Early Dutch radio astronomy (1940-1970) : the people and the politics

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CHAPTER IV: DESIGNING, CONSTRUCTING, AND USING THE NEW LARGE RADIO TELESCOPE

The first elaborate design of the new large radio telescope was presented in 1961. Later, at least four other designs followed. The telescope that was inaugurated in 1970 was indeed completely different from the design of 1961. In this chapter, we explore the reasons *why* the Dutch changed the design several times. As we will see, these reasons were sometimes scientific, but often they were also practical, political, and / or economic. Although on a much smaller scale, this radio telescope project was to a certain extent comparable to the making of the Hubble Space Telescope (launched on 24 April 1990). As the American historian of science Robert Smith said about the latter: design choices were not outside the political process of winning approval (Smith, 1992, p. 191). In our story, special attention will be paid to the developments abroad and to the hiring of foreigners for the project, as these factors truly 'shaped' the eventual design as well as the observational programme of the telescope.

In the mid-1960s, when the final design was put out to tender, a suitable location had to be found for the telescope. We explore why, after years of site surveys, a region close to the village of Westerbork (Drenthe) was finally chosen. Before this area was ready for use, some very serious obstacles had to be removed. For example, a military shooting range had to be closed and a number of Ambonese families had to be moved. How did Oort succeed in overcoming these obstacles and what does this reveal about his influence and the prestige of radio astronomy in general?

The construction of the telescope cost millions of Dutch guilders and hence, it was one of the most expensive Dutch scientific projects. (Other fields that consumed a great deal of money were nuclear physics and – since the mid-1960s – also space research.) First of all, we take a closer look at the rhetoric Oort used to get this expensive project accepted by the Belgian and Dutch governments. Then we consider two problems: first, the Belgians paid their share only after years of delays, and second, from the mid-1960s, Dutch government budgets were tightening. Then the question arises: *how* did ZWO – especially its director, Bannier - and the radio astronomers – especially Oort - deal with these problems?

Finally, we take a closer look at the development of the observational programme. The plans for the radio telescope were made at a time when cosmology and 'source counts' were hot topics in radio astronomy. Initially, the main research goal of the Dutch was to use radio source counts and radio source sizes to study cosmology. Indeed, this was even one of the justifications for building the new radio telescope. In the end, however, the telescope would be used for very different purposes. Why?

4.1 THE FIRST DESIGN: A LARGE CROSS ANTENNA FOR OBSERVATIONS AT 75 CM

As shown in the previous chapter, shortly after the commissioning of the radio telescope in Dwingeloo, ideas arose to build a larger and better instrument. In one of the early reports on the 'cross antenna project', we read *why* it was judged necessary to build this new telescope:

> The purpose of the project is to provide a radiotelescope of which the resolving power is of the order of one minute of arc, i.e. about 30 times better than what has so far been reached for metre waves, while at the same time the sensitivity (the smallest signal that it can clearly measure) is a factor 1000 greater than that of a conventional large telescope like the 25-metre paraboloid in Dwingeloo.[1]

At that time, radio astronomers all over the world were trying to build instruments with a higher sensitivity and, especially, a higher resolution (i.e. the power to distinguish details). Indeed, in the summer of 1958, Oort said that the 25-metre telescope in Dwingeloo 'works marvellously and produces very beautiful results. But in a few years' time it will no longer be able to compete with much larger instruments which are being built elsewhere.'[2] So if the Dutch aimed to stay at the forefront, no time should be wasted.

The first conceptual proposal for a large cross-shaped radio telescope, as we saw, was written in 1958 by the American engineer and radio amateur Charles L. Seeger. The idea was to construct a large array of small moveable antennas mounted on a horizontal plane and covering two perpendicular strips about 3 km long and about 30 metres wide. No definite suggestion of operating wavelength was made (Raimond, 1996, p. 17). However, it was said that the antenna should probably be designed to work at a wavelength of between 50 and 100 cm. More specific, 75 cm was a reasonable possibility. We assume that the choice for 75 cm had something to do with the following considerations. First of all, from a technical point of view, a low frequency (such as 75 cm), requires simpler receivers and has more relaxed constraints on dish accuracy. Moreover, non-thermal radio emission (as emitted by cosmic sources) is much stronger at low frequencies than at high frequencies. (Because the number of cosmic (point) sources increases rapidly with limiting flux density, this has an important effect.) And very important: 75 cm (or 408 MHz) was a protected frequency.[3]

We also assume that the choice for this wavelength had probably something to do with Seeger's experience: as we saw, he had previously developed a receiver for the Dwingeloo telescope to do continuum observations at 75 cm. At 75 cm, eruptions of the Sun could be measured, it was also a useful wavelength for Galactic and extragalactic research and for polarisation measurements. A few years earlier, when the observational programme of the Dwingeloo telescope was discussed, Oort said the following about this wavelength:

> The plan is first of all in Dwingeloo to measure the Sun at this wavelength, especially the 'eruptions' that regularly occur in the region of the radio waves. (…) This work will be done

[1] Coutrez, R., BCAP: interim report and cost estimate, June 1961, SA, NWO.
[2] Oort to Swings, 10 September 1958, SA, NWO.
[3] Personal communication of Leiden astronomer Frank Israel to author, 3 June 2014.

> with one of the 7 ½ -m mirrors. With the same receiver, as well with the 7 ½-m mirror as with the 25-m mirror, both Galactic and extragalactic radiation will be measured at 75 cm.[4]

During the years 1958 – 1960, Seeger would develop several instruments to perform polarisation measurements at 75 cm in a large region of the sky.

As Seeger's proposal was positively received at the meeting of the board of SRZM on 21 October 1958, it was decided that this idea should be further elaborated.[5] This was indeed done by two foreign scientists that were hired: the engineer, physicist and pioneer of Australian radio astronomy W.N. Christiansen and the Swedish astronomer J.A. Högbom. The importance of the hiring of these two men can hardly be overestimated: as we will explain, it greatly strengthened the connection between Dutch radio astronomy and radio astronomy in Australia and the UK, two other countries that were at the forefront in this field.

Christiansen and Högbom presented the first detailed design for the radio telescope in early 1961.[6] It was in fact an advanced version of the 'Mills cross' (see previous chapter), as Mills was by then 'the only person who has had much experience in using a cross-antenna for galactic and extra-galactic radio observations'.[7] The cross antenna would consist of cylindrical parabolic reflectors, each 30 metres in size, the axes of which lie in an east-west direction in both arms of the cross. The reflectors would be arranged in parallel east-west rows. The size suggested for each of the two arms of the cross antenna was 5000 m x 60 m. An array of four parallel lines of antennas would be used for the east-west arm. For the north-south arm, several hundred of parabolic cylinders would be used.

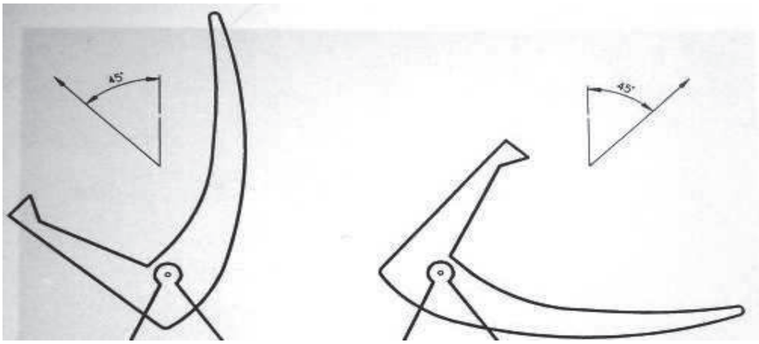

FIGURE 7. Cross-sections of the parabolic cylinders which were to be the basic elements of the Cross Antenna (Raimond, p. 1996, p. 21)

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[4] 'Het plan is om op deze golflengte in Dwingeloo vooreerst de zon te gaan meten, en in 't bijzonder de "erupties" die de zon telkens vertoont in 't gebied der radiogolven. (...) Dit werk zal met een der 7 ½ –meter spiegels gedaan zorden. Met dezelfde ontvanger zal zowel in de 7 ½- meter als ook in de 25-meter spiegel de straling van de Melkweg bij 75 cm golglengte gemeten worden en tevens de straling die uit het heelal buiten het Melkwegstelsel komt.' Oort, J.H., Iets over de onderzoekingen die in Dwingeloo in het eeerste jaar gedaan zullen worden, OA, 256.

[5] Minutes of the executive committee meeting of SRZM of 21 October 1958, SA.

[6] Christiansen, W.N. and Högbom, J.A., Benelux Cross Antenna Project. BCAP Technical Report No. 3. 'A design for the Benelux Cross Antenna', 1961, SA, NWO.

[7] Christiansen, W.N. and Högbom, J.A., Benelux Cross Antenna Project. BCAP Technical Report No. 3. 'A design for the Benelux Cross Antenna', 1961, SA, NWO.

The chosen wavelength was again approximately 75 cm (406-410 MHz). It is not explained *why* this wavelength was preferred, but according to E. Raimond[8], this choice was relatively arbitrary - like in the conceptual proposal of Seeger - and probably based on the successful observations of others at 75 cm (Raimond, 1996, p. 19). However, we think the choice of 75 cm was not entirely arbitrary. During 1960, the Dutch group seems to have tackled the question of the frequency to be chosen for the Benelux Cross Antenna. Seeger had visited the radio astronomy groups in Bologna and Cambridge. The group in Bologna was led by Professor Marcello Ceccarelli, who had initiated radio astronomy in Italy (Perola, 2006, p. 174). During a meeting of the Council of the BCAP on 29 November 1960, Seeger explained that the Bologna radio astronomy group was going ahead with extensive plans for 327 MHz (approximately 91 cm). He thought that therefore the use of a similar frequency in the Netherlands was undesirable. In Manchester, the 606-614 MHz (about 50 cm) band was successfully used, although it was not assigned to radio astronomy. This frequency was the gap between a European civilian radar band and the official worldwide UHF (610-940 MHz) TV band, which was not yet occupied. Seeger's conclusion was that the 406-410 MHz band (75 cm) remained the best choice, 'most particularly because the cross will be a general-purpose instrument and because this is one band recognized in Europe for radio astronomy'.[9] The other members of the Council agreed with Seeger. Rinia remarked that, as Europe needed many more broadcast frequencies than did the USA, one could expect enormous opposition to giving up any TV frequencies to radio astronomy. Moreover, the broadcast interests had well-developed plans for expansion in the 400-940 MHz band. This led Oort to acknowledge again that choosing and obtaining protection for a frequency for radio astronomy was a 'very important and difficult problem' [10] and that the 'Inter Union Committee on Frequency Allocations for Radio Astronomy and Space Research', which had recently been established by the ICSU (International Council of Scientific Unions) , should be invited to consider the matter with urgency.

This design of Christiansen and Högbom was discussed at the meeting of the Council of the BCAP on 21 February 1961 and it was received very positively. Van de Hulst called it a 'fine piece of work, cutting down the great number of possibilities to one possible design.'[11] No estimate was mentioned of the cost of the project. Therefore, it was decided at the Council meeting that a firm of consulting engineers, viz. Dwars, Heederik, Verhey in Amersfoort would be contracted to make a more detailed design and a cost estimate of the steel frames and foundations for the radio telescope.[12] This was ready in May 1961.[13] After including all other elements (electronics, terrain etc.) the astronomers came to the conclusion that the total investment costs of the project would be about Dfl 25 000 000:[14]

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[8] Ernst Raimond himself belonged to the first generation of radio astronomers in the Netherlands. After he had obtained his PhD in Leiden in 1964, he spent two years at Caltech and then joined SRZM. He directed the online control system of the WSRT and participated in the programming. He became the first director of the WSRT in 1970, see : Noordam, J., Biographical Memoir – Ernst Raimond, 2011, at : http://rahist.nrao.edu/raimond_bio-memoir.shtml (Accessed on 29 August 2012).
[9] Minutes of the Council meeting of the BCAP of 29 November 1960, SA.
[10] Minutes of the Council meeting of the BCAP of 29 November 1960, SA.
[11] Minutes of the Council meeting of the BCAP of 21 February 1961, SA.
[12] Minutes of the Council meeting of the BCAP of 21 February 1961, SA.
[13] Dwars, Heederik & Verwey, 'Interim Report – May 1961. Preliminary design of steel frames and foundations for a very large Cross Aerial' SA, NWO.
[14] 'Preliminary budget'[1961], SA, NWO.

AERIALS Steel structure Foundations Electrical and mechanical drives	Dfl 18 500 000
ELECTRONICS Antennae, transmission lines Mixers Central apparatus	Dfl 4 000 000
ELECTRICITY Power Line **SUPPLY** Cables along aerials	Dfl 500 000
FACILITIES Laboratory and workshop buildings Roads for access and along aerials	Dfl 500 000
TERRAIN Including farms to be used as housing	Dfl 1 500 000
TOTAL	**Dfl 25 000 000**

Besides the investment costs, there was also annual operating costs, including the cost of the personnel. These were estimated at Dfl 400 000:[15]

PERSONNEL 5 staff positions 8 technical positions	Dfl 100 000 Dfl 100 000
APPARATUS Auxiliary instruments	Dfl 30 000
MAINTENANCE Structures and drives Electronic apparatus	Dfl 30 000 Dfl 100 000
UNFORESEEN Including insurance for storm damage	Dfl 40 000
TOTAL	**Dfl 400 000**

At the next meeting of the Council of the BCAP on 27 June 1961, Oort mentioned that, to avoid delays, it would be necessary to approach the governments of both Belgium and the Netherlands as soon as possible.[16] In July 1961, an 'Interim Report and Cost Estimate'[17] was sent to the Belgian

[15] 'Preliminary budget'[1961], SA, NWO.
[16] Minutes of the Council meeting of the BCAP, 27 June 1961, SA.
[17] 'Benelux Cross Antenna Project. Interim Report and Cost Estimate' [1961], SA, NWO.

and Dutch Ministries of Education.[18] The report explained what the telescope would look like and what research purposes it would serve. It emphasised that the resolving power of one minute of arc was absolutely necessary for an adequate investigation of radio sources within the Galactic System and the nearest other galaxies, and certainly for the study of the most distant parts of the universe. To make clear that the project was not just another megalomaniac idea, but that it was indeed feasible, the design of Christiansen and Högbom was enclosed as an appendix.

The report clearly appealed to a then existing sentiment of what we could call 'Benelux idealism'. When the Benelux was founded, many joint initiatives were taken to bring prosperity and progress into these countries. Scientific cooperation was one of these:

> The project would provide the Benelux countries with a piece of scientific equipment that is unique in the world. The acquisition of such an instrument would certainly become an important factor in stimulating scientific research in the countries concerned. Already in its preliminary stages it has attracted a number of top experts in electronics from other countries for the design work. There is no doubt that the completed telescope will greatly increase the number of foreign scientists who will want to spend some time in the Benelux; it can hardly be doubted that this will be to the advantage of our countries.[19]

There can be no doubt that Oort *used* this Benelux rhetoric as a vehicle to get his project accepted. As mentioned above, he was not interested in international cooperation in itself. As a real pragmatist, he just tried to find the ways to get his projects realised as quickly as possible.

Matters of 'pure science' were emphasised, for example where the report said: 'It may be hoped that a telescope of the size envisaged will provide some insight in the outer limits of the expanding universe, as well as in its origin.'[20] Of course, it was also important to mention applications. Remember that when funding was asked for the building of the radio telescope in Dwingeloo, the 'practical applications' of that project were also emphasised. Now, the situation was no different. The report said:

> In the past, scientific research, even in domains which at the time seemed to be of no practical importance, has always proved to pay, by discoveries that led to unexpected technical applications. There is every reason to expect that this will continue to be so, and that it is therefore economically justified to spend relatively large amounts on scientific projects that have no direct practical application. In the present case the research envisaged is so closely tied up with practical problems, such as the construction of stable, low-noise receivers that there will also be a direct stimulation of research in important growth areas of technical science.[21]

Note that these promises of applications remain – as usual - very vague. As we saw in the previous chapter, things were very different in Belgium. Around 1960, in Belgium there was a great

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[18] Coutrez and Oort to the Minister of Education, Arts, and Sciences, 4 July 1961; Coutrez and Oort to the Minister of Education, 4 July 1961, SA, NWO.
[19] 'Benelux Cross Antenna Project. Interim Report and Cost Estimate' [1961], p. 3, SA, NWO.
[20] 'Benelux Cross Antenna Project. Interim Report and Cost Estimate' [1961], p. 3, SA, NWO.
[21] 'Benelux Cross Antenna Project. Interim Report and Cost Estimate' [1961], p. 3, SA, NWO.

emphasis on industrialisation, and scientific projects had to make very explicit what industrial benefits could be expected, if they wanted to be eligible for funding.

In the letter to the Dutch Minister that accompanied the report, it was stressed that 'already in the budget of 1962, money should be reserved for the construction, because otherwise most of the activities that were now in full swing should be ended.'[22] In September 1961, the Dutch government took the decision to support the project.[23] In the same month, the budget for 1962 of SRZM was sent to ZWO. As in the previous estimate, it was said that the total construction cost of the telescope would be Dfl 25 000 000. The estimate of the annual cost, however, was reduced to Dfl 300 000. This amount had to be divided over the two countries (Belgium and the Netherlands).[24]

In the meantime, something had changed in the funding process of ZWO. Starting in 1962, the budget that the Dutch government provided for ZWO, was divided into an 'ordinary budget ('gewone dienst') and an 'extraordinary budget' ('buitengewone dienst'). The ordinary budget was meant for research and apparatus and the extraordinary budget for investment in apparatus and construction.[25] This division of the budget was in the first place due to the rising construction and apparatus costs of certain projects, especially those of FOM (the organisation for nuclear research, see Chapter II). Especially in the late 1950s, tensions between FOM and ZWO grew, as ZWO could no longer comply with FOM's growing demand for funding (Kersten, 1996, p. 136ff). Until 1962, FOM sometimes received additional funding for the building and construction of laboratories that came *directly* from the government instead of from ZWO. This meant, however, that not all scientific projects were treated the same way. In order to restore fair treatment, it was decided that all applicants had to follow the same procedure for all kinds of funding. Extraordinarily large budgets, for example for the construction of a laboratory or a telescope, should thence be funded out of the extraordinary budget of ZWO. Of course this had as a consequence that the total budget of ZWO increased considerably: from Dfl 9 911 137, 80 in 1961 to Dfl 17 364 651,28 (ordinary budget = Dfl 12 613 651,28 and extraordinary budget = Dfl 4 751 000) in 1962.[26]

For the radio astronomers, this meant that the annual costs had to be paid out of the ordinary budget, the investment costs out of the extraordinary budget. Not entirely surprising, the budget of SRZM for 1962 was approved by ZWO without any trouble. This meant that, for that year, the astronomers got Dfl 150 000 (half of Dfl 300 000, the other 150 000 had to be paid by Belgium) of the ordinary budget. At the same time, it was decided to earmark an amount of Dfl 1 000 000 from the extraordinary budget, to cover a first part of the investments cost for the new large radio telescope. This amount, however, would not be made available as long as the Belgian government had not made an official decision about participation.[27]

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[22] 'dat reeds op de begroting van 1962 gelden voor de bouw uitgetrokken worden, daar anders de meeste der thans op volle gang zijnde werkzaamheden stilgelegd zouden moeten worden.' Coutrez and Oort to the Minister of Education, Arts, and Sciences, 4 July 1961, SA, NWO.
[23] Minutes of the Council meeting of ZWO of 22 December 1961, SA, NWO.
[24] Blaauw to the director of ZWO, 5 September 1961, SA, NWO.
[25] Annual report ZWO 1960, pp. 18-19.
[26] Annual reports ZWO 1961 and 1962.
[27] Minutes of the board meeting of ZWO of 16 December 1961, SA, NWO.

4.1.1 THE COOPERATION WITH AUSTRALIA: LIVING APART TOGETHER

It is worthwhile to give some special attention to Christiansen, who made this first design together with Högbom. The hiring of Christiansen fits a tradition of intense Australian-Dutch cooperation which can be traced back to 1951, when in the Netherlands, Harvard and Australia attempts were made to detect the 21-cm hydrogen line (see Chapter II). About these days, the Australian astronomer F.J. Kerr said: 'This whole episode was a fine example of international cooperation, which has always been the hallmark of most of the relationships in radio astronomy' (Kerr, 1984, p. 138).

Afterwards, Dutch radio astronomers stayed in touch with their Australian colleagues. In 1957, Kerr came to Leiden for several months and he and Gart Westerhout joined their respective maps to derive the first overall look at the hydrogen in the Galaxy. This map became known as the famous 'Leiden-Sydney map of the Milky Way' (Oort, Kerr and Westerhout, 1958) (see Chapter II).

Equally in the late 1950s, in Australia preparations were made for the construction of the Parkes radio telescope. As a matter of fact, since the late 1940s, E.G. Bowen, chief of the CSIRO Division of Radiophysics, and some of his colleagues had been thinking of building a large single-dish radio telescope. The reason for this may seem rather peculiar: it was not a specific research programme that lay at the base of the wish to build this instrument, but it was in the first place the conviction that radio astronomy would soon evolve in the same way as optical astronomy, where the best science and the important discoveries were carried out with the largest and most powerful optical telescopes (Robertson, 2011, p. 2). The crucial event that convinced Bowen that a large general-purpose telescope was the way of the future came in 1951, when Lovell's group at Jodrell Bank announced plans to build a giant parabolic dish. If Australia wanted to stay at the forefront in radio astronomy, it should build a giant dish too, according to Bowen (Robertson, 2011, p. 2). It is noteworthy that, notwithstanding the fact that the first radio astronomers were mostly not trained as astronomers, already in the early 1950s the idea prevailed to build 'ever larger and better radio telescopes' analogous to 'ever larger and better optical telescopes'.

What the Australians needed for their large radio telescope in the first place were good receivers. Since the start of radio astronomy at the CSIRO Division of Radiophysics, receivers had usually been improvised as the need arose. When the preparations for Parkes were made, Joseph Pawsey – assistant chief of the CSIRO division of Radiophysics until 1962 - decided this had to change. In august 1959 he established a specialist group to concentrate solely on receiver technology (Robertson, 1992, p. 170). It is in this context that the Australian Brian Robinson – a former research officer at CSIRO Division of Radiophysics – was sent to the Netherlands as a visiting scientist in 1958. The choice for Robinson was not arbitrary. Robinson – who was one of the pioneers of the hydrogen line – had just completed his PhD in Cambridge, entitled 'investigations of the e-layer of the ionosophere'. As a part of his thesis, he had designed and constructed an ionospheric sounder[28], which provided a power much higher than available with standard sounders (Sim and Whiteoak, 2006).

The choice for the Netherlands was not arbitrary either, given the good Australian-Dutch relations. More important, however, were the developments in receiver techniques in the

[28] An ionospheric sounder is a device that measures time delay and strength of the echo at various frequencies in the high frequency region by using basic radar techniques (Saverino et al., 2013, p. 100).

Netherlands. The role of C.A. Muller, engineer, can hardly be overestimated in this. Remember that when the 21-cm hydrogen line was detected with the Kootwijk telescope in 1951, this was done by a receiver that had been built by Muller (see chapter II). During the second half of the 1950s, the receivers of the Dwingeloo telescope underwent many modifications. Several receivers were developed to do observations at different wavelengths. In 1955-1956, there were two receivers available: one for the continuum at 408 MHz (75 cm) and one for the continuum at 1390 MHz (21 cm) and for line studies at 1420 MHz (also 21 cm). Later, receivers were installed for 242, 465, 610, 820 and 2700 MHz and for hydrogen line studies at 1612-1720 MHz (Van Woerden and Strom, 2007, p. 384). Both the design and construction of these receivers were the work of Muller in the first place.

About his departure to the Netherlands, Robinson said the following:

> I had just completed my doctorate at Cambridge and was back on the Radiophysics payroll. Pawsey asked me to go straight to the Netherlands and learn of the Dutch progress in receivers. I took up a position at the Kamerlingh Onnes Laboratory which had long been famous for its work on low-temperature physics. The radio astronomers at the nearby Leiden Observatory had been investigating maser receivers but the recent developments in parametric amplifiers[29] in the United States made them swing their effort in this direction. (...) Parametric amplifiers – or paramps as they were known for short – had the clear advantage of working at manageable temperatures, whereas masers had to be cooled down to just a few degrees above absolute zero with liquid helium (Robertson, 1992, p. 172).

The visit of Robinson was very fruitful for the Dutch: not only did Robinson learn of the progress of Dutch receivers, he also helped Muller develop a 21 cm parametric amplifier ('paramp') for the Dwingeloo telescope. Moreover, as Robinson's salary was paid by Australia, his achievements did not cost the Dutch a penny. In September 1959, Pawsey wanted Robinson back in Australia as soon as possible, as he was needed there. This was greatly to the regret of the Dutch. Finally, a deal was concluded: Robinson would stay in the Netherlands until the 21 cm parametric amplifier was ready. In return, he would construct an identical receiver for use in Sydney.[30] However, Oort started to irritate the Australians when he tried to get the most out of this deal. In December 1959, he wrote to Pawsey that Muller thought that he and his staff and Robinson would need two whole years to build the paramp when they would work fulltime on it. The cost of building this receiver – this included salaries, heating, material costs etc. – would be approximately Dfl 150 000. He continued: 'This is a very large sum and I was somewhat shocked when I first learned about it. (…) Would you find it reasonable to share the costs of development?'[31] Pawsey was rather upset about Oort's bold proposal. He felt the Australians had done their share by providing the free labour of Robinson: 'In making Robinson available to you for several years I felt we were indeed cooperating in the way you mention.'[32] Finally, a compromise was reached: Oort proposed that the Dutch would take on the full charge of the parametric development themselves and that the

[29] A parametric amplifier is a high-frequency, low-noise amplifier.
[30] Pawsey to Oort, 14 September 1959, SA, NWO.
[31] Oort to Pawsey, 30 December 1959, SA, NWO.
[32] Pawsey to Oort, 21 January 1960, SA, NWO.

Australians would only pay for those parts of the receiver which had to be bought elsewhere and the parts that had to be made in Dutch shops.[33] Pawsey agreed.[34]

Robinson returned to Australia in 1962. The new paramp was installed at Parkes and was used in a number of important observations of the hydrogen content of distant galaxies and clusters of galaxies. However, despite this major effort, the operation of the paramp in Australia was never entirely satisfactory. Very soon, the new receiver group at Radiophysics began to develop a whole range of other devices. One was the first Australian-made paramp (built by F. Gardner and D. Milne). It operated at 20 cm and was used in the first Parkes survey of radio sources (Robertson, 1992, p. 172).

In the meantime, W.N. Christiansen had arrived in the Netherlands in November 1960. Oort - who was delighted about the cooperation with Robinson - absolutely wanted to continue the cooperation with Australia after Robinson's departure. Therefore, in January 1960 he had already written to Bowen that he wanted another Australian co-worker, preferably W.N. Christiansen. Bowen had immediately agreed: 'We would be very happy for Christiansen to spend some time with you at Leiden in the manner you suggest. The collaboration between Leiden and the Radiophysics Laboratory has always been close and has had the happiest outcomes.'[35]

Being a close colleague of Bernard Mills (see Chapter III) Christiansen had built up a lot of experience in interferometry and cross antennas. In 1948 he was offered a position in the radio astronomy group - headed by J.L. Pawsey – of the Division of Radiophysics at CSIRO. Soon, he became the leader of the newly-established field station at Potts Hill (see below).

Shortly after it was decided to hire him, however, Christiansen was appointed to the Chair of Electrical Engineering at the University of Sydney. Oort sent him his congratulations, but was at the same time worried that this would prevent him from taking up his job in Leiden: 'I congratulate you with the appointment to the Chair of Electrical Engineering at the University of Sydney. I do hope that you will be able to organize your University duties in such a manner that you will keep enough time for your research in radio astronomy.'[36] Christiansen, eager to cooperate with the Dutch, did not take up his post immediately, but first spent fifteen months at Leiden (Frater, 2008, p. 86).[37]

The hiring of Christiansen caused a kind of 'snowball effect': several other Australians – often at the instigation of Christiansen - would follow. At the same time, the Dutch were not the Australians' exclusive partner in radio astronomy. As Munns pointed out, there was a nearly continuous trade in expertise among Australia, Great Britain, the Netherlands and the United States (Munns, 2013, p. 15). In the first decade after the Second World War, Australia had especially intensive contacts with the USA in the person of Bowen, who had been working in American war industry for three years (see Chapter I). The people with whom Bowen discussed the earliest proposals for what would ultimately become the steerable 64 m radio telescope in Parkes, were people with whom he had been involved in the days of microwave radar. Amongst

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[33] Oort to Pawsey, 3 February 1960, SA, NWO.
[34] Pawsey to Oort, 24 March 1960, SA, NWO.
[35] Bowen to Oort, 6 January 1960, OA, 176.
[36] Oort to Christiansen, 20 April 1960, OA, 176.
[37] Unlike Robinson, Christiansen was paid by the Dutch.

them was Vannevar Bush (Bowen, 1984, p. 99). (In the end, it was the Carnegie Corporation and the Rockefeller Foundation that funded about half of the cost of the Parkes telescope.)

One of the senior lecturers in electronics in the Electrical Engineering Department at the University of Sydney – C. T. Murray – was planning a sabbatical leave in 1960-1961 and was looking around for a suitable place where he could work during his leave. Christiansen wrote to Oort: 'It occurred to me that you might possibly be interested in someone to help on the electronics part of the Benelux Cross.' [38] Oort reacted very positively and was eager to have 'a man of such erudition and experience' working with his group.[39] The 'Committee of Three' (see Chapter III) agreed to appoint Murray and he joined the cross antenna project on 1 May 1961.[40] Another example was the appointment of Christiansen's colleague, the experienced radio technician Watkinson, who joined the project in February 1962.[41]

Although the relations with the Australians were very good, Oort never wanted them to join the cross antenna project formally. Oort - who always wanted to realise his projects with the smallest number of parties involved – strongly opposed further internationalisation of the project, and he made no exception for the Australians. Indeed, when Pawsey indicated that - because of the successful cooperation with Robinson – he was willing to let the Australians join the cross antenna project and put forward the idea to erect a second 'Benelux' cross in Australia, Oort refused:

> I do not think that the Benelux organization which has now been set up for this plan and for which at least some official support by the governments has been obtained, would or could decide to change the entire set-up so drastically as to plan for erecting a Benelux cross antenna in Australia. We do not believe that an attempt in this direction would further the matter of obtaining a large cross. Rather, I believe it would be detrimental to it.[42]

4.2 THE SECOND DESIGN: A SMALLER CROSS ANTENNA FOR OBSERVATIONS AT 21 CM

Already during the year 1961, plans were made to change the design. One of the main reasons was that the research that was done by engineer Hooghoudt and by the firm of consulting engineers Dwars, Heederik, Verhey soon made it clear that the cost of the telescope would be much higher than originally estimated. Especially the steel structure would cost much more than was originally thought, and this could increase the total investment cost by several millions. It also seemed likely that considerable further increases in cost would be caused by difficulties encountered in the detailed structural development of the feeds and of the driving mechanism.[43] And there were also two further reasons why a change was considered:

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[38] Christiansen to Oort, 19 May 1960, OA, 176.
[39] Oort to Christiansen, 15 August 1960, OA, 176.
[40] Rapport intérimaire dur le projet Benelux pour l'antenne en croix - Benelux cross antenna project (BCAP), 22 February 1961, SA, NWO.
[41] Minutes of the Council meeting of the BCAP of 19 March 1962, SA.
[42] Oort to Pawsey, 26 October 1959, OA, 112 e.
[43] Minutes of the Council meeting of the BCAP of 11 December 1961, SA.

(a) no guarantee was forthcoming that a channel *near* 75 cm was to be allocated to radio astronomy

(b) the design had very little flexibility for changing to other wavelengths. Moreover, it would offer no possibility for observations of the 21-cm line of hydrogen, observations that were such a powerful means of investigating the structure and dynamics of galaxies.[44]

Therefore, Högbom had elaborated a new design. The telescope would consist of some 400 parabolic reflectors – each with a dish of about 25 metres - usable for wavelengths of 21 cm and longer – instead of 75 cm - and giving a beam width of 1 minute of arc at 21 cm. A disadvantage was however, that the total receiving surface would be three times less than for the first design. Moreover, most of the radiation is three times weaker at 21 cm than at 75 cm and so a longer integration time[45] was required. This meant that much less of the sky could be covered in a given time.[46] However, this effect could be compensated more or less by the fact that the design with the parabolic reflectors allowed tracking sources for a considerable time, albeit at the expense of telescope time.[47]

Högbom presented a comparison of the two designs at the OECD meeting on 'Large Radio-Telescopes' in December 1961 (see also Chapter III).

He explained there were four reasons to switch to 21 cm: Firstly, a wide band around 1420 MHz had been guaranteed to radio astronomy, while the future of the band around 408 MHz was very uncertain. Secondly, in a 21 cm array it was relatively easy to switch to other wavelengths, while that was a difficult thing to do with a 75 cm array. This way, it would be relatively easy to get information about the spectra of radio sources. Thirdly, 1420 MHz was much more suitable for polarisation measurements. Fourthly, at 1420 MHz, 21-cm hydrogen line observations could be made (Högbom, 1963, p. 132).

Roughly, the telescope would look as follows:

[44] Minutes of the Council meeting of the BCAP of 11 December 1961, SA.
[45] In radio astronomy this is the interval over which data are averaged to reduce background noise and increase the signal-to-noise ratio.
[46] Minutes of the Council meeting of the BCAP of 11 December 1961, SA.
[47] Telescope time is the time the user spends on the telescope.

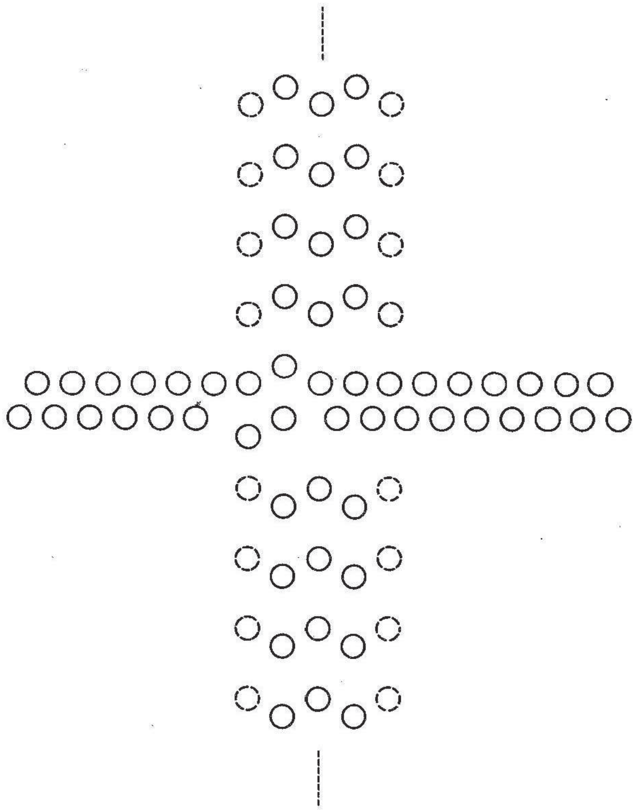

FIGURE 8. A possible basic pattern of 25 metre dishes (Högbom, 1963, p. 135)

The Council of the BCAP agreed that this design, consisting of individual paraboloids, had so many features that made it more attractive than the design of cylindrical paraboloids, that it should be adequately developed, before a final decision on the construction of the radio telescope was taken.[48]

Further research was done by the group and after several months, Högbom came to the conclusion that his initial idea of a 1420 MHz cross antenna consisting of 400 dishes of 25 m diameter, was unnecessarily complex. A smaller number of dishes – about 100 dishes of 35-40 m diameter was now considered.[49] For a brief period, it was also considered to give up the cross shape of the telescope. Indeed, in early 1962, Christiansen – just before he returned to Australia – had come up with the proposal of a 'matrix antenna' with the paraboloids arranged in a rectangle. Initially, it

[48] Minutes of the meeting of the Council of the BCAP of 11 December 1961, SA.
[49] Minutes of the Counil meeting of the BCAP of 19 March 1962, SA.

was thought that the simple structure of this matrix would offer some advantages concerning the electronics and the data processing. Högbom, however, studied this idea more thoroughly and soon realised that this was not entirely true. Moreover, the resolving power of the matrix cross would not be high enough. Therefore, the idea was quickly abandoned.[50]

When Christiansen returned to Australia, he was replaced by W.C. Erickson. Erickson had received his PhD at the University of Minnesota under the theoretical physicist Charles L. Critchfield in 1956 and had subsequently gained considerable experience in radio astronomy. First of all, he had accepted a Carnegie Fellowship at DTM the Department of Terrestrial Magnetism at the Carnegie Institution of Washington, where he carried out a 21 cm survey of neutral hydrogen at high Galactic latitudes (Erickson, 2005, p. 89).

Particularly useful for Erickson's later position in Leiden, however, was his next position at Convair Scientific Research Laboratory (CSRL) in San Diego, a small, company-funded research laboratory, founded by his former thesis advisor Critchfield, who had become Vice President and Director of Scientific Research for Convair, an aircraft and missile manufacturer. Erickson entered CSRL in late 1957. The staff was given complete freedom to choose its research projects, but the budget available was very limited. Erickson was the only radio astronomer. He wanted to undertake a research programme essentially on his own and on a low budget and therefore he made plans for the construction of a large array, with which he wanted to do some low frequency work. He found a suitable location at Clark Dry Lake, a desert plain about 100 km northeast of the city of San Diego. The first antenna Erickson and his colleagues built there was a 26.3 MHz array (Erickson, 2005, p. 90). Construction began in 1959 and the full array came into operation in 1961. It was a complex compound interferometer. The east-west array consisted of 8 banks of 19 dipoles on a 3.3 km baseline. The north-south array consisted of 4 banks of 19 dipoles placed along a 1.4 km baseline due south of the electrical centre of the east-west array (Polisensky and Kassim, 2005, p. 125).

By the time the full array came into operation (1961), however, Convair was in a deep financial crisis. Therefore the company decided no more money could be made available for a basic science laboratory. Almost all staff members left for academic or government positions and the CSRL disappeared (Erickson, 2005, p. 92). In 1963, the ownership of the 26.3 MHz array was transferred to the University of Maryland. It continued to operate until 1975 (Polisensky and Kassim, 2005, 125).

Thus, Erickson had accepted a faculty position at the University of Maryland, just before Oort asked him to come to Leiden for a year or two to work on the Benelux Cross Antenna Project. Erickson accepted Oort's offer, which he found very interesting. The Maryland administrators agreed to hold his position open in the meantime[51] (Erickson, 2005, p. 93).

In Leiden, Erickson together with Högbom worked out the alternative design for the Benelux cross antenna. By then, the Dutch had been cooperating with foreigners – especially with Australians – in designing this telescope for several years. Hence, the plans for the Dutch telescope resembled

[50] Minutes of the Counil meeting of the BCAP of 19 March 1962, SA.
[51] Remember that something quite similar happened to Christiansen, who was appointed to the Chair of Electrical Engineering at the University of Sydney, just before he went to Leiden.

other existing telescopes. However, it is noteworthy that Erickson later said that the concept of the Dutch telescope was clearly a product of optical astronomers:

> Because it [the instrument] had been conceived by astronomers, one of its requirements was that it should produce data like an optical telescope. An astronomer should be able to go to the telescope, take his “exposure”, and return to his home with a map of his specified area of sky. (Erickson, 2005, pp. 93-94)

The design of Erickson and Högbom was ready in September 1962.[52] Antenna structure, the design and mounting of the parabolic dishes, the amplifying and receiving system, the calibration system etc. were all worked out in detail. Erickson and Högbom emphasised that the main differences between this design and the previous one (of Christiansen and Högbom) were in its mechanical structure and its astronomical possibilities. The antenna system offered various options for future extensions to even higher resolutions in the form of interferometers, gratings, or *aperture synthesis.* This is the very first time that aperture synthesis is mentioned in this project. It is a specific type of interferometry that would ultimately be used in the large radio telescope, as we will see.

More specific, the telescope would consist of 65 30-metre parabolic dishes in the east-west arm and 38 in the north-south arm, which would give a total of 65 x 38 = 2470 possible combinations. However, some antenna combinations - which correspond to spacings smaller than the diameter of one dish - were missing in this system. Therefore, an extra parabolic dish with a diameter of about 70 m would be provided.[53]

An additional advantage of changing the wavelength from 75 to 21 cm was that the telescope could be much smaller.[54] While in the first design, each arm of the cross had to be 5 km, in the second design it only had to be 1.5 km for a resolution of one minute of arc. It was proposed to build the 1’ resolution device in two stages. First, a 3’ resolution portion with four arms extending from the centre would be built and operated. After experience had been gained operating this small 3’ instrument, it would be extended to 1’ resolution by extending the arms 750 m from the centre. The 70 m dish would be placed on one of the arms about 2.25 km from the centre.[55] The dimensions of the cross would be as follows:

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[52] Erickson, W.C. and Högbom, J.A., BCAP-Memo 20 A, 13 September 1962: A design for a 1420 Mc/Sec Benelux Cross Antenna, SA, NWO.
[53] Erickson, W.C. and Högbom, J.A., BCAP-Memo 20 A, 13 September 1962: A design for a 1420 Mc/Sec Benelux Cross Antenna, pp. 2-3, SA, NWO.
[54] The resolving power of a telescope is inversely proportional to the wavelengths of radiation it receives.
[55] Erickson, W.C., BCAP-memo 19, Site requirements for the Benelux Cross-Antenna Project, 10 August 1962, SA, NWO.

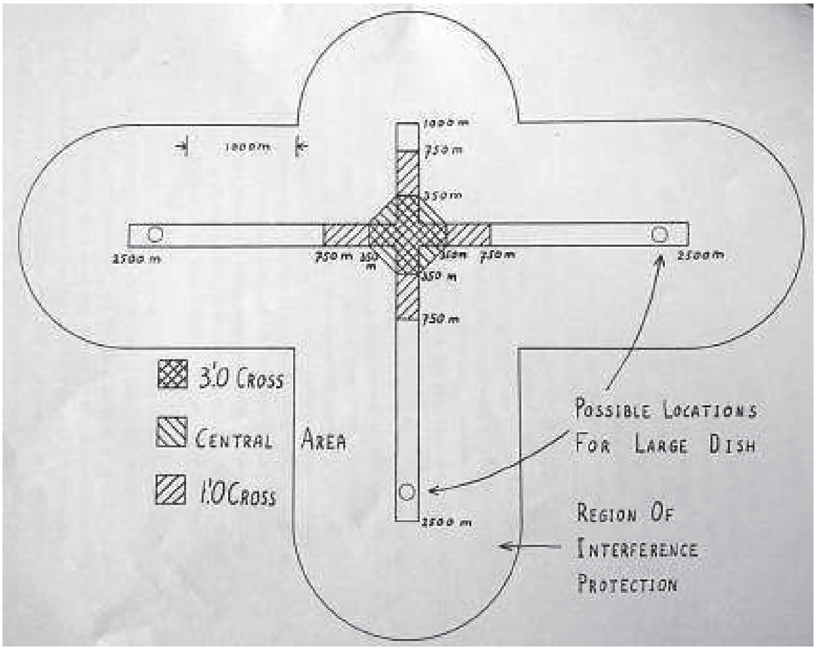

FIGURE 9. Site requirements for the Benelux Cross Antenna[56]

A cost estimate was made and in October 1962, this was sent to the members of the BCAP Council.[57]

The investment costs would roughly look as follows:

Cross antenna, 30-metre radio dishes (steerable)	16 million Dfl
70-metre radio dish	2 million Dfl
Electronic receiving installation	7 million Dfl
Buildings	1 million Dfl
General provisions (Electricity etc.)	2.5 million Dfl
TOTAL	**28.5 million Dfl**

Costs could increase by another 2.5 million Dfl for purchase of grounds and eventual damage claims, which could bring the total investment cost to about 30 million Dfl. According to Oort, this

[56] Erickson, W.C., BCAP-memo 19. Site requirements for the Benelux Cross-Antenna Project, 10 August 1962, SA, NWO.
[57] Oort to the Members of the BCAP Council, 15 October 1962, SA, NWO.

estimate was a 'minimum estimate', a choice he defended by saying that giving a higher estimate would automatically lead to spending more money.

Several parties had been involved in establishing this estimate: the cost of the 30-m radio dishes, for example, was estimated by the firm of consulting engineers N.V. Dwars, Heederik en Verhey and engineer Hooghoudt, and the estimate of the 70-m dish was derived from the price of an analogous dish of 90 m that was built in Green Bank (West Virginia, USA).

In addition, the operating cost was now estimated at around 2 million Dfl a year.

The construction of the antenna would start in 1963 and the whole was to be ready in 1967.

The report and cost estimate had to be sent to the governments of the two countries, but this was seriously delayed. On 26 October 1962, Oort had sent the report and cost estimate to Darimont, the president of the Committee of Three and Director of the Belgian Department of Higher Education of the Ministry of Public Education. Darimont in turn, had to send it to the Ministers of Education in Brussels and The Hague. It remains unclear what exactly happened, but in the council meeting of 21 January 1963, Deloz, an official at the Belgian Department of Higher Education, said that 'some delay had occurred in transmitting the report to the Governments, but that he expected that this transmission should take place in the first week of February.'[58] He also said that the Belgian Government wanted to consider the project together with more detailed data on the sites. Eventually, it was only at the end of February that the report was sent to the two ministries.[59]

It is not entirely clear whether the Dutch government had to approve this new design officially. Even in government circles, there seems to have been some confusion about it. In a letter of the Dutch Ministry of Finances of 7 December 1962 to Bannier, we read that, as the project had changed significantly and the cost would be several millions higher, it 'seemed' that a new decision of the government would be necessary.[60] In any case, no such a decision can be found in the archives. Furthermore, even after receiving the new plans, the Belgian government still did not make a decision about participation in the project.

For the year 1963, ZWO earmarked an amount of Dfl 3 000 000 of the extraordinary budget to cover part of the investment cost. Like the amount of Dfl 1 000 000 of the previous year, however, this amount would not be made available as long as the Belgian government had not made an official decision about participation.[61]

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[58] Minutes of the Council meeting of the BCAP of 21 January 1963, SA.
[59] Minutes of the Council meeting of the BCAP of 27 February 1963, SA.
[60] Vos to Bannier, 7 December 1962, SA, NWO.
[61] Aantekening ZWO, Kruisantenne-project, August 1963, SA, NWO.

4.3 THE THIRD DESIGN: A LINEAR EARTH-ROTATION APERTURE SYNTHESIS ARRAY

A few months after the plans of the second design had been submitted to the Belgian and Dutch governments, a radical change in the arrangement of the telescope was again considered.

The reason this time was that the resolving power of one minute of arc did not seem high enough anymore. When the project began around 1958, the idea was to construct an antenna system with a very high resolution. In those days, it seemed that a resolution of one minute of arc was high enough. As time went by and radio astronomical research progressed, however, it soon became clear that a much higher resolution was required to keep up with the most recent developments in radio astronomy. The first time this matter was discussed was in the Council meeting of BCAP on 27 February 1963:

> Discussing the general progress of the project, the President said that considerable thinking and discussion had been done in recent months about ways in which the highest resolving power could be reached more rapidly than had originally been planned. Recent developments in radio astronomy have emphasised the essential importance of obtaining beams of 10’’ or 20’’.[62]

Indeed, for the investigation of point sources (a single identifiable localised source) a resolution of about 10’’ was necessary. For several months, Högbom (together with Hooghoudt) had been studying the possible ways to obtain these higher resolutions in an earlier stage of the work. However, nothing had been said yet about the possibility of abandoning the cross shape. It was only in the summer of 1963 that Högbom proposed a linear east-west array of telescopes that would make use of the rotation of the Earth, instead of a cross antenna. The information which in the cross design would be provided by the combination of the reflectors in the north-south arm with those in the east-west arm, would in this set-up be provided by the rotation of the Earth.[63] Application of this ‘Earth-rotation aperture synthesis’ could offer a resolution between 10 and 20 seconds of arc, if about 30 25 m reflectors were set up in an east-west array.[64]

For this Earth-rotation aperture synthesis linear array, the Dutch had been inspired by important work that had been done in this respect by Martin Ryle and his group in Cambridge in the early 1960s, as Muller wrote:

> Meanwhile, RYLE at Cambridge had indicated a new possibility to achieve a higher resolution with a simpler alignment of a number of antennae in one array, i.e. a one-dimensional system, in which the necessary second dimension is obtained by rotation of the system with respect to the sky using the rotation of the Earth (...).[65]

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[62] Minutes of the Meeting of the BCAP Project of 27 February 1963, SA.
[63] Oort, J.H., ‘Proposal for constructing the Benelux radiotelescope as a synthesis instrument’, 25 March 1964, SA, NWO.
[64] Muller, C.A., ‘Memorandum over de ontwikkeling van het radiosterrenkundig onderzoek in Nederland’, 8 juli 1963, SA, NWO.
[65] ‘Door RYLE te Cambridge was inmiddels een nieuwe mogelijkheid aangegeven voor het bereiken van een groot scheidend vermogen met een eenvoudiger opstelling van een aantal antennes in één rij, dus een één-dimensionaal systeem, waarbij echter de noodzakelijke tweeden (sic) dimensie werd verkregen door draaiing van het systeem ten opzichte van de sterrenhemel met behulp van de draaiing van de aarde (...).’

That the Dutch were inspired by the Cambridge group should come as no surprise. A strong connection between the two groups was established in the person of Högbom, who had worked towards a PhD from Cambridge under the direction of Martin Ryle from 1955 until 1959 (see also below).

The main problem of the new design, however, was that for each complete observation, twelve hours of observation time were required. This meant that at most 700 complete observations could be done in one year. So the telescope could not be used to contribute to a large number of research projects in a short amount of time. Therefore, it was unsuitable as 'main telescope' for the different institutes in Belgium and the Netherlands. However, despite these disadvantages - and despite the technical difficulties involved in its construction – given the high resolving power, this design was considered the best choice. Moreover, there was the additional advantage that a 21-cm hydrogen line receiver could easily be installed in this kind of telescope. In the cross antenna, this could only be used in the interior parts of the cross. If this type of receiver would be used in the entire cross, an enormous amount of apparatus would be needed. The installation of a multiple-channel receiver even seemed entirely impossible in the cross.

Roughly, the telescope would look as follows:

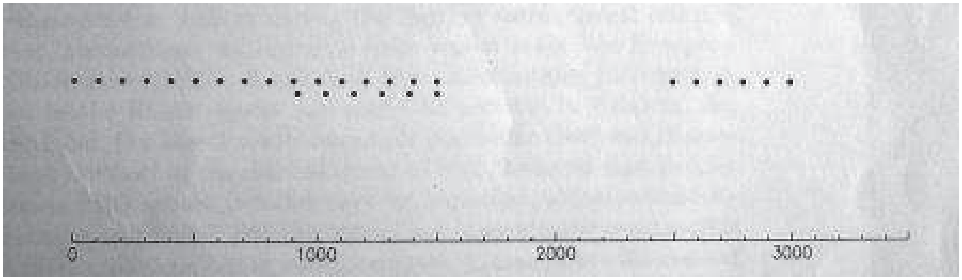

FIGURE 10. Schematic arrangement of the third conceptual design of the Benelux Radio Telescope: a cross antenna re-arranged to an east-west array. (Raimond, 1996, p. 24)

In addition to these dishes, like in the previous design, a steerable reflector telescope with a dish of about 65 m would be required.[66]

It is interesting that for a while this 65-m reflector was considered as a kind of 'transition instrument' between the 25 m radio telescope in Dwingeloo and the new radio telescope – in which this 65 m dish would only have a limited function.[67] As it would take several years before the entire radio telescope would be ready, it would be a good idea to construct this 65-m dish in

Muller, C.A., 'Memorandum over de ontwikkeling van het radiosterrenkundig onderzoek in Nederland', 8 July 1963, SA, NWO.

[66] Muller, C.A., 'Memorandum over de ontwikkeling van het radiosterrenkundig onderzoek in Nederland', 8 July 1963, SA, NWO.

[67] Muller, C.A., 'Memorandum over de ontwikkeling van het radiosterrenkundig onderzoek in Nederland', 8 July 1963, SA, NWO.

the first construction stage so that observations could begin before the whole instrument was ready. This instrument would have a higher resolution than the 25-m telescope in Dwingeloo. It could be used for the 21 cm investigation of the extragalactic nebulae and for short radio wave surveys of continuum radiation from the Galaxy. Remember that in this period the Dwingeloo telescope was nowhere near the largest telescope in the world any more: in Jodrell Bank in the UK, the 'Lovell' radio telescope of 76.2 m had been completed in 1957; in Australia at Parkes, the 64-m telescope had been completed in 1961; and in Greenbank in the USA, the 90 m radio telescope had started operating in 1962.

However, in the end these plans for a 'transition telescope' were never put into action.

After a further elaboration of the design later that year, an estimate of the price of this telescope could be made: the total investment cost of this project would be about the same as the previous design (30 million Dfl).[68]

The question was, of course, how Oort should communicate to the Governments that the design had – again – changed, and even in a very radical way this time. He chose to be very careful and made it appear that the change was no big deal. The document in which the design was described, was simply entitled *Note on a Possible Re-arrangement in the design of the Benelux Radio Telescope*. Moreover, Oort explained that the alteration in the original design was the result of a 'natural development', and that it did not affect the general type of instrument.[69]

4.3.1 THE DEVELOPMENT OF EARTH-ROTATION APERTURE SYNTHESIS

The change of a cross antenna into an Earth-rotation aperture synthesis linear array might have been the result of a 'natural development', yet, when we look at the history of Earth-rotation aperture synthesis, we might wonder why Oort did not come up earlier with the idea to use this technique for the new telescope.

Traditionally, the 'invention' of aperture synthesis is attributed to the Cambridge astronomer Martin Ryle. Graham Smith, former professor at Jodrell Bank Observatory, for example, said: 'Aperture synthesis, the simulation of a very large radio telescope by the use of multiple interferometers, was Ryle's supreme invention' (Smith, 1984, p. 18). And U.J. Schwarz of the Kapteyn Astronomical Institute in Groningen said about arrays of telescopes in one direction that use the rotation of the Earth: 'This (...) idea is called Earth-rotation synthesis, invented by the British radio astronomer Martin Ryle (...)'[70] (Schwarz, 1986, p. 247). Oort himself too, attributed aperture synthesis to Ryle:

> (...) in a synthesis telescope, like we have now in Westerbork, one needs to integrate over time. You cannot get an image immediately, but you have to observe for twelve hours – or at least for a certain amount of time – so that the one array you have in such a line-interferometer makes several position angles with respect to the sky; when you put these

[68] Minutes of the Council meeting of the BCAP of 17 October 1963, SA.
[69] Minutes of the Council meeting of the BCAP of 17 October 1963, SA.
[70] 'Dit (…) wordt de aardrotatie-synthese genoemd, uitgevonden door de Britse radioastronoom Martin Ryle (…).'

> together, you get a two-dimensional image. (...) This was invented by Martin Ryle several years ago.[71] (Oort, 1986, p. 252)

With regard to Ryle and aperture synthesis, one of his publications is especially famous, namely his 1962 article in *Nature* 'The new Cambridge radio telescope'.[72] In the 1960s, it was often referred to by the Dutch. When Oort explained why the new large radio telescope should make use of the rotation of the Earth, he referred to this publication: 'A radio telescope based on the synthesis principle, and giving a resolution of 25'', has recently been described by M. Ryle (Nature, 194, 517).'[73]

In 1974, Martin Ryle and his colleague, the British radio astronomer Antony Hewish, shared the Nobel Prize in Physics: Ryle for his 'observations and inventions, in particular of the aperture synthesis technique', and Hewish for his decisive role in the discovery of pulsars.'[74]

It can not be denied that in the early 1960s, Ryle made great contributions to imaging with aperture synthesis, but the principle itself existed long before. As Raimond put it:

> (...) Christiansen and Warburton (1955) produced a two-dimensional map of the quiet sun at a wavelength of 21 cm, using a combination of an east-west and a north-south array of parabolic reflectors. In fact, this could be called the first application of earth rotation aperture synthesis, although Ryle described the principle more explicitly in 1962[75]. (Raimond, 1996, p. 16)

Indeed, for the origins of Earth-rotation aperture synthesis, we have to go back to Australia in the early 1950s. And one of the pioneers was W.N. Christiansen, who later made the first design of the 'Benelux cross antenna'. As mentioned before, Christiansen was working in Potts Hill in the late 1940s. At that time, the main radio telescope there was a wartime experimental radar antenna that had been relocated to Potts Hill in 1948 for 'observation' of the partial solar eclipse of 1 November. Christiansen organised the observations of the partial solar eclipses of 1 November 1948 (together with Mills) and 1 April 1949. His experiences with the eclipses ultimately led him to the development of an east-west solar 'grating array' telescope at Potts Hill in 1951. This grating array, which consisted of 32 steerable paraboloids, allowed Christiansen to study the distribution of radio brightness across the Sun as the Sun drifted through the responses during the day. An important finding of this research was that enhanced emission at 21 cm came from regions in the lower corona of the Sun. Their dimensions and height above the photosphere could now be determined for the first time. (Frater, 2008, p. 86).

[71] '(…) bij een synthese-telescoop zoals we nu in Westerbork hebben moet je over de tijd integreren. Je kunt niet onmiddellijk een beeld krijgen, maar je moet twaalf uur lang waarnemen – of althans een tijd lang – zodat die ene arm die je hebt in zo'n lijn interferometer verschillende positiehoeken ten opzichte van de hemel maakt ; als je die samenvoegt kun je het tweedimensionale beeld krijgen.'

[72] Ryle, M., The new Cambridge radio telescope, in : *Nature*, 194 (1962), pp. 517-518.

[73] Oort, J.H., 'Proposal for constructing the Benelux radiotelescope as a synthesis instrument', 25 March 1964, SA, NWO.

[74] "Press Release: The 1974 Nobel Prize in Physics". http://www.nobelprize.org/nobel_prizes/physics/laureates/1974/press.html (Accessed 10 July 2012).

[75] The article that is meant is: Ryle, M., The New Cambridge Radio Telescope, in: *Nature*, 194 (1962), pp. 517-518.

One of the limitations of Christiansen's east-west array, however, was that the Sun could only be scanned in one dimension. In order to calculate the distribution of radiation across the solar disk, it was therefore necessary to assume a symmetrical distribution. But visual observations had revealed that the Sun is an oblate spheroid. Moreover, the eclipse observations had also indicated that the solar corona was far from symmetrical. Therefore, Christiansen decided to construct a second array, consisting of 16 parabolic dishes and arranged in a north-south direction, so that the Sun could be scanned at a variety of angles (Wendt, Orchiston and Slee, 2008, p. 177).

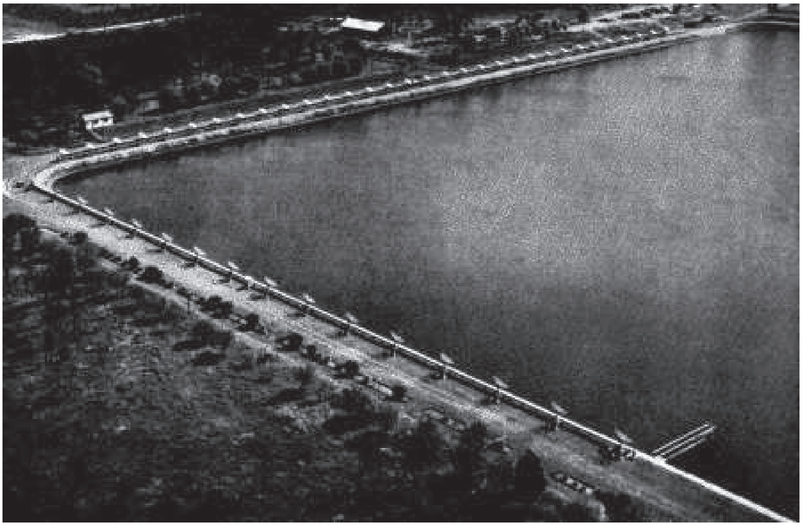

FIGURE 11. Aerial view of the 23-element east-west and the 16-element north-south arrays (Christiansen and Warburton, 1955a, p. 475)

With this telescope Christiansen made daily observations from September 1953 to April 1954, together with his colleague Joe Warburton. They published their findings in 1955 (Christiansen and Warburton, 1955a and 1955b). The observations allowed them to make a two-dimensional image of the radio brightness distribution of the Sun at 1420 MHz (21 cm):

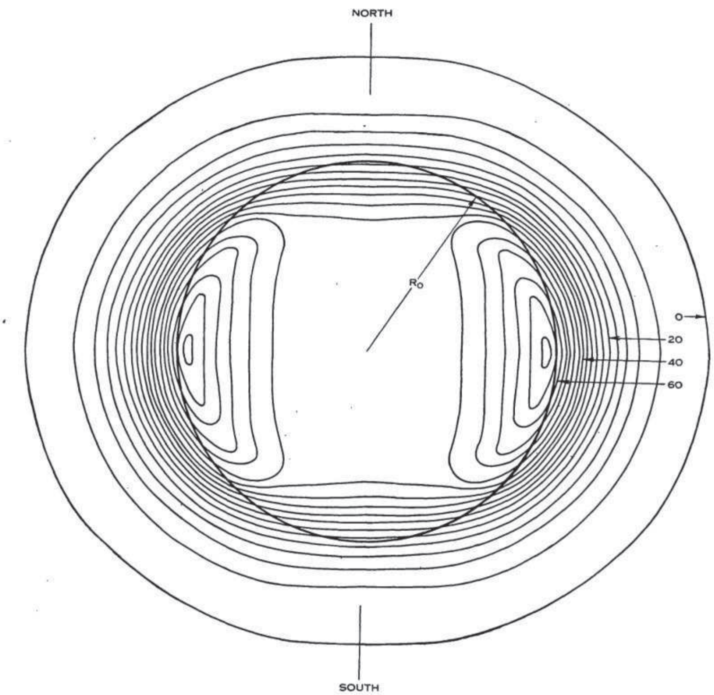

FIGURE 12. Derived two-dimensional radio brightness distribution (Christiansen and Warburton, 1955a, p. 482)

Wendt, Orchiston and Slee consider the above image the 'world's first application of Earth-rotational synthesis in radio astronomy' (Wendt, Orchiston and Slee, 2008, p. 178). Frater too acknowledges that their approach was 'an early application of Earth-rotational synthesis[76] to produce for the first time a radio map with a resolution as high as four minutes of arc' (Frater, 2008, p. 86).

However, the contribution of the Australians in this respect is not widely acknowledged.

Christiansen himself remained displeased with this lack of recognition for the rest of his life. In 1989, he wrote an article which carries the unambiguous title: *An omission in radio astronomy histories*. There, Christiansen explained that Earth rotation in synthesising a two-dimensional antenna aperture was used in Australia almost a decade before it appeared elsewhere:

[76] Aperture synthesis or synthesis is a type of interferometry that mixes signals from several telescopes to produce images that have the same angular resolution as an instrument that would have the size of the largest baseline of the array. Most interferometers use the rotation of the Earth to increase the number of baselines (the distance between two aerials) included in an observation. When data are taken at different times, measurements with different telescope separations and angles are provided, without the need for moving the telescope manually. The rotation of the Earth, namely, moves the telescopes automatically to new baselines.

> An essential element of this technique is the use of two or more antennas with accurately known positions and with accurately known electrical separations from a common receiver, these remaining known while the individual antennas turn to follow some fixed region of sky during many hours of observation. This prerequisite for the technique was developed first in Australia in 1952 (Christiansen 1953)[77] (...) Once this had been done, the development of earth-rotational synthesis was almost an obvious step to anyone aware of the geometry of the Solar System. Thus in Sydney we used the apparent change in the solar axis as the Earth rotated to synthesize a two-dimensional map of the Sun from one-dimensional observations. This work was (...) later published by Christiansen & Warburton (1955). (Christiansen, 1989, p. 357)

However, after the achievements of the early 1950s, developments in Earth-rotation aperture synthesis came to a halt for over a decade in Australia. According to Christiansen, the reason for this was that further developments required much faster methods than the hand-operated mechanical calculators then available in Sydney. The next decade, however, a necessary turning point took place at Cambridge, when the digital computer revolutionised the speed of computation.[78] From then on, powerful and very large radio telescopes were developed that make use of Earth-rotational synthesis (Christiansen, 1989, pp. 357-358).

So do we have to conclude that the Australians were the 'first' to develop Earth-rotation based aperture synthesis? It depends. P.A.G. Scheuer of the Mullard Radio Astronomy Observatory (and former student of Martin Ryle) in Cambridge found a notebook of Martin Ryle of 1954 in which this principle is already described. According to Scheuer, this is the first *written* mention of Earth-rotation synthesis. (Scheuer, 1984, p. 256). (The article of Christiansen and Warburton was indeed only published in 1955).

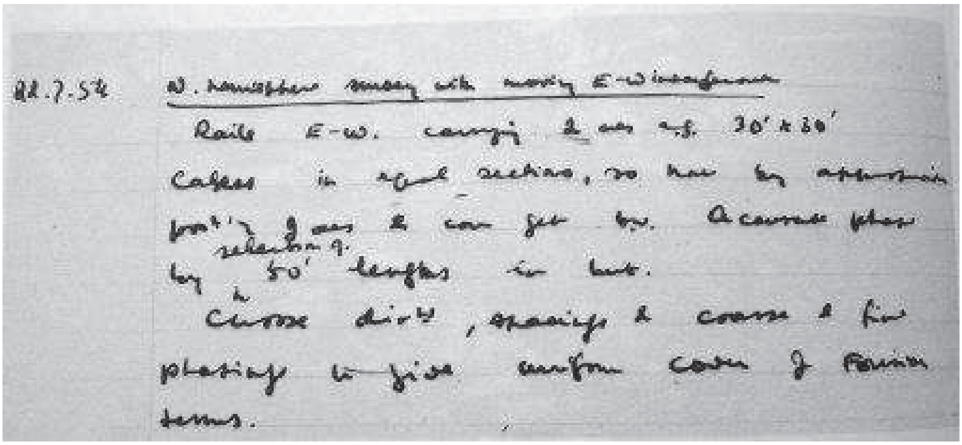

FIGURE 13. Entry in Ryle's laboratory notebook, 22nd July 1954 (Scheuer, 1984, p. 256)

[77] Christiansen, W.N., A high-resolution aerial for radio astronomy, in : *Nature*, 171 (1953), p. 831.
[78] Also in the Netherlands, computers have revolutionised the speed of computation in astronomy since the 1960s, see: Van Helvoort, 2012, pp. 62-76.

A transcription of the text in the notebook reads: "N hemisphere survey with moving E-W interferometer. Rails east-west carrying 2 aerials e.g. 30 ft x 30 ft. Cables in equal sections, so that by appropriate pos[itionin]g of ae[rial]s and can get b.[and] w.[idth]. Accurate phase by selection of 50 ft lengths in hut. Choose dir[ectio]ns, spacings and coarse and fine phasings to give uniform cover of Fourier terms." (Scheuer, 1984, p. 256)

Concerning the development of Earth-rotation based aperture synthesis, not only the role of the Australians, but also the role of Ryle's own PhD student, Högbom, is rather neglected in historiography.

As mentioned before, from 1955 to 1959 Högbom worked on a PhD in Cambridge under the supervision of Martin Ryle. His PhD dissertation - entitled *The Structure and Magnetic Field of the Solar Corona* - includes several chapters on aperture synthesis theory and earth-rotational synthesis. Ryle might have been the very first to write something down about Earth-rotation based aperture synthesis, but Högbom certainly *tested* Earth-rotation aperture synthesis before Ryle did. Kellerman and Moran acknowledge that Högbom previously used an array of simple dipole elements to test the principle of 'supersynthesis'[79], as part of his PhD dissertation work (Kellerman and Moran, 2001, p. 468).

It seems, however, that Ryle has deliberately neglected Högbom's contributions with respect to Earth-rotation based aperture synthesis. In a famous article he wrote in 1960, together with Hewish, *The synthesis of large radio telescopes*, no mention at all is made of Högbom. Scheuer says that, Ryle was 'apparently scarcely aware of the experiment and cannot recall it now' (Scheuer, 1984, p. 258). This, however, is very unlikely, as Högbom was Ryle's PhD student. Moreover, we have concrete proof that Ryle *was* at the time very well aware of Högbom's experiments in this respect, as he discussed them in a letter to Oort in 1961.[80]

Most likely, as a supervisor, Ryle was convinced he deserved the credits for this discovery. In these days, it was certainly not uncommon that supervisors were rewarded for the work their PhD students had done. Indeed, as noted above when in 1974, Ryle got the Nobel Prize in Physics for invention of aperture synthesis, he had to share this prize with Hewish, for 'his decisive role in the discovery of pulsars'. However, it was Hewish's PhD student Jocelyn Bell, who had actually done the research. Pulsars are remnants of massive stars that became supernovae. Jocelyn Bell - who in 1967 was a graduate student in radio astronomy at Cambridge – discovered the recurring signals given off by the rotation of these pulsars when she was analysing the data, gathered by a radio telescope she had helped to assemble. Jocelyn Bell's contributions, however, were – and in the astronomical community still are – widely known. Indeed, she got a 'wave of sympathy' after Hewish received the award. Bell not only had the 'disadvantage' of being a graduate student, but also of being a woman. In a very recent interview for *National Geographic* (May 2013), Bell – now a visiting astronomy professor at the University of Oxford - said:

> The picture people had at the time of the way that science was done was that there was a senior man – and it was always a man – who had under him a whole load of minions, junior staff, who weren't expected to think, who were only expected to do as he said. (Quoted in Lee, 2013)

[79] Earth-rotation based aperture synthesis was by often referred to as 'supersynthesis' in Britain.
[80] Ryle to Oort, 21 December 1961, OA, 114c.

The whole discussion about 'who had been the first' to develop Earth-rotation based aperture synthesis, might have in itself no great historical relevance. It might be just another example of Stigler's law, which says that no scientific discovery is named after its actual discoverer (Wilkins, 2011). However, the fact that in the 1950s, both Christiansen and Högbom were experimenting with it, is of great importance, as these very same persons were also key persons in the development of the radio telescope in Westerbork.

So the question arises why the Dutch did not come up sooner with the idea to use Earth-rotation based aperture synthesis. By the late 1950s, Oort must certainly have been aware of the principle: in a letter of Högbom to Oort, dated 11 August 1959, Högbom mentions it:

> I have been very interested in aerial theory, particularly interferometer technique, and I have made some preliminary tests with a new synthesis method which makes it possible to study point sources without using large aerials. In this the rotation of the earth is used to provide transport in one dimension. A simple interferometer with two small aerials spaced 60 λ on an NS axis has in this way given records equivalent to that of a 50 λ EW array.[81]

Although there was still a long way to go from studying point sources to making images of the sky, it is a bit odd that it took such a long time before it occurred to the Dutch that the new radio telescope could be based on Earth-rotation synthesis technique. According to Erickson, who made the second design together with Högbom, the reason was that they started with a much too complicated system in mind and they therefore overlooked all simpler options. Erickson says the main lesson he learned from his experience with the Benelux radio telescope was:

> BE CAREFUL NEVER TO OVER SPECIFY A SYSTEM – KEEP IT SIMPLE[82]. One must always be certain that all the specifications and requirements of a system are absolutely necessary. It is easy for features to creep into the specifications that are not vital even though they may contribute to the convenience of the system. They quickly are adopted and become so familiar that simpler alternatives are overlooked (Erickson, 2005**,** p. 98).

The question is then *when* Oort came upon the idea to use Earth-rotation based aperture synthesis. The various sources contradict one another in this respect.

Erickson's explanation is as follows. At a certain moment, Jan Högbom visited Cambridge to learn the details of the developments in Earth-rotation based synthesis over there.[83] He returned full of enthusiasm for the concept. Erickson and Hooghoudt, the mechanical engineer who designed the dishes and was responsible for the construction, embraced the idea immediately. Consequently, Hooghoudt, Högbom and Erickson convinced Oort to use it. Oort agreed with the design, but envisioned difficulties convincing other astronomers and funding agencies of the plans. The basic design was however more or less agreed upon by the time Erickson left Leiden at the beginning of March 1963 to take up his post at the University of Maryland (Erickson, 2005, p. 96).

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[81] Högbom to Oort, 11 August 1959, OA, 112c.
[82] Capital letters in original
[83] Erickson does not mention *when* Högbom visited Cambridge. Probably, this must have been somewhere at the end of 1962 or the beginning of 1963. However, we could not find any information in the archives about a journey of Högbom to Cambridge in this period.

Scheuer, on the other hand, comes up with a completely different explanation. In May 1960 and June 1961, a trial of Earth-rotation synthesis was made by Ryle and Ann Neville. It was a North Pole survey at 4'.5 angular resolution that was published in 1962 (Ryle and Neville, 1962).

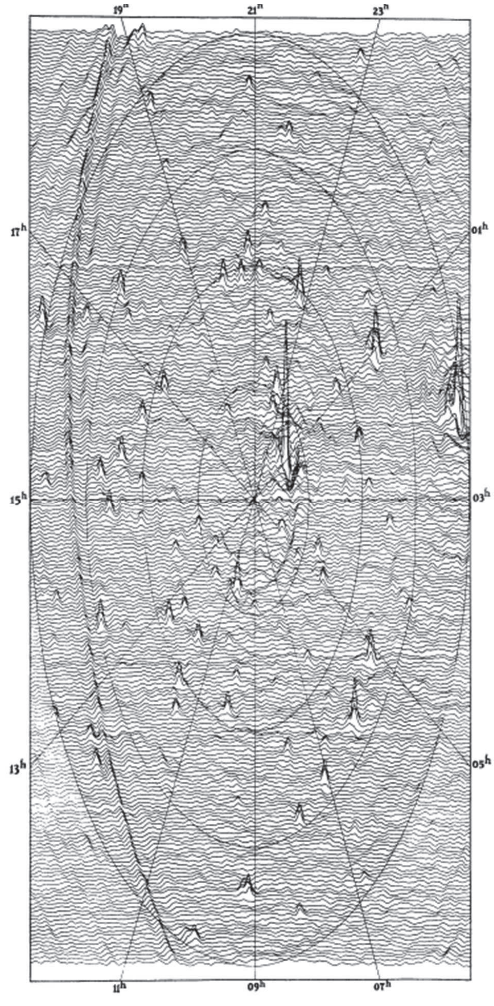

FIGURE 14. North Pole survey (Ryle and Neville, 1962, p. 46)

Scheuer called this survey the 'first earth rotation synthesis map' (Scheuer, 1984, p. 259). Particularly interesting is that Scheuer said that it can have been exactly *this* map that made Oort think of using Earth-rotation aperture synthesis for the radio telescope in Westerbork:

> The map (…) was exhibited at a Herstmonceux conference[84] and some of those who were there reported that Prof. Oort had looked at it thoughtfully for a very long time. Whether or not that was the moment of decision, the Benelux Cross Project soon metamorphosed into plans for the Westerbork Synthesis Radio Telescope. (Scheuer, 1984, p. 259)

The Herstmonceux conference Scheuer mentions here is probably the conference of 7-8 January 1963, devoted to 'the coordination of optical and radio astronomy' (Clube and Sargent, 1963, pp. 150-162). Ryle, Neville and Oort were present at this conference. Ryle gave a talk on 'Radio galaxies and cosmology' and discussed the aforementioned survey, made by the 'aperture synthesis interferometer' at Cambridge (Clube and Sargent, 1963, p 161).

Who is right: Scheuer or Erickson? Or was it perhaps a combination of the two events that convinced Oort? Or was it even something completely different? We will probably never know. The fact remains, however, that in the summer of 1963, the Dutch had firmly decided that the technique used in the new large radio telescope would be Earth-rotation aperture synthesis. (Note that the Belgians did not take part in these discussions on the techniques to be used.)

4.4 THE FOURTH AND FINAL DESIGN: A SIMPLICIFATION OF THE LINEAR ARRAY

When the year 1963 came to a close, the relations with Belgium were so troubled that the Dutch started thinking about continuing alone. However, in that case the project would have to be of a much more modest nature. In January 1964, Piekaar, head of the Division of Higher Education at the Ministry of Education, wrote the following to the Belgian Prime Minister Lefèvre: 'Under these circumstances they [the Dutch astronomers] wonder whether it might not be preferable to realise a more modest design without Belgian participation, possibly in connection to Dwingelo (...).'[85]

This 'more modest' design was prepared by Muller. In January 1964, he proposed a 'drastic simplification' of the plans, to which everybody agreed.[86] This simplification made it possible to reduce the previously estimated cost of 30 million Dfl to half that, 15 million Dfl. Moreover, it had the advantage that it could be built relatively quickly. This was important, as the Dutch were eager to start construction as soon as possible. The simplification was not at the expense of resolution and sensitivity, but rather at the expense of the speed of the observations.

The telescope would consist of 10 reflectors of 25 metres. 9 of them would be placed with a distance of 150 metres in between – which made an array of 1200 metres - and the 10th telescope would be a movable one on a rail-track of 300 metres length.[87]

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[84] The annual Herstmonceux conferences (which took place at the Royal Greenwich Observatory at Herstmonceux in East Sussex, UK) were organised by the British Astronomer Royal Sir Richard Woolley in 1957 (Parker, 2000, p. 287).

[85] 'Onder deze omstandigheden vragen zij zich af, of het niet verkieslijker zou zijn dan maar een meer bescheiden opzet te verwezenlijken zonder Belgische deelname, zo mogelijk in aansluiting op Dwingelo (…)' : Piekaar to Lefèvre, 13 January 1964, SA, NWO.

[86] Oort, J.H., 'Memorandum over de te bouwen grote radiotelescoop', Leiden, 13 January 1964, SA, NWO.

[87] Ferrier, 'Notitie met betrekking tot de Vergadering van de Raad voor het Benelux-Kruisantenneproject, gehouden te Leiden op 17 maart 1964', SA, NWO.

Why did Muller make this new design? Was he not fully taken up with his work in Dwingeloo? Or could nobody else be found? Indeed, the main problem had always been to find someone to lead the electronic design of the new radio telescope.[88] This had to be someone with a very specific and long experience. Muller met these criteria, but when the cross antenna project took off, he was very busy in Dwingeloo. So initially, he was no option. For several years Oort had searched for another leader for the design and construction period, but neither in Belgium, nor in the Netherlands could a suitable person be found. Of course, some very experienced researchers from abroad had been recruited, such as Christiansen and Erickson, but neither of them could stay long enough to start the execution of the project.

Not only was it difficult to find a project leader, it was hard to find competent engineers for the project in general. First of all, the work was highly specialised, but there were some additional problems. Recruiting engineers in Belgium, for example, was particularly difficult, as the salaries of engineers were considerably higher in Belgium than in the Netherlands. In order not to lose the possibility of attracting Belgian engineers, the executive committee of SRZM decided that this difference had to be taken into account when setting the salaries of the Belgian engineers. However, it should also be taken into account that they were working in a Dutch environment and therefore too big a difference in remuneration had to be avoided.[89] In the early 1960s, two outstanding young Belgian engineers of the Institut Montefiore, the Department of Electrical Engineering of the University of Liège, were attracted: G. Cantraine and O. Barbalat. Barbalat, however, never joined the project as 'he had been engaged abroad'.[90] Cantraine was appointed in July 1960, but he stayed for only about one year. Only one Belgian engineer, J.L. Casse, appointed by Belgium at the end of 1961, stayed until the opening of the telescope and beyond. He was a key person in the development of the electronic system of the telescope (Raimond, 1996, p. 29).

As it seemed a 'mission impossible' to recruit a sufficient number of engineers from Belgium and the Netherlands, the Dutch started looking overseas. Sometimes, this quest was successful (see the appointment of Robinson, Christiansen, Erickson etc.), sometimes it was not. Working in Holland did not always please people coming from more exotic places in the world. In the beginning of 1963, for example, an engineer from San Diego (California, USA), D.A. Williams, was hired. He was highly appreciated, as he had ten years of experience in engineering, experience in radio astronomy, in dealing with contractors etc.[91] However, in October 1963, Williams made it clear that he wanted to leave at the end of 1964, because he was not happy. At a council meeting of BCAP, Oort explained:

> (…) Williams had been somewhat disappointed by the character of the work on the project, which he had expected to be in a more advanced, production stage. Moreover his wife did not feel happy in Holland, and had decided to go back to the U.S.[92]

In early 1964, the construction of instruments in Dwingeloo did no longer require Muller full time, so he had considerable spare time to lead the electronic design of the new radio telescope.

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[88] Oort, J.H., 'Memorandum over de te bouwen grote radiotelescoop', Leiden, 13 January 1964, SA, NWO.
[89] Minutes of the executive committee meeting of SRZM of 19 October 1959, SA.
[90] Minutes of the Council meeting of the BCAP of 21 February 1961, SA.
[91] Minutes of the Council meeting of the BCAP of 20 September 1962; Minutes of the Council meeting of the BCAP of 21 January 1963, SA.
[92] Minutes of the Council meeting of the BCAP, held on 17 October 1963, SA.

Initially, it was planned that the telescope was to consist of 10 reflectors of 25 metres, 9 of them to be placed with a distance of 150 metres in between – which made an array of 1200 metres - and the 10th telescope would be a movable one on a rail-track of 300 metres length. However, later it was decided – it is not certain when exactly – that there were to be 11 reflectors, 10 of which would be placed with 150 metres in between and the 11th on a rail-track.[93]

It was this design that was finally put out to tender on 30 December 1964. Several companies – amongst which Werkspoor that had built the telescope in Dwingeloo – showed interest.[94] Although Belgium was still a partner, Belgian companies did not participate. They were contacted several times, but without result.[95] 3 May 1965 was the closing day of the tender. The contract for the construction of the telescopes was awarded to Wilton-Fijenoord, a shipbuilding and repair company in Rotterdam, which had made the lowest bid and could offer the eleven reflectors for Dfl 6 711 000.[96]

At that time, it had not been decided yet whether a second movable telescope would be added to the system. At the end of 1965, however, that decision was taken and a twelfth reflector was ordered.[97]

4.5 IN SEARCH OF A LOCATION AND A NAME

'Is het in de buurt van het vroegere doorgangskamp?'
'Het is op het terrein van het kamp,' zei Max, terwijl hij voelde dat zich iets verstrakte in zijn wangen.
Harry Mulisch, *De ontdekking van de hemel*

The question was now *where* the telescope should be built. To enable Muller to lead both projects – Dwingeloo and the new radio telescope – the new telescope had to be built close to Dwingeloo. This meant that most locations that had been considered previously had become irrelevant.

The quest for a suitable location for the new radio telescope had begun in 1960. Initially, the possibility was left open to look for a location outside the Benelux:

> It appeared to the Council that possibilities have to be carefully investigated, and that it is prematurate [sic] to define now a precise region for the location of this large cross. Possibilities in the Benelux have to be analysed first, before seeking a site in the neightbouring [sic] countries.[98]

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[93] Bannier to the [Dutch] Minister of Education, 27 May 1965, SA, NWO.
[94] Werkspoor Utrecht to Stichting Radiostraling van Zon en Melkweg, 15 January 1965 ; Wilton Feijenoord to Oort, 13 January 1965, SA.
[95] Bannier to Ferrier, 21 August 1964, SA, NWO.
[96] Bannier to the [Dutch] Minister of Education, 27 May 1965, SA, NWO.
[97] Note added on 20 December 1965 on the minutes of the meeting of 11 October 1965, SA.
[98] Minutes of the meeting of the BCAP, held on 4 July 1960, SA.

As early as 1961, the first site surveys were done. Soon it became clear that finding a location was a very complicated matter. Dr. G. Westerhout wrote a first report on the Dutch site survey.[99] The most important requirement was that the region should be free of interference, five kilometres east, south and west and one kilometre north. Moreover, solid ground over two five-kilometre strips – where the antennas were constructed - was required. Several sites were investigated, but ultimately judged unsuitable:

(a) Drenthe: the telescope could be placed near the Dwingeloo telescope. However, a local road passed at 1500 metres and the nature reserve 'Kralose Veld'[100] would be ruined
(b) Overijssel: the only place available was in the lakes area, where the telescope could only be built at great cost
(c) Gelderland: the wooded area on the Veluwe had been considered, but there were three disadvantages: intensively used recreation area, military training grounds and hills up to fifty metres
(d) Zeeland: this was too near the coast and too intensively cultivated
(e) Southern part of Limburg: there were too many hills and mining industry

Some further research was done, and ultimately it was judged that some regions of North Brabant and North Limburg were far the most suitable, especially the regions that were situated along the Belgian-Dutch border, as these were the most 'empty', but also because it was politically and practically interesting to build the telescope on the border of the two countries participating in the project. However, when it was decided that Muller would lead both telescope projects, only regions close to Dwingeloo were considered in the site surveys.[101] Soon the Dutch had their eye on a region east of the village of Hooghalen, namely the 'Boswachterij Hooghalen', the forestry of Hooghalen – property of the Forestry Commission - in the province Drenthe.[102] The forestry of Hooghalen was located about twenty kilometres from Dwingeloo. There were some 'minor problems' in this area that had to be overcome before the construction of the telescope could begin: a road had to be closed, a farm and a military shooting range had to be removed, and several Ambonese families had to be moved. The relative ease with which Oort had all these things done is illustrative of his influence on Dutch politics. At the same time, it made clear that by the mid-1960s, radio astronomy had become a mature and prestigious field of which the importance was no longer doubted. In the Netherlands, people were eagerly looking forward to the construction of the prestigious instrument. As early as 1965, Dutch newspapers proudly announced on a regular basis the construction of the 'Giant telescope' in Westerbork.[103] On the other hand, however, the construction of the radio telescope was also a welcome opportunity for the Dutch government.

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[99] Westerhout, G., 'Report on the preliminary site survey in the Netherlands' (Appendix at Minutes of the Council meeting of the BCAP of 21 February, 1961), SA.
[100] I.e. the 'Kraloërheide'.
[101] Minutes of the Council meeting of the BCAP of 17 March 1964, SA.
[102] Raimond, E., 'Possible sites for the Benelux Antenna in Drente' [sic: DrentHe was by then often written Drente], 30 April 1964, SA, NWO.
[103] Reuzen-telescoop komt in Westerbork, in : *De waarheid*, 1 July 1965. Some other examples: Grootste ter wereld. Telescoop in Westerbork tast naar « grenzen » in het heelal, in : *Friese Koerier*, 27 May 1968 ; Bij Westerbork verrijst enorme radiotelescoop. Waarschijnlijk volgend jaar in gebruik, in : *Friese Koerier*, 16 July 1968.

Let us first consider the Ambonese. In the forestry of Hooghalen, there were still remains of the camp 'Schattenberg', where some Ambonese families were living. Camp Schattenberg had a long history. At the dawn of the Second World War, Camp Westerbork – ten kilometres to the north of the village of Westerbork - was built as a refugee camp for (German) Jews that had fled Nazi Germany. When the Germans occupied the Netherlands, they made use of the existing structure to change the refugee camp into a transit camp for Jews, Gypsies, homosexuals etc. From Westerbork, they were transported to the death camps of Auschwitz, Sobibor, Theresienstadt and Bergen-Belsen (Mulder, 2003, p. 469).

After the war, the camp was used as an internment camp for members of the Dutch National Socialist Movement, who had collaborated with the Germans. This was not unusual. Also other Dutch camps – for example Camp Amersfoort , Camp Vught, Camp Schoorl and Camp Erika – were used as internment camps for Dutch people who had collaborated with the Germans (Hijink, 2009, p. 135). When, in 1948, the internment period came to an end, it was uncertain for a while what would happen to the camp. Several options were considered, even changing it into a pig farm. The former camp then served several short-time purposes (Mulder, 2003, p. 469).

However, this indecisiveness, did not last long. In December 1949, Indonesia became independent. The Ambonese or South Moluccans - inhabitants of the Ambon Island in Maluku – who had fought in the Royal Dutch-Indian Army against the Indonesian nationalists, were of course very unpopular in Indonesia after the independence. Therefore, the Dutch government decided to offer transport to the Netherlands, and to house them together with their families in the former Dutch camps. In hindsight, the way the Dutch dealt with the camp heritage is rather upsetting: the remaining objects of the camps were not preserved or made into memorials, although many former prisoners tried to achieve this. At the end of the 1940s, the camp inventories of Camp Vught and Camp Westerbork were even auctioned. It was only in the 1980s that the former camp possessions were considered to have museum value and exhibitions with these objects were organised within the structures of existing museums (Hijink, 2009, p. 136).

On 22 March 1952, the first Ambonese entered the former camp Westerbork, which was in the meantime renamed to 'Schattenberg', after a neighbouring hill. In the end, 3000 Ambonese would live in Schattenberg. It was a closed community that had little contact with the outside world. The intention was to house the Ambonese only temporarily in Schattenberg, but in the end, they would stay for almost twenty years (Mulder, 2003, p. 470).

Since the end of the 1950s, the Dutch government had tried to integrate the Ambonese people into the Dutch society.[104] It enforced this by no longer carrying out the necessary maintenance on their barracks. As a consequence, one barrack after the other became uninhabitable, so that the people living there had to leave. The question was what would happen to the area when the Ambonese had left. The plans for the huge radio telescope offered an excellent solution (Mulder, 2003, p. 470). At the same time, it was a welcome occasion to hasten the eviction of the remaining Ambonese families. In June 1967, there were still 1300 Ambonese people in Schattenberg. Oort had had a meeting with the Provincial Executive, during which the latter had assured him that the

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[104] See also the report it issued in 1957 : *Ambonezen in Nederland: rapport van de commissie ingesteld bij besluit van de Minister van Maatschappelijk Werk*, d.d. 24 Sept. 1957 nr. U 2598.

camp would be empty no later than 1 September 1968.[105] It was decided that the Ambonese would be rehoused in Bovensmilde, a small village to the west of Assen.

Although the evacuation of the Ambonese camp was already taking place at the time the construction of the radio telescope began, in the Dutch newspapers it was presented as if the arrival of the telescope was the one and only reason the camp had to be removed. At the end of October 1967, the newspaper *Nieuwsblad van het Noorden* reported:

> Mayor P. de Noord of Smilde announced yesterday evening at the beginning of the meeting of the city council that the Ambonese that are still staying in camp “Schattenberg” near Westerbork will be rehoused in Bovensmilde. (...) The discussions about the rehousing of these Ambonese, that will have to leave “Schattenberg” because of the construction of a radio telescope over there, went very well, said the mayor.[106]

However, the evacuation was delayed.[107] This was due to strong resistance of some of the remaining Ambonese. Despite the forceful intervention of the authorities, it took until February 1971 before the last Ambonese family was moved (Mulder, 2003, p. 470). In the end, the delay did not cause the Dutch astronomers too much trouble, as they just adapted their construction plans to this situation.[108]

Also the Forestry Commission showed itself a loyal partner in this prestigious project in Westerbork. In the area where the telescope would be located, there was a road leading to the Ambonese camp. As the area had to be free of interference, however, this road needed to be closed to all motorised vehicles. As it belonged to the Forestry Commission, it ‘could be closed without any difficulties’.[109] Furthermore, the Forestry Commission bought some neighbouring grounds where they subsequently banned all motorised traffic etc., to make sure that an interference-free zone could be guaranteed for the astronomers.[110] After the inauguration of the telescope, the Forestry Commission was very proud of having facilitated the arrival of this prestigious instrument. It published a special booklet *Boswachterij en Sterrenwacht* (Forestry and Observatory), in which it said: ‘Nature and technology have found each other in the 1200 hectares forestry of ‘Hooghalen’.[111] (Van Wageningen, 1970, p. 1)

The Dutch Ministry of Education and Sciences too, was very supportive. The farm in the area that needed to be removed was bought by the Ministry on 5 September 1967. The farmer was rehoused

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[105] Minutes of the board meeting of SRZM of 30 June 1967, SA.

[106] ‘Burgemeester P. de Noord van Smilde heeft gisteravond aan het begin van de gemeenteraadsvergadering meegedeeld, dat de thans nog in het kamp « Schattenberg » bij Westerbork verblijvende Ambonezen in Bovensmilde zullen wrden gehuisvest. (…) De besprekingen over de verhuizing van deze Ambonezen, die « Schattenberg » zullen moeten verlaten in verband met de bouw van een radiotelescoop aldaar, zijn zeer gunstig verlopen, aldus de burgemeester.’ *Nieuwsblad van het Noorden*, 27 October 1967.

[107] Toelichting bij de begroting 1968, SA, NWO.

[108] Toelichting bij de begroting 1968, SA, NWO.

[109] Raimond, E., ‘Possible sites for the Benelux Antenna in Drente’ [sic: DrentHe was by then often written Drente], 30 April 1964, SA, NWO.

[110] Minutes of the board meeting of SRZM of 19 August 1964, SA; Minutes of the board meeting of SRZM of 14 May 1965, SA.

[111] ‘Natuur en techniek hebben elkaar gevonden in de 1200 hectare grote boswachterij ‘Hooghalen’.

in the polder of East Flevoland. Moreover, the Ministry even decided to remodel the former farm as housing for the telescope observers.[112] Most striking, however, was that Oort got the military shooting range removed relatively easily. To his initial request to *close* the shooting range, the Ministry of Defence answered that it was impossible, as it was very intensively used. At the same time, however, it recognised the scientific importance of the radio telescope and therefore it was willing to *relocate* the range: 'Given the great scientific interest that is served by the construction of a radio telescope, there are in principle no objections from the side of the ministry against a relocation (…).'[113] The idea was to incorporate the shooting range into another shooting range nearby, the one in Witten (near Assen). However, the Ministry of Defence did not want to pay for the costs of this relocation.[114] The total cost of the expansion of the shooting range in Witten was estimated at Dfl 500 000. There were five battalions that would make use of the range. Two of them had previously used the range near Westerbork. Consequently, the reasoning of the Ministry of Defence was that 2/5 of this amount of Dfl 500 000, namely Dfl 200 000 should not be paid by this Ministry. Therefore, Oort asked Piekaar whether the Ministry of Education could pay this amount.[115] The Ministry immediately agreed.[116]

When the design was put out to tender, the telescope had no name yet. Oort, Rinia, Blaauw and Muller discussed this, and they agreed that 'Cross antenna' was no longer relevant as the final shape would definitely not be a cross. Moreover, 'Benelux' should no longer be used in the name, as Luxemburg had never participated. Because Belgian participation had also become highly uncertain, it was agreed that any reference to the participating countries in the name of the telescope should be avoided. Several names were then proposed: 'Earth-rotation Antenna Synthesizer', which could then be abbreviated to the acronym 'ERAS'. This name was Rinia's favourite. He preferred not to use the word 'Westerbork' in the name of the telescope, as this word 'sounded unpleasant' to many people.[117] Indeed, the name of the village of Westerbork was inextricably linked to the Second World War 'Camp Westerbork'. Therefore, if a reference to the place would be made, Rinia would prefer 'Schattenberg'. The others, however, were not keen on the name 'Schattenberg', because this name did not figure on any map[118] and because it was unpronounceable for foreigners.[119] Muller for his part wanted to make a distinction between the name of the project, which he would call 'Westerbork Synthesis Telescope Project' (WSTP) and the name of the observatory, which he would call 'Radio Observatory Westerbork'. In the latter, he preferred to speak of an *observatory* instead of of a *telescope* as he expected that later on several other telescopes would figure on this terrain[120] Blaauw especially warned that the word 'large'

[112] Oort to the Ministry of Education and Sciences, 12 July 1967, SA, NWO.
[113] 'Gezien het grote wetenschappelijke belang dat met de stichting van de radio-telescoop wordt gediend, bestaan van defensiezijde tegen een verplaatsing naar elders in beginsel geen bezwaren (…).' Taks, A.M.J., Colonel of the Army, to the Director of the State Office for the National Plan, 24 August 1964, SA, NWO.
[114] Taks, A.M.J., Colonel of the Army, to the Director of the State Office for the National Plan, 24 August 1964, SA, NWO.
[115] Oort to Piekaar, 25 March 1965, SA, NWO.
[116] Minutes of the board meeting of SRZM of 14 May 1965, SA.
[117] Rinia to Oort, 18 March 1965, SA, NWO.
[118] Muller to Oort, 5 April 1965, SA, NWO.
[119] Blaauw to Oort, 23 March 1965, SA, NWO.
[120] Muller to Oort, 5 April 1965, SA, NWO.

should absolutely be avoided, as it was to be expected that in the near future much larger instruments would be built.[121]

The name ultimately chosen was the Westerbork Synthesis Radio Telescope (Westerbork Synthese Radio Telescoop) or WSRT. The village of Westerbork, of course, was very happy – after its dark past - to see its name now connected with a new prestigious scientific facility (Raimond, 1996, p. 26).

4.6 CONSTRUCTING AND INAUGURATING THE WESTERBORK SYNTHESIS RADIO TELESCOPE

The construction of the WSRT began in the winter of 1965-1966. The start was problematic, because manufacturing defects in the supporting structures of the reflectors delayed the assembly of the reflectors until June 1967.[122]

The electronics were developed partly by a group at Leiden Observatory under the leadership of the Belgian engineer Casse and partly by the staff of the laboratory in Dwingeloo under the direction of Muller (Raimond, 1996, p. 29). To this end, the laboratory in Dwingeloo was expanded.[123] During 1967, the production of the receiver system – which consisted of about 20 interferometer receivers – began. Muller was responsible for the development of the digital part. He worked closely together with Philips, the Dutch electronics company, which was contracted to deliver the hardware and software for controlling the positioning of the telescopes.[124]

The mechanical part of the twelve radio telescopes was finished in the fall of 1968.[125] Although the plan was to have all the aspects of the telescope ready at the same time, in virtually all areas except the mechanical – electronics, computer control etc. - problems arose. To give an example, it was agreed that Philips would deliver the numerical control on 1 November 1968. In the summer of 1968, however, it became clear that this was impossible and that delivery would take place no earlier than the end of March 1969. This delay caused some friction between Philips and the board of SRZM. Philips put the blame for the delays on staff changeover in the company, on the May 1968 strikes in France and on the ever changing demands of the astronomers. The astronomers themselves, however, thought that Philips just started the work too late. Oort was in

[121] Blaauw to Oort, 23 March 1965, SA, NWO. In hindsight, this was a very smart suggestion of Blaauw : in 2011, for example, a prize contest was organised to rename New Mexico's 'Very Large Array', a giant radio telescope that was commissioned in 1980. According to the USA consumer magazine *Popular Science,* the Very Large Array was 'named in a fine tradition of utilitarian monikers like the European Extremely Large Telescope and the ultimately impractical Overwhelmingly Large Telescope.' (Adams, 2011). The 'European Extremely Large Telescope' is an ESO-telescope that will be the largest ground based optical/near-infrared telescope in the world and will be built in Cerro Armazones (Chile). The 'Overwhelmingly Large Telescope' was a conceptual design of ESO that was ultimately given up because of the high cost and the complexity. The simpler European Extremely Large Telescope was chosen instead. The Very Large Array got its new name in January 2012 : it is now called the 'Karl G. Jansky Very Large Array'.

[122] Stichting Radiostraling van Zon en Melkweg. Annual report 1967, p. 25.

[123] Minutes of the board meeting of SRZM of 30 June 1967, SA.

[124] Stichting Radiostraling van Zon en Melkweg. Annual report 1967, p. 26. Remember that Philips had been involved in radio astronomy since its very beginnings.

[125] Stichting Radiostraling van Zon en Melkweg. Annual report 1968, p. 23.

despair about the delays that were caused by Philips and said it was 'disastrous that, while the steel structures in Westerbork will be ready on 1 November, the telescope will only be ready for use several months later'.[126] Moreover, the estimate that the telescope would be ready for use 'several months later' would prove to be far too optimistic. Several other problems were encountered. The computer programs, for example, could not cope with the enormous amount of data to be reduced.[127] Another major problem was to get the pressurized coaxial cable system free of gas leaks.

And last but not least, there was a major problem that again shows how highly this project was valued and illustrates Oort's influential position: a severe source of interference was visible in all data and horizon scans revealed that the interference originated from a military base about ten kilometres to the south-west of the observatory. The culprit was a transmitter that was part of a NATO communications network in Western Europe. Its frequency coincided with one of the 'harmonics' of the WSRT's observing frequency, a frequency band in which interfering signals were rejected to a slightly lesser extent than elsewhere in the spectrum. Although transmitting in this band did not violate any frequency protection rules, the military authorities were willing to change the transmission frequency. After the necessary administrative procedures, the interference was removed in the fall of 1970 (Raimond, 1996, p. 31).

The numerous problems that arose in the construction of the WSRT made it clear that the astronomers had underestimated the whole project. At the end of 1968, Muller admitted: 'We must say that across the board, the work was partly underestimated, partly it was also delayed by external factors'.[128]

With the delays accumulating, the estimated date on which the entire telescope should be ready for use changed several times: from the fall of 1968 to the beginning of 1969 to the first of September 1969 etc. The inauguration date was also moved forward several times. At the meeting of the board of SRZM on 13 December 1968, two possible inauguration dates were proposed: September 1969 and April 1970. It was agreed upon that September 1969 was the best choice. This was because by then, it was still estimated that the first observations would be made in September. Publicity was expected and so it was considered a good idea to have the inauguration shortly after the first observations.[129]

The first test observations were made with a single interferometer in the spring of 1969.[130] However, not until February 1970 could observations be made under computer control and with digital recording of the data on magnetic tape (Raimond, 1996, p. 31). Contrary to what was initially expected, no media coverage followed. It remains unclear whether there was no interest of the media in the observations or whether the astronomers just did not write any press releases.

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[126] 'Het is rampzalig dat, terwijl de staalconstructies te Westerbork op 1 november klaar zullen zijn, de telescoop pas verscheidene maanden later zal kunnen worden gebruikt.' Minutes of the board meeting of SRZM of 24 June 1968, SA.
[127] Minutes of the board meeting of SRZM of 13 December 1968, SA.
[128] 'Over de gehele linie moet men zeggen dat het werk ten dele onderschat is, ten dele ook vertraagd door externe factoren.' Minutes of the board meeting of SRZM of 13 December 1968, SA.
[129] Minutes of the board meeting of SRZM of 13 December 1968, SA.
[130] Stichting Radiostraling van Zon en Melkweg. Annual report 1969, p. 24

Probably the latter. This in turn, was most likely due to the fact that the astronomers wanted to ensure plenty of media coverage when the inauguration took place.

The radio telescope was inaugurated on 24 June 1970 by the Dutch Queen Juliana. It was the second time – after the inauguration of the radio telescope in Dwingeloo - that she opened a prestigious Dutch radio telescope.[131] The inauguration was front-page news in several Dutch newspapers. As at the time of the inauguration of the radio telescope in Dwingeloo, the Dutch were again very proud of this prestigious scientific instrument.

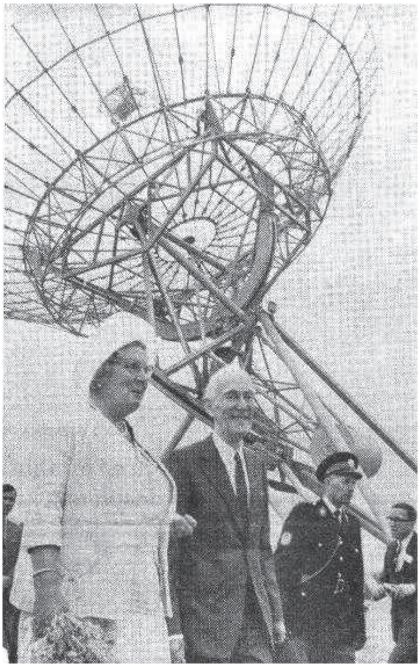

FIGURE 14. The Dutch Queen Juliana and Oort at the inauguration of the radio telescope in Westerbork (*Leeuwarder Courant*, 25 June 1970)

131 'H.M. Koningin Juliana opent radiosterrenwacht Westerbork', s.d., SA, NWO.

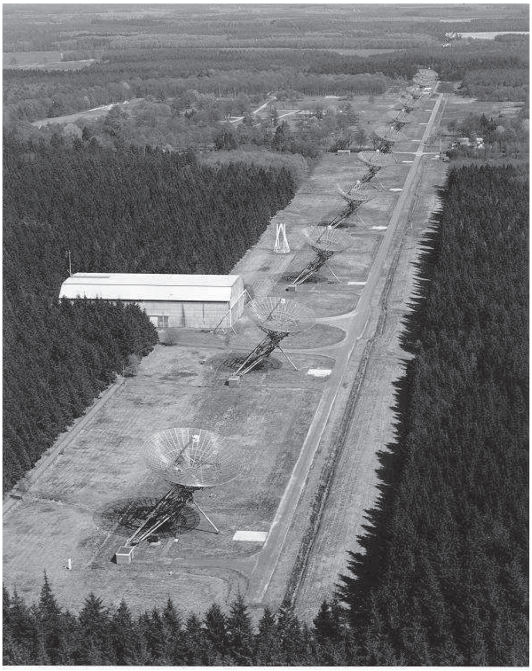

FIGURE 15. The radio telescope at Westerbork (http://www.astronomie.nl/#!/onderzoek/observatoria/_detail/gli/westerbork-telescoop/**)**

Even a company such as Philips, which had never showed itself a very enthusiast partner, in hindsight was very proud that it had participated in the development of this prestigious instrument. In 1970, it published a booklet, entitled *Billions of years and split seconds* in which it emphasised its contribution:

> The development and the realisation of the radio telescope was a joint venture of a number of highly specialised Dutch industries and of the staff of the foundation. Philips, being experts in scientific and industrial instrumentation and process control, contributed a computer and numerical control system. (Philips, 1970, p.1)

4.7 PAYING FOR AN EXPENSIVE INSTRUMENT OUT OF A TIGHTENING BUDGET

Until now, we have only briefly addressed the financial side of the story. However, it is worth dwelling on. First of all, it gives an idea on how the Dutch dealt with the delays in the Belgian contributions and what influence the Belgian arrears had on the course of the project. Moreover, it gives an excellent view of the changing Dutch science policy and tightening budgets during the 1960s. It also shows how Oort was struggling with this changing situation. Oort had been at the height of his career in the early post-war period, a time in which money for science was generously provided and prestigious university professors obtained extensive funding almost automatically. By the mid-1960s, however, these comfortable times were over.

In the total cost of the telescope, a distinction was made between the 'preparatory costs', the 'investment costs' and the 'operating costs' (or 'annual costs') of the project. In practice, however, these costs were not covered in sequence, starting with the preparatory costs and ending with the operating costs, nor were these different kinds of costs clearly separable. In 1960, ZWO provided a starting budget of Dfl 50 000 for the cross antenna project. Starting in 1962, an annual budget was provided to cover the investment costs. It was paid out of the 'extraordinary budget' of ZWO. The provision of money for the 'preparation of the cross antenna', however, continued through 1964. Beginning in 1965, ZWO used the term 'operating costs' instead of 'preparatory costs', although the telescope was far from being operational at that time. As a matter of fact, the distinction between preparatory costs, investment costs and operating costs was rather arbitrary. A sharp distinction could not be drawn, as Blaauw wrote to Oort in 1965: 'The transition of construction phase into operating phase will be a gradual one.'[132]

It is noteworthy that the Dutch share of the WSRT was *entirely* paid for by ZWO. This was in sharp contrast to what happened in most other countries. There, most often industry and/or the military were also involved. In Britain, for example, the Mullard Radio Astronomy Observatory (MRAO) in Cambridge, built in 1957, was partly funded by a grant from the Department of Scientific and Industrial Research (DSIR, see Chapter II) and partly by Mullard Limited, a British manufacturer of electronic components (Ryle, 1957, p. 110). The 'Lovell Telescope' (1957) in Jodrell Bank (see Chapter II) was funded by the British government as well as industry. Initially, it received money from DSIR and from the University Grants Committee (UGC). When the costs of the telescope spiralled, however, the private Nuffield Foundation and other government and military bodies, such as the Air Ministry and Ministry of Supply, were mobilised (Agar, 1998, p. xvii). Another example is the Effelsberg 100-m radio telescope (1972) of the Max Planck Institute for Radio Astronomy in Germany that was funded by the Volkswagen Foundation (Wielebinski, 1971, p. 115).

The fact that in the construction of the WSRT no military, industrial or private money was involved also meant that the radio telescope was not bound to perform any other than academic research. This was different for some of the other telescopes, the 'Lovell Telescope' in particular (see also Chapter II). Sven Grahn, involved in Swedish space research since the 1970s, has written an article on Jodrell Bank's role in early space tracking activities. He emphasised that the immense size and capability of this telescope was recognised as an invaluable asset when the USA decided to initiate a crash programme to send a probe to the Moon: the Able I project. Indeed, the USA ground tracking installations for this were inadequate. Able – and also some other American projects – definitely *needed* Jodrell Bank. The US Air Force and its contractor Space Technology Laboratories put trailers with equipment at Jodrell Bank and paid for the use of the telescope. At the same time, the success of the telescope in tracking US and Soviet space probes led to a donation from Lord Nuffield to pay off the telescope's remaining debt (Grahn, 2008).

[132] Blaauw to Oort, 23 March 1965, SA, NWO.

4.7.1 DEALING WITH THE BELGIAN ARREARS

The vague distinction between preparatory costs, investment costs and operating costs, however, caused some – further – trouble in the relation between the Belgians and the Dutch. As mentioned in the previous chapter, the Belgians only wanted to spend a maximum of 7 million Bfr - about Dfl 500 000 - annually on this project, initially for a period of 25 years. By then, they would have paid half of the total cost (preparatory costs/ investment costs / and exploitation costs) of the telescope. To the Dutch, however, this seemed an unrealistic scenario. According to them, it was a much more viable option to let the Belgians contribute for a period of 10 years. Taking the maximum of 7 million Bfr annually into account, the Dutch would then pay all of the investment costs, and the Belgians and the Dutch would each contribute 50% of the preparatory and operating costs,[133] which was agreed to by the Belgians.

So each year when the budget for the radio telescope project was prepared, the Dutch counted on an equal share of the Belgians in the preparation or operating costs. The amount due from each country from 1960 through 1963 was as follows:[134]

1960	Dfl 50 000
1961	Dfl 63 750
1962	Dfl 150 000
1963	Dfl 250 000

However, from the very beginning, the Belgian payments only arrived after long delays. Below, a list is shown of which amounts were sent on which date to secretary-treasurer Coutrez on a special BCAP account in the Belgian 'Banque Degroof & Cie' to cover the amount due from 1960 up to and including 1963:[135]

31 March 1961	Bfr 332 000
29 March 1962	Bfr 700 000
19 March 1963	Bfr 2 251 746
2 March 1964	Bfr 3 806 040

While in the Netherlands, each contribution for the operating year concerned was paid in December of the previous year (the contribution for 1964, for example, was paid in December 1963), in Belgium it was only paid in March of the year *after* the operating year concerned.

[133] 'Verslag van het interne Nederlands overleg over de Nederlands-Belgische samenwerking inzake het Synthese Radiotelescoop Project', held on 6 December 1965, SA, NWO.
[134] Bannier, J.H., 'Nota over de Belgische achterstand in de betaling voor de radioastronomische samenwerking', 26 July 1966, SA, NWO.
[135] Bannier, J.H., 'Nota over de Belgische achterstand in de betaling voor de radioastronomische samenwerking', 26 July 1966, SA, NWO.

Moreover, the Dutch did not actually receive the money on these dates in March. It often took several more months before these sums were deposited into the Dutch account at 'N.V. Slavenburg's Bank'.[136] In addition, no exact amounts were paid. For example, for 1960 Dfl 50 000 had to be paid, but the Belgians only paid Bfr 332 000, which is only about Dfl 23 000. They compensated this by paying more during 1963 and 1964. So in the end, they had paid a total amount of Bfr 7 089 786 or Dfl 513 750, which was the exact amount due.

After 1964 the situation worsened.

The table shows the amount of money both countries had to pay from 1964 through 1967:[137]

1964	Dfl 340 000
1965	Dfl 250 000
1966	Dfl 320 000
1967	Dfl 340.000

Without a clear reason, however, the Belgians did not pay their contribution for 1964. In February 1966, Coutrez offered a vague explanation for this state of affairs: '(…) I have received the instruction of the Minister of Public Education to provisionally end the transfer to the BCAP account in the Netherlands, while awaiting the outcome of the discussions between the parties involved.'[138] Otker - head of the administration of ZWO and administrative officer for the radio telescope project - was utterly astonished by this letter and wrote to Darimont of the Belgian Ministry of Public Education that he would '(…) very much appreciate it if you were able to use your high influence in order to arrange a quick settlement of the overdue payments.'[139] Unfortunately, Darimont died in a car accident on 27 February 1966 (Fraiture, 2006, p. 32). So an answer to this letter never came. A few months later, however, Deloz, an official of the Department of Higher Education and Scientific Research of the Belgian Ministry of Public Education, seems to have – verbally - communicated to Bannier that the Belgian contributions had come to an end because Belgium was only bound to participate in the 'preparatory stage' of the project.[140] The Dutch, however, found this an unacceptable explanation. They stressed that in practice, it was impossible to make a distinction between the 'preparatory stage' and the 'construction stage'.[141]

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[136] Bannier, J.H., 'Nota over de Belgische achterstand in de betaling voor de radioastronomische samenwerking', 26 July 1966, SA, NWO.

[137] Bannier, J.H., 'Nota over de Belgische achterstand in de betaling voor de radioastronomische samenwerking', 26 July 1966, SA, NWO; Bannier to the Minister of Education and Sciences, 6 March 1967, SA, NWO

[138] '(…) j'ai reçu instruction du Ministère de l'Education Nationale d'arrêter provisoirement tout transfert au compte BCAP aux Pays-Bas en attendant les résultats des discussions entre parties intéressées.' Coutrez to Otker, 9 February 1966, SA, NWO.

[139] '(…) bijzonder op prijs stellen als U Uw hoge invloed wilde aanwenden om een snelle afdoening van de achterstallige betalingen te regelen.' Otker to Darimont, 22 February 1966.

[140] Bannier, J.H., 'Nota over de Belgische achterstand in de betaling voor de radioastronomische samenwerking', 26 July 1966, SA, NWO.

[141] Bannier, J.H., 'Nota over de Belgische achterstand in de betaling voor de radioastronomische samenwerking', 26 July 1966, SA, NWO. Bannier also mentions that the OEEC was also bound to give support in the 'preparatory stage'. However, as the 'preparatory stage' did not come 'officially' to an end, the contract with OEEC was also never officially ended. OEEC ended the support after 1962, as the organisation had no money available to support this project further.

Eventually, the Belgians continued their payments – it is not clear why they decided to do so - but not until early 1968 (!) was the contribution of 1964 paid.[142] By this time, the contributions for 1965 and 1966 had been deposited in the Banque Degroof & Cie, but could not yet be sent to the Netherlands. Apparently, a new complication had arisen. The Belgian Inspectorate of Finance – responsible for administrative and budgetary control tasks - first wanted to have copies of the reports of the Central Accounting Service of the Dutch Ministry of Finances (Centrale Accountantsdienst van het Nederlandse Ministerie van Financiën) of the radio telescope project of the years 1965 and 1966.[143] Unfortunately, the reports of 1965 and 1966 were not ready yet.[144] A report of the years 1965-1967 was issued on 30 August 1968 and on 17 September Bannier sent a copy to Deloz.[145] However, after the receipt of this document, the Belgians remained silent. Several reminders of the Dutch followed during 1969.[146] In the beginning of December 1969, Deloz asked Coutrez to deposit the contributions for 1965 and 1966 into Slavenburg's Bank.[147] The final payment was received by the Dutch on 9 January 1970.[148]

So the Belgians paid their share of the preparation and/ or operation costs of the telescope from 1960 up to and including 1966. There was disagreement about whether or not Belgium had to pay the contribution for 1967: according to the Dutch, they should, according to the Belgians, they should not. On 25 July 1966, the Belgian ambassador in The Hague had had a meeting with the Dutch Prime Minister and the Minister of Foreign Affairs, during which he communicated the withdrawal of the Belgians from the radio telescope project (see previous chapter). The Dutch, however, did not consider this as an 'official' withdrawal. As we saw, they only considered the memorandum that was sent from the Belgian Embassy in The Hague to the Dutch Ministry of Foreign Affairs and to Oort on 14 July 1967 as final. Therefore, the Dutch thought that the Belgians still should pay the contribution for 1967. However, as the Belgians absolutely disagreed and the Dutch became aware that they would never be able to persuade them to pay, they considered the case closed.[149]

To deal with the Belgian delays, each year ZWO paid an advance to the Dutch astronomers to make up for the lacking Belgian amounts. When the amount due was finally received by the Dutch, it was paid back to ZWO.[150] This arrangement prevented serious delays in the project. So the complaints of the Dutch about the delays the Belgians caused – as you could read in the previous chapter – must be taken with a pinch of salt. Jean Casse - the Belgian engineer for the project – has confirmed that the 'financial problems in Belgium did not delay the project very much'.[151] The difficult relation with Belgium eventually forced the Dutch to simplify the design, but - as Casse emphasises – this happened very quickly (within a few months).[152] Although it is difficult to judge how the radio telescope project would have proceeded if we counterfactually assume that there

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142 Deloz to Bannier, 26 March 1968, SA, NWO.
143 Deloz to Bannier, 26 March 1968, SA, NWO.
144 Bannier to Deloz, 9 April 1968, SA, NWO.
145 Bannier to Deloz, 17 September 1968, SA, NWO.
146 Bannier to Deloz, 1 May 1969: Bannier to Deloz, 17 September 1969; Bannier to Deloz, 27 October 1969, SA, NWO.
147 Deloz to Coutrez, 5 December 1969, SA, NWO.
148 Bannier to Deloz, 28 May 1970, SA, NWO.
149 Minutes of the board meeting SRZM of 4 February 1971, SA, NWO.
150 See for example: Bannier, J.H., 'Nota over de Belgische achterstand in de betaling voor de radioastronomische samenwerking', 26 July 1966, SA, NWO.
151 Personal communication of Jean Casse to author, 8 February 2012.
152 Personal communication of Jean Casse to author, 8 February 2012.

had been no cooperation with Belgium, it is quite obvious that this cooperation was far from detrimental for the project. The Belgians had paid half of the preparation and operation costs of the telescope from 1960 until 1966, without having benefitted from any returns: Belgian industry was hardly involved in the construction of the telescope[153] and as they did not use the telescope, the Belgians did not claim any of the (limited) observation time.

To have an idea of the total amount the Dutch paid for the radio telescope in Westerbork, the following table gives an overview of the funding ZWO provided for the radio telescope project from 1960 up to and including 1970. Remember that since 1962, a division had been made between the 'Ordinary budget' and the 'Extraordinary budget' of ZWO. The investment costs of the telescope were covered out of the 'Extraordinary budget' of ZWO.[154]

1960	Dfl 50 000	
1961	Dfl 63 750	
	Ordinary budget	**Extraordinary budget**
1962	Dfl 150 000	Dfl 1 000 000
1963	Dfl 250 000	Dfl 3 000 000
1964	Dfl 340 000	/ *
1965	Dfl 250 000	Dfl 1 000 000
1966	Dfl 320 000	Dfl 3 000 000
1967	Dfl 340 000	Dfl 4 000 000
1968	/	Dfl 3 750 000
1969	/	Dfl 3 395 000
1970	/	Dfl 2 257 767

*For the year 1964, no lump sum for capital expenses was put on the budget, because it was thought unlikely that a sum exceeding two times four million Dfl – by then it was still the idea that Belgium would also pay half of the investment costs – would be needed before the end of 1964.[155]

As mentioned above, the budget that had been earmarked since 1962 to cover the investment costs was not made available while the Belgian government had not made an official decision about participation. When the preparations were made to start the construction in the fall of 1965, a first part of the amount was made available. Indeed, in February 1965, the Belgian Ministerial Committee had decided that Belgium would participate in the radio telescope project for a

[153] The largest Belgian company of light bulbs and electronic components, the Manufacture Belge de Lampes et Matériel Electronique (MBLE) was the only Belgian company that was involved in the BCAP. It developed a parametric amplifier for 408 MHz. In the end, this amplifier was not used, as the operating wavelength was changed to 1420 MHz. MBLE did not wish to be reimbursed for the amount of Bfr 267 500 which had been allotted for this work, but in return, it wanted to keep the rights on the results for itself. The Council of the BCAP agreed. See: Minutes of the Council meeting of the BCAP of 11 December 1961; Minutes of the Council meeting of the BCAP of 17 March 1964, SA.

[154] The amounts in the table come from the Annual Reports of ZWO of 1960 up to and including 1970.
[155] Minutes of the Council meeting of the BCAP of 18 July 1963, SA.

maximum of 7 million Bfr annually. [156] The procedure was that, each time an amount was needed, ZWO had to be asked for its release.[157]

4.7.2 TIGHTENING BUDGETS, STRICTER APPLICATION PROCEDURES AND OORT'S INABILITY TO DEAL WITH IT

As we saw, the Dutch economy flourished during the 1950s. In 1960, the economy was still growing, but tensions surfaced. A major problem was that, as a result of the tightening labour market, wages and prices were continuously rising. Therefore, since mid-1963, there had been a high inflation. This inflation problem existed also in other Western countries. However, it was most severe in the Netherlands, followed by France and Britain and it was much less serious in countries such as Belgium and the United States. Government spending had also greatly risen in the 1950s, because of entirely new investments, like the exploitation of natural gas. Furthermore, several industries had become much more capital-intensive. Other traditionally capital-intensive industries – such as the chemical industry and metallurgy – had grown considerably (Miljoennennota 1967, pp. 7-9).

Therefore, in the mid-1960s, the restoration of economic equilibrium became a priority of the Dutch government. Government spending had to be limited. Measures that were taken were a hiring freeze that was imposed on 1 June 1966 and lasted until the end of 1966, the deferment of new investments, and a general restraint on government spending (Miljoenennota 1967, p. 24).

Not surprisingly, this government austerity was also experienced by ZWO and Dutch science. A letter of Bannier to the board of SRZM could hardly be more explicit:

> As you probably know, in the context of the wage and price policy the government has decided to reduce public spending by introducing a hiring freeze, by postponing new investments and by exercising the necessary caution when making other outlays. These measures apply primarily to the departments and government agencies, as well as to other government administrations. Formally, these provisions do not strictly apply to bodies that do not belong to the above, but that are financed chiefly from public funds. However, the government has urged them to join the austerity measures as much as possible and they will not be able to avoid doing so. Such an appeal has also been made to Z.W.O., and we in turn have to appeal to your Foundation.[158]

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[156] 'Naar aanleiding van de jongste vergadering van het Ministerieel Comité heb ik het genoegen U thans zonder verwijl mede te delen dat het Ministerieel Comité beslist heeft dat België zou deelnemen in de werkingskosten van de radiotelescoop (…). De deelneming van België zou evenwel het bedrag van de 7 miljoen F per jaar niet overschrijden.' Spaey to Oort, 19 February 1965, SA, NWO.
[157] Minutes of the board meeting of SRZM of 23 November 1965, SA.
[158] 'Zoals U bekend zal zijn heeft de Regering in het kader van het loon-en prijsbeleid besloten tot een beperking van de overheidsuitgaven door invoering van een personeelsstop, door temporisering van de investeringen en door het betrachten van de nodige terughoudendheid bij het doen van andere uitgaven. Deze maatregelen gelden in eerste instantie voor de departementen en rijksdiensten, alsmede voor de verdere overheidsdiensten. Voor lichamen die hiertoe niet behoren maar die wel voor het grootste deel uit rijksgelden worden gefinancierd gelden de bepalingen formeel niet in strikte zin, maar de Regering heeft op hen een zeer duidelijk beroep gedaan zich zoveel mogelijk bij de bezuinigingsmaatregelen aan te sluiten

In practice, this meant that the hiring of new personnel had to be supported by strong arguments and the explanatory notes to the annual budgets had to be very detailed. Cars, business trips, new machinery and the like would become more difficult to obtain. Concerning the investment costs of the telescope, not many problems were expected, as these had been approved by the government several years before.[159]

The austerity measures were not, however, entirely new in 1966. They had gradually come into force years earlier. Although in absolute terms the government budgets for scientific education and research kept rising[160] (Kersten, p. 166), the explosive growth of the student population and the increasing number of research projects necessitated thrift. Bannier himself had had to get used to the situation that money for scientific research was not as abundantly available anymore. For the year 1963, for example, the astronomers asked for Dfl 75 000 to cover the costs of apparatus. Bannier was inclined to give them Dfl 100 0O0, as this sum was available. But this was not to the liking of the Dutch Ministry of Finances:

> It seems to me that, despite the appeal for thrift, it is putting the fox in the henhouse if Z.W.O. would announce that there is Dfl 100 000 available, while the board of the foundation itself believes that Dfl 75 000 is sufficient.[161]

In the 1950s, SRZM submitted its annual budgets to ZWO with very brief explanatory notes and often too late. Nevertheless, the budgets were always approved. This changed during the 1960s. When in September 1963, SRZM submitted the budget for 1964 Bannier wrote to Oort that the explanatory note accompanying the budget was much too brief. To decide about such an amount of money, the advisory committee and the board of ZWO needed a much more detailed explanation,[162] which the astronomers then wrote and the budget was approved.

Oort – who had been used to getting what he wanted, without following the procedures rigorously – found it difficult to cope with the new restrictions. He had a habit of always submitting his grant applications much too late, a habit that now started to irritate Bannier. Since 1963 Bannier had regularly reminded Oort or the then secretary of SRZM, A. Blaauw, of the deadlines for the applications.[163]

However, the situation did not improve. Although Oort and Bannier had always been on good terms, after a few years Bannier started to lose his patience:

> I should point out to you once more that I have serious objections to the way in which you continuously submit requests to me for approval on (and even *after*) the date on which the decision has to be made. In future, I will no longer take such requests into consideration, unless valid reasons for the late submission are given.[164]

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en zij zullen zich daaraan niet kunnen onttrekken. Zulk een beroep is ook gedaan op Z.W.O. en wij moeten dat onzerzijds weer doen op Uw Stichting.' Bannier to the Board of SRZM, 22 July 1966, SA, NWO.

159 Bannier to the Board of SRZM, 22 July 1966, SA, NWO.

160 Specificly for the budgets of ZWO, see: Annual reports ZWO, 1960-1965.

161 Vos to Bannier, 7 December 1962, SA, NWO.

162 Bannier to Oort, 9 September 1963, SA, NWO.

163 For example : Oort to Blaauw, 9 January 1963, SA, NWO.

164 'Ik wijs U er nogmaals op dat ik ernstig bezwaar heb tegen de wijze waarop U bij voortduring stukken ter goedkeuring aan mij voorlegt op (en zelfs ná) de datum waarop de beslissing moet worden genomen.

Oort was very offended by Bannier's criticism and wrote a furious reply:

> The last paragraph of your letter has surprised me. I fully realise that our requests to your organisation for decisions at short notice may be difficult for you. However, I believe that we agree that the fastest possible construction of the radio telescope is an essential factor for the value of the project, the more so because of the plans that exist in the USA for the construction of composite radio telescopes. Therefore, when designs are ready, we should be able to sign contracts for the production on short notice, while sometimes decisions on incidental needs also have to be made quickly. Moreover, we should not lose sight of the fact that, because of the coherence of the different components of the project, a delay in one area very often entails a delay in other areas. (...) But even if you do not find these reasons convincing, I have serious objections against the tenor of the last paragraph of your letter. By now I find it hard to be corrected like a school boy.[165]

This reply offered Bannier an opportunity to get off his chest all the things that were bothering him about Oort. In particular, he had a problem with the way Oort was leading SRZM. In an attempt to deal with government austerity and stricter procedures, Oort's attitude as president of SRZM became more and more authoritarian, as Bannier said: 'the regime has changed from democratic into authoritarian'.[166]

The examples Bannier gave, were indeed typical for Oort's personality. At the meeting of the board of SRZM on 23 November 1965, some things had happened that had terribly irritated Bannier. First of all, Oort had invited an engineer to the meeting (L.H. Sondaar) without discussing this previously with the other members of the board. Furthermore, Oort wanted to have a journey to America of M.M. Davis reimbursed. Davis was an American who had been working in Leiden for several years and who had made a survey of radio sources at 21 cm in Dwingeloo. He planned to finish a PhD on this topic in the fall of 1966. But to this end he needed to make some additional observations with the 300-feet telescope in Green Bank.[167] Oort had previously arranged that Davis's trip would be partly funded out of the Kerkhoven-Bosscha Fund, a fund that was established in Leiden in 1954 to stimulate Dutch and Indonesian astronomical research. At the meeting of the board, Oort presented this to the other members of the board and asked for additional funding for the trip from ZWO. Bannier refused.[168] In his letter he wrote: 'You had the

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Dergelijke stukken neem ik in het vervolg niet meer in behandeling, tenzij plausibele redenen voor de late indiening worden aangevoerd.' Bannier to Oort, 8 December 1965, SA, NWO.

[165] 'De laatste alinea van Uw schrijven heeft mij verwonderd. Ik besef volkomen dat onze verzoeken aan Uw Organisatie om beslissingen op korte termijn voor U bezwaarlijk kunnen zijn. Ik geloof echter dat wij het erover eens zijn dat, mede in verband met in de Verenigde Staten bestaande plannen voor de bouw van samengestelde radiotelescopen, een zo snel mogelijke bouw van de radiotelescoop een essentiële factor is voor de waarde van het project. Het is daarom nodig dat wij, wanneer ontwerpen gereed zijn, op korte termijn de contracten voor de fabricage kunnen afsluiten, terwijl ook tot meer incidentele voorzieningen af en toe snel besloten zal moeten kunnen worden. Bovendien mag niet uit het oog verloren worden dat door de samenhang van de onderdelen van het werk vertraging van één deel dikwijls ernstige vertraging van andere werkzaamheden meebrengt. (…) Maar zelfs indien deze redenen niet afdoende geweest zouden zijn, moet ik ernstige bezwaren maken tegen de strekking van de laatste alinea van Uw brief. Ik kan moeilijk meer accepteren als een schooljongen terechtgewezen te worden.' Oort to Bannier, 15 December 1965, SA, NWO.

[166] 'het regime is veranderd van democratisch in autoritair.' Bannier to Oort, 4 January 1966, SA, NWO.

[167] Minutes of the board meeting of SRZM, of 23 November 1965, SA, NWO.

[168] Minutes of the board meeting of SRZM of 23 November 1965, SA, NWO.

matter with (...) the Kerkhoven Fund in the bag and you presented it (...) to the board in such a way that it had hardly any option but to agree.'[169]

However, a far bigger problem, according to Bannier, was that Oort did not treat the different projects the same way. Things he himself found of prime importance – such as the expansion of the laboratory in Dwingeloo, where the electronics for the new radio telescope were developed – were discussed very thoroughly. Other plans – such as of the construction of antennas for solar research in Westerbork – were hardly discussed at the board meetings.[170] This is not surprising. Oort was, as we saw, hardly interested in solar research. On the other hand, it *is* remarkable that Oort's dominant position and his ability to determine the research programme more or less on his own, was still going on in the later 1960s. Over time, however, Oort's idiosyncratic way of arranging things started to annoy his colleagues more and more.

Not only was Bannier irritated by the authoritarian way Oort led SRZM, but he also disapproved Oort's habit of contacting the government *directly* instead of going through ZWO. Remember that in 1945, Oort contacted Prime Minister Schermerhorn directly to discuss his plans for the building of a large radio telescope (see Chapter I). And it was not only in matters of radio astronomy that Oort acted like this. A memorable event was also his 1956 initiative to write a letter to the then Prime Minister Drees to protest against the announced hiring freeze at the Dutch state universities. Oort was at that time the dean of the Faculty of Mathematics and Sciences at Leiden University. The curators of Leiden University had already had contacts with Dutch members of parliament and a parliamentary debate about the budget was planned. However, Oort did not want to wait for this. He proposed to address a letter to the prime minister in the name of the deans of the science faculties of the state universities. Several other deans supported his initiative. Hence, on 7 December 1956 a letter was sent to Prime Minister Drees. With this action – on the initiative of Oort - the deans ignored their own faculties, the university senates and curators. This was a very unusual proceeding, but according to Oort, the only thing that mattered was that it was the fastest way to get things done. Moreover, it was inappropriate to address the letter to the prime minister and not to Minister Cals, the Dutch Minister of Education, Arts and Sciences, whom it concerned. Oort, however, was convinced that Cals did not have sufficient influence in the Dutch government (Baneke, 2012, pp. 114-115). Oort's action would finally lead to the installation of the 'Commissie Ontwikkeling Natuurwetenschappelijk Onderzoek' (the 'Commissie-Casimir') in December 1957 (see Chapter III).

Indirectly, Bannier had heard that Oort had once said that he would have been very happy to arrange everything directly with the Ministries of Education and Finances, without the mediation of ZWO. This remark had seriously hurt Bannier. According to the latter, ZWO had made every effort to speed up the whole radio telescope project. If ZWO had not existed, things would have gone much slower:

> (...) you still do not understand (...) how hopeless the situation would have looked if Z.W.O. had not energetically involved itself and if the project had been treated by the Department

[169] 'Je had de zaak met (...) het Kerkhoven-fonds al geheel in kannen en kruiken en stelde deze (...) aan het bestuur zó voor dat dit bijna niet meer anders kon doen dan akkoord gaan.' Bannier to Oort, 4 January 1966, SA, NWO.
[170] Oort to Bannier, 15 December 1965, SA, NWO.

> according to the prescribed channels. In such a case, even the public tendering of the paraboloids might not have taken place yet.[171]

Not only was Bannier personally insulted by the way Oort time and again ignored ZWO, he was also convinced that this was a very risky way of doing business. His colleagues at ZWO were becoming irritated by Oort's idiosyncratic way of arranging things. It might not take much longer before they would lose their interest in the whole radio telescope project, said Bannier. Not only for his own project, but also more in general, Oort's attitude was detrimental to Dutch science: ZWO had always been a very successful mediator between the scientists and the Dutch government and Oort's attitude was seriously undermining this position of ZWO.

After this open conflict between Oort and Bannier, the relation between the two old friends seemed to have calmed down somewhat, but the funding procedures never again went as smoothly as in the previous period.

When the budget for 1966 was submitted at the end of 1965, problems arose again. For the first time, the budget was *not* approved. The total sum the astronomers had asked for 'research on radio emission of the Sun and the universe' (this did *not* include the cross antenna project) was Dfl 771 400. Bannier wrote that ZWO would only contribute a maximum of Dfl 700 000. To this end, the astronomers had to submit a new budget that did not exceed this amount.[172]

The next year, in October 1966, the Ministry of Education and Science asked SRZM whether it was possible to substantially decrease the operational costs of the large telescope. But for the board of SRZM, this was really a bridge too far: 'The board believes that a further significant lowering of the annual costs is not possible without an essential violation of the entire project of the synthesis telescope.'[173]

4.8 THE OBSERVATIONAL PROGRAMME: SOURCE COUNTS RULE

Like the radio telescope in Dwingeloo, the radio telescope in Westerbork would ultimately not be used for the research it was originally intended for, or at least not entirely,.

In itself, this is not so strange. As Raimond and Genée write in their introductory chapter in the volume they edited on the history of the WSRT: in order to discuss and fix the requirements for so expensive an instrument as the WSRT, at least some consideration of astronomical aims was unavoidable in the first place. But in the second place:

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[171] '(…) begrijp je dus nog steeds niet(…) hoe hopeloos de situatie er op het ogenblik ongetwijfeld zou hebben uitgezien indien Z.W.O. er zich niet energiek mee bemoeid had maar de zaak volgens de voorgeschreven ambtelijke wegen behandeld zou zijn door het Departement. Zelfs de aanbesteding van de parabolen zou dan wellicht nog niet hebben plaatsgehad.' Oort to Bannier, 15 December 1965, SA, NWO.
[172] Bannier to the Board of SRZM, 30 December 1965, SA, NWO.
[173] 'Het bestuur is van mening dat een verdergaande aanzienlijke verlaging van de jaarlijkse kosten niet mogelijk is zonder een wezenlijke aantasting van het gehele project van de synthese telescoop.' Oort to the Ministry of Education and Sciences, 17 February 1967, SA, NWO.

> (…) as has been so regularly the case in research with new types of instruments and new methods, it may well be that the instrument will lead into new, at present unpredictable, types of research; and these might become the most important. (Raimond and Genée, 1996, p. 3)

The plans for the construction of the large Dutch radio telescope arose at a time when radio 'source counts'[174] were a major issue in radio astronomy.

In the early 1950s the idea arose that radio source counts could be used to study the structure of the universe. In 1951, the British astronomer Graham Smith measured the positions of the two brightest radio sources in the northern sky, Cygnus A and Cassiopeia A. Smith's measurement, which had an accuracy of about 1 minute of arc, led to the optical identification of Cygnus A and Cassiopeia A by W. Baade and R. Minkowski, using the Palomar 200-inch telescope. Cassiopeia A was associated with a young supernova remnant in our own Galaxy, Cygnus A was associated with a faint, distant galaxy. The latter observation was very important, as it showed that radio sources could be used in cosmological studies. Fainter radio sources would lie at a significantly greater cosmological distance, and hence probe the Universe at earlier epochs (Longair, 2005, p. 107).

The subsequent study of source counts was dominated by Cambridge, more specifically by – again – Martin Ryle. Initially Ryle had supported the view that discrete radio sources were 'radio stars' in our own Galaxy. But the optical identification of radio sources, especially the identification of Cygnus A, made him change his mind. From then on, he adopted the view – which later turned out to be correct - that most of the radio sources observed in directions away from the Galactic plane (the densest part of the Galaxy) are distant extragalactic objects (Longair, 2005, p. 107).

To carry out a deep survey of the radio sky, Ryle and Hewish constructed a large four-element interferometer, operating at 81.5 MHz. In 1954, it was used for the second Cambridge survey of radio sources and the results were published the year after (Shakeshaft et al., 1955). Ryle and his colleagues found that the small-diameter radio sources were uniformly distributed over the sky and that the numbers of sources increased enormously as the survey extended to fainter and fainter flux densities (brightness). The only reasonable interpretation of these data, Ryle concluded, was that the sources were extragalactic, that they were objects similar in luminosity to Cygnus A, and that there was a much greater number density of sources at large distances than nearby (Longair, 2005, pp. 107-108). The source counts were considered to be strong evidence against the Steady-State theory, which claimed that the absolute luminosity and spatial density of radio sources were constant (Ryle, 1955, p. 146). The Steady-State theory had originated in England shortly after the Second World War as a counterpart of the Big-Bang theory. Almost all discussions and attempts to develop this theory further also took place in England (Kragh, 1999, p. 204). Outside England, responses to the Steady-State theory were fewer and less appreciative (Kragh, 1999, p. 223). It was not taken all too seriously outside England – except by Soviet astronomers.[175] In England, however, its advocates were the 'loud and articulate' trio Fred Hoyle,

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[174] 'Source counts' are the increase in the number of radio sources as one observes fainter sources (Van der Kruit, 2011, p. 21). It is the statistical relation between numbers and flux density of radio sources. The predicted relation differs for the various models of the structure and evolution of the universe.

[175] Steady state fitted into the world view of the Soviets, see: Elbers, A., De relaties tussen Nederlandse astronomen en hun Sovjetcollega's tijdens de Koude Oorlog: tussen pragmatisme en idealisme, in: *Studium. Tijdschrift Voor Wetenschaps- En Universiteits-Geschiedenis* - *Revue D'Histoire Des Sciences Et Des Universités*, 5 (2012), pp. 21.

Thomas Gold, and Hermann Bondi, which made the theory quite influential in the country.[176] But according to Ryle, the source counts made it clear that the Steady State theory should be dismissed and evolutionary theories embraced (e.g. the Big Bang):

> This is a most remarkable and important result, but if we accept the conclusion that most of the radio stars are external to the galaxy, and this conclusion seems hard to avoid, then there seems no way in which the observations can be explained in terms of a Steady-State theory. According to evolutionary theories, on the other hand, both the luminosity and the spatial density of the radio sources are likely to change with time (…) (Ryle, 1955, p. 146).

That such profound conclusions could be drawn from the counts of radio sources, however, was met with some scepticism, especially because in those days the physical nature of radio sources was not understood yet and only the brightest twenty or so objects had been associated with relatively nearby galaxies (Longair, 2005, p. 108). Moreover, further research revealed that the second Cambridge survey was severely flawed. At about the same time, the radio astronomy group in Sydney performed a survey of the southern sky with the Mills cross. This catalogue revealed no obvious cosmological effects at all. Moreover, the discrepancy between the two catalogues was so immense, that one of them had to be completely wrong (Mitton, 2011, p. 185).

In May 1957, Mills and Slee published an article, the summary of which must have made grim reading in Cambridge:

> A preliminary catalogue has been prepared of radio sources observed in a sample area of about one steradian[177] near the celestial equator (…) The catalogue is compared in detail with a recent Cambridge catalogue which includes the sample area; it is found that they are almost completely discordant. A theory is developed which explains this discordance in terms of instrumental effects and it is concluded that a major part of the Cambridge catalogue is affected by the low resolution of their radio interferometer. (Mills and Slee, 1957, p. 162)

Indeed, the Cambridge survey was corrupted, because the resolution of its interferometer was too low. This had the effect that several of its radio sources were in fact blends of two or more weaker sources (Mitton, 2011, p. 185). And of course, as the Cambridge catalogue itself was corrupted, the Australians concluded that 'accordingly deductions of cosmological interest derived from its analysis are without foundation' (Mills and Slee, 1957, p. 181).

Years of confusion followed. A bitter conflict was raging between the two Cambridge astronomers Hoyle – a strong advocate of the Steady-State theory – and Martin Ryle – a proponent of the Big Bang,[178] a conflict Mitton aptly describes as a 'clash of Titans' (Mitton, 2011, p. 167). Between 1955 and 1963, research on source counts was undertaken. By the mid-1960s, the situation had calmed

[176] Interview of Martin Rees by Alan Lightman on 30 March 1988, Niels Bohr Library & Archives, American Institute of Physics, College Park, MD USA, http://www.aip.org/history/ohilist/34300.html (Accessed on 6 September 2012).
[177] The steradian is the unit to measure a solid angle.
[178] Ironically, the name 'Big Bang' was invented by Fred Hoyle. In 1949, Hoyle appeared on the BBC radio programme *The Nature of Things*, in which he defended the Steady-State theory. When his opinion was asked on the idea that the universe had started at a definite moment and point in time in the past – an idea that was first suggested by Georges Lemaître in 1927 – Hoyle responded that he could not conceive of the universe as having been born in what he contemptuously referred to as 'Big Bang' (Kidger, 2007, p. 157).

down. Although the radio source counts did not decisively settle the conflict between the Steady-State theory and evolutionary cosmological models[179], the majority of scientists by then accepted Ryle's cosmological interpretation (Sierotowitcz, 1991, p. 80).

It was at the height of the radio source counts controversy that in the Netherlands the plans arose to build the cross antenna. From the very beginnings, ideas – although not elaborated yet – were formulated about what should be investigated with this telescope. Not surprisingly, using radio source counts and radio source sizes to study the structure of the universe was one of the justifications for building the WSRT. This clearly indicates that - although HI research was still dominant in the Netherlands in those days - the Dutch were not operating in a void and their research programme was influenced by international developments.

In the beginning of November 1958, Bourgeois and Oort let the OEEC Governing Committee on Scientific and Technical Personnel know what they wanted to do with the instrument. At this time, the description of the research goals was still rather vague:

> The principal aims for which the instrument is intended are the investigation of the large-scale properties of the universe, the detailed investigation of the regions of ionized hydrogen and of their distribution throughout the Galactic System and near-by external galaxies, the study of the sources of the non-thermal (so-called "synchrotron") radiation in these same systems; in addition detailed studies of sun and moon may also be considered.[180]

Over the next ten years, the aims were repeated several times. In the meantime, Oort regularly discussed source counts with Ryle. They exchanged ideas on recent publications on source counts - for example on publications by the British astronomer P.F. Scott - and Oort also showed a great interest in Ryle's own research in this field. In February 1963, for example, Oort wrote to Ryle:

> Dear Ryle, Thank you very much for your information concerning the new source counts. I was most interested to see how nicely these fit in with the counts that Scott and you published earlier. They seem to give a fine confirmation of the excess of faint sources.[181]

In the 1964 proposal for constructing the telescope as a synthesis instrument, Oort explicitly emphasised that he and his colleagues were primarily interested in the investigation of the *structure* and *evolution* of the universe, something for which the source counts were particularly useful. It was said that the fundamental problems the telescope should solve 'concern in the first place the structure and origin of the very powerful radio sources and their relation with the structure and the evolution of the universe.'[182]

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[179] The whole issue was superseded by the discovery of cosmic microwave background radiation by the American radio astronomers Arno Penzias and Robert Wilson in 1964. Cosmic microwave background radiation is a kind of 'left over' radiation from an early stage in the development of the universe. Its discovery secured the Big Bang as the best theory of the origin and evolution of the cosmos (Schiller, J., 2010, p. 27).

[180] Bourgeois and Oort to the Governing Committee on Scientific and Technical Personnel, 3 November 1958, SA, NWO.

[181] Oort to Ryle, 12 February 1963, OA, 33.

[182] Oort, J.H., Proposal for constructing the Benelux radiotelescope as a synthesis instrument, 25 March 1964, SA, NWO.

Over time, the descriptions of the observational programme became more detailed. Although at the end of the 1960s, source counts had lost their relevance in the Steady-State versus Big-Bang discussion, it was still believed that radio sources were important for cosmology. For example, in the SRZM activity programme for 1969, we read:

> It is obvious that the first programmes will be chosen amongst issues for which the synthesis telescope is particularly suited: detailed structure (…) of bright radio sources; discovery, and determination of the general characteristics (angular size, flux, polarisation) of weaker radio sources; statistics of the characteristics of radio sources – to determine their distribution in space and their significance for cosmology; spatial distribution, intensity and polarisation of continuum radio radiation in nearby galaxies.[183]

Around the middle of the 1960s, 'quasars' had been discovered by Oort's former student, Maarten Schmidt. Quasars are astronomical objects of very high luminosity, found in the centres of some galaxies.[184] Together with the source counts, it was believed that quasars could reveal important cosmological information. They too, became a 'hot topic' of research.

So it happened that the main interest of Irish astronomer George Miley – whom Oort gave a full position in Leiden to work with the WSRT in 1970 – was using the radio size of quasars as a means of measuring the geometry of the universe. Oort immediately approached Miley to discuss the angular size-redshift relation and the possibility of using the WSRT in this area (Miley, 1996, p. 156). However, in the end the WSRT would only be used to a small extent for this kind of research. Miley says about this:

> Several years later I found out that using radio source size to study cosmology was one of the justifications for building the Westerbork Telescope. Although the preparation of a detailed scientific justification is a necessary evil when seeking funding for new instrumentation, subsequent important discoveries are often unrelated to this justification. This was the case with the angular size-redshift relation and Westerbork. (Miley, 1996, p. 156)

The reason why the angular size-redshift relation research was abandoned was – according to Miley – because the angular resolution of the WSRT was insufficient to make fundamental contributions to the research (Miley, 1996, p. 156). However, there was more at stake. Around 1970, it had become clear that in general, the relevance of the investigation of extragalactic radio sources for cosmology was disappointing (Kellerman, 1972, p. 531).

So in the end, little work was done on radio source size, because the resolution was insufficient. Radio source counts were actually carried out, but they soon turned out to be useless for determinations of the structure of the universe. But then, what topics *were* investigated with the WSRT during its early days? For the first time, the largest known radio sources, the giant radio

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[183] 'Het ligt voor de hand dat deze eerste programma's zullen worden gekozen uit die onderwerpen waarvoor de synthese-telescoop bijzonder geschikt is: gedetailleerde structuur (…) van heldere radiobronnen; ontdekking, en bepaling van de globale eigenschappen (hoekafmeting, flux, polarisatie), van zwakkere radiobronnen; statistiek van de eigenschappen van radiobronnen – ter bepaling van hun verdeling in de ruimte en hun betekenis voor de kosmologie; ruimtelijke verdeling, intensiteit en polarisatie van de continue radiostraling in nabije sterrenstelsels.' Stichting Radiostraling van Zon en Melkweg, Programma van werkzaamheden voor het jaar 1969, 29 August 1968, SA, NWO.

[184] As they have a 'starlike' appearance, quasars were initially called 'quasi-stellar radio source', which was in 1964 shortened to 'quasar'.

galaxies, were mapped with the WSRT. Research was done on neutron stars (a type of stellar remnant), on the continuum radiation of spiral galaxies, spectral lines – neutral hydrogen, ionised hydrogen etc. – were measured, detailed investigations were made of stars, ionised regions, molecular clouds, supernova remnants in galaxies etc. One of the great discoveries that were made with the WSRT, was the presence of a radio spiral structure in several galaxies.[185]

In other words, although the observational programme differed greatly from what was originally envisaged, we cannot deny that the diversity of the research topics was enormous, as one author said: 'The discoveries are as varied as the differences between the tropical wealth of the Moluccas and the bare mountain sides of Terra del Fuego.'[186]

4.9 CONCLUSION

The reason why the Dutch started thinking about building another radio telescope as soon as observations with the radio telescope in Dwingeloo were made was because they needed higher resolving power to keep up with the recent developments in radio astronomy. They chose a cross-shaped interferometer. Cross interferometers were being constructed in several countries, which indicates that the new Dutch telescope was to a certain extent 'shaped' by its international counterparts. Indeed, by means of the hiring of foreigners, Oort brought the worldwide expertise in radio telescopes into Holland. The first elaborate design, for example, was made by the Australian Christiansen together with Högbom, a former PhD student of Ryle. Notwithstanding these strong international influences and the initial cooperation with Belgium, Oort wanted to keep the new telescope a Dutch matter as much as possible: despite the fruitful relations with the Australians, he never agreed with a formal cooperation. It is also noteworthy that despite the international influences, the peculiar start of Dutch radio astronomy remained visible in the conception of the Westerbork telescope. Indeed, the American Erickson – who elaborated the second design together with Högbom – characterised the Dutch plans as 'clearly developed by *optical* astronomers'.

When we take a closer look at the motivations that drove the Dutch astronomers, it is clear that these were not only scientific. The decision as to which operating wavelength would initially be chosen - 75 cm - , for example, was motivated by the wavelengths that were used elsewhere, by technical and scientific advantages, by Seeger's personal experience and last but not least: by the fact that in Europe this band was recognised for radio astronomy. That the design was changed several times was also often motivated by other than scientific considerations. During 1961, it became clear that the telescope would cost much more than originally estimated. Moreover, there were no guarantees that a channel *near* 75 cm was also going to be allocated to radio astronomy. And last but not least, the design had little flexibility for changing to other wavelengths. Therefore, a second design was developed.

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[185] S.n. 'Vijftien jaar ontdekkingen met de Westerbork Telescoop' [1986], SA, NWO.

[186] 'De ontdekkingen zijn even gevarieerd als de verschillen tussen de tropische rijkdom van de Molukken en de kale berghellingen van Vuurland.' S.n. 'Vijftien jaar ontdekkingen met de Westerbork Telescoop' [1986], SA, NWO.

However, a few months after the plans of the second design had been submitted to the Belgian and the Dutch governments, the design of the telescope was *again* radically changed. The reason was now that the resolving power of one minute of arc did not seem high enough anymore. At the end of the 1950s, when the first ideas for the telescope arose, a resolution of 1' was considered to be very high. By the beginning of 1963, however, this resolution was already outdated. Therefore, in the summer of 1963, Högbom proposed an instrument that would make use of *Earth-rotation aperture synthesis*. It would be a linear east-west array of telescopes, which could offer a resolution between 10'' and 20'' (when operating at 1420 MHz).

When the year 1963 came to a close, the plans changed again, due to financial reasons this time. The relations with the Belgians were so troubled that the Dutch started thinking about continuing alone. However, the project would have to be of a 'much more modest nature' then. In other words: it should be cheaper. In January 1964, Muller therefore proposed a new design, which was a 'drastic simplification' of the previous one. It enabled them to construct the telescope for about 15 million Dfl, about half of what the previous design would have cost.

At the location that was ultimately chosen – the forestry of Hooghalen – some obstacles needed to be overcome before the construction of the telescope could begin: a road had to be closed, a farm and a military shooting range had to be removed, and several Ambonese families had to be moved. The ease with which Oort got this all done, testifies to his prestige and to the fact he had a great influence on decision making in the Dutch government, as well as - more in general - to the prestige radio astronomy had gained by the mid-1960s and. At the same time, we should not forget that the construction of the telescope was a welcome opportunity for the Dutch government to hasten the relocation of the Ambonese. Thus, there was a certain 'convergence of interests'.

Notwithstanding the radical simplification of the eventual design, the telescope remained one of the most expensive Dutch scientific projects. At the same time, there were two financial problems. First, the Belgians were always late with their payments. To deal with this, each year ZWO paid an advance to the Dutch astronomers to make up for the lacking Belgian amounts. When the amount due was finally received by the Dutch, it was paid back to ZWO. So this problem was in fact easily solved. Therefore, the complaints of the Dutch about the delays the Belgians caused must be taken with a pinch of salt.

A second problem was that Dutch government budgets had been tightening since the mid-1960s. Government austerity was also felt by ZWO. As a result, grant application procedures became more and more strict. Oort – who had been used to getting what he wanted, without rigorously following the procedures – had great difficulty adapting to this. After some minor incidents, this situation led to a serious conflict between Oort and Bannier. The latter blamed Oort for being authoritarian, for not respecting procedures and for undermining ZWO's position as a mediator between the scientists and the Dutch government.

Last but not least, there was a striking difference between the eventual – very diverse - observational programme of the telescope and what was originally envisaged. However, this is not entirely surprising. The entire process of planning, designing and constructing the telescope, took almost twelve years. In the meantime, scientific research progressed. Although using radio source size to study cosmology was one of the justifications for building the Westerbork Telescope, around 1970 it had become clear that the relevance of the investigation of extragalactic radio sources for cosmology was disappointing. Moreover, the resolution of the WSRT proved to be insufficient for studying topics like the angular size-redshift relation. Hence, we may conclude that funding a scientific project almost inevitably entails a huge amount of uncertainty about exactly *what* is funded.