and a former associate of Bowen's at the Radiation Laboratory in Boston during WWII) had written that "the general prospects are favourable rather than unfavourable"; Bowen replied a few weeks later to thank Weaver "for keeping the fires of hope burning".[16] As will be described, the official news announcing the Rockefeller Foundation grant of US$250,000 arrived later in the year, 7 December 1955. **Apparently, following in the example of the Carnegie Corporation, the Rockefeller Foundation, would continue to promote US science diplomacy. [our emphasis]**

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[13] NAA, C3830 A1/3/11/3 Part 3. Also White wrote Casey on the next day (20 April) thanking Casey for his help in getting the matching funds commitment from the Prime Minister.
[14] *op.cit.*
[15] The Rockefeller Foundation had a long history of funding astronomical instruments such as the 200 inch telescope which began the association with the Rockefeller Foundation funded International Education Board in 1928. Also for the Australians the membership of Alfred Loomis, a friend of Bowen's, on the Rockefeller Board was an asset.
[16] *op.cit.*

In early June 1955, Bowen arrived in the UK from the US. He hoped to meet Barnes Wallis in person but this was delayed until early July. By this time it was clear to Bowen that there were no firms in the US or the UK that could both design and construct the prospective antenna. Also, Bowen and Pawsey wanted to avoid the complex management structure experienced during the construction of the Manchester telescope. This structure consisted of

> [A]n extraordinary contractual situation ... which we should be careful to avoid. The three parties principally concerned are Lovell, the Bursar [of the University of Manchester] and Husband, all very excellent people ... Lovell states the requirements, Husband gets the design work done ... and the Bursar then calls for tenders for each part of the structure as the design is completed. There are a large number of contractors and no one of them has overall responsibility. In effect the Bursar not only holds the money but is also acting as the main contractor. [This was not the intended situation.] ... but this is the way it has worked out ... they thought Husband would be the main contractor but in practice this is not so- he acts as consultant and takes a consultants [sic] fee.[17]

On 2 June 1955, Bowen (in London) wrote to Pawsey in Sydney. At this time it was clear that the best way to proceed was to "call for a design study from one or more of the likely people. This could be subjected to careful scrutiny and an independent assessment. When we were completely satisfied with it, we would call for tenders for the construction or [even] call for a further study as the case may be".[18] This careful division of design and then construction was seen as the process to avoid the chaos of the Manchester experience. Bowen and Pawsey were now ready to start the design process. The uncertainty and pessimism of the previous March were alleviated.

Bowen was impatient to get the ball rolling on the design study from his base in London. On 2 June 1955 he sent a complex set of instructions to Pawsey in Sydney that would ensure that the design contract could be placed when Bowen was back home in Sydney in mid August 1955:

(1) form the GRT Technical Advisory Committee (TAC) consisting of CSIRO staff: Pawsey, Fred White, and Arthur Higgs as secretary plus two outside structural experts, Prof J. "Jack" W. Roderick of Civil Engineering at the University of Sydney and H.A. "Arthur" Wills, of the Aeronautical Research Laboratory of the Department of Supply – an

[17] NAA C3830 A1/3/11/1 Part 4 from Bowen in London to Pawsey in Sydney, 4 July 1955.
[18] NAA C3830 A1/3/11/3 Part 3 from Bowen to Pawsey, 2 June 1955.

Australian Government department.[19] The function of the committee was to draw up a draft specification for the design study, evaluate the designs which would be received and make recommendations to CSIRO as to whether to proceed to construction.

(2) Convert the Associated Universities Inc. document, which was written on 2 May 1955 ("Request for a Bid Proposal to Furnish a 131-Foot Radio Telescope"), from a request for bids for construction to a document calling for a design study for the GRT. Bowen enclosed an additional document, "Suggested Modifications to the AUI Specification for 130 [sic] ft. Radio Telescope", written by himself consisting of changes that were to be made to the original AUI document. (Note the different diameters- 131 ft. is 40 metres, the intended size of the AUI antenna. This antenna did become the 140 ft. Green Bank antenna after completion in 1965.)[20]

(3) Since it would be some weeks before the TAC could meet, Bernie Mills, Harry Minnett and Lindsay McCready were to be asked to re-draft the AUI document in the form of the design study for the GBT.

(4) Present this draft to the TAC for their first meeting.

(5) Then prepare a final version ready for Bowen's return to Sydney in mid August 1955.

(6) Finally place the design study with a suitable engineering firm when the finance questions were settled.[21]

Before the first TAC meeting on 22 July 1955, a draft GRT document had been prepared by Mills, Minnett and McCready: "Specification for a Giant Radio Telescope for Which a Design Study is Required", dated 30 June 1955. This version was sent to Bowen in the UK on 1 July 1955. After the first meeting, a second draft was prepared at RP on 29 July 1955 after input from Roderick and Wills; examples of new additions were more details concerning the tolerances on the proposed dish and mount. The final version of the "Specification" was prepared on 23 November 1955, after the second TAC meeting on 16 August 1955.[22]

Pawsey replied from Sydney to Bowen in London on 30 June 1955 with an update on numerous activities at RP.[23] The AUI document had been edited:

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[19] The TAC met eight times from July 1955 to June 1959. Later two additional academics from the University of Sydney joined the committee: Prof William Wittrick of Aeronautical Engineering and H.K Messerle of Electrical Engineering.

[20] As an example, the original section in the AUI document describing the size of the aerial was to be changed in the GRT design study to "The final size will depend on the amount of money available but I suggest we call for the size range 200-250 ft. as a good working figure for the moment."

[21] NAA C3830 A1/3/11/1 Part 3

[22] NAA C3830 A1/3/11/1 Part 5

[23] NAA C3830 A1/3/11/1 Part 3

> This draft differs from the AUI Specifications you sent in the way you indicated: it is a request for a study of how the thing can be built and we have tried to say which things are essentials from the radio point of view and which things are arbitrary and subject to compromise on mechanical grounds ... we have been guided by our engineering members, Wills and Roderick ... our draft uses the booklet [the "publicity booklet"] as a sort of appendix which elaborates on various questions where latitude should be given to the designer. The next moves are two-fold. (i) We shall go ahead with the redrafting procedure you suggested and (ii) we are relying on you [Bowen] to make the necessary preliminary approaches to appropriate engineers. Who these may be is not yet clear.

As possible options, Pawsey mentioned Husband ("detailed experience"), Wallis ("bright ideas") and Freeman, Fox and Partners (consultants of the Sydney Harbour Bridge construction, completed 1932) who had "experience and ability in the design of large steel structures".[24] Pawsey was also encouraged to have received news of the favourable reports of the prospects of a grant from the Rockefeller Foundation.

Then Pawsey started a new discussion with his proposal to combine the GRT with other antennas in order to achieve **higher angular resolution**:

> I have therefore started discussion in the group on general developments which are required in Radio Astronomy and how they may be realized ... My starting point was the idea of integrating a big telescope into a wider program. I think there is a natural field here for both big parabolas and trick methods [he means combining the GRT with other elements to form an interferometer array] and the two should be integrated into one program. The AUI program [of design and construction of a 131 ft. dish along with designs for a 300, 450 and 600 ft. dishes] is a most interesting challenge ... Can we, say with a 200 ft. dish plus accessories, or by other means, render the 600 ft. dish obsolete before it is built, as we essentially did to Lovell's original concept of a dish working down only to 1 metre wavelength ... Because our ideas are still so half-baked I won't try to tell you about them, but there are some thoroughly interesting developments crystallized by your return [in mid-August 1955).[25]

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[24] In September 1954, Pawsey had met the firm Freeman, Fox and Partners. (Chapter 27). This is one of the first times that Freeman, Fox and Partners (R.E.Fordham, C.T.Wolley, Ralph Freeman and Gilbert Roberts) was mentioned in 1955. Sir Ralph Freeman (1911-1998) was the son of Sir Ralph Freeman (1880-1950), the designer of the Sydney Harbour Bridge. Roberts was knighted in 1965 and was elected a Fellow of the Royal Society in 1965; he played a major role in the GRT design (Chapter 27, 29 and 32).
[25] Apparently, the Australians did not know of the May 1954 proposal of Robert Dicke (Princeton) for an earth rotational instrument (Chapter 37) from June 1954.

The intense discussions at RP, that had started a fortnight before the 30 June 1955 letter to Bowen, began with a four-page memo from Pawsey to the entire radio astronomy staff of 15 scientists: "Notes on Requirements for Radio Telescopes and Various Possible Methods of Meeting Them"[26]. On the same day (15 June 1955) Pawsey sent a memo to the staff: "The current state of negotiations for a giant steerable radio telescope is promising. It is desirable, before we have to finalize the design, to discuss carefully how it can be used in radio astronomy so that the design may be one which fits into the overall program." The "Notes on Requirements" were enclosed. In the following two months, three meetings of "The Radio Astronomy Planning Meeting" were held, 17 June, 29 June and 12 August 1955 with Pawsey as the chair. Bowen did not attend any of the meetings since he was overseas until about 13 or 14 August 1955. The earlier ten meetings in 1954 and March 1955 had been a smaller group with the title "Planning Committee- Giant Radio Telescope".

The purpose of the "Notes on Requirements" was to examine the question of achieving higher angular resolution, or "detail":

> ... it was decided to attempt to clarify [the issue of various forms of a radio telescope] while following up the giant parabolic design questions raised by Dr Bowen. The essential issue is this. There is a limit to the size of a giant steerable parabola (set by strength of materials and costs) which sets a corresponding limit to angular resolution and sensitivity. Higher angular resolution is often desirable and is already attainable in selected cases but by means which are, as yet, very cumbersome. Similarly, higher sensitivity (greater area) is attainable if really wanted. Long-term plans must envisage the attainment of such detail [angular resolution], preferable by methods which are more elegant than those used so far. Thus we should now formulate plans as to how we may make not only general surveys (presumably with giant parabolas and Mills Crosses) but also obtain further details. Since a giant parabola appears available [the GRT], it would appear advantageous if it could be incorporated in the high-resolution arrangements. At this stage it would be possible to modify the design of the giant parabola, if desirable for this purpose. We can only do this intelligently if we can now see how best to obtain the details [angular resolution]. This may require a new invention, which we should attempt to simulate now by a study of ways and means.

Already in 1955, Pawsey recognised the limitations of the finite resolution that could be achieved with a single dish aerial. In his plans for NRAO, Chapter 39 he was fully aware of this limitation as he discussed the future of the National Radio Astronomy Observatory at Green Bank.

[26] From the Richard McGee collection NAA C4633/3.

In Additional Note 1, the continued discussions on the possible uses of the GRT from December 1955 are summarised.

A general set of specifications then followed, including the idea that the astronomers needed an overall image of the entire sky with a resolution of 0.5 degree, coupled with the ability to image interesting regions with a resolution of 1 arc min.[27] The intensity sensitivity of the new instruments should enable the detection of several thousand discrete sources, with the ability to resolve some fraction of the radio sources associated with external galaxies. Of special importance was the 21 cm line of neutral hydrogen, imaging the Milky Way spiral arms and even some hundreds of external galaxies in HI.

The methods to achieve these goals led to a proposal for several different instruments: for the surveys the use of the giant steerable parabola, Mills Cross, arrays and possibly a fixed spherical dish. To obtain high resolution, various schemes were possible: variable spacing and variable orientation interferometers using equal aerials or one large aerial plus a collection of smaller aerials (compound interferometer), Christiansen grating arrays (such as the Potts Hill solar instrument), the Chris Cross such as the new instrument at Fleurs, or a scheme based on the Hanbury-Brown intensity interferometer. Finally, Pawsey had a small list of items, "the pious hopes", which included: "use of a group of say 6 medium sized aerials[28] (say 100 feet) in flexible form to [simulate] (a) single aerials, (b) compact array, (c) interferometer [presumably with a larger baseline] and (d) a cross with same area as a 250 ft aerial".

At the three meetings over the next two months, many aspects of the astronomical requirements and the form of the possible instruments were discussed in detail. Pawsey assigned a number of topics to the scientific staff for further evaluation. Frank Kerr[29] made a prescient addition to the list of astronomical requirements: **polarisation** determination of the radio emission from discrete sources and the galactic background. He continued with a detailed

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[27] A favourite analogy of Pawsey's was formulated for the first time: "This concept of survey +detail follows exactly from the Palomar scheme of the [Schmidt all sky survey] plus the 200 inch." As we will see later, Pawsey returned to this comparison in 1962 as he formulated plans during the initial stages of becoming the second Director of NRAO later in the year.

[28] Similar to the original Australian Synthesis Telescope proposal of the middle 1970s.

[29] Frank Kerr (1918-2000) had worked at RPL during WWII with Pawsey's group. After the war he was a pioneer in HI spectral work at RP. He played major roles in planning for the GRT and was an early user of the Parkes telescope for HI investigations of the galaxy. In 1966 he moved to the University of Maryland until retirement in 1985. (See Sullivan, W.T., III. (1988). "Frank Kerr and Radio Waves: From Wartime Radar to Interstellar Atoms." In The Outer Galaxy, vol. 306, p. 268).

summary of the desired HI surveys of the galactic spiral structure and the Magellanic Clouds as well as external galaxies. He discussed HI absorption lines in the direction of discrete sources and also mentioned other spectral lines that would be valuable: deuterium at 327 MHz, OH at 18.3 cm, CH at 9.45 cm. Also, Kerr wrote:

> One method of investigation would be to view Sagittarius A in absorption at the appropriate frequencies, requiring high aerial gain. [A number of desiderata were mentioned for] "cosmic" continuum studies: full sky coverage, high resolution to avoid confusion, radio radiation from the planets, and detailed high resolution images of discrete sources to investigate the number, positions, intensities, sizes and spectra of all sources.

Bernie Mills presented details of expanding to a large Mills Cross with an angular resolution of 10 arc min at 80 MHz (size 2300 metres), detecting more than 30,000 sources (compared to about 2,000 sources with the first Fleurs Mills Cross instrument). Possibly, Mills may have used the term "**Super Cross**" for the first time in these discussions. Mills also suggested that the highest frequency possible for a Super Cross would be close to 700MHz.[30]

A number of large aerials of restricted coverage were also discussed such as "Kraus" type transit aerials, various spherical aerials as well as parabolic cylinders. For these fixed aerials, an important consideration was the ability to observe the galactic centre (close to the zenith in Australia), the Magellanic Clouds (south of the zenith in Australia) and a portion of the ecliptic plane for planet observations. Another prescient suggestion was made that lunar occultations would be important as radio sources disappeared behind the moon, a type of observation requiring a fully steerable dish.

In the end many of these ideas were to be developed a few years in the future. In 1955 and the next few years, the GRT was to occupy most of the attention of the RP staff. The high resolution discussions of mid -1955 do, however, foreshadow the controversies of 1959-1960 preceding Christiansen's and Mills's departures for the University of Sydney, and in 1961-1962 as Pawsey left for NRAO in the US. Can it be that these discussions of higher resolution radio astronomy in mid-1955 foreshadowed the conflicts of 1959 between Bowen and Pawsey-Mills-Christiansen?[31]**.**

In mid-August, Bowen returned from the UK and the US and presented a colloquium on 26 August 1955 describing some of the problems which had arisen in the construction of the Giant Radio Telescope. Within a few days, Pawsey was to depart for the UK, attending the IAU

[30] Mills likely was developing many of the ideas that were to become the Super Cross plan of 1959.
[31] Pawsey likely viewed the dish combined with an array as a compromise solution that might satisfy Bowen and Mills.

Symposium on Radio Astronomy at Jodrell Bank from 25-27 August 1955, in addition to carrying out discussions with Lovell, Husband, Wallis, Freeman, Fox and Partners as the pace of the GRT design study accelerated.

Barnes Wallis – increased contacts, July to December 1955

Both Pawsey and Bowen had exchanged correspondence with Wallis earlier in 1955; Bowen was looking forward to meeting Wallis for the first time in July and Pawsey was to meet him for the second time in September 1955. Bowen (1981) has provided a partially distorted summary of the role of Wallis in "The Pre-History of the Parkes 64-m Telescope".[32]

In the 6 July 1955 correspondence, Bowen reported to Pawsey about his first meetings with Barnes Wallis[33]:

> He is keenly interested in the problem [the GRT design] and would very much like to be involved in the project. However there are difficulties with Vickers [Wallis's employer] and it may be extremely difficult for us to persuade them to allow him to become involved ... the main problem is how to find an administrative arrangement by which Wallis can put time on the problem. He is afraid that if the top management knew of his present interest they would not agree to his spending time on it.

In the end, a complex series of negotiations were carried out by the High Commissioner of Australia and the Chairman of Vickers, General Charles A.L. Dunphie (a prominent figure in the North Africa campaign of 1943, WWII), in which it was agreed that Wallis would be allowed to act in a consultative role in the design of the GRT (date-1 and 2 November 1955).

Bowen summarised a number of Barnes Wallis's ideas. An example was the self-compensated structure with the parabolic surface (made of light alloys) in tension and the backup structure in compression, "the whole being constrained to take the correct shape by adjustable members at about three points along the radius arm". With this clever scheme (the "incompressible

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[32] *Proc Astronomical Society of Australia*, vol 4, no 23, 1981, page 267. As Robertson (1992) has pointed out Bowen's story of the "invention" of the master equatorial- the analogue device to convert from the telescope coordinates of azimuth and elevation to the astronomical coordinates of hour angle and declination by Wallis at a meeting at the Athenaeum Club in London was clearly apocryphal. The master equatorial was described in some detail in the 14 October 1955 proposal for "Giant Radio Telescopes". Bowen has Wallis saying: "It's obvious. The place to put the equatorial unit is at the intersection of the two axes of rotation- [the small equatorial telescope and the main dish itself] ... He went away that same afternoon and patented it. From that moment it was part and parcel of the design."

[33] NAA, C3830 A1/3/11/1. In addition, copies of the Wallis correspondence with RPL were placed in a separate file NAA C3830 A1/3/11/32 by Sally Atkinson, 23 September 1980.

column”), Wallis saw no problem in building a 1000 ft dish since the whole surface would remain a parabola under the variations of gravity and wind as the dish moved across the sky.[34]

At this point, Freeman, Fox and Partners (FFP) became a major player in the deliberations. Pawsey had suggested that FFP might be a possible source for the GRT design. Likely the first meeting with Freeman and Gilbert Roberts[35] was on Friday 8 July 1955.

Bowen gave them a copy of the publicity booklet and the draft specifications. In mid-1955 Bowen was again convinced that a polar mount was required; as we will see, opinion on this point oscillated considerably in the following two years. More details about this meeting were given to Pawsey on 13 July 1955:

> I have had a preliminary talk with Freeman, Fox and Partners and put the problem to them. My first impressions were good and they seemed to get an excellent grasp of the problem in a very short time. I have left a draft specification with them, and I will get their considered views in a few days’ time. We must remember, however, that their approach is likely to be the heavy one with masses of structural steel all over the place.

After 20 September 1955, Arthur Wills of the ARL was also in London, joining Pawsey in visits to the Manchester aerial, as well as meetings with Husband and Lovell. A major goal during Pawsey’s visit was to organise discussions between Barnes Wallis and Freeman Fox for the first time. Bowen had written Wallis on 2 August 1955from London: “Dr Pawsey will be in England in the last week of August and during September and I hope that matters will be sufficiently far advanced at our end for him to be able to make a definite arrangement at that time.”[36] Thus Bowen hoped that Pawsey would be able to effect a collaboration between Barnes Wallis and FFP, as well as starting the process of the design study during his visit.

As Bowen was leaving London (28 July 1955) he wrote Pawsey with the status of the negotiations. He provided a summary of Barnes Wallis’s design and then suggested a plan of action: “Commence design work at once on Wallis’s ideas using one of three consultants: (1)

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[34] The concept was a foreshadowing of the homology concept in larger antenna design, that is, at various elevations, the main reflector deforms from one paraboloid into another.
[35] Roberts (1899-1978). See his obituary Kerensky, O. A. (1979). "Gilbert Roberts. 18 February 1899-1 January 1978." *Biographical Memoirs of Fellows of the Royal Society* 25: 477-503. Roberts was one of the designers of the Sydney Harbour Bridge in the 1920s. In the 1950s, as one of the partners of Freeman, Fox and Partners he played a major role in the Parkes radio telescope design (see Chapters 27, 29 and 32 and NRAO ONLINE 42-43 and 45-46). Late in life he was involved in the design of the West Gate Bridge (Yarra River), Melbourne,1970.
[36] NAA C3830 A1/3/11/1. In addition to Freeman, Fox and Partners, Bowen had also been in touch with two other London firms that were approached for a design study, Sir William Halcrow and Partners and Head, Wrightson and Company. Bowen told Barnes Wallis: “If the question of a choice between them arose you may be sure that we would be guided entirely by your wishes in the matter.”

FFP, (2) Sir William Halcrow and Partners or (3) Head, Wrightson and Company to carry out the detailed work."

Then a three stage process was suggested: "(1) Make a preliminary study to establish a curve of size versus cost [for the Wallis design] ... (2) Having settled on the approximate size, proceed with a complete design study. This might take six months and cost £10,000 to £20,000. (3) [If pleased with the latter] ... call for tenders for construction from the appropriate engineering firm."[37]

However, there were problems back in Australia getting the agreement of CSIRO. Bowen was clearly frustrated to report to Pawsey (in London) on 26 August 1955:

> Both White and Casey agree with our plan for a design study but they are afraid to proceed until we are more certain about finance. We may not be able, therefore, to enter into a definite arrangement until there is an announcement from the Rockefeller and/or Ford foundations. This means that you can still talk to the consulting engineers and Wallis along the lines we outlined but you will not be able to finalise any arrangements with them for the moment.[38]

Thus some of the rationale for Pawsey's visit to London disappeared. Surprisingly, the mood at CSIRO oscillated to a less pessimistic tone within two months.[39] On 27 October 1955, a meeting at the highest level of CSIRO was held in Australia with Bowen, Pawsey (back in Sydney since early September), Clunies Ross (Chairman of CSIRO) and White (CEO of CSIRO), along with members of the CSIRO executive staff, for the purpose of discussing the future of the design contract. It was decided that the US $250,000 from the Carnegie Corporation "... represented a minimum target with which some aspect of large aerial work could be undertaken, even if no further money were to come to hand ... we are therefore justified in beginning to spend money on a design contract".

In late September, Pawsey was impatient to wrap up the negotiations in London; an essential task was the introduction of Barnes Wallis to Freeman and Roberts. Apparently, Bowen and Pawsey had already decided that FFP was the best choice for the design study; on 20 September 1955, Pawsey wrote Bowen: "... I am at present convinced that Freeman Fox is the best choice". He had met personally with Barnes Wallis, Freeman and Arthur Wills from APL who had just arrived in the UK from Australia. Wallis had even "gratuitously remarked that he

[37] *Ibid*

[38] *Ibid.*

[39] NAA C3830 A1/3/11/3 Part 3

thought very highly of [Ralph] Freeman", whom he had not met previously[40]. In the same letter Pawsey was quite frank (20 September 1955):

> My assessment of the position, I think, agrees with yours. It is that Wallis's design could be outstanding, and it is up to us to find out. Of the consultants we have thought of I think Freeman, Fox and Partners are probably outstanding and since they are thoroughly interested there is an excellent opportunity for getting them. The present position is that I arranged a joint discussion between Wallis and Mr Freeman at which Arthur Wills and I were present. The atmosphere was first-rate as Wallis outlined his ideas. These, of course, had gone for beyond anything Freeman had had time to think of and he seemed impressed with a number of bright thoughts. As far as I can judge we could get a high degree of co-operation between the two ... [I think] that he [Freeman] will draft a letter from his firm to the RPL Division setting out the terms under which his firm would undertake a design study ... [including] an assessment of the general feasibility of the Wallis type of design and an approximate estimate of the cost size relationship. ... It seems to me that the outstanding point for me to get cleared up is this one, to get a good firm of consultants lined up for checking and developing Wallis's ideas and I hope you agree with the sort of arrangements which appears to be coming out ...[41]

Bowen sent a cable on 26 September 1955 to Pawsey in London agreeing with his points. Bowen's earlier concerns that FFP would insist on a rigid surface and thus be unable to work with Wallis were not confirmed. However, as we will see, in the end Barnes Wallis was unable to work with FFP and their collaboration failed in the course of 1956-1957.

A week later (28 September 1955) Pawsey met with Freeman and Roberts at the London FFP office. As he left Europe, Pawsey saw his role as having been to make: "working arrangements between the respective parties"; he had had little opportunity to discuss technical details. This discussion could only take place after a final agreement had been reached.[42] Pawsey was optimistic (28 September 1955):

> [Freeman and Roberts] agree in principle to understanding the design study along the lines we wish ... They are quite agreeable to collaborating with Wallis. The position as I see it is that the designing engineers are employed by us, but are the responsible people in producing the design. Wallis would be in an advisory capacity. The current relations

[40] NAA 33830 A1/3/11/1 Part 4
[41] *Ibid*
[42] *Ibid*

> between the two look quite good and I think that the responsibility should be set fairly on [FFP] ... The way they handle a design study is to start from what appears to be the most promising design, in this case it would be the general scheme put forward by Wallis, and to investigate this along with other ideas. This means that they would attempt to assess the relative merits of steel and light alloys, of a rigid as opposed to a compensated structure, of alt-azimuth as opposed to an equatorial one etc. Since this is their procedure, they do not think it desirable that an independent parallel study should be undertaken ... the study would take about six months [an estimate that turned out to be vastly underestimated]. Liaison with [CSIRO] RPL looks to be to be very difficult and requires consideration.[43]

In the last three months of 1955, two decisive events occurred that had a lasting impact on the evolution of the GRT: the launching of the design study by FFP and the announcement of the Rockefeller grant.

On 14 October 1955, Barnes Wallis sent his completed text "Giant Radio Telescopes" to Walter Ives[44], the Chief Scientific Officer of the Australian Scientific Liaison Office in London, to be forwarded to Pawsey in Sydney.[45] The report has the date "September 1955" printed on the title pages; based on a handwritten note by Barnes Wallis, it appears that the actual date of the final document was 14 October 1955. The report consists of numerous general concepts and many analogies to the successful rigid airship R.100, designed by Wallis and built by Vickers; this airship successfully completed a round trip from the UK to Canada in 1930. However, after the crash in France of the competing airship R.101, designed and built at the Royal Airships Works, the successful airship R.100 was scrapped.

Barnes Wallis's foreword made the connection with his airship design experience: "The design of a large Radio Telescope involves many of the same problems as did in the past the design of large Rigid Airships, for the construction of a giant Radio Telescope is a venture into the unknown which certainly involves the creation of a large and costly structure." His 13-page text

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[43] *Ibid.* Harry Minnett was slated to be the liaison RPL staff member, arriving in London in early 1956. After this conference on 28 September 1955 with Freeman and Roberts, Pawsey composed a one page summary of the meeting which included additional technical details (e.g. the type of surface material for the dish, either mesh or solid) not included in the letter to Bowen on 28 September 1955. The determination of the size cost relation and the practicality of the size for an appropriate cost were major desiderata.

[44] In a letter from Bowen to Ives a few weeks later explaining the details of the contract for the design study with FFP, Bowen wrote: "Wallis is the genius likely to have bright ideas, and Freeman Fox the hard-headed engineers."

[45] CSIRO Archive, CASS Marsfield, 2011.

combined his design philosophy with his practical experience based on airship and aircraft design:

> These conclusions indicate the form that the structure of the dish should take. At first sight it is natural to think of a surface of revolution as being defined by a rotating generator, which in turn suggests construction of radial and circumferential members. The quality of homogeneity however forbids the use of two such different geometrical forms (as far as the primary of skeletal structure is concerned), a prohibition that leads to the only single curve that partakes of both, namely the spiral. The type of spiral required is obviously an equiangular spiral described in the surface of a paraboloid of revolution, since by using right and left hand spirals of this kind to define the primary structural form, a network is produced in which every nodal intersection is geometrically similar[46] ... the support of the dish must be concentrated, isotropic and therefore central. [Wallis's emphasis] ... Success or failure will depend as much on the mounting as on the dish itself. Two types of mounting are well known to astronomers, namely the Equatorial and the Alt-Azimuth ... the desired rigidity of mounting and accuracy of tracking will only be obtained using the Alt-Azimuth type ... It is the difficulty of doing this [changing both altitude and azimuth simultaneously with varying rates] with sufficient accuracy that has led to the abandonment of the Alt-Azimuth in favour of Equatorial Mounting ... Modern developments ... have led to a reconsideration of this problem, and it is now possible to install a small Equatorial Mounting having its axes coincident with the axes of the Alt-Azimuth Mounting, in such a way that deviations of the optical axis of the tube or dish of less than 0.1 arc sec can be detected and corrected. The small Equatorial model [the master equatorial] thus acts as the master, and [the dish] as the slave, thus eliminating the difficulties of tracking that previously made the latter type unsuitable for accurate work. With this improvement the Alt-Azimuth type becomes greatly superior to the Equatorial, as all the structural advantages lie with the Alt-Azimuth.

The Barnes Wallis proposal of October 1955 included 13 figures of HMA R100, many showing the construction of the airship. There were only a few (3-4) figures of the GRT design; in Fig 6a, we show the sketch of the GRT with an unspecified diameter (Wallis provided scales for 1000, 750,500 and 250ft.) Bowen (1984) wrote: "Characteristically, his original drawing did not give a diameter, but he was quite certain that such an instrument could be built up to a thousand feet in diameter and he encouraged us to go for it and hang the cost!" The final FFP design (of 1959)

[46] In the completed Parkes radio telescope, the "spirals" became the spiral purlins or the geodetic structure, ensuring that the surface of the dish maintained a parabolic shape due to varying gravitational forces as the dish is tipped.

did include a number of the innovations proposed by Barnes Wallis, especially the spiral purlin and master equatorial. In Fig 6b we show the final GRT design of FFP circa 1961.

Ironically, a schism between FFP and Wallis developed toward the end of the design phase (possibly 1957; unfortunately, the date remains uncertain). On 12 March 1959[47], Bowen wrote White about the possibility of paying the fee of £1,000 to Wallis (to be paid to a RAF charity in Wallis's name, the Royal Air Force Foundation of Christ's Hospital School).

> As you know, Barnes Wallis did play an important role in the design study ... Unfortunately, towards the end of the design study he [Barnes Wallis] suffered some of the frustration which I have been suffering myself during the past few weeks, and he lost patience with Freeman Fox. He told them to jump in the lake in quite colourful terms and, among other things, told them to forget about this fee.

Apparently FFP did not tell RPL about this at the time- circa 1957. A month later in 1959 (20 April)), Bowen wrote Wallis with an apology about the trouble with FFP, "… [W]e have run into similar troubles ourselves and can quite understand your point of view." Six weeks later, Bowen told White: "Unfortunately for us he has some hard feelings about the part he was able to play in the Telescope and his relations with Freeman Fox." For the next few years, Wallis did meet Bowen in London on several occasions; in 1961 and 1963 Bowen wrote letters to Wallis with glowing descriptions of the new scientific results that the Parkes telescope was producing. In the end the fee was never paid to Barnes Wallis.[48]

Rockefeller Foundation– end of 1955

Since the contacts between Weaver and Bowen in June 1955, Bowen had kept the Rockefeller Foundation up to date on progress with the design study. There was an expectation that the foundation would reply within some months. Shortly after his return from the US and the UK in mid-August 1955, Bowen wrote Casey with a request for an interview, undoubtedly to tell him the status of the design study plans. Bowen told Casey that the Rockefeller and Ford Foundations would be coming to a decision about the GRT grant applications in mid-September 1955. As the Foreign Minister of Australia (in addition to being Minister in Charge of CSIRO), Casey would be visiting New York to attend the United Nations from 10 to 30 September 1955. Bowen was anxious that the foundations hear the viewpoint of the Australian government about the GRT. Bowen then wrote the two foundations with the suggestion that Casey could

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[47] NAA C3830 A1/3/11/32.

[48] See the Royal Society obituary of Barnes Wallis: Pugsley, A., & Rowe, N. E. (1981). Barnes Neville Wallis. 26 September 1887-30 October 1979. *Biographical Memoirs of Fellows of the Royal Society*, *27*, 603-627.

visit. Unfortunately Weaver was to be in Japan; Dean Rusk, the President of the Rockefeller Foundation (soon to be Secretary of State in the Kennedy and Johnson administrations of the 1960s), wrote to Bowen on 24 August 1955, "we should be delighted to talk to him [Casey] while he is here in September". Rowan Gaither, the President of the Ford Foundation and a personal friend of Bowen's, was reserved: "Since further consideration at this time of the giant radio telescope project may be premature, I hesitate to impose upon Mr. Casey's time. He knows, of course, that he is always welcome at the Foundation." Later in the year, the Ford Foundation informed the Australians that they were not ready to make grants for physical science projects. On 8 December 1955, Casey was informed by the Rockefeller Foundation that the sum of $250,000 was awarded to CSIRO in the period Jan 1956-1959 for the construction of the GRT. Contrary to Bowen's recollections (1981), the Rockefeller Foundation made no stipulations about matching funds at this time in the negotiation; in any case Menzies had already stated six months earlier that the government would match the private grants "pound for pound". The official announcement of the grant to the Australians was made on 17 December 1955 with a news release. As we shall see, in 1959 the Rockefeller Foundation was to make an additional grant of $130,000 after the bids for construction were received and an additional budget shortfall occurred.

The Design Study with FFP is formalised

After Pawsey's visit to the UK in August-September 1955[49] and the meeting of Bowen and Pawsey with Clunies Ross and White on 26 October 1955, the stage was set to formalise the design contract with FFP. An official letter with the terms of the design study was sent on 16 November 1955 from FFP to Bowen in Sydney; the contract would be settled by an exchange of letters. The Australian response (from White) was sent back to FFP on 28 November, with some suggested modifications. The final version was sent to White on 23 December 1955; this was accepted by the Australians in January 1956.

Robertson (1992, "Beyond Southern Skies: Radio Astronomy and the Parkes Telescope." Cambridge University Press) has provided an excellent summary of the five main conditions of the proposed design study[50]:

> (1) To investigate the structure of the aerial, including the surface, the mount, the foundations including both a rigid structure and a self-compensating structure. The choice of materials whether steel, alloys or combinations was to be studied.

[49] On 28 September 1955, Pawsey had initiated the process in his meeting with Freeman and Roberts.
[50] NAA C3830 A1/3/11/1 Part 5

(2) To investigate the two choices of mounting: alt-azimuth or equatorial with the attendant drive and control systems.

(3) To examine the cost of the dish as a function of dish diameter.

(4) To initiate any required outside tests to evaluate stresses and deflexions. Examples would be wind tunnel tests to evaluate survivability and pointing issues.

(5) To evaluate effects of temperature changes on the performance of the dish.

(6) To prepare a report allowing a decision to be made on the size and nature of the aerial consistent with the total funds available.

There had been discussion that the design study could be completed in six months; in any case, FFP had agreed to provide an interim report by June 1956. However, the 16 November 1955 document did not mention a fixed time-line. As we will see, the discussion of the time scale for the study was to become contentious. There was also discussion of the processes that were to be followed in case FFP were to become the consulting engineers to supervise the tendering process and later the construction of the GRT.

White (CEO of CSIRO) responded on 28 November 1955. There was agreement on most points. The basis for the design study was to be the "Specification of a Giant Radio Telescope for Which a Design Study is Required", the version of 23 November 1955. White was insistent on one point: "We feel too that there should be some understanding about the approximate time for the completion of this design study. In discussions with Dr. Pawsey it was suggested that the design study might be completed in about six months. It is important to CSIRO to have the design completed promptly and it is understood that you will endeavour to complete it in a period of this order." White informed FFP that Prof J.W. (Jack) Roderick (member of the Technical Advisory Committee), Civil Engineering, University of Sydney, was departing Sydney on 28 November 1955 for London. The purpose of his extended stay in London was to discuss the specifications with FFP. He was to discuss the points in White's 28 November 1955 letter; then a final letter of agreement could be posted from FPP to White in Melbourne. White was optimistic that final agreement would be reached in the next weeks.

After Roderick had been in London for some weeks, he sent surprising news about the contentious issue of time-scales. "They [FFP] also had second thoughts on the duration of the design study, mainly as a result of the views expressed by Wallis. I gather he would like to be entirely free of any time limit, and while I would naturally not agree with this I realise from what has been said here that wind tunnel and other model tests may make it impossible to reach any worthwhile conclusions in six months."

The final version of the "Proposed Radio Telescope Design Study" was sent from FFP to White on 23 December 1955; this was accepted by White on 31 January 1956. There were two key points in Freeman's response:

> ... When the Study is completed our estimate of cost will include an item for professional fees and will at that time also give you a statement of how our fees [in case FFP were to be chosen as the consulting engineers for construction] would be assessed. We would be prepared to merge in those fees such part of the study fee as might fairly represent design work directly useful to the development of the project. We would of course be prepared to call competitive tenders for construction [of the GRT].

The controversial point of the six-month time-limit was not accepted. FFP were of course anxious to complete the study but could not promise to do so within six months. The major problem was uncertain timescales for the experimental work: "We shall do our utmost to complete our report in six months and if we find it will take appreciably longer we shall let you have an interim report at the end of June 1956 indicating the stage that our investigation has reached and the conclusions that may be drawn from it."

As will be seen (Chapter 27 and NRAO ONLINE 42 and 43), there was an interim report in September 1956 with the full report a year later.

ADDITIONAL NOTE 1: **7 December 1955, Discussions of Possible Uses of the GRT**

On 7 December 1955, Pawsey and Minnett organised a meeting with Mills, Kerr and Christiansen to continue the discussions earlier in the year concerning possible uses of the GRT and the implementation of instrumentation planning. A final report was written on 16 December 1955.

The agenda consisted of three major categories: (1) scanning and following routines for the telescope; (2) location of the radio equipment and laboratory arrangements and (3) allocation of responsibilities.

A schematic diagram of the control room of the GRT was discussed with locations of various displays for the observers. The anticipated personnel were Station Manager, Director, control and maintenance staff plus the radio astronomers and assistants.

A prescient list of applications for the new GRT consisted of:

(1) "Single frequency surveys of cosmic noise over whole or part of the sky"

(2) "Multi-frequency eg H line surveys of cosmic noise over whole or part sky"

(3) "Survey of regions of intense sources – e.g. to establish directional diagram of the aerial"

(4) "Search for new lines"

(5) "Single or multi-frequency observations of the sun and planets"[51]

(6) "One element of an interferometer"

(7) "Form an image in focal plane, which is either scanned or examined by an array of separate pick-up aerials and receivers**."** **This proposal may be the first discussion in Australia of a multi-feed array**. [our emphasis] Forty years later, the Parkes telescope 13 beam focal plane array at 21 cm began operation in 1997. (Staveley-Smith, L., Wilson, W. E., Bird, T. S., Disney, M. J., Ekers, R. D., Freeman, K. C., ... & Wright, A. E. (1996). The Parkes 21 CM multibeam receiver. *Publications of the Astronomical Society of Australia*, *13*, 243-248)

(8) "Radar-long wavelength of sun, moon and planets"

(9) "Radar – short wavelengths – same objects"[52]

(10) Calibration procedures. "Direct feed aerial away from dish – switch to auxiliary aerial" (i.e., beam switching).

Fig 1 Foreword of *A Proposal for a Giant Radio Telescope* by Bowen and Pawsey, May 1955

[51] Solar observations were never attempted.

[52] Radar at Parkes was not implemented

FOREWORD

THE YOUNG SCIENCE of radio astronomy is rapidly extending our knowledge of the universe around us. In all this work Australia has played a foremost part.

The time has now been reached where the greatest advances in radio astronomy will come from the use of a very large radio telescope. Such an instrument is already under construction in England, and a strong case can be made out for building a second one in Australia.

The Carnegie Corporation has made a very generous grant of $250,000 (about a quarter of the required sum) to C.S.I.R.O. for this purpose, on condition that the remainder of the money is obtained from other sources. The design requirements and the programme of research which would be carried out with an instrument of this type have been considered in great detail. If the remaining sum of money can be found, the project will be put in the hands of an engineering contractor immediately, with the Radiophysics Laboratory exercising close supervision.

This booklet has the dual objectives of stating a case for building a giant radio telescope in Australia, and giving a detailed discussion of the design factors. It begins with an account of the new science of radio astronomy and the reasons for the construction of the proposed instrument. The astronomical and technical factors involved in the design are discussed at length, leading to a tentative specification. The factors governing the choice of site for the instrument are then stated, some possible methods of construction are illustrated, and an estimate is made of the overall cost.

E G Bowen

Chief, Division of Radiophysics

J L Pawsey

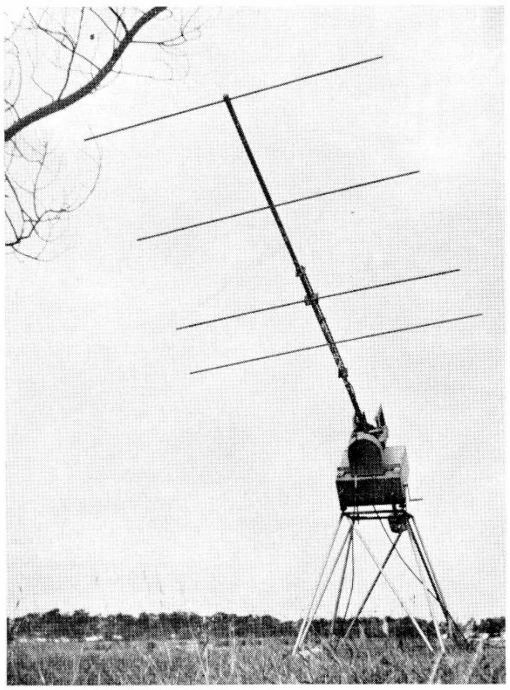
Assistant Chief

Fig 2. Introduction of the Proposal for a Giant Radio Telescope

RADIO ASTRONOMY

RADIO ASTRONOMY IS THE STUDY OF celestial bodies by observation of radio waves which they emit or reflect. This new science has come into prominence only since the end of the war, but in a very short time it has taken an important place alongside optical astronomy and already it has a number of exciting scientific discoveries to its credit. In the pioneering years of the new science, rapid progress was made with relatively simple radio techniques and simple equipment. The stage has now been reached, however, where many of the current problems can be solved only with more powerful equipment than is at present available. In particular, the smaller aerials used so far neither receive enough energy from the distant objects nor locate them with sufficient precision.

Australia has established a leading position in radio astronomy, but *this can be maintained only if a very large aerial is built in this country.*



A YAGI AERIAL, *one of the simple types used in the early days of radio astronomy.*

PART OF THE MILKY WAY, *in the constellation of Sagittarius, as seen by the 100-inch telescope at Mt. Wilson. Hundreds of millions of stars can be seen by such a telescope, but radio observations show that the Milky Way extends far beyond the telescope's limit of visibility.* (Mt. Wilson-Palomar photograph.)

Fig 3. The “swashplate design”, a favourite of Bowen. Jacks on turntable: the reflector is carried and tilted by a system of jacks mounted on a rotating platform. From *A Proposal for a Giant Radio Telescope* by Bowen and Pawsey, May 1955

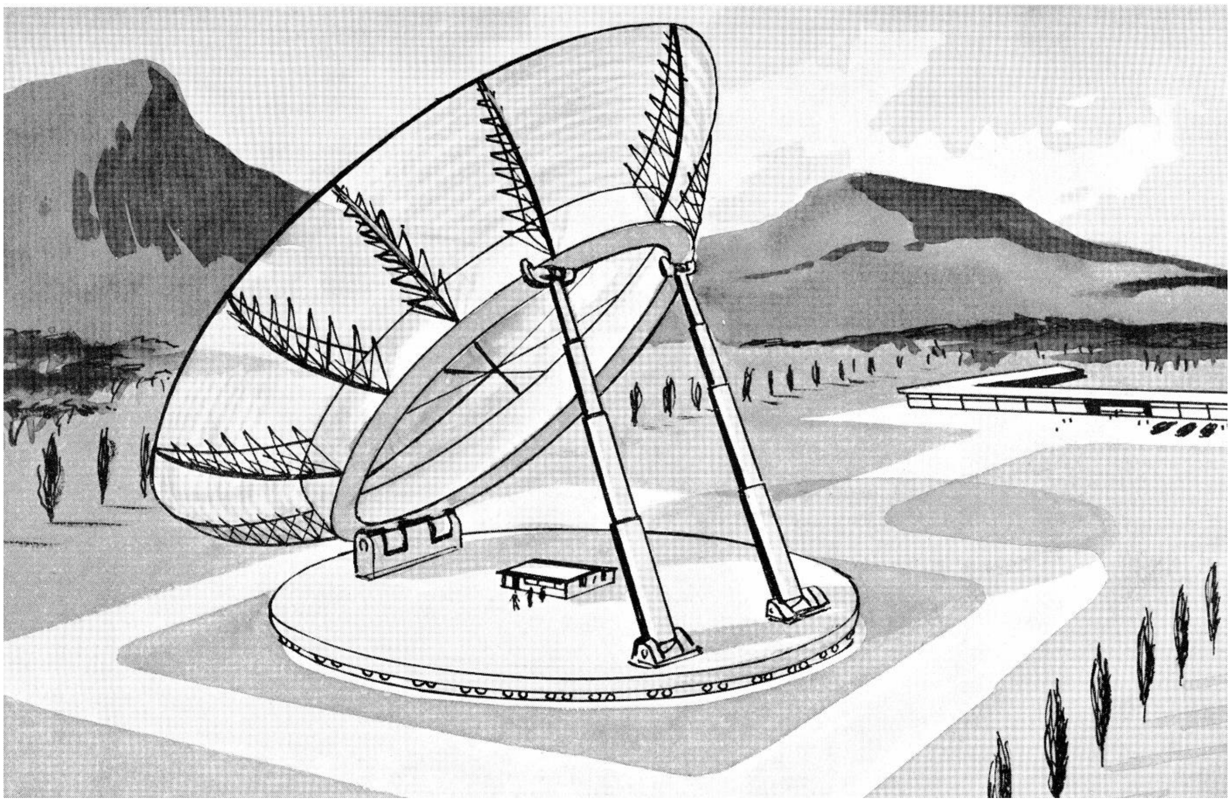


Fig 4. A "hole in the ground" antenna. Reflector moving on tracks inside a hemispherical hole in the ground. A very large excavation is required but some of the structural and windage difficulties are overcome. *A Proposal for a Giant Radio Telescope* by Bowen and Pawsey, May 1955

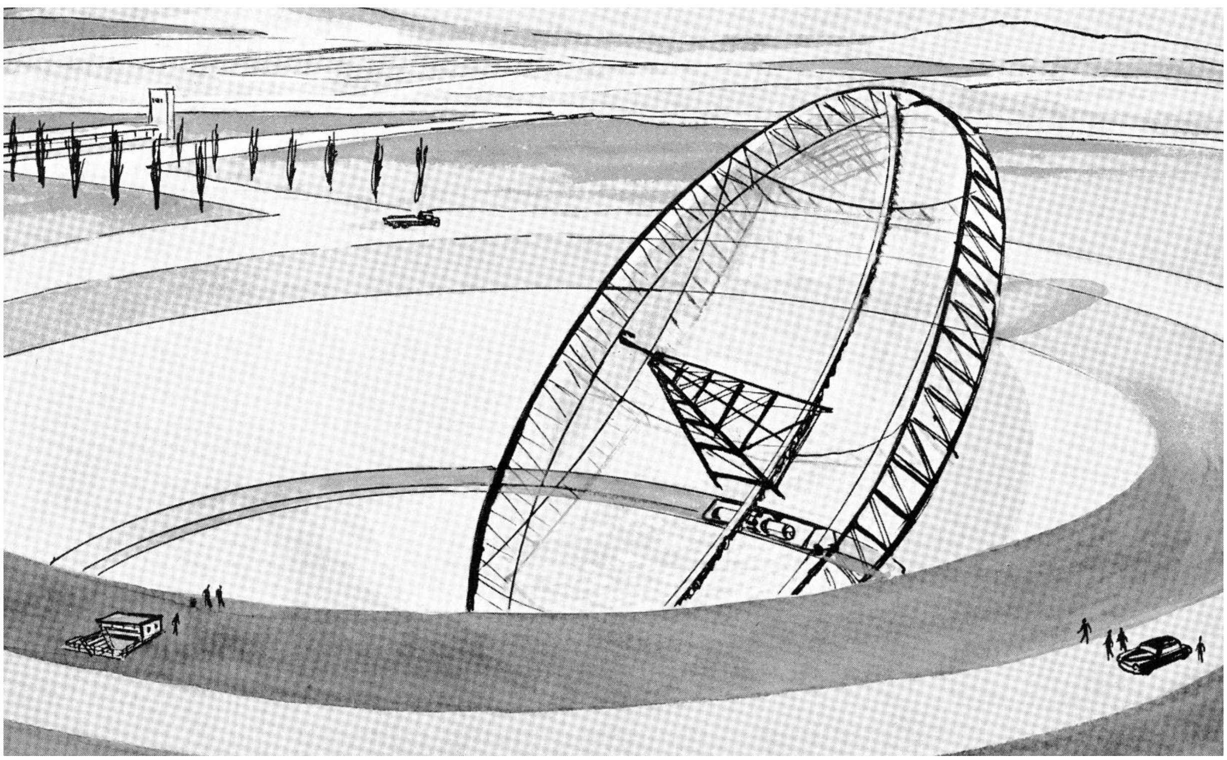


Fig.5. conventional design of a horizontal yoke carried on a central support. Similar to the final design of the Freeman Fox design of the GRT. *A Proposal for a Giant Radio Telescope* by Bowen and Pawsey, May 1955

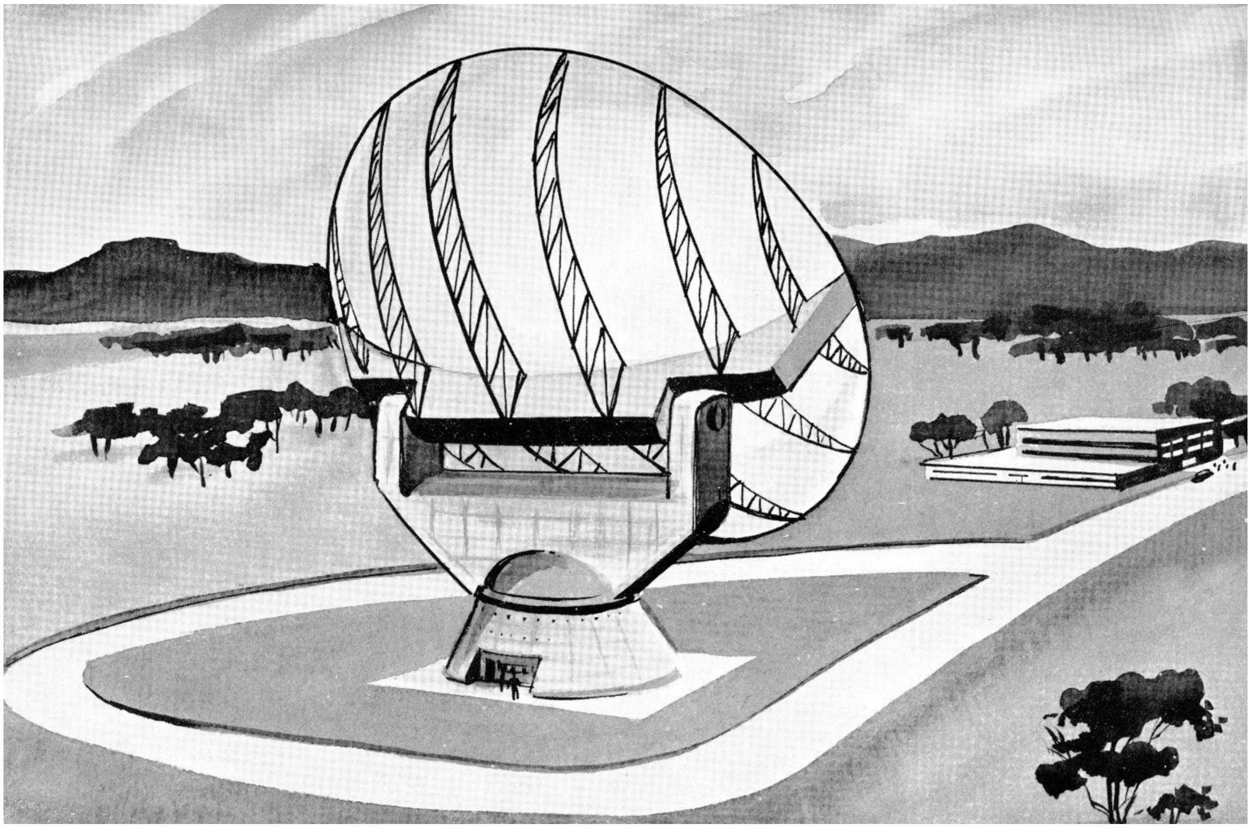
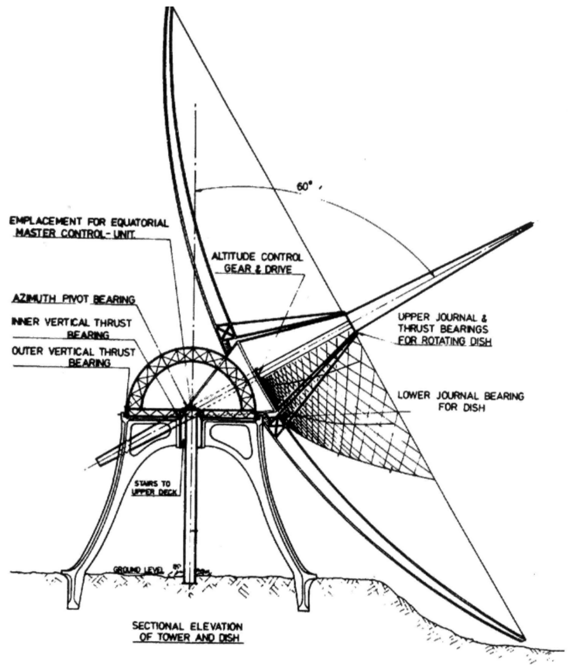
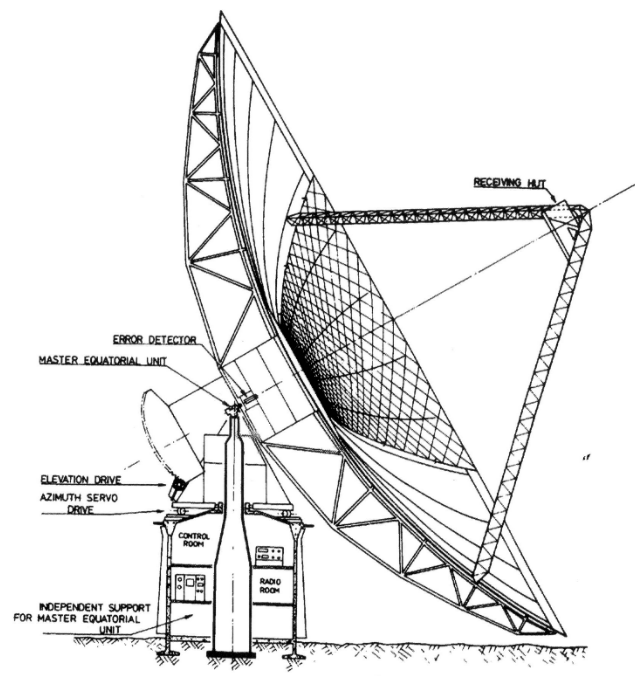


Fig 6 . The Barnes Wallis Proposal from Sept 1955 (Fig.6a) and the Parkes Radio Telescope of 1961 (Fig. 6b)



BARNES WALLIS'S ORIGINAL CONCEPT OF SEPT. 1955



THE PARKES RADIO TELESCOPE 1961