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

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CHAPTER I: THE BEGINNING OF DUTCH RADIO ASTRONOMY: ASTRONOMERS TAKE THE LEAD

During the Second World War and its immediate aftermath, a new field of astronomy was born: radio astronomy. Radio telescopes - the instruments of this field - shared the technology of wartime radar installations. Therefore, in most countries engineers and physicists with a background in wartime radar research were the first to take the initiative for radio astronomical research. This was a logical consequence of the wartime work they had been doing. The early post-war radio astronomy group in the Netherlands was one of the most important radio astronomy groups in the world. However, it differed strongly from the other groups in that the initiative was led by 'real astronomers', which meant: people who had been trained in optical astronomy. It also needs to be mentioned that 'optical astronomy' was a concept that arose only *after* the introduction of radio astronomy. Before, all astronomy was 'optical' astronomy, so there was no need to add this adjective (Sullivan, 2009, p. 422). While the beginnings of Dutch radio astronomy have been researched and discussed (for example Strom and Van Woerden, 2006; Sullivan, 2009, pp. 395–406), the *consequences* of this different approach have rather been neglected. Nor has the take-off of Dutch radio astronomy been firmly placed in the context of Dutch science policy and Dutch efforts aiming at the post-war recovery of the nation. Therefore, the questions that will be answered in this chapter are: how did the Dutch astronomers manage to invade this unknown territory without the required skills and expertise and nevertheless turn their efforts into such a success story? This is all the more striking given the relatively high costs of radio astronomical research and the bleak conditions in a war-stricken country like the Netherlands. And more important: in which way did this peculiar take-off of Dutch radio astronomy influence the early field? It will become clear that the fact that the initiative for radio astronomy was taken by astronomers had profound long-lasting effects.

In order to answer these questions, the Dutch post-war context also needs to be considered. As will be shown, the astronomers greatly benefited from Dutch post-war politics in which science and scientific applications took a very prominent place. Moreover, the small scale of the undertaking and intelligent networking contributed to the fast take-off of radio astronomy.

First, however, the situation of Dutch astronomy during the interwar period will be discussed. It was exactly in that period that the protagonists of this story appeared on the scene and influential networks were established.

1.1 DUTCH ASTRONOMY IN THE INTERWAR PERIOD

During the interwar period, Dutch astronomers had firmly established their position in the international scientific community. The observatory at the University of Leiden – which would later also become the centre of Dutch radio astronomy - became an international centre of astronomy. Under the directorship of Willem de Sitter (1918–1934), the observatory was thoroughly reorganised, which led to an enormous increase in quantity and quality of output. Historian of science David Baneke summarises these changes as follows:

> In the decade after the First World War, Dutch astronomy changed from a small, guild-like community into a slightly bigger community that had all the characteristics of a modern academic discipline, with specialized graduate programs, a laboratory culture that was characterized by division of labour, a professional journal and a national professional organization. (Baneke, 2010, p. 191)

Two of De Sitter's staff members were instrumental in securing the reputation of the Leiden Observatory. The first was the Danish astronomer – chemical engineer by training - Ejnar Hertzsprung, best known for his development of what is now known as the Hertzsprung-Russell diagram, a classification system for stars relating their luminosity (or absolute magnitude) to their colour (or temperature). Hertzsprung would succeed De Sitter as director of the observatory. The second was Jan Hendrik Oort, who in turn would succeed Hertzsprung as director immediately after the Second World War. Around 1930, Oort had firmly established his reputation by empirically proving the theory of galactic rotation of the Swedish astronomer Bertil Lindblad. Lindblad - director of Stockholm Observatory from 1927 to 1965 - showed that the system of stars can be divided into several subsystems that rotate around a common axis. Each subsystem had its own rotation rate and consequent degree of flattening. In 1927, his theory was confirmed by Oort by a variety of observational data (Kron, 1954, p. 110).

Research into the structure of the Galaxy had always been one of Oort's main fields of interest. This was due to one of Oort's teachers, the Groningen astronomer J.C. Kapteyn (1851 - 1922). Kapteyn was one of the most influential Dutch astronomers ever. His work thoroughly influenced several generations. In 1877, he became the first professor of astronomy at Groningen University. He wanted to found an observatory at the university, but the Dutch government did not support his plans: the Netherlands had already two observatories – one in Leiden and one in Utrecht – and three observatories would simply cost the government too much. In 1896, Kapteyn founded an 'Astronomical Laboratory' in Groningen, a laboratory without a telescope. Nevertheless, by means of international collaboration, Kapteyn succeeded in becoming famous as 'astronomer without a telescope'. One of his great projects was his collaboration with the Scottish astronomer D. Gill, director of the observatory in Cape Town (South Africa). From the 1880s onwards, Kapteyn collaborated with Gill on the *Cape Photographic Durchmusterung*, a star catalogue of the southern hemisphere (DeVorkin, 2000a, p. 131).

In 2000, a book with the telling title *The legacy of J.C. Kapteyn* appeared, which discusses the different aspects of his research and personality that left an important mark on Dutch astronomy. Most important for this story, however, is that since the beginning of the twentieth century Kapteyn had spurred on Dutch astronomers to work on unravelling the structure of the Galaxy (Sullivan, 2000, p. 229). This would remain a dominant research programme in Dutch astronomy for several decades. During the last part of Kapteyn's life, however, it became clear that the largest part of the Milky Way was inaccessible for observations at optical wavelengths because of the extinction of the light by interstellar dust (Oort, 1981, p. 24).

Astronomers had already resigned themselves to the fact that they would only having indirect knowledge about a large part of the Milky Way. All this changed, however, with the emergence of radio astronomy.

1.2 RADIO ASTRONOMY: EARLY BEGINNINGS

Traditionally, the history of radio astronomy is traced back to the two twentieth-century American 'founding fathers' Karl Jansky and Grote Reber. However, radio waves were discovered much earlier. In the 1860s, James Clerk Maxwell, a Scottish physicist and mathematician, developed an extensive theory of electric and magnetic phenomena, built upon his conception of electromagnetic fields surrounding magnets, charged bodies, and current carrying wires. In his 1864 paper *A Dynamical Theory of the Electromagnetic Field*, he showed that disturbances in the electric and magnetic fields can spread in a wavelike manner with a velocity that is roughly equal to the speed of light. Furthermore, he concluded that, most likely, light itself was a type of electromagnetic radiation and he suggested that there were other wavelength ranges on either side of the optical spectrum (Hatt, 2007, pp. 29-30).

Inspired by the work of Maxwell, Heinrich Hertz succeeded in producing electromagnetic waves by using a special circuit, including a Ruhmkorff-coil-driven spark gap. In 1887, he managed to generate transverse waves with a wavelength of several metres, well within the frequency range of electromagnetic waves known as radio waves (roughly from 1 millimetre to 100 kilometres). At this time, astronomers were not able to register these wavelengths yet. But soon, it was suggested that 'radio astronomy' (although this word was not used yet) had to be feasible. As radio astronomy and communications have always been closely associated, it is not surprising that the next contribution to 'radio astronomy' came from one of the pioneers of communications, Thomas Edison. Edison collaborated with the American electrical engineer Arthur Edwin Kennelly in a proposal to detect radio waves from the Sun, by using a huge induction coil, wound around an iron ore mass in New Jersey (Smith, 1994, p. 71). Kennelly - who had predicted the existence of the ionosphere - wrote in 1890 to professor Edward Singleton Holden of Lick Observatory:

> Along with the electromagnetic disturbances we receive from the sun which of course we recognize as light and heat (...), it is not unreasonable to suppose that there will be disturbances of much longer wave length. If so we might translate them into sound.[1]

There is no record of the outcome of the experiment, but as the apparatus was very insensitive and could only detect very long radio waves, it is extremely unlikely to have succeeded. Indeed, the ionosphere reflects such long radio waves back into space and thus prevents them from reaching the Earth's surface (Smith, 1994, p. 71).

In the following decades, several attempts followed to detect solar radio waves, though all proved unsuccessful. It took until the 1930s before the first radio waves from space were detected. The discovery was due to Karl Jansky, a physicist from the University of Wisconsin. Jansky joined the staff of the Bell Telephone Laboratories in New Jersey, in 1928. At Bell, he was assigned to a project investigating possible sources of interference in shortwave radio communications (10 metres) across the Atlantic. Therefore, he built a directional antenna to locate the sources of radio noise. His equipment was set up in Holmdel, a rural part of New Jersey, in 1930. Soon, data collecting began. He expected to find only terrestrial sources of radio noise, like thunderstorms and the inner workings of the radio receivers themselves. But in addition to this noisy static produced by

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[1] The entire letter is published in: Shane, C.D., Radio astronomy in 1890 : A proposed experiment, in : *Publications of the Astronomical Society of the Pacific*, 70 (1958), pp. 303-304.

terrestrial sources, he detected a persistent and faint hissing noise, somewhat like 'an angry cat' (Lang, 2006, p. 104).

It was during the autumn and winter of 1931-1932 that Jansky began to isolate this 'hiss type static'. At one point, it appeared to come from some unmodulated carrier,[2] but he soon became convinced that it had a natural origin. At first, he thought it came from the Sun, for the direction of its origin seemed to coincide quite closely with the position of the Sun. By February 1932, however, he noticed that the static was no longer aligned with the Sun, but preceded it by an hour. Although it was now clear that these radio waves did not come *directly* from the Sun, Jansky still thought that they were somehow controlled by the Sun (Sullivan, 2009, p. 36). He published these results in the *Proceedings of the Institute of Radio Engineers* (Jansky, 1932). During the following months he continued his research. He found out that the static was definitely not coming from the Sun, but that '(...) the source of this noise is located in some region that is stationary with respect to the stars' (Jansky, 1933a, p. 66). In other words: the noise came from *outside* the solar system. In another article in the *Proceedings of the Institute of Radio Engineers* (Jansky, 1933b), Jansky made this suggestion more specific: the waves probably originated in the centre of the Milky Way, in the direction of Sagittarius (Jansky, 1933b, p. 1398).[3]

On 27 April 1933, Jansky gave a talk before the URSI (Union Radio-Scientifique Internationale) in Washington, where he presented these results. A press release issued a week later by Bell Labs made Jansky an 'instant celebrity' (Sullivan, 2009, p. 39). Newspapers all over the world reported his discovery. On 5 May 1933, *The New York Times* wrote about it in a front page article, entitled *New radio waves traced to centre of the Milky Way*. Therefore, in hindsight, Jansky's talk is generally seen to have been a decisive moment in the history of radio astronomy. The Italian radio astronomer F. Mantovani even goes as far as to say that 'That date is officially considered the beginning of radio astronomy' (Mantovani, 2004, p. 1). However, it should not be forgotten that – contrary to the media coverage Bell's press release brought about – Jansky's talk *itself* garnered little reaction, neither from his colleagues, nor from astronomers. Jansky's fellow engineers or physicists saw his work rather as an 'interesting curiosity' (Sullivan, 2009, p. 44). Jansky himself tried to kindle the interest of his colleagues, but without success. The only other observations of any depth that were carried out as a kind of follow-up of Jansky's research were those of the physicists G.W. Potapenko and D.F. Folland at the California Institute of Technology in the mid-1930s. They tried to confirm Jansky's result and to explain the mechanisms of the emission. However, they had only very basic antennas available that yielded results that were too rough to publish. A large antenna was needed to do the job properly. This, however, would cost about 1000 dollars and the head of the Physics Department and President of Caltech, R.A. Milikan, could not be convinced this amount would be well spent. This was the end of radio astronomy at Caltech (Sullivan, 2009, p. 45).

Of course, it must not be forgotten that it was the middle of the Great Depression, which can explain why institutes were not so eager to spend lots of money on rather uncertain projects. Bell

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[2] This is a carrier wave (such as to be used for AM or FM) whose phase, amplitude or frequency has not yet been varied so as to contain meaningful information.

[3] It is noteworthy that Jansky made his observations during a sunspot minimum. Had he continued his observations during a period of high sunspot activity, he would undoubtedly have detected solar radiation (Kraus, 1981).

too, was not interested in a follow-up of Jansky's research. Jansky himself, on the other hand, wanted to investigate radio waves from the Galaxy more thoroughly. For this he needed to build a 30-m dish antenna. But Bell had found out what they wanted to know, namely that radio waves did not disturb transatlantic telephone traffic very much. And this was the only thing that mattered for the company. Therefore, they put Jansky on another project (Van Delft, 2008, p. 55).

Jansky also tried to reach the astronomical community with a publication in *Popular Astronomy* (Jansky, 1933c), a magazine for amateur astronomers, published between 1893 and 1951. But his conclusion that '(...) data have been presented which show the existence of electromagnetic waves in the earth's atmosphere which apparently come from a direction fixed in space' (Jansky, 1933c, p. 555) was too vague to arouse much enthusiasm among professional astronomers. Moreover, observatories were also reluctant to take on (expensive) new projects, because of the economic depression.

Jansky never returned to astronomical research, nor did he receive a scientific reward for his discovery (Lang, 2006, p. 104)

To summarise, besides the budgetary tightness, the main problem with Jansky's research was that on the one hand, the results seemed unimportant for communication research and, on the other hand, they were too vague for professional astronomers to know how they should deal with them, or as the American astronomer Sullivan said:

> In the context of contemporary research into radio communications and astronomy, Jansky's fundamental discovery was a misfit. Neither fish nor fowl, it was unable to be appreciated by either scientists or engineers, and therefore lay untouched as an isolated curiosity (Sullivan, 2009, p. 29).

Around 1935, however, there was a sign of interest in Jansky's work: a letter arrived from Grote Reber, an electronic engineer (and radio amateur) from Wheaton, a suburb of Chicago. He had read Jansky's work and was fascinated by it. He contacted Jansky, applying for a job that would allow him to collaborate with Jansky on this project, but was surprised and disappointed to learn that Bell Labs did not plan any further work in this area (Kellerman, 2004, p. 704).

In the first place, Reber wanted to find out how the intensity of radio emission changed with position in the sky and with wavelength. Therefore, in the summer of 1937, he built a steerable paraboloid of 30 feet in a vacant lot next to his mother's house. It took him some time to detect any radiation. Finally, in the spring of 1939, he detected Jansky's Galactic radio noise, which he called 'cosmic static'. He could also confirm Jansky's observation that the maximum radiation came from a direction near the centre of the Galaxy. By the end of the summer of 1939, he figured that he had collected enough data to merit publication. It was only 'natural' that he sent his paper to the journal that had also published Jansky's papers, namely the *Proceedings of the Institute of Radio Engineers*. The paper was published in February 1940 (Reber, 1940a). It presented many plots of signal level recorded as the Milky Way drifted through his beam. Reber's article differed from that of Jansky insofar as it contained only a brief description of the equipment and concentrated on an *astronomical* interpretation of the radiation (although the journal was not intended for an audience of astronomers) (Sullivan, 2009, p. 60).

This was indeed a noteworthy difference between Jansky and Reber: unlike Jansky, Reber made considerable efforts to get his findings known by the community of professional astronomers, as he was convinced his findings were very relevant to astronomical research. Therefore, it was crucial to get his results published in the astronomical literature. There, however, he had to face great difficulties. The astronomical community was at first very sceptical. Reber submitted the results of his research to the *Astrophysical Journal*. According to Jesse Greenstein, who was then a young astronomer at the Yerkes Observatory, 'it produced a flurry at Yerkes [where the ApJ editorial offices were] since Reber had no academic connection, and unclear credentials' (Kellerman, 2004, p. 705). Nevertheless, several astronomers – such as Chandrasekhar, Greenstein and Keenan - were intrigued and went to Wheaton to inspect Reber's equipment. Kennan reported that Reber's apparatus 'looked modern' and that his work 'looked genuine' (Kellerman, 1999, p. 372).

The resistance that Reber faced from the astronomical community needs further clarification. Astronomy is a discipline in which the contribution of amateurs has always been very much welcomed. Characteristic for the community of amateur astronomers is their good organisation: amateurs had and have their own magazines (which were also read by professional astronomers) – remember that in 1933, Jansky too published an article in *Popular Astronomy*, a magazine for amateur astronomers, they had their own organisations etc.[4] However, a closer look at the *kind* of contributions of amateurs reveals that these consist in the first place of *generating data*. That does not mean that they are always merely passive observers. McCray underscores that in Operation Moonwatch, for example, observers *actively* participated in the research programme. By volunteering in global efforts to spot the first satellites and informing and educating their neighbours about the new science of satellites amateur scientists of Moonwatch played 'an integral and visible role in the Space Age's opening days (McCray, 2008, p. 164).

However, the fact remains that throughout history the contributions of amateur astronomers to astronomy generally did not concern the *methodology* of doing astronomy. And this was exactly the problem with Reber, who was an amateur astronomer and foremost a 'loner'. That Reber met with such resistance might have been because he did not just add some data to the existing body of astronomical knowledge, but his detecting and measuring of radio waves implied another way of *doing* astronomy. And letting an amateur tackle astronomical methodology was apparently a bridge too far for the community of professional astronomers.

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[4] In the Netherlands, for example, amateur astronomers have since 1901 been active in the Dutch Association for Meteorology and Astronomy ('Nederlandse Vereniging voor Weer- en Sterrenkunde') (later: *Royal* Dutch Association for Meteorology and Astronomy). Since 1903, this organisation has been publishing the magazine *Hemel en Dampkring* ('Sky and Atmosphere') - now *Zenit* - to which professional astronomers also sometimes contribute. One of the most remarkable contributions of amateur astronomers is perhaps the famous 'Operation Moonwatch'. In this programme, initiated in 1956 by the American Smithsonian Astrophysical Observatory, amateur astronomers and ordinary citizens were mobilised to help professional scientists to spot the first artificial satellites. Often with homemade telescopes, these amateurs provided crucial information. In his book *Keep Watching the Skies,* historian of science Patrick McCray explores the relation between amateur and professional scientists in Operation Moonwatch (McCray, 2008). Today, amateur astronomers still play an important role in astronomy. John S. Lewis, professor emeritus of planetary science at the University of Arizona, explains that amateurs made and still continue to make valuable contributions in variable star observations, meteor observations, comet seeking etc. (Lewis, 2011). Moreover, this excellent organisation of amateur science can also be found in entirely different fields. In the middle of the 1960s, for example, several groups of amateur computer scientists arose. In 1966, the Amateur Computer Society (ACS) was founded by Stephen Gray, computer editor of the American journal *Electronics*. Soon, it was an international organisation with members from the USA, Canada, Switzerland, Italy and Japan. They issued a bimonthly newsletter in which they exchanged ideas on how to build your own computer, on technical information about electronic parts etc. (Veraart, 2008, p. 71).

1.3 WARTIME DISTRIBUTION OF ASTRONOMICAL LITERATURE: THE EFFORTS OF BART BOK

The fact that Reber's article was eventually accepted, however, was in the first place due to the efforts of Bart Bok, a Dutch astronomer who had migrated to the USA in 1929 to work at Harvard College Observatory. Bart Bok was the referee of Reber's article. He too decided to visit Reber's equipment and took the editor, Otto Struve, along. Bok said the journal should not reject something that might later turn out to be important, and convinced Struve to publish Reber's paper. It was indeed accepted, but only as a short note (Reber, 1940b).

The American physicist Marc L. Kutner concludes from this that Bart Bok 'was the first traditional optical astronomer to understand the importance of radio astronomy' (Kutner, 2003, p. 68). This may be a little exaggerated – some astronomers like Jesse Greenstein of Caltech were also truly interested in Reber's work –, however, the importance of the action Bok undertook to get Reber's work published in the *Astrophysical Journal* can hardly be overestimated. This publication, indeed, forced the first links between radio scientists and astronomers (Kellerman, 2005, p. 52).

And it was also due to Bart Bok that Oort was actually able to *read* Reber's article, which was by then not so self-evident. Indeed, Reber's article appeared during the Second World War. While before the outbreak of the war, there was a constant world-wide exchange of astronomical literature, after the German invasion of the Netherlands in May 1940, this exchange was severely disturbed. Bart Bok was bothered by this. Still very concerned about his former Dutch colleagues, he wrote to Oort:

> It was great to hear that all Dutch astronomers came safe and sound through the invasion of the beginning of May. (…) I write to you (…) to ask whether you would like to let me or Shapley[5] know whether we can simplify in one way or another your work or that of other Dutch astronomers. You know the possibilities and also the difficulties in America, but if there is anything with which we can be at your service, you know that the Dutch astronomers have a lot of friends in America. You write in your post card that it will continue to be difficult to receive American journals in Holland. (…) If sending is possible, we can probably arrange within America, that Leiden, Groningen, Amsterdam and Utrecht each receive a copy of the AP.J. [Astrophysical Journal], A.J. [Astronomical Journal] etc. on a regularly base.[6]

At the instigation of Bok, the American Astronomical Society appointed in September 1940 a *Committee for the Distribution of Astronomical Literature* (CDAL), chaired by Bart Bok. The task of

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[5] Astronomer Harlow Shapley was the director of Harvard College Observatory.

[6] 'Het was heerlijk te hooren dat alle Nederlandsche astronomen veilig en wel door de inval van begin mei zijn gekomen. Ik schrijf je (…) om je te vragen of je mij of Shapley zoudt willen laten weten of wij op de een of andere manier je werk kunnen vergemakkelijken of dat van andere Nederlandsche astronomen. Jij kent de mogelijkheden en ook de moeilijkheden in Amerika, maar indien er iets is waarmee wij van dienst kunnen zijn weet je dat de Nederlansche astronomen heel veel vrienden in Amerika hebben. Je schrijft in je briefkaart dat het moeilijk zal blijven om Amerikaansche tijdschriften naar Holland te krijgen. (…) Indien verzending mogelijk is kunnen wij het waarschijnlijk wel van uit Amerika regelen dat Leiden, Groningen, Amsterdam en Utrecht elk een copie van het AP. J., A.J. etc. regelmatig blijven ontvangen.' Bok to Oort, 31 July 1940, OA, 151b.

the CDAL was 'promoting as far as possible the continued world-wide flow of astronomical literature' (Bok and Kourganoff, 1955, p. 22). Astronomers from several countries assisted the work of the committee: Wilhelm Brunner in Switzerland, Bertil Lindblad in Sweden, Kathleen Williams in Great Britain, and G. Neujmin of the USSR. Much help was also received from Oort in Holland and A. Kopff in Germany. About a dozen copies of each astronomical publication from the USA, Great Britain and Canada were distributed in this fashion and in return, the CDAL received many publications from the cooperating countries to distribute in the USA, Great Britain and Canada.

The importance of the CDAL for the exchange of astronomical literature can hardly be overestimated. In the following months, there was an extensive correspondence between Bok and Oort that indicates that several journals and articles were successfully sent from one country to another. It was thanks to the efforts of the CDAL, that Oort received Reber's article in the *Astrophysical Journal* of June 1940. In the beginning of November 1940, Bok sent this issue to the Netherlands[7], Oort received it on 24 December.[8]

1.4 THE FIRST RADIO ASTRONOMY GROUPS: AN ORIGIN IN RADAR

Oort's reading of Reber's article was a decisive moment in the history of radio astronomy in the Netherlands.

Several accounts on the history of early radio astronomy have been written by astronomers themselves (e.g. Sullivan, 1984; Sullivan, 2000; Sullivan, 2009; Ryle, 1971; Lovell, 1968; Strom and Van Woerden, 2006, Hey, 1973 etc.). These histories are sometimes criticised by professional historians as being teleological, too linear, written as inevitable success stories, retelling one another until they get the status of 'fact' etc. It is exactly in these stories that the history of radio astronomy is sometimes traced back merely to the 'founding fathers' Karl Jansky and Grote Reber. Almost mockingly, historian of science Jon Agar, said in this respect:

> Cosmic radio waves were first identified in America before the war, by the two lone figures of radio astronomy mythology: Karl Jansky and Grote Reber, retrospectively elevated to everpresent 'founding fathers' in the linear histories of radio astronomy, although their work was largely unknown in Britain or Australia (...). (Agar, 1998, p. 27)

However, Agar's words need to be taken with a pinch of salt. Sometimes these historical accounts written by astronomers - certainly the more recent ones – strongly mitigate the influence of Jansky and Reber. Sullivan, for example, said it 'is surprising that Jansky and Reber, despite their prewar discoveries, little influenced the postwar decade of radio astronomy, especially outside the US' (Sullivan, 2009, p. 13).

Indeed, outside the Netherlands, there was little *direct* influence of Jansky and Reber on early post-war radio astronomy. Several pioneers hardly knew the work of either Jansky or Reber. In Australia, for example, it is unclear to what extent the pioneers of Australian radio astronomy, such as John Bolton, Bernard Mills, and J.L. Pawsey were familiar with their work. Mills, for

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[7] Bok to Oort, 4 November 1940, OA, 151b.

[8] Oort to Bok, 14 January 1941, OA, 151b.

example, makes no reference to Jansky or Reber in his account of the origins of radio astronomy in Australia (Mills, 2006). Nevertheless, it remains a fact that the explosive development of radio astronomy in Australia after the Second World War was centred in the Radio Physics Laboratory of the CSIR, the *Council for Scientific and Industrial Research*[9], and E.G. Bowen, chief of this Laboratory, was well aware of Jansky's work in the 1930s. Bowen's first exposure to the concept of radio 'noise' – interference at radio wavelengths - from outer space came in 1935, when he joined the small team of Sir Robert Watson-Watt, assembled to build the first air-warning radars in Britain. Bowen and his colleagues called the cosmic noise their receivers were exposed to the 'Jansky noise' (Bowen, 1984, p. 87). And although most pioneers of British radio astronomy might not have known the work of Jansky or Reber, Stanley Hey (see below) was well aware of Reber's work, as even Agar admits (Agar, 1998, p. 27). And Hey in turn, strongly influenced the course of early post-war radio astronomy (Sullivan, 2009, p. 13). So the *indirect* influence of the pre-war 'heroes' might not be entirely negligible, although it is difficult to determine to what extent Reber's work influenced the *content* of early radio astronomy.

Of far greater importance for the post-war emergence of radio astronomy in most countries, however, were wartime developments in military radio and radar electronics.

Radar uses radio waves to detect the presence of objects and to find their position. This is done by a transmitter sending out a radio signal which scatters off anything it encounters and a small amount of energy is scattered back to a radio receiver. After amplification in the receiver, the signals are processed by a combination of electronic signal processing and computer software (Kingsley and Quegan, 1999, p. 1). Although the basic notion to bounce radio waves off metallic objects at large distances had been known since the first decade of the twentieth century, it was only in the 1930s that practical systems were developed for showing the positions, ranges, and speeds of ships and aircraft through clouds or darkness (Sullivan, 2009, p.79). Radar was not invented at a specific time in a specific place. The systems developed during the 1930s owed a great deal to simultaneous developments in other areas, such as television. The first truly operational radar system, however, was developed by the aforementioned Englishman Watson-Watt between 1935 and 1938. From the earliest days, radar was developed within the military sphere. Watson-Watt's work was commissioned and strongly supported by the British Air Ministry. With the growing German threat, Britain had realised that it would be powerless against an air attack from the German *Luftwaffe*. By the start of the war in 1939, twenty 'Chain Home' stations ('Chain Home' was the code name for the British radar system during the Second World War) covered the southern and eastern coasts of England. Britain not only had an early start in radar, it stayed at the forefront of innovation during the Second World War and it shared the developments in radar technology with four of the Commonwealth nations: Australia, Canada, New Zealand, and South Africa.

Of course, Britain was not the only place where radar was being developed. In the USA, the Army and Navy also developed radar from the 1930s onwards. The Germans also had a strong radar capability at the start of the war and were even ahead of the Allies in the use of higher frequencies. The Gesellschaft für electroakustische und mechanische Apparate (GEMA) had developed an early warning radar, called Freya, for the German navy in the late 1930s. This was a kind of mobile version of the Chain Home transmitter/receivers. Even more flexible Würzburg radar dishes were

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[9] Now called the Division of Radiophysics of CSIRO (the Commonwealth Scientific and Industrial Research Organization)

introduced in 1940 (Agar, 2012, p. 272). The Würzburg dishes play a very important role in the history of radio astronomy. As will be explained, Würzburg precision reflectors were used extensively by a number of radio astronomy groups for a decade after the war. In the Netherlands, ground-breaking research has been done with one of these reflectors. The Würzburg dishes were one of the most well-constructed and reliable radar antennas during the war. Although the standard wartime operating wavelength was 54 cm, the Würzburg could operate at wavelengths as short as 10 cm. Sizes of 1.5 m, 3 m, and 7.5 m were built. It was especially the largest version – the *Riese* – that was useful for radio astronomical research (Sullivan, 2009, p. 78). However, after a very promising start, German radar research stagnated between 1941 and 1943, due to 1941 decisions to cut long-term advanced research on the presumption that the war would soon be over (Zaloga, 2009, p. 16). There were also relevant radar developments in France, Italy, the USSR, Japan, and – last but not least – in the Netherlands.

As the technology of radio telescopes is very similar to that of radar, it is not surprising that the first radio astronomy groups originated in wartime radar research. During the war these radar operators often encountered anomalous radio phenomena which pulled them in the direction of radio astronomy. The pursuit of radar work, indeed, led unexpectedly to radio-astronomical discoveries, namely the radio emission associated with solar flares, the observations of radar echoes from ionised meteor trails, and the discovery of a discrete radio source in the constellation of Cygnus (Hewish, 2002, p. 171).

Immediately after the war, several radio astronomy groups were formed, among which five stood out: three in England, one in Australia and one in the Netherlands (Sullivan, 2009, pp. 5-10). All these groups – except the Dutch group – had their origins in wartime radar research.

The first group was that of the British physicist S. Hey. During the war, Hey was a radar-operations researcher at the Army Operational Research Group (AORG) (a research group that was under control of the Ministry of Supply). In 1942, he came to the conclusion that the apparent jamming of British coastal radar installations was in fact due to interference by radio radiation from the Sun.[10] His interest was aroused and led him to investigate the nature of these solar emissions. In 1946, he published his first article on this topic in *Nature* (Hey, 1946). Until 1948, Hey led a small Army group that conducted scientific research in all aspects of radio astronomy. For example, they discovered the first discrete radio 'star', later known as Cygnus A (Sullivan, 2009, p. 7).

A second English radio astronomical group was the one led by B. Lovell at Jodrell Bank, near Manchester. Lovell - who had a PhD in physics from the University of Bristol - had been doing cosmic ray research at the Physics Department of the University of Manchester since 1937. During the war, he became involved in radar research. On 3 September 1939, he was in the control room of the Staxton Wold radar station when Prime Minister Chamberlain broadcast to the nation that Britain was at war with Germany. Lovell immediately expected to see large numbers of echoes, signalling the advance of German bombers. There were indeed numbers of echoes, but there were no German bombers. The operators explained to Lovell that these echoes derived from the 'ionosphere' (Lovell, 1984, p. 194). Lovell then realised that the echoes might be radar reflections from the ionisation caused by extremely energetic cosmic ray showers. In the meantime it occurred to him that with radar, he now had a powerful new technique to investigate the high

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[10] Note that this was a period of enhanced solar activity, compared to the early 1930s, the days of Jansky's early observations.

energy region of the cosmic ray spectrum. In the spring of 1940, Lovell joined the Telecommunications Research Establishment (TRE), the main centre of radar development in Britain. In his spare time, he studied the ionospheric literature in the library of TRE. Together with P.M.S. Blackett – a former professor of physics in Manchester whom Lovell had worked with before the war – he published an article, entitled *Radio echoes and cosmic ray showers* in 1941 (Blackett and Lovell, 1941). After the war, Blackett returned to his post in Manchester. Lovell followed him as a lecturer in the Physics Department. With ex-army radar equipment, he restarted his research on cosmic rays. However, the interference caused by electric trams forced him to look for another observation site. He was directed to the botanical grounds of the University about 25 miles south of the city. This was a small area known as Jodrell Bank. There, he received a report of Hey about the latter's investigation of the attempts to detect the German V2 rockets when the V2 bombardment of London commenced in September 1944. The operators of the radars had seen frequent echoes and gave warnings of the approach of rockets which did not arrive. Indeed, at the times reported, no rockets had been launched by the Germans. Hey concluded that the transient echoes probably had an ionospheric origin and that some of them might be associated with the radar reflections from the ionised trails of meteors (Lovell, 1984, p. 197). And it was exactly Lovell's reading of this report that triggered the start of the study of meteors at Jodrell Bank.

A third English radio astronomy group was established by Martin Ryle at the Cavendish Laboratory, the Physics Department at Cambridge University. In the late 1930s, Ryle – a physicist from Oxford - had been doing ionospheric research at the Cavendish Laboratory. He was a member of a small research group of about five researchers, led by J.A. Ratcliffe. At the outbreak of the war, the Cavendish became a place of greatly reduced activity. Many of its staff vanished into various defence research establishments. So did Ratcliffe and Ryle. Like Lovell, both men joined TRE, where they made important contributions to airborne radar. At the end of the war, Ratcliffe went back to the Cavendish to rebuild his ionospheric research group. Ryle rejoined him, but his interest quickly shifted to other areas. Influenced by his work at TRE and intrigued by Hey's work on solar outbursts, he was soon investigating radio waves from the Sun and radio 'stars', 23 of which (including Cassiopeia A) his group had found by 1949. Ryle had a keen interest in the development of new observation techniques. He was the driving force in the improvement of astronomical interferometry[11] (in the late 1940s he built the famous Long Michelson interferometer, a radio telescope interferometer) and aperture synthesis[12], which greatly contributed to the upgrading of the quality of radio astronomical data (see also Sullivan, 2009, pp. 155-170).

The largest of all post-war radio groups – and also the most important for this story as will be shown in the following chapters - however, was the one in Sydney (Australia). This laboratory was created in August 1939 as a secret branch of CSIR ('CSIRO' since 1949). It was agreed that the Radiophysics Laboratory would do radar research and development in close cooperation with British laboratories and with the Australian military. The laboratory was housed in the National Standards Laboratory in the grounds of Sydney University. In 1940, the Radiophysics Laboratory was replaced by the 'Division of Radiophysics'. When the war came to an end, the staff numbered

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[11] In short, interferometry means that there is an array of telescopes, working together as if it were one telescope. This will be further explained in Chapter IV.

[12] A specific type of interferometry, see also Chapter IV.

about three hundred. As many as fourteen of them became notable in radio astronomy after the war (Sullivan, 2009, p. 120).

Unlike TRE, which continued military radar development in peacetime, the Radiophysics Laboratory was transformed into a research and development centre for the civilian technologies that Australia hoped would carry the nation into the modern age (Buderi, 1996, p. 281). E.G. Bowen became the head of the Division of Radiophysics of CSIR in 1946. Bowen had a long experience in radar. The Welshman Bowen was a physicist from the University of Wales. In 1933, he completed a PhD in atmospheric physics at King's College in London under the direction of Appleton. Two years later, he joined the British 'air-warning radars team' of Watson-Watt, where he was for the first time exposed to the 'Jansky noise'. When the war broke out, Bowen became a member of the famous 'Tizard Mission' that delivered radar secrets to the United States. He remained in the USA for three years, where he developed airborne radar systems at the MIT Radiation Laboratory. At the end of 1943, Bowen's work in the USA was virtually finished and it became clear that sooner or later the Allies would invade Europe. So he started looking for another job and was invited to join the CSIR Division of Radiophysics. In early 1944, he went there as 'deputy in chief'. In 1946, he became the director.

Soon, Bowen worked out several peacetime research proposals that were 'warmly received and quickly endorsed' by his CSIRO superiors (Sullivan, 2009, p. 121). He made plans for research programs in vacuum tube technology, radio propagation, radar navigation, electronic surveying, meteorology and last but not least: astronomy, although none of the staff members had ever taken a college course in astronomy (Buderi, 1996, p. 282).

Some of the programs – for instance vacuum physics – quickly died away. The two research programs that were most successful were – indeed – radio astronomy and rain and cloud physics (Sullivan, 2009, p. 123).

One of Bowen's most able researchers was the Australian-born J.L. Pawsey. He was a world expert in antenna development and did a PhD at Cambridge University in 1934 where he had studied radio wave propagation under Ratcliffe. Then, for five years he developed television equipment for the BBC station at Alexandra Palace. At the outbreak of the war in 1940, he joined the Division of Radiophysics.

Intrigued by reports of anomalies from radar stations, Pawsey and his colleagues tackled solar observations (Sullivan, 2009, p. 124). In September 1945, assisted by his colleagues Ruby Payne-Scott and Lindsay McCready, Pawsey began observations of the Sun at Collaroy (a suburb of Sydney), using a series of existing Air Force radar antennas. The experiment was designed for a standard radar wavelength of 1.5 metres. The observations made it clear that some regions of the Sun had temperatures as high as one million degrees Celsius. This was far higher than was thought possible at the time, as optical measurements of the solar surface had made it clear that temperatures there were around 6000 degrees Celsius. Only later did researchers develop a full theory explaining the temperature gradient from optical wavelengths to 1.5 metres as largely due to partially ionised atoms of solar radiation that cause the very thin outer layer of the Sun's atmosphere to heat to enormous temperatures visible only at longer wavelengths (Buderi, 1996, p. 283).

Pawsey had also read Hey's wartime work. He concluded from it that the intensity of the Sun's radio emissions seemed to vary with sunspot activity. Therefore, in early 1946, during a large sunspot eruption, Pawsey turned his attention to these sunspots. It became clear, however, that existing radar aerials could not pinpoint sunspots as the source of this type of radiation. Therefore, Pawsey designed an instrument that became known as the 'sea interferometer', which he placed on a cliff-top at Dover Heights, facing out to the sea. Like the British, especially Ryle, Pawsey had realised that accurately pinpointing the source of radio emissions depended on achieving a much greater angular resolution than was possible with a single aerial. An interferometer would be the solution. In this experiment the aerial would pick up two signals, one directly from the Sun and the other reflected from the surface of the sea. The combination of the two signals could then be combined to form an interference pattern, making it possible to determine the point of origin of the radiation (Buderi, 1996, p. 283). Indeed, after several weeks, Pawsey accurately located the source of this enhanced noise on the face of the Sun and showed unequivocally that it came from the vicinity of sunspots (Bowen, 1984, p. 89).

The importance of the observations with the interferometer can hardly be overestimated. As Buderi said: 'The experiment would put Australian radio astronomy on a par with the group in Cambridge, where Martin Ryle was deploying his radio interferometer to resolve the same question' (Buderi, 1996, p. 283). Between the two groups, there was a fair amount of rivalry. Bowen recalled an incident in this respect:

> I have a vivid recollection of describing these results, prior to their being published, at a lecture I gave at the Cavendish Laboratory in Cambridge on September 20th 1946. (…) About thirty or forty members of the post-war Cavendish team were there, including Martin Ryle. At the end of the lecture, Ryle rose quickly to his feet and assured the audience that on two counts I was dead wrong: the solar temperature could not possibly be a million degrees, and there was something very wrong about (…) [the] observation of circular polarization. It was some time before they were to change their minds! (Bowen, 1984, p. 89)

From that point on, Bowen suspected Ryle[13] of striving to undermine the reputation of the Australian group, and the tension between the two groups increased over time (Buderi, 1996, p. 284).

Nevertheless, both the British and the Australian group made important contributions to interferometry which became the fundamental technique used in many of the world's radio telescopes, as will be shown in Chapters III and IV.

Pawsey's sea interferometer was also used by several others of Bowen's researchers, for example by John Bolton and Gordon Stanley. John Bolton was a native Yorkshireman who had studied physics at Cambridge University, had served during the war as a Royal Navy radar officer, and joined Radiophysics after the war. Gordon Stanley was an electrical engineer from New Zealand who had joined the Lab during the war. Like Pawsey, both men performed also solar observations. Intrigued by an observation of Hey, who had accidentally discovered an oddity in the direction of the constellation of Cygnus – one of the strongest radio sources in the sky - Bolton and Stanley set out to measure Cygnus (Buderi, 1996, p. 285). They succeeded in determining the size of Cygnus

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[13] As will be explained in the next chapter, Ryle had a very difficult character.

A to be smaller than 8 minutes of arc, which was considered to be a very important finding. Their results were published in *Nature* (Bolton and Stanley, 1948)

1.5 DUTCH RADIO ASTRONOMY: ASTRONOMERS TAKE THE LEAD

As in the Netherlands radio astronomy did not emanate from wartime radar research, one might wonder whether there had been any radar research in the Netherlands at the time.

However, in war-related research, the role of the Dutch should not be underestimated. For example, they played a vital role in radar development.[14] When vacuum tubes were developed, Philips Company in Eindhoven soon became the largest vacuum tube manufacturer in Europe. In 1914, Philips established the *Natuurkundig Laboratorium* (NatLab), its research laboratory. The decision of Philips to establish an industrial laboratory followed an international trend, initiated by German chemical concerns at the end of the nineteenth century and continued by American companies at the beginning of the twentieth century, to hire scientists. In the early twentieth century, American companies such as General Electric, DuPont, Bell and European companies such as Siemens and Philips had established industrial research laboratories to broaden scientific and technological knowledge. And this knowledge in turn should support and enhance the production process (Boersma and De Vries, 2003, p. 288).

In the early 1930s, much radar research was done by NatLab researchers such as K. Posthumus and C.H.J.A. Stall. The Dutch Navy sponsored this research. In 1939, plans were started by the company Nederlandse Seintoestellen Fabriek (NSF) (a joint venture of Philips, Marconi (UK) and Radio Holland, after the war entirely taken over by Philips), to build a chain of warning stations to protect the major ports. Some field testing was done, but after the German invasion in May 1940, the project came to a halt. It was secretly continued within the Philips NatLab until 1942. During the Second World War, Philips was placed under German supervision of two 'Verwalter' (administrators), Dr. O. Bormann and O.J. Merkel. This 'supervision', however, was little more than a formality, as Bormann and Merkel were already familiar business partners of Philips before the war. The Germans required large quantities of transmitter and receiver equipment for their army and forced Philips to supply this equipment. As Philips did not appear to deliver according to expectations, German control was enforced. Ludwig Nolte, a company manager of the Allgemeine Elektricitäts Gesellschaft (AEG) took over production supervision from Bormann and Merkel in February 1942. Under Nolte, the regime seems to have become much stricter and huge supplies were sent to the Germans. Consequently, on 6 December 1942, the British Royal Air Force bombed a number of Philips factories in Eindhoven to prevent further supplies being delivered to the German Army. A second air raid was carried out on 30 March 1943 (Boersma, 2002, pp. 68-69).

The attitude of Philips towards war-related research during the Second World War is unclear.[15] Boersma and De Vries conclude that in the first years of the war, research and production continued as far as possible. In the last period of the war, however, certain research programmes

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[14] For an overview of radar in the Netherlands, see: Watson, 2009, pp. 337-441.

[15] As there are not many Philips archival records left from this period and Philips is very reluctant to give people access to their archives, much is open to speculation. Several attempts were made to consult the archives, but without success.

were interrupted. In particular Natlab's war-related research – such as research into radar technology – ceased (Boersma and De Vries, 2003, p. 299).

Another Dutch radar centre was the Laboratorium voor Fysieke Ontwikkeling (LFO, 'Laboratory for Physical Development') (Watson, 2009, pp. 339-341). This laboratory had its origin in the rumours about so-called 'death rays' in the 1920s. In 1924, the Dutch parliament set up a Committee for the Applications of Physics in weaponry under the direction of Professor G.J. Elias of Delft Polytechnic to examine these rumours. The committee quickly discounted the 'death rays'. However, it established the LFO, which was dedicated to supporting the Netherlands Armed Forces. In order not to arouse suspicions, the LFO was called the Meetgebouw ('Measurements Building'). It was opened in December 1927 and located on the plain of Waalsdorp in the dunes near The Hague. The building was shared with the Dutch Military Weather Service. J.L. van Soest, engineer, led the initial research efforts, which were aimed at developing sound devices for detecting aircraft and infrared detection apparatus. J.L.W.C. von Weiler, engineer, joined the LFO in 1934 and together with S.G. Gratama, he started research on a 1.25 m communication system to be used in artillery spotting. The Dutch Ministry of Defence realised that the system might be a method for detecting aircraft and supported the continuation of the research. In April 1938, an 'electrical listening device' was demonstrated to the inspector-general of the Army and detected an aircraft at a range of 18 km. The set was rejected, however, because it could not withstand the sand and water environment of Army combat conditions. The Navy was more receptive. They provided funding for the final development and M. Staal – an engineer of Delft Polytechnic – was added to the team. The work was carried out in great secrecy. Just before the outbreak of the war, several sets were completed, and one was put into operation on the Malieveld in The Hague. It worked well, spotting enemy aircraft at 120 km during the first days of fighting, but there were no associated anti-aircraft guns. As the country capitulated, essentially all assemblies and plans for the radar were destroyed. Von Weiler and Staal fled to England. Later, Gratama and van Leeuwen also escaped to England. All eventually worked on equipment for the Dutch Navy through the research Department of HM Signal School in Portsmouth (Watson, 2009, p. 341).

At the end of the 1930s, 37 people were employed at the LFO. In 1941, the Meetgebouw was incorporated in the PTT (the Dutch Post, Telegraph, and Telephone Service) and became the Physisch Laboratorium (Physical Laboratory).[16]

So the Netherlands were clearly experienced in radar research, although during the war their efforts were cut short. (An analogous situation occurred in Italy and France.)

Remarkably enough, nobody working in Dutch radar research thought of using radio waves to study the universe. We do not have a conclusive explanation for this, but it may have had something to do with traditional astronomers turning to it so early. As explained, in most other countries the first radio astronomical initiatives were taken by radar workers during the full war. In the Netherlands, on the other hand, as early as December 1940, Oort received Reber's 1940 article in the *Astrophysical Journal* from Bart Bok. Intrigued by this article, he also sent it to H. Rinia, an engineer at Philips NatLab. After reading it, Rinia wrote to Oort: 'Enclosed I send you the issue of the Astr. Journal back, with thanks. I read the article of Reber with great interest; and I

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[16] Today, the Museum 'Waalsdorp' mirrors the history of Dutch defence from 1927 onwards: http://www.museumwaalsdorp.nl/

have seen that now there is at least a good theory about the origins of such radiation. It is nice, that in this way it is possible to "see" a spiral nebula during the day and when it is cloudy.'[17]

From Rinia's answer, it becomes clear that Oort must have realised that Reber's findings could be extremely important for astronomical research. The great advantage of radio waves was that they were neither hindered by interstellar dust, nor by earthly clouds. The latter made them—contrary to optical waves - very suitable for 'observation' in the cloudy Dutch climate, even during the day. Oort also realised that it was not the continuous radio radiation that would be most helpful for astronomy, but radiation at one specific frequency, emitted by a specific chemical element that is widespread among the interstellar matter, in other words a single spectral line. He wondered whether a spectral line could be found in the radio frequency range. And he found a suitable person to investigate this matter in the Utrecht astronomy student Hendrik (Henk) van de Hulst.

1.6 VAN DE HULST AND THE DISCOVERY OF THE 21-CM HYDROGEN LINE

> *'(…) Waarop ben je gepromoveerd?'*
> *'Op waterstoflijnwerk.'*
> *'Wat is dat in hemelsnaam?'*
> *'Dat kun jij niet begrijpen. Daar moet je heel knap voor zijn.'*
> Harry Mulisch, *De ontdekking van de hemel*

Oort may have had a grand vision about the possibilities for radio-astronomy in the Netherlands, it would not be easy to launch such an ambitious project. Scientific research had been seriously hampered during the wartime years and so had scientific education. The German decision of November 1940 to fire all Jewish professors met with strong resistance. At the Technical University in Delft a strike broke out. As a consequence, the School was closed. A similar situation occurred at Leiden University: the dean of the faculty of law, R.P. Cleveringa gave a speech on 26 November 1940 to protest against the forced resignation of the Jewish professor E.M. Meijers of the Faculty of Law. As a consequence, Cleveringa was imprisoned and the university was closed too. Elsewhere, university life continued more or less as before. The universities of Utrecht and Amsterdam were very likely to register the former students of Leiden. Research stagnated too. There was a lack of money for research materials and energy. Scientific staff was sometimes taken hostage or had gone into hiding and international contacts were broken. Some laboratories, such as the Kamerlingh Onnes Laboratory in Leiden, were looted by the Germans. During the first two years of the war the damage was rather limited, but the situation worsened during the last two years. In 1943, the Germans required the students to sign a loyalty declaration. As many of them refused to do so, they had to go into hiding if they wanted to escape from forced employment in Germany (Van Berkel, 2000, p. 332).

At the end of 1942, Oort too went into hiding to avoid problems with the Germans. He moved to 'De Potbrummel', a small cottage in Hulshorst, a tiny village about hundred kilometres from

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[17] 'Hierbij zend ik U de aflevering van de Astr. Journal met dank terug. Ik heb het artikel van Reber met zeer veel interesse gelezen; en ik heb gezien dat er nu tenminste een behoorlijke theorie is over het ontstaan van dit soort straling. Het is wel aardig, dat het op deze wijze mogelijk is een spiraalnevel overdag en bij bewolkte lucht te kunnen "zien".' Rinia to Oort, 12 March 1941, OA, 94.

Leiden. He also resigned from his positions as associate professor and as deputy director of the Observatory. This resignation was official as of the beginning of February 1943, when the Department of Education, Science and Cultural Protection wrote to him that the Department 'HAD APPROVED: effective as of 1 February 1943 to give to Dr. J.H. Oort - following his request - honorable discharge as an associate professor at Leiden University and as a deputy director of the observatory.' [18] However, Oort stayed in touch with his colleagues. They exchanged letters regularly. It is not even clear how 'secret' his new address really was, as most of his colleagues and several people of the Dutch government (for example of the Department of Education) knew it.[19] Oort also visited the Observatory now and then by bike (which meant a 100 kilometres ride!) (Smith, 2008).

It was in the midst of this war turmoil that Oort met Henk van de Hulst. Van de Hulst was a student of the astrophysicist Marcel Minnaert, director of Sonnenborgh Observatory, the observatory of the University of Utrecht. In the spring of 1942, Minnaert introduced his talented student to Oort:

> Previously, you have raised the possibility that we would "exchange" students. At the moment, I have an excellent young man, Mr. H.C. v.d. Hulst, who obtained his bachelor's degree two years ago and who is a very versatile talent. He is a good experimenter and an even better theorist, moreover he knows the border area of physics pretty well. (...) I would be very pleased if he could work for 2 months at Leiden Observatory (...).[20]

It was settled that Van de Hulst would work in Leiden during October and November 1942.[21] However, things went differently. Because Van de Hulst was still a student, it was uncertain that he would get a permit to work at Leiden Observatory. Moreover, as the University's near future was uncertain because of the war, Oort even discouraged Minnaert from applying for the permit.[22]

It is unclear when Oort and Van de Hulst met each other in person for the first time. From 1 to 3 July 1942, the second Dutch Astronomers Conference ('Nederlandse Astronomenconferentie') was held in Doorn (Utrecht). Both Oort and Van de Hulst gave a talk there. Oort on *The fundamental system of proper motions* ('Het fundamentaalsysteem der eigenbeweging') and Van de Hulst on *Atmospheric oxygen bands* ('Atmosferische zuurstofbanden'). So they must certainly have met there.[23]

One should realise that organising a conference during the war was not so easy. First of all, travelling was difficult. Moreover, the war hardship becomes clear from the accompanying information to the participants that said: 'Bring along ration coupons for bread, butter or fat,

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[18] 'HEEFT GOEDGEVONDEN: met ingang van 1 Februari 1943 aan Dr. J.H. Oort op zijn verzoek eervol ontslag te verleenen als buitengewoon hoogleeraar aan de Rijksuniversiteit te Leiden, en als adjunct-directeur van den sterrewacht.' Jan Van Dam to Oort, 28 January 1943, OA, 96.

[19] See several letters: OA, 96.

[20] 'Je hebt indertijd de mogelijkheid geopperd dat wij studenten zouden "uitlenen". Ik heb op dit ogenblik een voortreffelijke jonge man, de heer H.C. v.d. Hulst, die al 2 jaar candidaat is en een zeer veelzijdige aanleg heeft. Hij is een goed experimentator en nog beter theoreticus, daarenboven kent hij het physische grensgebied al heel aardig. (…)Ik zou het buitengewoon op prijs stellen indien hij 2 maanden aan de Leidse Sterrewacht zou kunnen werken (…).' Minnaert to Oort, 20 April 1942, OA, 162a.

[21] Minnaert to Oort, 20 April 1942, OA, 162a.

[22] Oort to Minnaert, 1 May 1942, OA, 162a.

[23] Programme of the Dutch Astronomers Conference in Doorn, 1-3 July 1942, OA, 95.

potatoes, porridge oats, sugar and meat. You have to bring a sleeping bag, or sheets and a pillow case, towel and soap.'[24]

In the meantime, the war had taken its toll on Minnaert too. From May 1942 until April 1944, Minnaert was taken hostage by the Germans in the camp at Sint-Michielsgestel. This was a special camp for the elite: amongst the prisoners were well-known Dutch writers, scientists and politicians. The regime was much less strict than in other camps: prisoners had enough to eat, there was good medical care and a lot of intellectual and creative activities were organised by the prisoners themselves. (De Keizer, 1979). To understand how Minnaert ended up in this camp, one needs to read his biography (an extensive biography on Minnaert has been written by Molenaar, 2003). The Belgian Minnaert was born in Brugge in 1893. He got a PhD in biology at Ghent University in 1914. In his student days, he became a radical 'Flamingant' and hence he was a strong supporter of the 'Dutchification' of the then French speaking Ghent University. During the First World War, a Dutchified Ghent University was opened at the insistence of the German governor-general Moritz von Bissing. This fitted in with the German 'Flamenpolitik', which meant that the German occupier supported the Flemish in their conflict with the French-speaking community. By doing this, the Germans hoped to get the sympathy of the Flemish, which would enable them to enforce their grip on the country (Elbers, 2010, p. 14). When the Germans had lost the war in 1918 and Minnaert realised he could get in big trouble because of his Flamingantism - this could be seen as collaboration with the Germans – he fled to the Netherlands with his mother at the end of October 1918. Minnaerts fear to be accused of collaboration proved to be justified: in July 1920, he was sentenced in absentia to fifteen years hard labour.

The Netherlands was not entirely new for Minnaert: in 1915, he had already taken some physics courses at Leiden University. At the end of 1919, Minnaert was appointed observer at the Heliophysical Institute of Utrecht University. Professor Willem Henri Julius was the director of the Physical Laboratory. In 1910, he had founded the Heliophysical Institute as an experimental research centre that was part of the Physical Laboratory. Julius was one of the pioneers of the research on the Sun, in which Minnaert would specialise too, as will be shown. Besides his work at the observatory, Minnaert also accepted a position at the Royal Dutch Meteorological Institute (KNMI). Under the supervision of Julius, Minnaert got a PhD in physics, entitled *Irregular Refraction of Light Rays* ('Onregelmatige Straalkromming'). In 1932, he became a Dutch citizen. Four years later, in 1937, Minnaert accepted the position of director of Sonnenborgh, the Observatory of Utrecht University.

Minnaert developed into an extremely versatile person: he was a talented scientist, a friendly and competent teacher, a poet, a piano player, and he spoke seven languages fluently. Moreover, he remained a man of strong political convictions. Just as these convictions brought him into serious trouble when he was in his twenties, they brought him again into trouble during the Second World War, albeit the situation was entirely different then. In the Netherlands, Minnaert became an internationalist and he developed communist sympathies. Especially the latter lay at the basis of his arrest by the Germans on 4 May 1942. When his wife – the physicist Miep Coelingh – asked the *Sicherheitsdienst* (Security Service) for the reason of his arrest – after all, Minnaert was not anti-German - she was told that it was because 'he had made a communist fist at the funeral of De Clercq' (Molenaar, 2003, p. 279). Indeed, ten years earlier, on 12 June 1932, the Flemish poet René De Clercq was buried in Utrecht. Like Minnaert, De Clercq was a Flamingant who had fled to the

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[24] Programme of the Dutch Astronomers Conference in Doorn, 1-3 July 1942, OA, 95.

Netherlands after the First World War. At his funeral, an incident took place that would be remembered long after. As there had been a connection between Flamingantism and National Socialism, several National Socialists were present at the funeral. While they sang anthems, a lot of attendees gave the fascist greeting. As a reaction, Minnaert made a 'communist fist'. This aroused the anger of the fascists, who started to threaten Minnaert. Finally, Minnaert had to leave the funeral (Molenaar, 2003, pp. 239-240).

There is of course a certain amount of irony in the fact that after the First World War, Minnaert left Belgium because he feared to be accused of collaboration with the Germans, while in the Second World War, he was imprisoned by these same Germans.

While in Sint-Michielsgestel, Minnaert found a useful occupation in teaching his fellow prisoners some astronomy and other sciences. He was also allowed to send and to receive letters. Oort and Minnaert corresponded intensively during these years. Oort sent his letters from Hulshorst, which proves that this 'secret' residence was actually not secret at all. In September 1942, for example, Oort wrote to Minnaert:

> From the many messages from St Michiels Gestel (sic), I deduce that you are making yourself very useful by teaching your fellow hostages something of the beauty of research into nature and to tell them about the wonders of the inorganic world.[25]

To keep his unfortunate colleague up to date with astronomical developments, Oort also proposed to send him a photographic reproduction of the latest issues of the *Astrophysical Journal* which he had himself received through Bart Bok.[26]

The imprisonment of Minnaert seems to have been an incentive for Van de Hulst to informally shift his studies to Leiden (Sullivan, 2000, p. 238). Although we do not know exactly how long he stayed there, he must have been there for several months during 1943-1944. He regularly met with Oort during this period. Oort in turn, was very pleased with Van de Hulst's visit: 'At the moment, we have Van de Hulst visiting us for a few months here in Leiden. I am looking forward to discuss all kind of things with him.'[27]

And it was during this stay, in the spring of 1944, that Oort asked Van de Hulst to look for the spectral line in the radio frequency range. Van de Hulst later remembered Oort saying to him:

> We should have a colloquium on the paper by Reber; would you like to study it? And, by the way, radio astronomy can really become very important if there were at least one line in the radio spectrum. Then we can use the method of differential galactic rotation[28] as we do in optical astronomy (Van de Hulst, 1957, p. 3).

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[25] 'Ik merk uit vele berichten die vanuit St Michiels Gestel komen dat je je daar heel erg nuttig maakt met den medegijzelaars iets van het prachtige van het natuur-onderzoek bij te brengen, en hen over de wonderen der anorganische wereld te vertellen.' Oort to Minnaert, 24 September 1942, OA, 162a.

[26] Oort to Minnaert, 24 September 1942, OA, 162a.

[27] 'We hebben hier in Leiden nu van de Hulst voor eenige maanden op bezoek. Ik verheug me er op om allerlei met hem te kunnen bepraten.' Oort to Minnaert, 11 January 1944, OA, 162a.

[28] Differential galactic rotation means that the angular velocity of stars or gas moving around the center of the Galaxy is not a constant, but varies as a function of radial distiance to the nucleus. As a consequence, along any given line of sight through the Milky Way, different regions of hydrogen gas observed will be moving with different radial velocities with respect to us. Oort understood that detectable spectral lines in

At a clandestine meeting of the Dutch Astronomers Club ('Nederlandse Astronomen Club') on 15 April 1944 at Leiden Observatory, van de Hulst confirmed the existence of this spectral line in a talk, entitled *The Origin of Radio Waves from Space* ('Herkomst der Radiogolven uit het Wereldruim')[29] By scrutinising the literature on spectroscopy, he had discovered a spectral line of hydrogen at 21 cm, well within the radio spectrum. As Van de Hulst pointed out, hydrogen was the most abundant element in interstellar space in the Galaxy, so detection of the extremely weak line might very well be possible. The detection of the line could be used to unravel the structure of the Milky Way beyond the small part that was observable by means of optical waves.

The importance of Van de Hulst's discovery of the 21 cm line can hardly be overestimated. As radio astronomer Richard Strom stated: 'This discovery would set the agenda for generations of radio astronomers in Holland and elsewhere' (Strom, 2005, p. 94).

1.7 HOW TO BUILD A TELESCOPE?

The obvious next step was to build a radio telescope. But how could this be done?

As mentioned before, in other countries it was engineers and physicists with a background in the war industry who were pushing ahead with radio astronomy. These people had the necessary knowledgeof receiver techniques and they knew how to build a radio telescope. Oort and his colleagues, however, were university-based astronomers with little engineering knowledge. Therefore, they had to look for people who could provide them with the necessary technical know-how. To this end, Oort contacted people from Philips NatLab, from Delft Polytechnic and Reber himself.

That Oort contacted members of Philips NatLab should not come as a surprise: during the pre-war period, Philips NatLab was after all one of the two centres of development of radar technology in the Netherlands. Moreover, since the foundation of Philips NatLab (1914), there had been a connection with Leiden University. The first director of the NatLab was Gilles Holst, a physicist who had worked at the Kamerlingh Onnes low temperature physics laboratory at Leiden University. From 1930 until 1938, Holst was also professor of industrial physics at Leiden University. In 1946, Holst retired from the NatLab and was succeeded by the triumvirate H. B. G. Casimir, H. Rinia and E. J. W. Verwey. With Casimir - a former professor of physics at Leiden University - the Leiden connection was continued.

The first written record we have of contact between Oort and an employee of Philips about radio astronomy was the letter of Rinia to Oort of 12 March 1941. Rinia was an electrical engineer from Delft Polytechnic. In 1928, he joined the staff of Philips NatLab. Although we do not know much about Rinia's life or his contacts with Oort, it seems he had a great personal interest in astronomy (Teer, 1986, pp. 176-177).[30]

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the radio spectrum could be used, through Doppler shifts of these lines, to investigate the location and rotation of interstellar gas throughout the galactic system (Smith, 2008).

[29] Van de Hulst, H.C., "Lezing", April 1944, VdH, 38.

[30] Several people of NatLab were involved in amateur astronomy. In 1935, the 'Eindhovense Weer en Sterrenkundige Kring' (Eindhoven Meteorology and Astronomy Circle, EWSK) was founded and consisted mainly of Philips employees. By means of a generous donation of A.F. Philips, the EWSK was able to found

More important were Oort's contacts with another member of Philips NatLab: the physicist C.J. Bakker. At the aforementioned meeting of the Dutch Astronomers Club on 15 April 1944 where Van de Hulst confirmed the existence of the spectral line of hydrogen at 21 cm, Oort had invited Bakker to explain the technical possibilities for building a receiver for the radio telescope that would allow detection of the 21-cm hydrogen line. Both Bakker and Van de Hulst's talks were published as a joint article in the Dutch physics journal *Nederlands Tijdschrift voor Natuurkunde* (Bakker and Van de Hulst, 1945).

One may wonder why Bakker was so interested in radio astronomical research. As a matter of fact, this was in line with his activities at Philips NatLab. Between 1934 and 1941, he investigated electronic problems that occurred when developing radio tubes at Philips. In the company, he was also influenced by the physicist Balthasar van der Pol. Van der Pol had performed research in areas such as the propagation of radio waves, the theory of electrical circuits and vibrations. These experiences drew Bakker's interest to radio waves from the Sun and the Galaxy (De Boer, 1960, p. 284). As early as 1942, Bakker published an article in the journal *Nederlandsch Tijdschrift voor Natuurkunde* (Bakker et al., 1942) together with the astronomers M. Minnaert (Utrecht Observatory), A. Pannekoek (University of Amsterdam) and the geophycisist J. Veldkamp (Royal Dutch Meteorological Institute KNMI). This article contains a section on radio research of the ionosphere, written by Bakker. (During the war Bakker was also a member of the editorial board of this journal.)

A few days after the meeting of the Dutch Astronomers Club, Oort wrote to Bakker that he wanted to continue the cooperation with Philips:

> After having reconsidered the possibility that the Observatory with the help of Philips Factories could start an investigation into the interstellar radio radiation, it seems more and more attractive if at least such an investigation could happen entirely with your cooperation. Because it only makes sense to start this work if there is a reasonable possibility that we will be able to do it better than elsewhere (…)[31]

This letter also contains the first written record that Oort intended to build a radio telescope with a mirror of 10 to 20 metres diameter. He asked Bakker whether Philips could build the receiver for this telescope. But Bakker replied:

> Following your letter of 19 April, I have had a conversation about this with Prof. Holst, the director of our laboratory. In principle, he was very positive towards the idea that we

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an observatory in Eindhoven. This observatory was (and still is) a public observatory, aiming at bringing astronomy closer to the general public. Also prominent astronomers, such as Oort and Hertzsprung, regularly gave talks at this observatory. See also: http://www.dse.nl/~sterrenwacht/ (accessed on 6 February 2013).

[31] 'Na nog eens nader te hebben gedacht over de mogelijkheid dat de Sterrewacht met behulp van de Philips Fabrieken een onderzoek zou kunnen beginnen over de interstellaire radiostraling, lijkt me dit hoe langer hoe meer aantrekkelijk, indien althans zo'n onderzoek geheel in samenwerking met U zou kunnen geschieden. Want het heeft alleen zin dit werk te beginnen als er een redelijke kans op is dat we het beter zullen kunnen doen dan elders (…)' Oort to Bakker, 19 April 1944, OA, 158a.

> would provide you with a suitable receiver installation, but he considered it practically impossible to deliver it to you before the end of the war.[32]

Why it was impossible to build this receiver during the war, Bakker did not explain. Philips, however, was under German control in those days. And it is very likely, of course, that under these circumstances, the company could not deliver war-sensitive materials such as a receiver. So Oort would have to wait at least until the war was over to execute his plans.

An extensive correspondence between Bakker and Oort followed in which they discussed the size of the mirror in relation to the wavelengths Oort wanted to measure.[33] The resolving power of a radio telescope is proportional to the diameter of its dish and inversely proportional to the wavelength that is used. To increase the resolving power – provided that the wavelength stays the same - the diameter of the dish needs to increase too. Oort wanted to obtain an opening angle[34] of one degree, which meant that, for a wavelength of 50 cm, he would need a dish as large as about 30 m diameter, as Bakker had calculated. A problem, however, was the wavelength of 21 cm Oort was aiming for. At the time, Philips did not have much experience with receivers for wavelengths shorter than 1 m. But Bakker promised Oort to try to develop a receiver for a wavelength 'as short as possible'.[35] And Oort did not only ask Bakker for advice concerning the size of the dish in relation to wavelength, he also contacted several other persons. He corresponded with Reber[36] and with von Weiler (who had joined LFO in the 1930s to do radar research). To von Weiler, Oort explained that he wanted to build a receiver installation to detect radio radiation emitted by interstellar gas and with a wavelength between 50 cm and 1 m[37]. Reber's instrument had an opening angle of only 12 degrees, which was, according to Oort, insufficient 'to obtain valuable new data on the structure of the Galaxy and the distribution of the interstellar gas'.[38] He asked von Weiler for advice in these matters.

To conclude, it can be said that during the war, Oort laid a firm claim on 'radio astronomy'[39] in the Netherlands. Although there was still no 'radio telescope', no observations had yet been made and no funding was provided for this kind of research, between 1941 and 1945 Oort did extensive preliminary research and made clear he *intended* to perform radio research. As early as 1941, he

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[32] 'Naar aanleiding van Uw brief van 19 April l.l. heb ik thans een gesprek hierover gehad met Prof. Holst, den directeur van ons laboratorium. Deze voelde er in principe veel voor, dat wij U aan een geschikte versterkerinstallatie zouden helpen, maar hij achtte het practisch uitgesloten, dat wij deze vóór het einde van de oorlog zouden kunnen leveren.' Bakker to Oort, 3 May 1944, OA, 158a.

[33] Correspondence between Bakker and Oort, OA, 158a.

[34] The opening angle of the smallest resolvable angular unit is the 'beam' of the radio telescope.

[35] Oort to Bakker, 19 April 1944, OA, 158a.

[36] Oort to Reber, 30 August 1945, OA, 98c; Reber to Oort, 17 September 1945, OA, 251.

[37] At the time, Philips could not yet provide a receiver for shorter wavelengths.

[38] 'waardevolle nieuwe gegevens over de structuur van het sterrenstelsel en de verdeeling van het interstellaire gas verkrijgen', Oort to von Weiler, 26 March 1964, OA, 251.

[39] The word 'radio astronomy' did not yet exist in those days. It is unclear when the word was used for the first time, but Sullivan said the earliest written mention he could find was in a review article written by the Russian Vitaly Ginzburg in 1947 (Sullivan, 2009, p. 423). When the Dutch used the term for the first time is also unclear. In the early days, terms they used to refer to 'radio astronomy' were: 'research into radio waves from the interstellar gas'; 'research into radio waves from interstellar space'; 'research into interstellar radio waves' etc. (Sullivan, 2009, p. 422). What is said here may seem in contradiction with the words Oort spoke to Van de Hulst in 1944 to ask him to look for a spectral line in the radio spectrum, as Van de Hulst mentions in his 1957 article (see above). In this quote, both 'radio astronomy' and 'optical astronomy' are used. However, we think this is a rather 'liberal' post factum interpretation of Oort's words by Van de Hulst. It is highly unlikely that Oort actually used these terms in 1944.

contacted people (Rinia for example) from Philips - which had been a centre of radar research – and made it clear to them what he wanted. Here is a possible explanation why in the Netherlands, the initiative for radio astronomy was not taken by former radar researchers: from the very beginnings, Oort held the reins firmly and therefore his partners – who had nevertheless a clear interest in the topic - in a certain way never got the chance to take any initiative in this respect.

1.8 SEEKING FINANCIAL SUPPORT AFTER THE WAR

The Netherlands was liberated on 5 May 1945. Oort was appointed full professor and director of Leiden Observatory that same year and then considered it the right time to return to his plans for a radio telescope, which he then pursued with more vigour than ever.

He asked Grote Reber how much his telescope had cost:

> At the Leiden Observatory we have been much interested in the interstellar gas and its distribution through the Galaxy, and I am considering the possibility of erecting a large mirror and receiving set for ultra-short waves in this country. Naturally, the plans are vague, and it is still quite uncertain whether we shall be able to carry them out. However, in this stage, it would be of value for us to be able to make a general estimate of the cost of the instrument. If it is possible for you to give us a rough idea of the expenditure for your 31 feet mirror this would be of some help in the general planning. I should be greatly obliged if you could give us this information. Of course all other advice you could give would be warmly welcomed.[40]

Reber responded enthusiastically: ‘Your interest in this work is greatly appreciated by me because for a very long time now, It (sic) seems that I have been the only enthusiast and it has been rather lonesome.’ [41] He gave a detailed explanation about the cost of his telescope. The mirror had been made of galvanised iron 0.20 inches thick and the frame or carrier was of wood, fastened together by gusset plates and machine bolts. The cost of the structure was as follows:

Foundations	$ 73.15
Steel Stock	$ 181.73
Wood	$ 127.92
Hardware	$ 150.24
Paint carriage	$ 109.80
Paint mirror	$ 34.12
Total	**$ 676.96**

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[40] Oort to Reber, 30 August 1945, OA, 98c.

[41] Reber to Oort, 17 September 1945, OA, 251.

Moreover, the cost of the labour of one man for four months had to be added. The necessary electrical apparatus to get the results he had published in his 1940 article in the *Astrophysical Journal* was about 500 dollars plus again several months of labour to get it working.

After his 1940 'success', Reber thought the correctness of his general system was proven and he decided to go ahead on a larger scale. So he bought in addition:

General Radio D.C. Amplifier	$ 225.00
Esterline Angus recorder	$ 292.81
Cabinet for housing these	$ 36.17
Total	**$ 553.98**

Furthermore, between 1942 and 1944, Reber spent more than $ 3000, mainly on new electrical equipment. A large amount of labour was again needed to make things work.

Reber also gave Oort some other advice. First of all, he pointed out that his own location was near the street and automobiles were passing at about 100 feet, which brought about a lot of interference. Therefore, Reber recommended that Oort choose a location at least a mile from all automobiles. Moreover, as Reber himself had experienced a lot of problems with the amplifiers, he urged Oort to try to obtain the services of first class radio engineers. And as will be shown in the next chapters, finding suitable engineers was a problem Dutch radio astronomy had to cope with for several decades.

At the same time, Oort asked the advice of the physicist J.M. Burgers of the Laboratory for Aero- and Hydrodynamics at Delft Polytechnic:

> Concerning still vague plans for the construction of a parabolic "mirror" for the registration of radio waves from the interstellar gas (…) I would like to talk to someone who understands the building of large steerable metal constructions. To be more specific, it concerns the construction of a "mirror" of about 20 metres diameter (…).[42]

But for Burgers too, building a 'radio telescope' (the word did not exist yet) was an entirely new undertaking. He answered:

> The problem you propose, seems very interesting to me – firstly the thought itself, the detection of radio waves from interstellar space; and secondly also from a mechanical point of view. Although I am not an expert in these matters, I would still like to discuss them with you. I also contacted Biezeno[43], and he is willing to help you further.[44]

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[42] 'In verband met nog vage plannen voor den bouw van een parabolische "spiegel" voor het registreren van radiogolven uit het interstellaire gas (…) zou ik graag eens praten met iemand die verstand heeft van den bouw van groote beweeglijke metaalconstructies. Het zou nl. gaan om het bouwen van een "spiegel" van plus minus 20 meter middellijn(...).' Oort to Burgers, 30 August 1945, OA, 98a.

[43] Biezeno was a professor in applied mechanics at Delft Polytechnic.

[44] 'Het probleem dat je stelt, lijkt me erg interessant – ten eerste de gedachte zelf, het opvangen van radiogolven uit de interstellaire ruimte; en ten tweede ook in mechanisch opzicht. Al ben ik in deze dingen geen expert , toch zou ik het prettig vinden er met je over te mogen spreken. Ik heb me ook al tot Biezeno gewend, en die is bereid verdere hulp te geven.' Burgers to Oort, 6 September 1945, OA, 98a.

Burgers had regular contacts with staff members of the Dutch construction company Werkspoor, with whom he discussed Oort's plans. From these discussions, it became clear to Burgers that 'the mirror has to be carried by a network, made from welded steel pipes, similar to the type that is used in the construction of fuselages'.[45]

A few days later, Werkspoor sent Oort an 'Avant projet' ('preliminary draft') of the construction for a mirror of 25 m diameter.[46]

As the project promised to be very expensive – a rough estimate of a price-tag was Dfl 100 000 (Katgert-Merkelijn, 1997, p. XXII) – Oort realised that government support would be necessary. He wrote to Burgers: 'I am trying to contact Schermerhorn to find out whether it is possible to get financial support from the government for this plan. Without this support, it is hardly even possible to start.'[47]

Indeed, two days later, on 8 November 1945, Oort wrote a letter to Prime Minister Schermerhorn, in which he asked for a meeting:

> Is there a possibility to have a talk with you about two astronomical projects[48] which are rather large and cannot be realised without special government support? I would be very grateful if I could have the opportunity to visit you to discuss these.[49]

This manoeuvre was very typical for Oort. When he wanted to get something done, he always tried to avoid the official procedures and *directly* contacted the highest official, the prime minister in this case. In the next chapters, this will become increasingly clear.

Oort actually visited Schermerhorn on 16 November 1945.[50] We do not have much information about what was exactly said during this visit. We only know that afterwards, Oort sent Schermerhorn a memorandum about his plans, which he asked him to discuss with the Minister of Education, Arts and Sciences. In the accompanying letter, he also explained that he had contacted Schermerhorn directly, because a fund for 'special scientific research' was non-existent. Otherwise, he would have contacted this fund.[51]

Oort also tried to get government support for his project in another way: on 26 November 1945, Oort sent the plans for his 25-m telescope to the board of the KNAW (Royal Netherlands Academy of Arts and Sciences). One of the tasks of the Academy was to serve as an advisory body for the

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[45] 'de spiegel gedragen zal moeten worden door een netwerk, dat uit gelaste stalen buizen kan worden opgebouwd, enigermate van een type als wordt toegepast bij de constructie van vliegtuigrompen.' Burgers to Oort, 23 September 1945, OA, 251.

[46] Theunissen to Oort, 25 September 1945, OA, 251.

[47] 'Ik probeer nu contact te krijgen met Schermerhorn om te zien of er van regeeringszijde geld voor het plan te krijgen zou zijn. Zonder steun van die zijde zullen we het nauwelijks kunnen beginnen.' Oort to Burgers, 6 November 1945, OA, 98a.

[48] One of them was the radio telescope, the other one was probably the (second) Leiden expedition to Kenya. This astronomical expedition - which took place from August 1947 until October 1951 – was carried out to determine accurate declinations of stars, see: Katgert-Merkelijn, 1991.

[49] 'Zou het mogelijk zijn dat ik bij gelegenheid eens een onderhoud met je had om over twee astronomische projecten te spreken, die van eenigszins grooten omvang zijn en niet zonder bijzonderen steun van de Regeering aangepakt kunnen worden? Ik zou het bijzonder op prijs stellen dat je me daarvoor eens kon ontvangen.' Oort to Schermerhorn, 8 November 1945, OA, 98c.

[50] Secretary of Schermerhorn to Oort, 12 November 1945, NA, 2.03.01 (Algemene Zaken), inv 5713.

[51] Oort to Schermerhorn, 17 November 1945, NA, 2.03.01 (Algemene Zaken), inv 5713.

government in matters of science (Van Helvoort, 2005, p. 46). Therefore, Oort asked the board of the Academy to recommend the project to the government and to request financial support.[52] However, despite all Oort's efforts, the cost of the project was a problem. His estimate of Dfl 100 000 was about as large as the government's total budget for scientific instrumentation and consequently his request was turned down (Katgert-Merkelijn, 1997, p. XXII). Fortunately, there was an alternative.

1.9 THE FIRST RADIO TELESCOPE IN KOOTWIJK: A 'PRESENT' OF THE PTT

On the Dutch coastline, the Germans had left behind several Würzburg radar reflectors which they had used during the war. These were the so-called 'Würzburg-Riesen'. During the war, about 1500 of these 'Riesen' were built. They were part of the 'Atlantikwall', the German line of defence between France and Norway. Along the Dutch coast, there were about 40 of these radar installations (Beekman, 1999, p. 154). When the war came to an end, there was a considerable interest among radio engineers in German radar technology. This was not only the case in the Netherlands, but all over Europe and overseas (Strom and Van Woerden, 2006, p. 12). This meant that almost everywhere, these Würzburgs were recycled for scientific research after the war.

The post-war history of the Dutch Würzburgs is only partly documented. The Würzburg with the best known history is the one that was used by the Dutch Organisation for Applied Scientific Research (TNO, a joint organisation of industry, universities and the government). During the war it was part of the radar installation of the Dutch island of Rozenburg. In 1947, it was moved to the Waalsdorper Vlakte on the outskirts of The Hague for experimental use by the Physics Laboratory of the Dutch State Defence Organisation ('Rijksverdedigingsorganisatie', which later became a division of TNO) (Strom and Van Woerden, 2006, p. 12).

The Dutch radio astronomers and the PTT also used several of these Würzburgs, but the history of these antennas is not well documented. It is generally accepted that the initiative to acquire the PTT Würzburgs came from engineer A.H. de Voogt (Strom and Van Woerden, 2006, p. 13; Muller, 1980, pp. 65-66; De Voogt, 1952, p. 211[53]). As the head of the PTT Central Department for Radio, De Voogt was in charge of the transmitting and receiving stations for communication with the Dutch East Indies in particular. This long-distance communication was crucial in the early post-war years, because the relations with Indonesia were deteriorating seriously. (Indonesia would finally gain independence in December 1949.) After the war, De Voogt therefore launched a research programme to understand how the ionosphere influenced radio propagation and which effect solar activity had on it. This appears to have been his motivation for acquiring several Würzburgs in about 1947 and installing them at the PTT stations (Strom and Van Woerden, 2006, p. 13). Subsequently, one of these Würzburgs was made available to the Dutch astronomers for studies of Galactic radiation (Strom and Van Woerden, p. 5). However, the details of this arrangement are not known.

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[52] Oort to the Board of the Royal Academy of Sciences, 20 November 1945, OA, 251.

[53] De Voogt mentions that these Würzburgs were acquired by the PTT, but he does not explicitly mention his own initiative in this respect.

The first question we can ask is how Oort came by the idea that such a Würzburg Riese could be used for radio astronomical research. The story goes that shortly after the war Oort and the physicist J.H. Bannier, (later the first director of the funding organisation ZWO) were walking along the coast of the North Sea and there they saw some of these Würzburgs the Germans had left behind. Oort would then have seen immediately that with some modifications these reflectors could easily made suitable for radio astronomical research (Beekman, 1999, p. 154). However, this story is rather unlikely. From a letter of Minnaert to Oort in the Oort Archives it appears that Rinia from Philips NatLab showed the astronomers the way to these Würzburgs: 'Rinia told me that the mirrors he refers to are at various locations in the dunes, especially in Terschelling. According to him, they have a diameter of 8-10 metres (...).'[54] Furthermore, it seems that the antennas (or at least some of them) had at that moment not yet been transported to the transmitting station of the PTT, but the PTT had already laid a claim on them. This becomes clear from the fact that Minnaert said they needed to contact some people from the PTT to obtain one of these Würzburgs: 'He [Rinia] does not know another possibility to obtain these [the Würzburgs] than through colleague von Weiler – so I fear the worst.[55] I wonder if we could try van Soest, whom I do know and who is the head of the military laboratories.'[56]

In any case, in the beginning of 1948, the PTT made one of these Würzburgs available for the Dutch astronomers. The reason why the PTT was so eager to help the astronomers was because they thought they would benefit from the radio astronomical research too. More specifically, the PTT took an interest in the solar research the astronomer Marcel Minnaert and his team had been doing for several years. Indeed, solar research could be very valuable for communication. As pointed out above, solar activity influenced the ionosphere[57], which in turn influenced the propagation of radio waves through the ionosphere.

The solar research of Minnaert not only drew the attention of the PTT, but also of the Royal Dutch Meteorological Institute (KNMI), where Minnaert had been working in the interwar period. The KNMI was interested in solar research for similar reasons: the Sun influenced the ionosphere and this in turn influenced the weather conditions. Already during the war, there were contacts between the Utrecht astronomers and the KNMI, especially with Minnaert's assistant Houtgast, who was the deputy director of Utrecht Observatory when Minnaert was imprisoned in Sint-Michielsgestel. In 1944 for example, Houtgast participated in a colloquium of the KNMI with a paper on *The scintillation of stars* ('Het scintilleren van sterren'), which was thought to be connected to the weather.[58]

As the Netherlands had a special interest in this kind of solar research, not only from a scientific perspective, but also because of its overseas territories, Houtgast had proposed the creation of a new institute for solar and ionospheric research with observing stations at home and in the

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[54] 'Rinia vertelde mij, dat de door hem bedoelde spiegels van de Duitsers hier en daar in de duinen staan, inzonderheid op Terschelling. Volgens hem hebben ze een middellijn van wel 8-10 meter (...).' Minnaert to Oort, 29 February 1948, OA, 162b.

[55] It is unclear why this is so 'bad', but probably this was just because Minnaert did not have any connection with von Weiler.

[56] 'Hij kende geen andere weg om hieraan te komen dan collega von Weiler – ik vrees dus het ergste. Het is de vraag of we 't zouden kunnen beproeven met van Soest, die ik wel ken, en die immers aan het hoofd van die militaire laboratoria staat.' Minnaert to Oort, 29 February 1948, OA, 162b.

[57] Solar activity had reached a maximum in 1947.

[58] Houtgast, J., 'Het scintilleren van sterren', talk for the colloquium of the KNMI on 18 February 1944, MA, 838, Box 19, Folder 6.

colonies (Strom, 2005, p. 97). Although these plans were never realised, Houtgast and Minnaert effectively joined forces with the PTT and the KNMI in March 1946 to study the ionosphere and its connection with radio wave propagation and solar activity (Houtgast, 1946, p.93).

So the first radio telescope in Kootwijk was in fact a 'present' from the PTT. The dish was much smaller and less sensitive than the one Oort originally planned—only 7.5 m—, nor was the receiver built by Philips: it was an adapted surplus American radar receiver that professor C. J. Gorter of the Kamerlingh Onnes Laboratory at Leiden had provided. Thus for several years, the astronomers did their research with a much smaller and less sensitive telescope than they had originally planned.

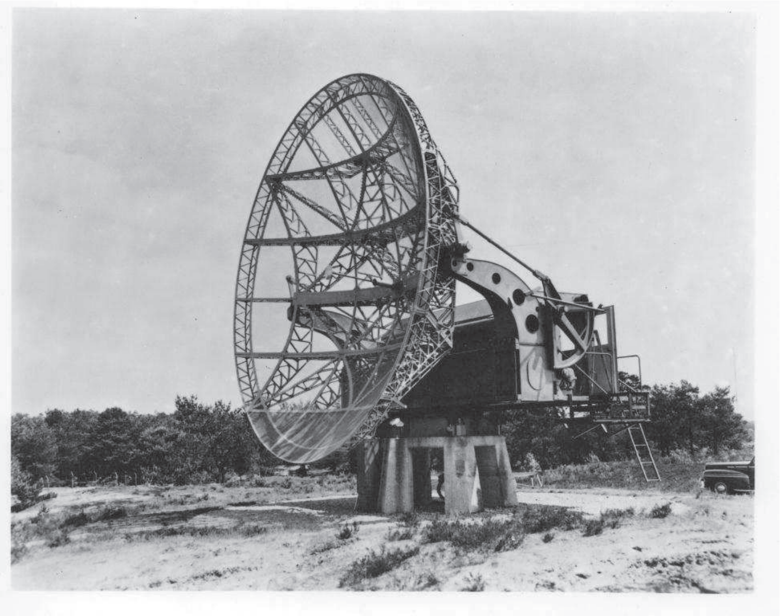

FIGURE 1. The first radio telescope in Kootwijk (Leiden Observatory Archives)

1.10 TOWARDS A 'KNOWLEDGE-BASED ECONOMY'

The Second World War had left the Netherlands with a devastated economy and, as we saw, science had been hit hard as well. After the war, it took a while before life was back to normal. Many basic products, like clothing, were hard to obtain. It is telling that in the late summer of 1945 Oort wrote to the city of Leiden to inquire whether it was possible to give shoes to the staff of the observatory:

> Among the staff of the Observatory are some people whose footwear is in such a condition that there is a good reason to fear that they will soon no longer be able to come to their jobs, because of a lack of footwear. (…) I would very much appreciate if you could let me know whether there is a possibility to provide footwear for the members of the staff for whom this is most urgent.[59]

It was also in this context that in 1945, Oort's request to the Dutch government for Dfl 100 000 for the building of a radio telescope with a mirror of 25 m was turned down.

Despite this setback, however, Oort did not give up. He kept hoping that in the short term it would be possible to build such a telescope. However, it remained to be seen whether such a project would be viable in the post-war context. Could science be a priority in a country that had been devastated by the war? To answer this question, it is necessary to put the Dutch post-war science policy in context.

Understandably, the main aim of the first post-war Dutch Prime Minister, Willem Schermerhorn, was the reconstruction of the country. And in this reconstruction *science* had to play a major role. Indeed, the main purpose of science was to serve the economy, as Schermerhorn made clear in his radio speech to the Dutch nation on 27 June 1945:

> Scientific research, improvement of existing products and the launch of new products, the reduction of the cost, partly by (…) extensive market analysis and needs analysis are (…) essential, if eventually the Netherlands want to maintain a prominent place in quality production.[60] (Schermerhorn and Queen Wilhelmina, 1945, p. 15)

In other words, the Netherlands had to evolve towards what since the 1960s has been known as a 'knowledge-based economy'. More specifically, Schermerhorn wanted to create a special organisation, a kind of brain trust of researchers linked to both industry and government, which was to conduct research into several new fields. This was supposed to stimulate industry and economic growth (Kersten, 1996, p. 10).

Eventually, this would lead to the foundation of the Dutch Organisation for Pure Scientific Research or ZWO ('Zuiver Wetenschappelijk Onderzoek'). It was formally founded in 1950, but provisionally already active in 1947.

A closer look at the foundation of ZWO reveals that from the very start academe, industry and the government were involved. On 13 September 1945, Schermerhorn had his first meeting about the topic with the Minister of Education, Arts and Sciences Professor G. van der Leeuw, the Minister

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[59] 'Onder het personeel der Sterrewacht zijn eenigen, wier schoeisel in zoodanigen staat verkeert, dat er gegronden reden is om te vreezen dat zij binnenkort door gebrek aan schoeisel niet meer naar hun werk zullen kunnen komen. (…) Ik zou het bijzonder op prijs stellen indien U mij wilde mededeelen of er een mogelijkheid bestaat schoeisel te verstrekken voor die leden van het personeel voor wie dit het meest urgent is.' Oort to the Central Distribution Office ('Centraal Distributiekantoor') of Leiden, 21 August 1945, OA, 98a.

[60] 'Het natuurwetenschappelijk onderzoek, de verbetering van bestaande en het op de markt brengen van nieuwe producten, verlaging van de kostprijs mede door (…) uitgebreide markt- en behoefteanalyse zijn (…) onmisbaar, wil Nederland op den duur een vooraanstaande plaats in de kwaliteitsproductie behouden.'

of Trade and Industry H. Vos, the president of TNO, Professor H. R. Kruyt and the Secretary General of Education, Arts and Sciences H. J. Reinink.

Schermerhorn decided to set aside 5 million Dfl annually for the expansion of the national research capacity and for improved education of scientific researchers. Not only the natural sciences, but also economics, the social sciences and the humanities were meant to benefit from this (Kersten, 1996, p. 10). The question was how all this could be organised. In order to set the wheels in motion, Schermerhorn and Van der Leeuw founded a special committee in April 1946. It was presided over by Reinink and therefore it was referred to as the 'Reinink committee'. There were 11 representatives of the government, industry and science on the committee (Reinink, 1950, p. 7).

The Reinink Committee drafted a bill during the first half of 1947 to formally establish the new organisation. This bill was largely based on a report of TNO president H. R. Kruyt, who took the organisational structure of the Belgian National Fund for Scientific Research (Nationaal Fonds voor Wetenschappelijk Onderzoek or NFWO) as an example (Reinink, 1950, p. 9). (NFWO had already been founded in 1928. Its organisational structure was roughly based in turn on that of the Rockefeller Foundation.) After the necessary recommendations and revisions, the bill was presented to the Dutch parliament on 26 April 1949. It was approved, after some amendments, by the Lower Chamber on 7 October 1949 and finally by the Upper Chamber on 4 January 1950. Between 1947 and 1950, the Reinink Committee operated as the provisional board of the 'Organisation for Pure Scientific Research in the course of formation'.

As Schermerhorn was a former professor of geodesy at Delft, it is tempting to draw the conclusion that his preoccupation with science was due to the fact that he was a scientist himself. But that seems to be only a minor part of the explanation. The view that science had to be a key factor in post-war politics was widespread at the time. In the USA for example, Vannevar Bush—the director of the Office of Scientific Research and Development—had just written his famous report for the president *Science: The Endless Frontier*. This report would ultimately serve as the basis for the creation of the American National Science Foundation (NSF) in 1950.

In this report, Bush argued for a national science policy and extensive support of science from public funds (Bush, 1945). He laid the emphasis on 'pure' or 'basic' research as this would ultimately lead to useful practical applications. According to Bush, scientific progress had proven to be extremely valuable during the Second World War. For example, medical applications—based on former basic research—had reduced the death rate in the Army. Many of the leaders in the development of radar had been doing basic research in physics (for example exploring the nucleus of the atom) before the war. Radar had played a vital role in defeating the Germans and driving back the Japanese (Bush, 1945). Understandably, Bush did not say a word about the secret Manhattan project, conducted to develop the first atomic bomb, because the report dated from 25 July, 2 weeks before the Americans dropped their atomic bombs on Hiroshima and Nagasaki, respectively on 6 and 9 August. Bush's reasoning was the following:

> Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science. (Bush, 1945)

The 'Bush report' was well-known in Europe as well. Van Helvoort claims 'it became the starting point for government sponsorship of scientific research in many European countries, including Germany, the Netherlands and Belgium' (Van Helvoort, 2003, p. 3). However, to consider this report as a 'starting point' for government sponsorship of science may be a little exaggerated. In Belgium and in most other European countries, for example, government sponsorship of science had come into existence during the interwar period. Moreover, in these countries, after the Second World War, the emphasis had shifted from 'pure science that leads to applications' to 'applications' itself (see also Chapter III). And in the Netherlands, the content of the Bush report corresponded with a conception of the role of science that was already prevalent. At the meeting of 13 September 1945, Schermerhorn already explicitly stated that pure scientific research should be stimulated. Hence, instead of being the starting point of Dutch science policy, the Bush report must rather be seen an authoritative expression of the conception of the role of science that existed also in the Netherlands.

The report became known in the Netherlands, because Prime Minister Schermerhorn had sent his friend F. A. Vening Meinesz—head of the KNMI (Royal Dutch Meteorological Institute) and professor of geodesy at Utrecht and Delft—to the USA to find out how support for scientific research was organised over there. Before the Second World War, financial support of scientific research in the USA was largely in private hands and was not considered a federal responsibility. Therefore, the report of Vening Meinesz's visit, presented in December 1945, mainly contained an analysis of the structure of private funding organisations: the Carnegie Institution of Washington (founded in 1902) and the Rockefeller Foundation (founded in 1913). In addition, he also presented an analysis of the recent report of Vannevar Bush (Kersten, 1996, p. 11).

The aforementioned Reinink committee—the founding committee of ZWO—read the report of Vening Meinesz and in turn referred to the Bush report, when presenting its first report:

> In his Report to the president on a program for Postwar Scientific Research, entitled: 'Science the endless frontier,' V. Bush, director of the Office of Scientific Research and Development in the USA, writes: 'In the nineteenth century, Yankee mechanical ingenuity, building largely upon the basic discoveries of European scientists, could greatly advance the technical arts. Now the situation is different. A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill.' Indeed, America took on a leading position only after it had boosted its basic research (…) (Reinink, 1950, p. 8)

The benefits were proven by the example of Philips, according to the Reinink Committee: 'At Philips Companies in Eindhoven (…) in fields in which basic research has been done, it has been possible to get to the forefront with relatively few people, and to occupy a leading position in the world.'[61] (Reinink, 1950, p. 8)

Concerns about the relevance of science for the national economy were not entirely new after the Second World War. Although the Netherlands had remained neutral in the First World War, the country was plagued by shortages in the late 1910s. The idea then prevailed that science had to

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[61] 'In de Philips fabrieken te Eindhoven (…) in de gebieden waarin fundamenteel onderzoek verricht is, is het gelukt met weinig menschen vooraan te komen en een wereldpositie te veroveren.'

come to the rescue. In 1917, the Royal Netherlands Academy of Arts And Sciences (KNAW) asked the Dutch government:

> Is it not urgently needed, with all the power of science and experience the Netherlands has, to look for means and ways to get as much use out of the few available resources and means of production?[62] (Quoted in Lintsen et al., 2012, p. 20)

The Dutch government listened to this request. Its actions would lead to the establishment of the Organisation for Applied Research TNO in 1932 (Kersten, 1996, p. 6). However, TNO differed fundamentally from ZWO: it remained an independent institution (no government institution) and its focus was on applied research.[63]

1.10.1 BETWEEN PURE SCIENCE AND APPLICATIONS

As mentioned above, from the very start the ultimate goal of pure science in the post-war Netherlands was *applications*. But it was never made explicit how application-directed this pure science should be. Different parties involved in the founding of ZWO held different opinions about this question.

On 22 November 1947, for example, a conference took place on the organisation of basic research in the Netherlands. The provisional board of ZWO and several scientists were present. The conference was organised by the Association of Scientific Researchers or VWO ('Verbond voor Wetenschappelijke Onderzoekers'). VWO was an association of socially engaged scientists, founded immediately after the Second World War (Molenaar, 1994). The president of VWO was none other than Marcel Minnaert. In his introductory talk at the conference, Minnaert endorsed the plans for the foundation of ZWO: '(…) it is of crucial importance that the government prepares an organisation to stimulate pure scientific research. All scientific workers in the Netherlands appreciate this greatly'[64] (VWO, 1948, p. 1). Although VWO was clearly in favour of government support for pure science, the association strongly opposed science that was undertaken exclusively 'for its own sake.' As it stated in its mission statement: 'It is out of the question that the scientific researcher can or may always explore what he feels like (…)' [65] (VWO, 1947, p. 7). VWO recognised that completely free, unbridled research had yielded interesting results in the past, but to think that this kind of research was still possible at the current period of time, was in its eyes an 'anachronistic naivety' (VWO,1947, p. 7).

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[62] 'Is het niet dringend nodig, om met alle kracht van wetenschap en ervaring waarover Nederland beschikt, te doen zoeken naar middelen en wegen om uit de weinige beschikbare grondstoffen en productiemiddelen een zo groot mogelijk nu te trekken?'

[63] To read more on the history of TNO, see: Lintsen, 2012.

[64] '(…) is het van de grootste betekenis, dat de Regering een organisatie voorbereidt om het zuiver wetenschappelijk werk energiek te bevorderen. Alle wetenschappelijke werkers in Nederland stellen dit op hoge prijs.'

[65] 'Er is geen sprake van, dat de wetenschappelijke onderzoeker altijd kan of mag exploreeren waartoe de lust (…) hem drijft.'

This view of VWO was in sharp contrast with the view of the Minister of Education Van der Leeuw, who stressed that applied research was impossible without 'the entirely free pure research, which takes off and doesn't know where it is going to take us'[66] (Van der Leeuw, 1947, p. 120).

Although the main goal of the Dutch government to stimulate science was to help the rebuilding of the country, it seems that the early ZWO had no clear vision on the question as to what promises of applicability a pure science project had to hold in order to justify funding. In fact, a lack of well-articulated visions and plans was a characteristic of the general policy of ZWO, especially during the founding period (1947–1950). In these days, the government just followed the initiatives from the scientists themselves (Kersten, 1996, p. 19). Indeed, it was a conscious policy not to have a well-articulated vision. As it says in the annual report of 1950: 'In the founding period, ZWO has worked mainly "passively": people waited for initiatives to be taken by others, whereupon they examined which of these were to be selected for support'[67] (Annual report ZWO, 1950, p. 17). Moreover, ZWO was not inclined to change this attitude. Indeed, a more active approach that would focus on promoting unexplored fields was considered to involve the risk of a lack of capable, interested and experienced researchers. (Annual report ZWO, 1950, p. 18). This was of course a smart strategy: if one of the new initiatives would prove to be very successful, ZWO could easily claim the success.

This vagueness concerning possible applications of scientific projects was also an opportunity for scientists of course. As will be shown, funding could be obtained rather easily, especially if a project offered some vague promises of applications.

Of course, the astronomers were well aware of the fact the Dutch government had a special interest in possible applications of their research. Therefore, Oort was very happy to have Philips amongst his partners. When companies such as Philips showed an interest in his research, he could at least *pretend* it had potential spin-offs. Therefore, in the beginning of 1946 he wrote a letter to a member of Philips NatLab in which he said: 'It would certainly stimulate the execution of the plans if Philips Companies would show their active interest in this project (…)'[68] And when in 1948, Oort had written a memorandum for ZWO to acquire funding for radio astronomical research, Minnaert explicitly advised him to add a reference to the potential applications in telecommunication:

> In fact, it is a pity that it says nothing about the practical meaning of the research for the radio service: knowledge of the ionosphere and the disturbances in it; probably the possibility to predict these disturbances. I certainly believe that this consideration would be an argument to give us a grant. Maybe you should add a paragraph to the memorandum on a third page.[69]

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[66] 'het volkomen vrije fundamentele onderzoek, dat uitgaat, niet wetende waar het komen zal.'

[67] 'In de oprichtingsperiode is Z.W.O. hoofdzakelijk "passief" te werk gegaan: afgewacht werd welke initiatieven door anderen werden genomen, waarna werd onderzocht welke daarvan voor steun in aanmerking dienden te komen.'

[68] 'Het zou de uitvoering der plannen zeker bevorderen als de Philips Fabrieken (…) blijk zouden geven van hun actieve belangstelling in deze onderneming.' Oort to Balthasar Van der Pol, 28 January 1946, OA, 251.

[69] 'Eigenlijk is het jammer dat er niets staat over de praktische betekenis van het onderzoek voor de radiodienst: kennis der ionosfeer en der daarin optredende storingen; wellicht de mogelijkheid, die storingen te voorspellen. Ik geloof zeker dat deze beschouwing een argument zou zijn om ons een toelage te bezorgen.

However, the question remains whether industry was *really* interested in this radio astronomical research. In the case of the PTT, this interest cannot be doubted. In the case of Philips, on the other hand, the situation was different. Although a few individuals of the NatLab of Philips had a personal fascination for the radio astronomical work, the company as a whole was rather indifferent.[70]

Moreover, the astronomers themselves soon realised that their radio astronomical research would yield no spin-offs at all. In their grant applications to acquire funding for the telescope with the 25-m dish – which was approved in 1951, as will be shown in the next chapter – they always stressed spin-offs in telecommunication. Nevertheless, already in 1949 Minnaert realised that a dish of 25 m was useful for *Galactic* research, but it was redundant for *solar* research, and it was only the latter that could yield these spin-offs. With regard to getting a grant, this was of course a rather upsetting conclusion. Minnaert wrote to Oort:

> We must have been mistaken at some point. (…) A mirror of 7.5 metres is as good for the observation of non-localised solar phenomena as a mirror of 25 metres. That means that an important point in our program becomes obsolete.[71]

Fortunately for them, however, Oort and Minnaert never mentioned this new 'insight' in their grant proposals: they kept on stressing that their project would have important spin-offs in telecommunication, although they knew it would not. So in a certain way, they fooled their funders.

In hindsight, Minnaert's prediction that the telescope with the dish of 25 metres was redundant for solar research was correct: almost no solar research was done with this telescope. Only in the 1970s was some solar research done with a 60-channel spectrograph (Strom and Van Woerden, 2007, p. 385).

Het zou denkbaar zijn, aan het memorandum een paragraaf toe te voegen op een 3e blad.' Minnaert to Oort, 29 March 1948, OA, 162b.

[70] It was difficult to gather more information on this topic. Our point of view, however, is sustained by the fact that in the Oort Archives the correspondence with Philips is limited to correspondence with individuals of Philips NatLab, who did not act as representatives of the company in these matters. Moreover, some personal accounts of people involved in early radio astronomy confirm our story. Alexander Ollongren - emeritus professor of computer science and guest professor of astronomy at Leiden University - remembers this very well. Ollongren has cooperated for a while with Ben G. Hooghoudt, an engineer of Delft who has been involved in Dutch radio astronomy from the very beginnings. Hooghoudt was an important advisor of Oort and the telescope with the mirror of 25 metres was constructed under his supervision (see also the next chapters). Ollongren - who performed some strength calculations for Hooghoudt - recalls that Hooghoudt regularly complained about the passive attitude of Philips. (Personal communication of Alexander Ollongren to the author, 12 May 2011). Klaas Wildeman – former project manager at the Netherlands Institute for Space Research SRON – says that this lack of interest from Philips is not surprising. Indeed, to expect the opposite would be very unrealistic. Philips – which was also involved in space research - was especially interested in products that could be manufactured on a large scale or that could yield knowledge that Philips could apply in other fields. It was clear from the very beginnings that radio astronomy offered neither. (Personal communication of Klaas Wildeman to the author, 11 October 2011).

[71] Minnaert to Oort, 12 September 1949, OA, 162b.

1.11 A SMALL NETWORK WITH A BIG IMPACT

From 1948 onwards, the astronomers received a subsidy from the provisional ZWO for its radio astronomical research with the small telescope in Kootwijk. For the year 1948, they received Dfl 13 650. With 62 applicants for that year and a total ZWO-budget of Dfl 804 144, this was a nice sum of money, but nothing exceptional. At the same time, taking into account that radio astronomy was still a new and uncertain field this sum was very easily obtained. As already mentioned before, because of the interest of companies such as Philips and the PTT in radio astronomy, predictions could be made about spin-offs. In an age in which the applications of 'pure science' were highly esteemed, this furthered the astronomers' case.

But there was more. The reason that funding was easily obtained was not only due to a clever rhetoric in the grant proposals. The astronomers greatly benefited from the fact that astronomy was still a very small-scale undertaking. In the Netherlands, there were only a dozen tenured positions for astronomers in the 1930s (Baneke, 2010, p. 184). During the first post-war years, this hardly changed. Similarly, ZWO was still in an embryonic stage and hence it was a very small organisation.

The fact that so few people were involved also meant that the impact of a personal network could be enormous. Indeed, Minnaert and - to a lesser extent - Oort had established a network of influential people from industry, politics, government and science. Although radio astronomy was mainly Oort's project, it was especially Minnaert's network that Oort used to further his own case. As we saw, Oort's network was mainly confined to some individuals of Philips NatLab. Minnaert, on the other hand, had joined forces with the PTT and the KNMI, but his network also involved some influential politicians. One of Minnaert's students who contributed to the research into the solar spectrum, for example, was J. H. Bannier. In 1936 Minnaert had published an article with Bannier in the *Zeitschrift für Astrophysik* (Minnaert and Bannier, 1936). After the war, Bannier worked at the department of Higher Education and Sciences for several years before he became the first director of ZWO. In this position, he was capable of seriously furthering the case of radio astronomy. As early as September 1949, he attended the meetings of the radio astronomers and discussed the possibilities for funding.[72]

Another acquaintance of Minnaert was none other than the Dutch post-war Prime Minister Willem Schermerhorn, whom he had met in Sint-Michielsgestel. There was a lot of intellectual activity in the camp. So-called 'circles' were organised. These were groups of politicians, industrialists and officials who discussed how the post-war Netherlands should be organised. As a matter of fact, the Dutch post-war Schermerhorn cabinet was prepared in these circles in Sint-Michielsgestel (Molenaar, 1994, p. 283).[73] Minnaert cooperated too: he was a member of the circle on educational policy and of the art circle'. We do not have any details about contacts between Minnaert and Schermerhorn in Sint-Michielsgestel. But as Minnaert was there from May 1942 until April 1944 and Schermerhorn from May 1942 until December 1943, they certainly must have met.

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[72] Minutes of the board meeting of SRZM of 20 September 1949, SA.

[73] The role of the discussions of Sint-Michielsgestel on post-war politics has never been doubted: see for example the dissertation of Ruitenbeek (1955). In this dissertation, Ruitenbeek emphasises the role of the discussions in Sint-Michielsgestel in the founding of the Dutch Labour Party (PVDA) in 1946.

When we take a closer look at the funding procedure, we see that the people who had to judge the project were very often acquaintances of the astronomers. Moreover, some people were judge and party at the same time. The science committee of ZWO, which had to advise on astronomical projects, consisted of 11 members, 2 of whom were at the same time members of the board of SRZM (the national foundation for radio astronomy)[74] namely Minnaert and Rinia. As was to be expected, this science committee gave a positive advice to the board of ZWO. This board, which consisted of 17 members, in turn gave a positive advice to the Minister of Education, Arts and Sciences. This was also not so surprising, considering that the head of the KNMI (and personal friend of Prime Minister Schermerhorn) – F.A. Vening Meinesz - was at the same time a member of this board and a member of the board of SRZM. And Bannier—the director of ZWO and former student of Minnaert—was the secretary of the board. What is even more important is that Bannier combined his function at ZWO for about half a year with the function of deputy director at the Department of Higher Education and Sciences at the Ministry of Education. So he was working for the Minister of Education, Arts and Sciences J. Gielen, who had to give the final approval. (In most cases, the minister followed the advice of the board.)

1.12 THE RESEARCH PROGRAMME: GALACTIC VERSUS SOLAR RESEARCH

It is difficult to determine how, and even more to what extent the background of the first radio astronomers influenced their research questions. There are many other factors that may influence which questions are asked. Funding systems for example, can have non-negligible effects, as we will see in Chapter II. Nevertheless, to some extent we can still discern the effects of the researcher's background. In general, it is striking that the vast majority of radio astronomical research during or immediately after the war was radio astronomy of the *Sun*. As radar workers were often confronted with interference by radio radiation from the Sun in the metre-wave range, it was obvious that the first radio astronomical measurements were mostly solar measurements in this wave range. Nations such as Canada, Japan, France, and the Soviet Union initially focused almost exclusively on solar radio astronomy (Orchiston and Mathewson, 2009, pp. 28-29).

In Britain, Hey deduced in 1942 that the apparent jamming of British coastal radar installations was in fact interference by radio radiation from the Sun (see above). It is not surprising that his very first radio astronomical research concentrated on the nature of these solar emissions. At Cambridge too, the Cavendish Laboratory group initially concentrated on solar observations. Jodrell Bank on the other hand, specialised in the radar study of meteors and the ionosphere. Although this was not solar research, it was a continuation of the work Lovell and others had been doing during the war, as we saw. Moreover, it was still astronomical research 'close by'.

The Dutch group was one of the few groups to look *beyond* the ionosphere, in focusing on Galactic radio astronomical research. This focus was clearly shaped by pre-war astronomical research. In fact, it was a continuation of that research by means of a new technology. As mentioned above, until the 1960s Dutch astronomy was strongly influenced by the work of Kapteyn. He was especially concerned with the 'sidereal problem': the study of the locations and motions of the

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[74] SRZM or 'Stichting Radiostraling van Zon en Melkweg' was formally established on 23 April 1949, but informally already active in the autumn of 1948 (see next chapter).

stars. This was one of the main astronomical questions of the time (also Kapteyn's contemporary, the German astronomer Hugo von Seeliger was working on it). By the end of his life, he had constructed the 'Kapteyn Universe', a model in which our Milky Way was relatively small and the Sun was located at or near the Galaxy's centre. This model proved to be completely wrong, but unravelling the structure of the Galaxy became the main goal of Dutch astronomy. The fact that this tradition, initiated by Kapteyn, was continued, is mainly due to Kapteyn's student – and later supervisor of Oort - Van Rhijn. In 1904 Kapteyn inaugurated a systematic sampling method that made it possible to obtain representative data in a fraction of the time that a complete star by star investigation of the Galaxy would involve. The whole sky, north and south, and also faint distant stars had to be included. This project was called the 'Plan of Selected Areas' (Lynds, 1963, p. 89). International cooperation was required for such a project. It was Van Rhijn's life work to coordinate this project and to involve observatories all over the world.

When radio astronomy originated, unravelling the structure of the Galaxy was still the main goal of Dutch astronomy, as Sullivan pointed out:

> Despite the wholly new technology compared to Kapteyn's day, there was no discontinuity in either research style or content – the radio astronomical problems too were tackled in a very Kapteynian manner. (Sullivan, 2000, p. 229)

Oort himself saw radio astronomy explicitly as the continuation of a program about 150 years old. It was a 'third phase' in the development of the quantitative investigations of the Galactic System, that had been started by the German-born British astronomer W. Herschel (1738 - 1822). A first development came from Kapteyn. Consistently pursuing the ideal of revealing the general structure of the entire stellar system, Kapteyn had initiated essentially all the methods that were used around 1950. A second great development began around 1914 by the American astronomer H. Shapley (1885 – 1972), when he started to study the distribution of globular clusters (dense spherical collections of stars). From the spatial distribution of these clusters, he inferred the true dimensions of the Galaxy and the position of its centre. About radio astronomy, Oort said the following:

> It seems that at present a third phase in the development of galactic research has begun by successful reception of radiation at radio frequencies. This research is still in its early infancy, comparable perhaps to the stage that Sir William Herschel had reached some hundred and fifty years ago by his star gauges in the visible radiation. What has been reached in the few years since active radio-astronomical research was started can hardly be expected to give more than the faintest glimpse of the changes of insight that the next years are likely to bring about. (Oort, 1952, p. 233)

1.13 ORGANISATIONAL ASPECTS: BIG SCIENCE – LITTLE SCIENCE

As is often pointed out in historiography, the Second World War thoroughly shaped post-war science. Historian of science Peter Galison made clear that in the USA, the consequences of the war for science were manifold: as far as research funding was concerned, the war configured the relations between the academic, governmental, and corporate worlds; university research became increasingly tied to military affairs; the relations between physicists, engineers, and technicians changed thoroughly (The three groups had to learn to work intensely together. So-called 'trading zones'[75] marked their contact sites.); there was a continuity between wartime weapons development work and post-war research, reaching back before the war to points of common peacetime research (which Galison calls 'continuity of technique, discontinuity of results'); and last but not least, the 'work organisation' thoroughly changed: pre-war, mainly individual research had changed into large-scale research with a complex organisation, specialisation and expensive equipment (Galison, 1997, pp. 239-311).

Outside the USA too the influence of the Second World War on science was non-negligible. The foundation of the national funding organisation ZWO in the Netherlands, which was to a large extent motivated by the post-war aim of the rebuilding of the country, has already been discussed. It has also been made clear that the research questions in early radio astronomy were shaped worldwide by wartime experiences. Now it is worthwhile to dwell on the organisation of early radio astronomy. In the USA, following their wartime experiences, physicists saw the organisation of their work as being completely different from its prewar shape. As Galison said: '(...) it is about the link between physicists' wartime experiences in radar and atomic bomb projects and the new picture they formed of how research would proceed – the picture of a collaborative, factory-scale effort that would displace the ideal of individual and small-group work.' (Galison, 1997, pp. 34-35) Indeed, academic research before the war was mainly individual research, pursued sometimes together with one or two colleagues (Fawcett, 1994, p. 34). We might call this working in small teams without a clear labour division 'Little Science'. During – and because of - the war, however, substantial changes had occurred in science: we had entered the era of 'Big Science'. Historian of science Steven Shapin associates the following characteristics with Big Science: a contract system binding academic research to the Federal Government, industrial sponsorship of science, the scale and expense of scientific instruments, the specialisation of scientific knowledge, the division of labour and so on (Shapin, 2008, pp. 166-167). Historian of science R.W. Smith, however, stresses that we should not focus exclusively on big technologies and on the number of researchers, but we have to take into account the differences in social organisation in the first place: the war had taught scientists to work together in groups, it had shown that progress was made by unified action (Smith et al., 1993, p. 21).

Radio astronomy is a prime example of a branch of science that was shaped through the war, as it owes its very existence to a large extent to the war. So the question is how and to what extent these new ways of organising science became visible in radio astronomy. One might expect that at least in countries where engineers and physicists with a background in war industry took the lead (not in the Netherlands), radio astronomy – like the war industry – was Big Science. This would be consistent with what Smith argues: radio astronomy was the first branch of astronomy to become 'Big', because the field was largely founded by engineers and physicists, who had been used to Big Science ways of working during the war and who, at least initially, employed apparatus the development of which owed much to the war (Smith, 1992, p. 185).

However, we doubt whether that is entirely true.

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[75] A 'trading zone' is an intermediate domain in which procedures would be coordinated locally even where broader meanings clashed (Galison, 1997, p. 46).

Let us take the example of Britain. Britain had an extensive war industry. As mentioned above, successful radio astronomy groups were established by the physicists Ryle and Lovell, who had been working at the Telecommunications Research Establishment (TRE). TRE's history dates back to the middle of the 1930s. It has its origin in radar research. The majority of the staff at TRE were research scientists, who had to make the adjustment to development and applications. The Big Science way of working at TRE was in sharp contrast with the way of working many staff members had previously experienced at the universities. TRE grew significantly during the war. In 1942, the staffing level was about 2000 people. By 1945, the increased electronics production had brought this number to about 3500. At that time, it was the largest research establishment in Britain. Research was performed around an extensive range of topics: radar, radio navigation, radio jamming, the development of cathode ray tubes, flight simulators and so on.

As far as radio astronomy was concerned, however, it is noteworthy that TRE staff members Ryle and Lovell did *not* establish their radio groups within the context of TRE. On the contrary, they went back to their universities: Ryle to Cambridge and Lovell to Manchester (Jodrell Bank). The way they organised their radio astronomical research at the universities was by no means comparable to the Big Science way of working at TRE. By the middle of 1946, Lovell had been joined by two of his wartime colleagues. Although the group at Jodrell Bank grew fairly quickly in size (8 researchers by the end of 1946, 21 by the end of 1951 (Edge and Mulkay, 1976, p. 16)) and research output, this undertaking can hardly be called Big Science during the first decade. There was very little technical advance: they just used the wartime apparatus for astronomy, without developing the technology further. Moreover, Lovell's university salary ran at half his TRE wages (Buderi, 1996, p. 278).

Like Lovell, Martin Ryle also returned to his old university. Before the war, Ryle had been doing ionospheric research at the Cavendish Laboratory. In 1945, he rejoined the Cavendish Laboratory and started investigating radio waves from the Sun with a small research group. The Cambridge group grew more slowly than the one at Jodrell Bank. (It counted 4 people in 1946, 9 in 1951 (Edge and Mulkay, 1976, p. 24).)

So contrary to what one might expect, the first British radio groups were small groups working with modest resources and using adapted war equipment. Hence, their organisation resembled Little Science – or at best 'Middle' Science - rather than Big Science. The American author Robert Buderi described them aptly: 'Most of the radio astronomers were young men working in small teams and doing all the dirty repair jobs themselves.' (Buderi, 1996, p. 288)

Unlike their foreign colleagues, Dutch radio astronomers had never left their universities to work in the war industry. Therefore, it is not surprising that the organisation of early post-war radio astronomical research in the Netherlands hardly differed from the organisation of their astronomical research in the previous period. First of all, the whole undertaking remained very small: in 1951, only six people were involved in radio astronomy. There was no outspoken labour division and the first radio telescope in Kootwijk was made out of adapted war equipment.

Hence, we come to the rather surprising conclusion that the organisation of early radio astronomy *nowhere* resembled the organisation of the research that took place in the war laboratories: not in the Netherlands – which was obvious, as research there was undertaken by university scientists

– but also not elsewhere, were the first radio astronomers were engineers and physicists with a background in war industry.

1.14 RADIO ASTRONOMERS VERSUS OPTICAL ASTRONOMERS

Last but not least, the fact that in the Netherlands radio astronomers and optical astronomers were the very same persons caused radio astronomy immediately to be recognised as a full-fledged branch of astronomy. In other countries, the first radio astronomers were not trained in astronomy and hence they lacked the interpretative skills optical astronomers had. Indeed, the first radio workers were astronomical novices who were frequently blundering in their astronomy. Therefore, they were not taken too seriously by the astronomical community. The Canadian astronomer Williamson recognised this already in 1948:

> (…) the radio engineer, well-versed in this [technical] side of the problem and perhaps possessed of the equipment for taking observations, may well find himself at loss to know best how to use it to obtain astrophysical data. (Williamson, 1948, pp. 13-14)

It was mostly this lack of astronomical insight that was responsible for the indifferent or even hostile attitude of the great majority of astronomers towards the new field. An example of this hostile attitude, is the opinion of (optical) astronomer D. Popper of Lovell's new chair of astronomy at the University of Manchester (1951), expressed in a book review of Lovell and Clegg's *Radio Astronomy* of 1952:

> The senior author is Professor of Radio Astronomy (!)(…) An astronomer will naturally be particularly alert to catch errors committed by these interlopers into his domain. (Popper, 1952, p. 210)

Not until around the early 1950s did the gap between the optical astronomers and the radio astronomers narrow. Crucial in this respect was the optical identification of radio sources. The first people to propose optical identifications of radio sources were Bolton, Stanley and Slee in Australia in 1949 (Sciama, 1975, p. 54). In an article in *Nature*, they identified the radio source Taurus A with the Crab nebula, Virgo A with the galaxy NGC 4486 and Centaurus A with the galaxy NGC 5128 (Bolton, Stanley and Slee, 1949). Optical identifications were very important from an astronomical point of view – they could provide information on temperature, density, chemical composition etc. – but more important for our research is that they lent 'a sense of reality and reliability to the very existence of radio sources' (Sullivan, 2009, p. 349).

In the Netherlands, this problem was non-existent of course. As radio astronomers and optical astronomers were the very same persons there, there was no 'gap' between the two communities that needed to be bridged. There was no need to wait for optical identifications before radio astronomy was taken seriously. In other countries, the gap between the two communities sometimes seriously slowed down the take-off of radio astronomy. This was especially the case in the United States, as we will see in Chapter III.

1.15 CONCLUSION

During the interwar period, the Netherlands – and especially Leiden Observatory – became an international centre of astronomy. The rising star in Leiden was the astronomer Jan Hendrik Oort, who had been a student of the Groningen astronomer Kapteyn. Under the influence of Kapteyn, research into the structure of the Galaxy had become one of Oort's life-long interests. However, it had become clear that the largest part of the Milky Way was inaccessible to observations at optical wavelengths because of the extinction of the light by interstellar dust. Astronomers had already resigned themselves to the fact that they would only have indirect knowledge about a large part of the Milky Way. All this changed, however, with the emergence of radio astronomy.

The history of radio astronomy can be traced back to the first half of the nineteenth century, but we have to wait until the 1930s when the first radio waves from space were detected by Karl Jansky. Ten years later, in the early 1940s, Grote Reber made his analogous detection known to the community of professional astronomers through the publication of an article in the *Astrophysical Journal.* Although Reber is considered to be one of the 'founding fathers' of radio astronomy, in most countries it was not Reber's article that initiated radio astronomy. The Dutch group was anomalous in this period. There, Oort's reading of Reber's article was a decisive moment in the history of radio astronomy. In the other countries, however, far more important than Reber's work were wartime developments in military radio and radar electronics. As we saw, immediately after the war, several radio astronomy groups were formed, among which five stand out: three in England, one in Australia and one in the Netherlands. All these groups – except the Dutch group – had their origins in wartime radar research. Indeed, technologies of radar installations and radio telescopes were closely linked. During the war, the radar workers – mostly engineers and physicists – were often confronted with interference, in the first place coming from radio radiation from the Sun. Some of them wanted to explore this radio interference further and hence, the first 'radio astronomers' were engineers and physicists with a background in wartime radar research. In the Netherlands, this was not the case. Although the Netherlands were vital in radar development – with important centres such as Philips and LFO – not a single radar researcher took the initiative to investigate radio waves further. We think this is probably due to the fact that Oort already laid a firm claim on radio astronomy in the first years of the Second World War. As early as 1941, he contacted people from Philips with whom he wanted to cooperate in *his* project. So from the very beginnings, Oort held the reins firmly and therefore his partners – who had nevertheless a clear interest in the topic - in a certain way never got the chance to take any initiative in this respect.

The reason why Oort needed industrial partners such as Philips was that as an optical astronomer without a technical background, he did not have a clue about how he should build a radio telescope. In the end, however, these contacts would offer much more than merely technical know-how. Indeed, in the context of post-war politics - in which science came to be seen as the key-factor in the rebuilding of the country – it was a great advantage for scientists to have industrial companies as their partners. The Dutch government heavily supported pure science, as it was believed that this pure science would yield the necessary applications to stimulate the economy. And if scientists could show that the industry had an interest in their research, this was in a way a 'proof' that the project would yield applications. So the initial disadvantage Dutch optical astronomers had - their lack of engineering know-how – turned out to be an advantage, in the context of post-war science policy. Therefore, Oort did not let an opportunity pass to emphasise that Philips had a great interest in his plans, as he thought this would stimulate their execution. However, although a few members of Philips NatLab had a personal fascination for radio-astronomical work, the company as a whole was rather indifferent.

Besides these relations with NatLab, the Dutch astronomers also had good relations with the Dutch Post, Telegraph and Telephone Service (PTT). These contacts with the PTT had earlier been established by Marcel Minnaert. For years, there had been a cooperation between Utrecht Observatory, the Royal Dutch Meteorological Institute (KNMI) and the PTT, as these three institutions were involved in solar research. In March 1946 Minnaert and Houtgast (his assistant) had effectively joined forces with the PTT and the KNMI to study the ionosphere and its connection with radio wave propagation and solar activity. Just like the contacts with Philips 'proved' that possible industrial applications of the radio astronomical research were to be expected, the relations with the PTT 'proved' that the project would yield possible spin-offs in telecommunication. However, unlike Philips, the PTT was truly interested in radio astronomical research. Thanks to the PTT, the radio astronomers had their first radio telescope in Kootwijk.

The rhetoric of the possible spin-offs facilitated funding of radio astronomical research. ZWO-funding had been received since 1948, when a sum of Dfl 13 650 was provided. This was intended for research to investigate the necessity of building a large and expensive radio telescope with a dish of 25 m. Funding for this large telescope was approved in 1951 (see next chapter). In their grant applications, the astronomers always stressed spin-offs in telecommunication. Nevertheless, already in 1949 Minnaert had realised that a dish of 25 m was only useful for *Galactic* research, but it was not needed for *solar* research, and it was only the latter that could yield these spin-offs. With regard to getting a grant, this was of course a rather upsetting conclusion. Fortunately for them, however, Oort and Minnaert never mentioned this new 'insight' in their grant proposals: they kept on stressing their project would have important spin-offs in telecommunication, although they knew it would not. So in a certain way, they fooled their funders.

Funding was not only easily obtained because of the smart rhetoric of possible spin-offs, but also because astronomy was still a very small-scale undertaking in the early post-war period. Even so, ZWO was still in an embryonic stage and hence it was a very small organisation. The fact that so few people were involved meant that the impact of a personal network could be enormous. Although Oort finally came to dominate radio astronomy, it was in the first place Minnaert's network that could be used to further the case of radio astronomy. Oort's network was in the first place confined to people from Philips NatLab, while Minnaert had established fruitful relations with influential politicians (for example the prime minister), with the PTT, with the KNMI and with Bannier, the later director of ZWO. When we take a closer look at the funding procedure, we see that the people who had to judge the project were very often acquaintances of the astronomers. Moreover, some people were judge and party at the same time.

The fact that in the Netherlands the initiative for radio astronomy was taken by optical astronomers also had an influence on the research questions. Worldwide, the vast majority of radio astronomical research during or immediately after the war was radio astronomy of the *Sun*. That was because during the war radar workers had often been confronted with interference by radio radiation from the Sun in the metre-wave range. So it was obvious that the first radio astronomical measurements were mostly solar measurements in this wave range. The Netherlands in turn, focused on Galactic radio astronomical research. This focus was clearly shaped by pre-war astronomical research. It was just a continuation of that research by means of a new technology.

Thus, Dutch astronomers did not have a background in war industry, and hence their research questions were not shaped by it. Just like their research programme was a continuation of pre-war astronomical research, the organisation of their research was also a continuation of pre-war research. That meant: small-scale research that made use of wartime surplus material. Although this might not be surprising, what *is* surprising, is that the organisation of early radio astronomy *nowhere* resembled the organisation of the research that took place in the war laboratories: not in the Netherlands, but also not elsewhere were the first radio astronomers were engineers and physicists with a background in war industry. Everywhere, radio astronomers were working in small teams with wartime surplus material.

Last but not least, the fact that in the Netherlands radio astronomy was initiated by optical astronomers, meant that there was no ‘gap’ that needed to be bridged between the communities of optical and radio astronomers. Indeed, radio astronomers and optical astronomers were the same persons. In other countries, on the other hand, as radio astronomers were astronomical novices that frequently made astronomical blunders, they were not taken too seriously by the community of optical astronomers. There it was necessary to wait for the first optical identifications around 1950 before radio astronomy began to be taken seriously.