Journal of Astronomical History and Heritage, 9(1), 3-20 (2006).

THE BEGINNINGS OF RADIO ASTRONOMY IN THE NETHERLANDS

Hugo van Woerden
Kapteyn Astronomical Institute, University of Groningen, P.O. Box 800, 9700 AV Groningen, The Netherlands.
E-mail: hugo@astro.rug.nl

and

Richard G. Strom
ASTRON, Postbus 2, 7990 AA Dwingeloo, The Netherlands; and Astronomical Institute "Anton Pannekoek," Kruislaan 403, 1098 SJ Amsterdam, The Netherlands.
E-mail: strom@astron.nl

Abstract: The birth of Dutch radio astronomy can be rather precisely dated to 15 April 1944, when H.C. van de Hulst presented the results of his theoretical research into the origin of radio waves from space. We have investigated the events leading up to the momentous suggestion that hydrogen emission at 21 cm ought to be detectable. Both published material and letters from the Oort Archive have been consulted. Not having direct access to either radar technology or trained engineers, as was the case in countries like England and Australia, Jan Oort had to turn to a diversity of organizations: Philips Electronics Company, the Post Office, and academic colleagues in other disciplines. It was the Post Office's head of radio, A.H. de Voogt, who provided a 7.5 m Würzburg radar reflector and technical support at the Kootwijk station, starting in 1948. We trace the events leading up to the 21 cm line's detection in 1951, and discuss the early results. After a year spent rebuilding and thereby improving the receiver, C.A. Muller, together with Oort, Van de Hulst and others, was able to initiate an extensive HI survey of the Galaxy. The results fully justified the year's wait: a map of the Galaxy, spiral arms, the first rotation curve, and a much improved system of Galactic coordinates. We also present a discussion of Würzburg antennas used for research in the Netherlands, and a brief biography of A.H. de Voogt.

Keywords: radio astronomy, 21 cm hydrogen line, Oort, Van de Hulst, Muller, Netherlands, Kootwijk, NERA

1 INTRODUCTION

At its General Assembly in Sydney in 2003, the International Astronomical Union (IAU) formed a Working Group on Historical Radio Astronomy, with the task to document and, where possible, preserve radio-astronomical instruments of historical significance. Our goal in the present paper is to document the first radio telescopes used in The Netherlands. Our paper roughly covers the period 1944-1956; we intend to discuss the 25-meter reflector, inaugurated at Dwingeloo in 1956, in a later paper. The present paper thus concentrates on the 7.5-meter Würzburg reflector used between 1951 and 1955 for studies of 21-cm line radiation from atomic hydrogen in the Milky Way Galaxy (Section 4), and on the several other Würzburgs used mainly for solar radio astronomy (Section 5).

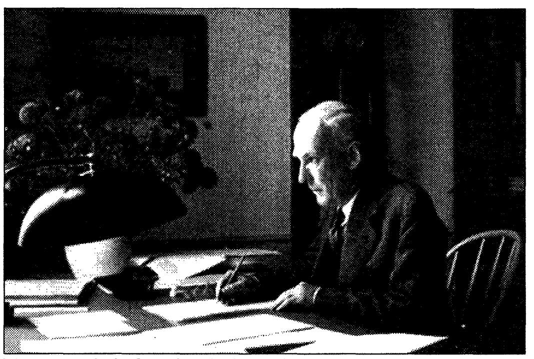

Figure 1: J.H. Oort behind his desk at Leiden Observatory, 1953 (photo by H. Kleibrink).

As compared with developments in some other countries, the beginnings of Dutch radio astronomy had a special character in several respects. In Australia and England radio-astronomical research was started in 1945 by radio engineers and physicists who had acquired extensive experience with radar receivers during World War Two; the Australians, moreover, had access to large amounts of war surplus equipment (Bowen, 1984; cf. also Sullivan, 2005). In The Netherlands, such experience and equipment were essentially lacking. The country had been occupied during the War; the universities had been closed for two years; the Institute of Technology at Delft, the only source of engineers at academic level, had even been closed for four years. On the other hand, in The Netherlands the drive towards radio astronomy came from leading individuals at classical astronomical observatories, notably Jan H. Oort at Leiden, who saw new, major opportunities for studies of Galactic structure.

These differences in circumstance were of such importance that we consider it appropriate to sketch the background of Dutch radio astronomy in two separate Sections (2 and 3).

2 A SPECTRAL LINE AT RADIO WAVELENGTHS!

During World War II the paper on "Cosmic Static" published by Grote Reber (1940) in the *Astrophysical Journal* came to Oort's attention. Reber was a remarkable radio astronomy pioneer (e.g. see Kellermann, 2005) who, using a paraboloid of 9 meters diameter which he had built in his backyard, had found strong radio radiation at wavelengths of order 2 meter, distributed over the sky and peaking near the position of the Galactic Centre. Oort (Figure 1) realized that radio waves would suffer no extinction by interstellar dust particles, and hence might allow an unhindered, complete view of the Galactic System—a major leap forward. In 1927, from a careful analysis of stellar motions, Oort had found evidence for differential Galactic rotation, and derived rough estimates of the rotation speed and mass of the Galaxy. However, interstellar extinction limited the reach of optical observations to a few kiloparsecs at best, while the distribution and distances of globular clusters indicated a distance to the Galactic Centre of order 10 kpc. Hence, the structure of the Galaxy remained essentially unknown. Oort sensed that radio astronomy might, in principle, change this situation drastically.

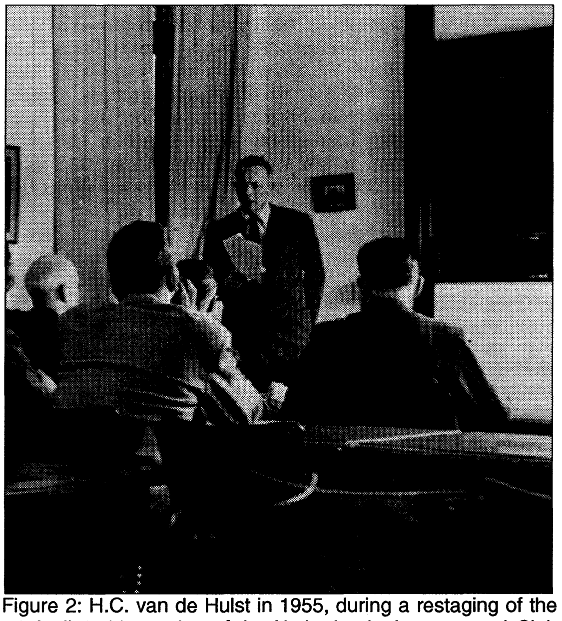

Figure 2: H.C. van de Hulst in 1955, during a restaging of the 15 April 1944 meeting of the Netherlands Astronomers' Club at Leiden Observatory, for the Kleibrink film (1957). The fully-visible heads (left to right) are: J.H. Oort, J.J. Raimond and J. Houtgast.

In 1941 Leiden University had announced a prize competition on "The formation of solid particles in the interstellar gas",[1] and in 1942 essays were submitted by three graduate students: D. ter Haar from the Lorentz Institute for Theoretical Physics in Leiden, H.C. van de Hulst from the Sonnenborgh Observatory in Utrecht and A.J.J. van Woerkom from the Observatory in Leiden. Together with Oort, these three young astrophysicists discussed their results at an Inter-university Colloquium of the Netherlands Astronomers' Club (NAC) on 9 January 1943 (Ter Haar et al., 1943). It may have been on this occasion that Oort first met Van de Hulst. Sometime early in 1943, Oort invited Van de Hulst for an extended visit to Leiden, but the War circumstances led to a delay (Van de Hulst, 1943a). M.G.J. Minnaert, Director of the Utrecht Observatory, had been held hostage in a detention camp since 1942. In October 1943, during a short leave from his camp, Minnaert was able to discuss the planned visit with Van de Hulst; he gave full approval, provided the stay at Leiden would be *temporary* (Van de Hulst, 1943b). Early in January 1944, Van de Hulst came to Leiden for a period of three months; his program was still open.

Oort was then planning another NAC Colloquium, this time about "Radiogolven uit het Wereldruim" (Radio Waves from Space), to discuss Reber's findings. Dr C.J. Bakker from the Philips Physical Laboratory would speak about the reception of radio waves, and Van de Hulst was invited to discuss their origin. Oort mentioned 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 as we do in optical astronomy. (Van de Hulst, 1957b: 3).

In a brilliant paper at the NAC Colloquium (Figure 2) on 15 April 1944, Van de Hulst (1945) presented his results. Modifying earlier work by Henyey and Keenan (1940), he calculated the continuous spectrum expected from a layer of ionized hydrogen, and suggested that this might explain the radiation reported by Reber. He further considered various possible spectral lines. For the transitions between high-excitation levels of the hydrogen atom, now known as 'recombination lines', he overestimated the broadening by the Stark effect and concluded that the lines would be fully effaced (this mistake was caused by a substitution error; see Van de Hulst, 1998: 4). But a hyperfine transition in the ground state of the hydrogen atom appeared promising. This 'spin-flip' transition, in which the electron spin changes from parallel to the proton spin into anti-parallel, would correspond to a wavelength of 21 cm. Van de Hulst found that the line would stand out from the background continuum, provided that the transition probability exceeds 10^{-16} sec^{-1}, corresponding to an average lifetime for the upper level of less than 300 million years. (The lifetime was later shown to amount to 11 million years.) Although at the time receivers were not sensitive enough, Van de Hulst (1945: 219) stated: "The matter does not look hopeless, although the existence of the line remains speculative."

In fact, the situation looked quite favourable indeed: line emission expected from the most abundant atom, present essentially everywhere in interstellar space! And that at a wavelength of 21 cm, where even a reflector of 10 meter diameter would provide an angular resolution of ~1.5°! The War delayed publication of the papers by Bakker (1945) and Van de Hulst (1945) until December 1945. An independent investigation by Shklovsky (1949) confirmed the findings of Van de Hulst. However, it would be several years before the 21-cm line was actually detected.

3 THE LONG ROAD TOWARDS A RADIO TELESCOPE FOR 21 CM WAVELENGTH

After the NAC colloquium on 15 April 1944, Oort immediately made plans to obtain equipment for observations at radio wavelengths.[2] On 19 April 1944, Oort wrote to C.J. Bakker, asking him whether Philips could provide a receiver for wavelengths of order 50 cm; Oort thought that the mechanical workshop at Leiden Observatory could construct a reflector of 20 m diameter; in fact, he wanted an angular resolution of about 0.5° (Katgert-Merkelijn, 1997: xx). Bakker answered that a receiver might become available after the War; he further pointed out that the desired angular resolution would require a larger telescope, or going to shorter wavelengths.

Soon after the War, Oort wrote to a variety of persons and institutions, enquiring about possibilities for construction of a radio telescope and for obtaining receivers (Oort, 1944-48). These enquiries led to a 'pre-project' by Werkspoor, the company which had built several railway bridges, and even to a tentative design in 1945. Apparently, Oort had dropped the idea to have a large reflector built by the Observatory Workshop.

In November 1945 Oort presented a plan for a radio reflector of 25 m aperture to the Board of the Royal Netherlands Academy of Sciences, which supported a request for funding of this project (Oort et al., 1951: 53). The request probably was submitted to the Department of Education, Arts and Sciences. On 8 November 1945 Oort wrote to the Prime Minister, Ir. W. Schermerhorn, and a few weeks later they discussed the plan (Oort, 1945). Schermerhorn, who had been Professor of Geodesy at the Delft Institute of Technology, and was anxious to restore Dutch science after the setbacks suffered during the War, was strongly interested in the 'kippegaas-telescoop' (chicken-wire telescope), as he called it (Oort, 1970), but in the immediate post-war period no funds of the required magnitude were available (Katgert-Merkelijn, 1997: xxii).

The lack of funds and of suitable engineers, together with worries about the required sensitivity, at times made Oort wonder whether the plan should be completely dropped (Oort, 1947). However, a Netherlands Organization for the Advancement of Pure Scientific Research (ZWO) was founded in 1949, following ideas conceived by Prime Minister Schermerhorn and the Minister of Education and Sciences, G. van der Leeuw, as early as 1945/1946 (Oort et al., 1951: 53). And even before the official start of ZWO, its Director-to-be, J.H. Bannier, strongly supported Oort's plans. On 23 April 1949, the *Stichting Radiostraling van Zon en Melkweg* (Netherlands Foundation for Radio Astronomy, SRZM) was officially founded (it actually had already started work in 1948); its goal was "to investigate the radio radiation coming from outside the Earth." The Board of SRZM was formed by representatives of the astronomical institutes at Leiden and Utrecht, later also Groningen, plus the Post, Telephone and Telegraph Service (PTT), the Physical Laboratories of Philips at Eindhoven, and the Royal Netherlands Meteorological Institute (KNMI) at De Bilt. In fact, in 1946 the solar physicists M.G.J. Minnaert and J. Houtgast from Utrecht Observatory had already joined forces with the KNMI and PTT in studies of the ionosphere, and its relationship with radio propagation and solar activity (Houtgast, 1946; 1949). The new Foundation, chaired by Oort, provided a broad base of knowledge and interest, suitable to administer the large amounts of money required for the construction of the big radio telescope first conceived in 1944. The strong support given by ZWO, PTT and Philips partly compensated the handicaps imposed by the lack of experience and equipment mentioned above (Oort, 1952).

Clearly, finance, design and construction of the envisaged 25-meter dish would still require several years. Meanwhile, however, Ir. A.H. de Voogt, Head of the PTT Central Department for Radio, who was involved in radio studies of the Sun and ionosphere, had salvaged several Würzburg radar reflectors used by the German forces along the coast during the War, and brought these to the Radio Transmitting Station at Kootwijk (cf. Section 5.3.1, below). One of these (Figure 3) was made available to SRZM for studies of Galactic radio radiation. In 1948 Professor C.J. Gorter from the Kamerlingh Onnes Laboratory at Leiden University had provided a war-surplus radio receiver; a student of electronics, H. Hoo, started attempts to measure the 21-cm line using it with the Kootwijk dish. Progress was slow, and on 10 March 1950 a fire destroyed the receiver; many months of development work were lost.

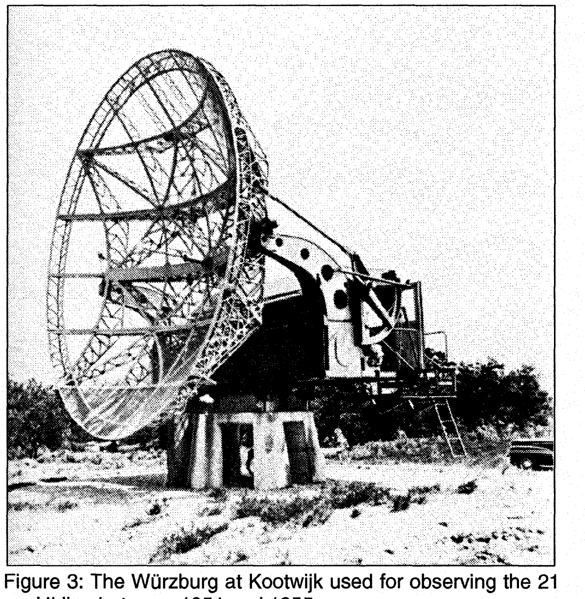

Figure 3: The Würzburg at Kootwijk used for observing the 21 cm HI line between 1951 and 1955.

In December 1950, C.A. Muller, a young engineer fresh from Delft, started development of a new receiver, using equipment made available after the fire by Dr F.L. Stumpers of Philips. Muller (1980: 65-67) recalls:

> On a snowy day in December 1950 I bicycled through the woods from Apeldoorn to Kootwijk-Radio, the central transmitting station of the Dutch Post Office, to start my work for the Netherlands Foundation for Radio Astronomy. Some months before I had finished my studies in physical engineering at the Delft Technical University and this was my first job. I was to continue the work started in 1948 by Mr. Hoo towards the discovery of the 21.2 cm line of neutral hydrogen. This line had been predicted … at a colloquium on "Radio Waves from Space" held in 1944, during the war, at Leiden Observatory.
>
> This colloquium marks the beginning of Dutch galactic radio astronomy. It was probably the first time that professional astronomers discussed the possibilities of radio astronomy and it is obvious that Oort had stimulated this meeting … At the Post Office it was Mr. A.H. de Voogt … who had an interest in solar radio astronomy … He had rescued a few of the 7½-meter Würzburg antennas, which had been part of a German radar chain along the coast during the war, from destruction and had them repaired for radio-astronomical purposes. One of these antennas was made available to the new Foundation for its hydrogen-line experiments. It

had been placed on the southern slope of a small hill at the Kootwijk-Radio transmitting station, overlooking a beautiful area with heath and woods, but uncomfortably close to high-power transmitting antennas!

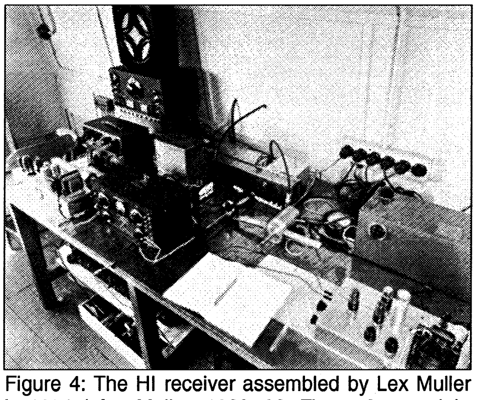

Figure 4: The HI receiver assembled by Lex Muller in 1951 (after Muller, 1980: 68, Figure 2; copyright 1980 by D. Reidel Publishing Company; with kind permission of Springer Science & Business Media).

Here I started my work with one assistant. Though the experiments had been going on for two years, I had to start almost from scratch because all receiver equipment had been destroyed in a small fire earlier that year. However some parts for a new receiver were already under construction at the Philips laboratories under the supervision of Mr. F.L. Stumpers [see Figure 4]. I knew almost nothing of astronomy or radio astronomy at the time, and looking back it seems a small miracle that some five months later we observed the 21-cm line [Figure 5]. I think this miracle was possible because all the circumstances were favourable for it. The discovery of the line was primarily a technical problem of constructing a suitable receiver, and it was a great help that I was working in the almost ideal surroundings of the small transmitter-construction division at Kootwijk with its group of enthusiastic collaborators, a well-equipped laboratory and a large workshop, which worked quickly and efficiently. With my experience as a fervent radio amateur I fitted quite well into this group. The same group also had experience with equipment for radio astronomy because it had constructed the receivers for solar observations.

Figure 5: Lex Muller shown on the platform of the Kootwijk Würzburg in 1952 (Raimond, 1952: 141).

Our discovery of the line was hastened by the fact that Van de Hulst was visiting the United States at the time. At Harvard he met H.I. Ewen, who a few weeks later would make the first observations of the 21-cm line. In a letter which I received early in March, he told me that Ewen was working for his thesis on a hydrogen-line receiver with frequency switching in the second local oscillator. This information came just at the right moment. Our first experiments with part of the receiver had clearly shown that the stability of a simple non-switching receiver would be insufficient, and from the literature I had available, it was clear that it would be necessary to use some form of Dicke receiver in which the input was switched periodically between the antenna signal and the signal from a noise source. A synchronous detector would then measure the difference between the two signals. Then the letter arrived with the proper solution to our problem: the noise-source signal could be replaced by an antenna signal at a different frequency. The construction of the frequency-switched receiver did not take too much time. We modified the Harvard concept somewhat by using frequency-switching in the first local oscillator, by adding a reactance frequency modulator to the 6.4-MHz oscillator of the crystal-controlled Philips-built frequency multiplier. We also added a tunable second local oscillator and a narrow-band second i.f. amplifier as well as a 30-Hz amplifier-synchronous detector section and some calibration facilities, and then we were ready for our first attempts to observe the line. I think it was on the second night, on May 11, 1951, that the line was found.

I remember very little of that night. There is a vague recollection of sitting in the telescope cabin on a nice spring evening, switching the second local oscillator every few minutes between the two frequencies, which in the presence of the line should give alternately a positive and a negative deflection on the recording meter, while a region near the galactic plane drifted through the antenna beam, but that is all. I think that at that time I hardly realized the importance of what I was doing and perhaps I had enough confidence in our equipment to expect the line to show up. At that time I must have known that it was there, because Ewen had already observed it some six weeks earlier.

At Harvard, H.I. Ewen and E.M. Purcell had first detected the line on 25 March 1951, using a horn antenna with a 12° beam. After that detection, Purcell asked H.C. van de Hulst from Leiden and F.J. Kerr from Sydney, who both happened to be at Harvard at that time, to report the detection to their home institutes, and to enquire whether the detection could be confirmed (Kerr, 1984: 137). As a result, reports by Ewen and Purcell (1951) and by Muller and Oort (1951) were published side-by-side in *Nature*, under the heading "Observation of a line in the Galactic radio spectrum", together with a confirming telegram from J.L. Pawsey of the CSIRO's Division of Radiophysics in Sydney, where "W.N. Christiansen and J.V. Hindman had started on a crash program and were able to assemble the necessary equipment and make a detection after a short period of six weeks ..." (Kerr, 1984: 138). As noted by Kerr (ibid.): "This whole episode was a fine example of international cooperation, which has always been the hallmark of the relationships in radio astronomy."

The successful observations at Kootwijk (for details see Section 4) obviously were a strong boost to the plans for a 25-meter radio telescope. ZWO now firmly approved these plans, and made funds available. In November 1951 Werkspoor undertook design studies; the design was completed early in 1954, and construction started the same year, with supervision by Ben G. Hooghoudt (another young Delft engineer) on behalf of SRZM. The telescope was completed, and erected in Dwingeloo, in the summer of 1955. Meanwhile, the Kootwijk Würzburg had mapped the interstellar hydrogen in the Galaxy (see Section 4.2.4).

4 THE KOOTWIJK HI 7.5-METER WÜRZBURG

4.1 Description of the Instrument

The paraboloid employed at Kootwijk for Galactic HI studies was one of several Würzburg reflectors used in the post-war period in The Netherlands (Section 5). The telescope was located at the Kootwijk Radio Transmitting Station of the Netherlands Post and Telegraph Service (PTT), about 15 km west of Apeldoorn, at geographical co-ordinates $\varphi = +52^\circ\ 10'.2$ and $\lambda = -5^\circ\ 50'.7$ (Van de Hulst et al., 1954: 119). In 1948, the dish was made available to SRZM for its research program, and the 1951 detection of the 21-cm line by Muller followed.

From July 1952 to August 1955 the dish was used almost exclusively for hydrogen-line studies of the Galaxy; its main achievements are summarized in Section 4.2. Two brief studies of continuum sources at 1390 MHz (wavelength 21.6 cm) were reported by Westerhout (1956a; 1956b). When, in August 1955, SRZM moved its equipment to the new Radio Observatory at Dwingeloo (Muller and Westerhout, 1957: 151), the 'HI Würzburg' was left behind at the Kootwijk Radio Station; at Dwingeloo, two other Würzburgs were installed (Section 5). In April 1956, at Dwingeloo, Van Woerden was told that the 'Kootwijk HI Würzburg' had broken down; the telescope was probably scrapped (cf. Section 5).

The properties of the HI Würzburg and the receivers used with it are well documented in various research papers (Kwee et al., 1954; Muller, 1956a, 1956b; Muller and Oort, 1951; Muller and Westerhout, 1957; Van de Hulst et al., 1954). The focal length was 1.7 meter. The beamwidth between half-power points was originally reported as 2.8° (Muller and Oort, 1951). The later papers listed above mention widths (FWHM) of 1.9° (or 1.85°) in the horizontal and 2.7° (or 2.78°) in the vertical plane. The telescope was fixed to an altitude-azimuth mount. In March-May 1952, before the first major HI-line survey started, Van Woerden had calibrated the axes and coordinate scales; as a result, the telescope could be pointed to an accuracy of 0.1° (Van de Hulst et al., 1954: 119). Telescope settings had to be done by hand, and no automatic guiding was available. Since the recording of a full line profile (intensity versus frequency) at a fixed position in the sky took a few hours, this required many manual setting corrections (at 2.5-minute intervals!); Westerhout (2002: 27) gives a vivid, witty description of the operations, in which dozens of students were involved.

The receiver developed by Muller was improved several times throughout the years 1951-1955; Figure 6 compares line profiles obtained in the same direction, but at different stages of improvement. Muller and Westerhout (1957) give an extensive description and illustration (see Figure 7) of the final three-stage superheterodyne receiver. The detection paper (Muller and Oort, 1951) mentions a 'noise factor' of about 25, which is probably equivalent to a system temperature of about 7,000 K. The first major survey (Van de Hulst et al., 1954: 120) was done with a noise figure N of 10 (T_{sys} about 2,600 K); the second major survey ended with N = 6.0 ($T_{sys} \sim$ 1,500 K) (Muller and Westerhout, 1957: 155). In order to obtain maximum stability, and following (but modifying) the principle developed by Dicke (1946), switching between two frequencies (in the first local oscillator, see Section 3) was employed, and the difference signal recorded. The roles of the two frequencies, serving as signal frequency and comparison frequency, were interchanged every few minutes in the second local oscillator. For the first measurements, the switch rate was 30 times per second, and the two frequencies were only 110 kHz (i.e. 23 km/sec) apart. The major surveys were done with a switch rate of 430 or 400 Hz, and the frequency difference was raised first to 648 kHz = 137 km/sec, and later to 1,080 kHz = 228 km/sec. The frequency resolution of the profiles was about 40 kHz, or 8 km/s; in 1951, it was 25 kHz. Both Van de Hulst et al. (1954) and Muller and Westerhout (1957) give extensive discussions of the frequency and intensity scales of the observations.

The story of Kootwijk has been told in many places. The film about the construction of the Dwingeloo Telescope made by Herman Kleibrink (1957) also deserves mention in this connection.

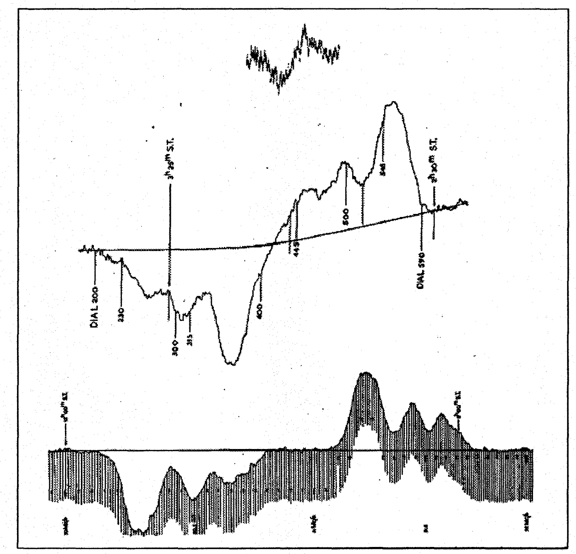

Figure 6: HI profiles of a point in the Galactic Plane at 50° longitude (old system) obtained with the Kootwijk Würzburg in (from top to bottom) 1951, 1952/1953, and after November 1953. The frequency scale is the same, but the band width for Dicke switching was increased twice (see text). As a result of the switching in frequency, each profile appears twice, positive and negative. The frequency of the lowest profile increases to the right, opposite to the one above it (after Van de Hulst et al., 1954: 123)

4.2 Scientific Achievements of the Kootwijk HI Würzburg

This section intends to summarize the main scientific results obtained with the Kootwijk HI Würzburg. It briefly mentions related work done elsewhere (at Harvard and Sydney), without any attempt at completeness. During its few years of scientific use, the Kootwijk HI Würzburg was extremely productive. Its studies of Galactic 21-cm line radiation were groundbreaking indeed; they included the first maps of the distribution of Galactic neutral hydrogen, and the first rotation curve of the Milky Way Galaxy.

4.2.1 First Results, and a New Receiver

Even the very first paper (Muller and Oort, 1951), based on only a few weeks of preliminary measurements, yielded results of fundamental importance. Drift scans across the Galactic Equator, at various constant declinations, indicated latitude distributions of about 8° width, and upon discussing the same material Van de Hulst (1951) stated that intensities fell to half the maximum value at latitudes of ±4°–8°. Since the random motions in the gas appeared to be of order 5 km/s, allowing distances from the Galactic Plane no greater than about 50 pc, the hydrogen radiation had to come from distances less than 500-1000 pc, suggesting that the 21-cm line becomes opaque within this short distance. Ewen and Purcell (1951) had come to the same conclusion, on the basis of their measurements of spin temperature and line width, combined with an estimate of the average hydrogen density. From a measurement of line width at a longitude 30° away from the Galactic Centre, Muller and Oort estimated a rotation speed of 190 km/s. At the same position, hydrogen with a radial velocity of + 55 km/s, with an estimated distance of 8 kpc, was found to have a very narrow latitude distribution. At positions like these, clearly the differential Galactic rotation prevented the line from becoming optically thick.

After the first few weeks of exploratory observations, Muller felt that a much better receiver was required. He dismantled his receiver and completely rebuilt it. After a year the first major survey could be started. Muller (1980: 68-69) recalls:

> The year between the discovery of the hydrogen line and the beginning of the first survey I remember as a most productive period in my life. It meant understanding and solving all problems of a new technique. We learned how to build suitable components for a radio astronomy receiver and we learned to cope with strong interference from the nearby transmitters. It laid the foundation for further receiver developments in later years, in which a steady improvement in sensitivity and stability took place as well as a gradual development towards multi-channel receivers. It was not until many years later that I realized how difficult the long delay between the discovery and our first systematic observations must have been for Jan Oort. I still appreciate very much the fact that he never showed any impatience or annoyance, but just had confidence in us and gave his full support. This attitude towards us in those early days and in fact during all the years I worked with him in radio astronomy is, I think, typical of his attitude towards the instrumentalist in his field of science.

4.2.2 The First Survey: Spiral Structure

In June 1952 the first major survey was started, consisting of profiles (intensity versus frequency) taken at fifty-four positions, at 5° intervals in Galactic longitude along the Galactic Equator (Van de Hulst, 1953). A quick analysis of the first results allowed Oort to derive locations of hydrogen concentrations in the Galactic Plane; these gave hints of spiral arms—a major success for Oort in September 1952, which he was able to report at the IAU General Assembly in Rome.

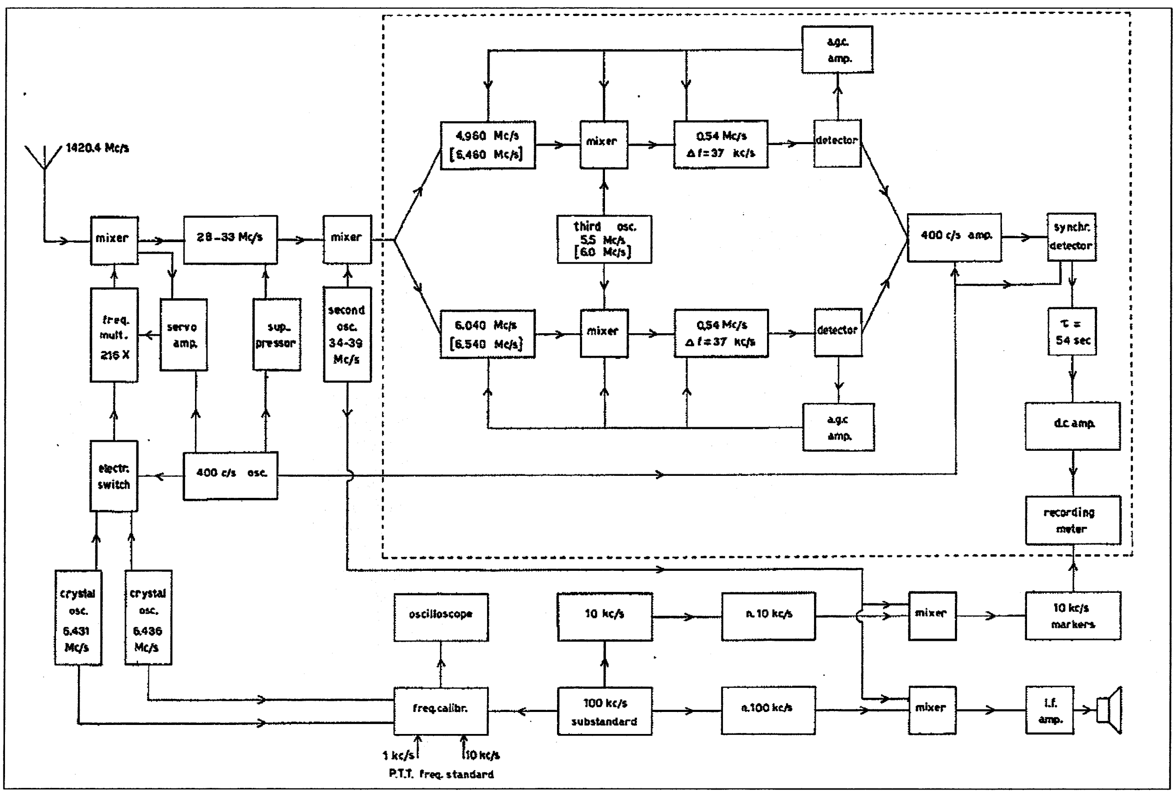

Figure 7: Block diagram of the HI receiver used in 1953-1955 (after Muller and Westerhout, 1957: 153).

A hint of spiral arms had also been found by Christiansen and Hindman (1952), from a three-month survey (1951 June-September) immediately following the observation confirming the first detections (Section 3). The aerial used for this survey was a 25-m^2 section of a paraboloid, with a beam of 2.3° FWHM. The receiver was switched 25 times per second between two frequencies 160 kHz apart and had a passband of 50 kHz width. The survey covered a wide strip of 270° length along the Galactic Equator. Line doubling at (old) longitudes between 170° and 240° suggested the presence of two spiral arms. Line intensities were found to vary along the Galactic Equator, reaching a maximum $T \sim 100$ K near the Galactic Anticentre. Enhanced intensities were found away from the equator, in the Taurus and Ophiuchus dark clouds. A thickness of 250 pc was found for the hydrogen layer.

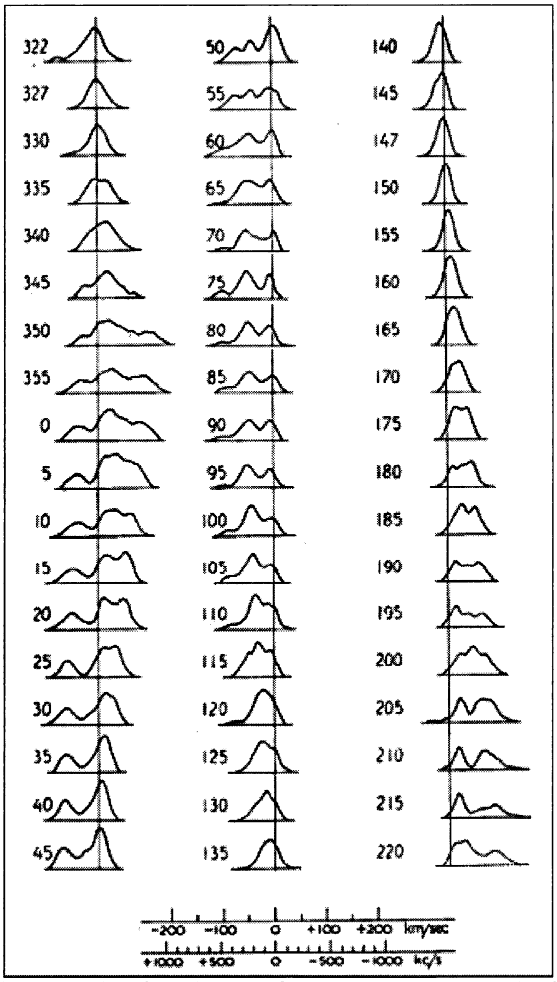

Figure 8: HI profiles along the Galactic Equator, at intervals of 5° in (old) longitude as indicated. The frequency and velocity scales are shown at the bottom (after Van de Hulst et al., 1954: 125).

In his Halley Lecture in Oxford on 13 May 1953, Van de Hulst (1953) presented a first complete set of results from the Kootwijk survey along the Galactic Equator. After a crisp outline of the advantages and disadvantages of radio as compared to optical astronomy, he discussed the various causes of Doppler shifts in the 21-cm line: the orbital motion of the Earth around the Sun, the motion of the Sun relative to its surroundings, the thermal and turbulent motions in the gas, and the differential Galactic rotation. Before applying the differential rotation to derive locations of gas from the measured radial velocities, corrections for the various shifts were required. Also, measurements had to be brought to common intensity and frequency scales, and averaged: the fifty-four profiles shown were the result of four hundred noisy tracings. Meanwhile, the set of profiles in Figure 8 was the result of a crash effort of about a dozen students and Observatory personnel, sitting together in the Observatory's lecture room and working hard for a week in April under Van de Hulst's guidance. Using preliminary values for the rotation constants, the intensity maxima and minima in the profiles could be interpreted as maxima and minima in the density distribution of hydrogen in the Galactic Plane; the resulting map clearly showed two spiral arms, and Van de Hulst noted that their location agreed well with the sections of spiral arm found by Morgan et al. (1952) from HII-regions and bright OB-stars.

The full results of the Galactic Equator survey were published by Van de Hulst, Muller and Oort (1954). The paper discusses in detail the receiver properties and observing procedures, the frequency and intensity scales, the correction for standard solar motion, and the use of differential Galactic rotation to locate positions in the Galactic Plane corresponding to maxima in the line profiles. In deriving densities at these locations, the profiles were corrected for the smoothing effects caused by random cloud motions; these motions were assumed to follow an exponential distribution, with an average velocity (in one coordinate) of 8.5 km/s. Figure 9 shows the density distribution of atomic hydrogen in the Galactic Plane so derived. This map contains only the parts of the Plane accessible to observation from The Netherlands, and lying outside the 'solar circle', i.e. the circle through the Sun around the Galactic Centre; inside the solar circle a distance ambiguity still had to be resolved. Nevertheless, for a few years this diagram was considered *the* map of spiral structure in the Galaxy.

Figure 9: The first HI map of the Galaxy outside of the solar circle, showing spiral structure, with contour shading to indicate "points of equal density" (after Van de Hulst et al., 1954: 146).

After completion of the Galactic Equator survey in June 1953, Muller again made many major improvements to the receiver. In fact, the new measurements in late 1953 were so much better that Oort said to Van de Hulst (as recalled by one of us [HvW]): "We cannot publish the old stuff; the new material is so much better!" But Van de Hulst answered: "Are you mad? It will be years before we have the new results complete." Fortunately, Van de Hulst won this brief debate.

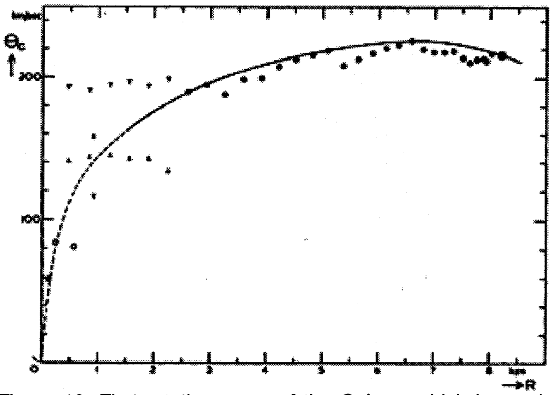

Figure 10: First rotation curve of the Galaxy, which is nearly flat from 3-8 kpc (after Kwee et al., 1954: 219).

4.2.3 The Galactic Rotation Curve

The first major project with the new receiver was a solid determination of the rotation curve of the Galaxy (Kwee et al., 1954). At various fixed declinations and frequencies, drift curves were obtained, giving the position and the width of the layer of neutral hydrogen. Since in the first Galactic quadrant (that is, at longitudes between 0° and 90° on the current system) the maxima of these drift curves generally fell close to latitude −1.5°, a correction of that order to the Galactic Pole assumed by Ohlsson (1932) was indicated, and the derivation of a rotation curve was based on a set of profiles taken at (old) latitude −1.5°, at 2.5° intervals in longitude between old longitudes l = 320° and 45° (with the Galactic Centre lying near longitude 328°). Assuming hydrogen to be present everywhere in the disk, and moving in circular orbits, with angular velocities decreasing monotonically towards greater Galactocentric distances, the highest radial velocity in each profile would come from the point on the line of sight lying closest to the Centre (the 'subcentral point'), and in combination with the rotation speed at the Sun's position, this highest velocity in the profile would yield the rotation speed at that subcentral point. Before this method could be applied, the profiles had to be corrected for beam smearing, for extinction and background continuum radiation, for optical-depth effects, and for smoothing by random cloud motions. Figure 10 shows the rotation curve obtained: almost flat at 200-220 km/s between 3 and 8 kpc from the Centre; the minor dips were ascribed to a lack of hydrogen at the subcentral points. At longitudes less than 20° from the Centre, long profile wings were found, and interpreted as turbulent motions (of order 50 km/s and more) at distances less than 3 kpc from the Centre.

From the rotation curve derived by Kwee et al. (1954), Schmidt (1956) constructed a model for the mass distribution in the Galaxy. This model has a total mass of (only) 7×10^{10} solar masses; the escape velocity at the Sun exceeds the local rotation speed by (only) 70 km/s. The major difference with later mass models lies in the fact that Schmidt had no data on rotation outside the solar circle, and assumed that the mass distribution declined strongly there.

4.2.4 The Second Survey: Three-dimensional Mapping

The second major Galactic 21-cm line survey started in November 1953 and was finished in August 1955. It covered a strip along the Galactic Equator from (old) longitude 320° to zero and on to longitude 220°. Over most of this strip, the longitude spacing was 2.5°, and it reached out to latitudes +10° and −10°, in steps of 2.5°. The catalogue of 21-cm line profiles resulting from this survey and published by Muller and Westerhout (1957) contains profiles for 694 positions. With the survey going on twenty-four hours per day, and manned by dozens of volunteer students, the total observing time for this programme was 7,500 hours; the reductions took more than 23,000 man-hours; in total, about forty-five people were involved in observations or reductions. Muller and Westerhout give extensive discussions of the antenna and receiver (see Section 4.1), of the calibration of frequencies and intensities, of extinction and sky radiation, of observing procedures and of velocity corrections.

The survey just discussed required intensity scanning in three coordinates: Galactic longitude and latitude, and frequency. The image is blurred in *l* and *b* by the limited angular resolving power of the telescope ('beam smearing'), and in frequency by the finite bandwidth of the receiver. Transformation of frequency into distance from the Sun, through differential Galactic rotation, involves further distortion by the deviations from circular motion, for instance by random cloud motions. Ollongren and Van de Hulst (1957) developed methods to correct for these various smearing effects, which were used in the analysis of the profiles by Westerhout (1957) and Schmidt (1957).

Westerhout (1957) derived the distribution of atomic hydrogen in the outer parts of the Galactic System from 620 profiles between (old) longitudes 340° → 0° → 220°, latitudes −10° and +10°. In correcting for profile smoothing by random cloud motions, he assumed a Gaussian distribution with dispersion 6 km/s. From the measured intensities, optical depths were calculated assuming a temperature of 125 K; no evidence was found for important deviations from this value. In calculating distances from (corrected) radial velocities, a rotation law was used, based on the final mass model adopted by Schmidt (1956). The results (density as a function of distance from the Sun and from the Galactic Plane) are displayed in a series of seventy-one cuts perpendicular to the Plane. (Since the mass model in the outer parts is open to question, so are these cuts.) The maximum densities found in each vertical column were projected on one plane; the resulting colour plate (Westerhout, 1957, Plate B; cf. Figure 12 below) displays these and represents a partial 'face-on view' of atomic hydrogen in our Galaxy (but without integration along the vertical lines!). Within 8 kpc from the Centre, the mean plane of the hydrogen turned out to be very well-defined, and flat to within 100 pc, but the outer parts showed deviations exceeding 300 pc. The Pole defined by the hydrogen plane in the inner parts was found to lie at longitude 322°, latitude +88.56° on the old (Ohlsson) system.

The distribution of hydrogen in the inner parts of the Galactic System was determined by Schmidt (1957). He used a complete grid of line profiles spaced by 2.5° between (old) longitudes 340° and 40°, and by 2.0° between latitudes −5.5° and +2.5°, plus 215 drift curves at constant declination, spaced by 40 kHz in frequency, and crossing the Galactic Equator at longitudes spaced 5° between 340° and 35°. Lines of sight through the inner parts of the Galaxy, inside the solar circle, contain pairs of points at the same distance from the Centre. Hence, gas with a certain observed radial velocity may lie at either or both of these points. Separation of the contributions from these two points can in principle be obtained from the latitude distribution of the radiation, if the linear distribution perpendicular to the Plane is known. This z-distribution was measured at the tangent points (or 'subcentral points'), where the radial velocity in a profile reaches a maximum and the distance ambiguity vanishes. At Galactocentric distances exceeding 3 kpc, Schmidt found layer thicknesses averaging 220 pc, and showing surprisingly little variation. Applying similar corrections as Westerhout (1957) for beam and band smearing, continuum radiation, optical-depth effects and random cloud velocities, Schmidt derived maximum hydrogen densities and mean z-values for vertical columns through 808 points in the Galactic Plane. These results were incorporated in the colour plate mentioned above. Schmidt also discussed the spiral arms found in the inner parts of the Galaxy.

The above results had a major impact on two symposia held in August and September 1955 on "Radio Astronomy" (Van de Hulst, 1957a) and on "Comparison of the Large-Scale Structure of the Galactic System with that of other Stellar Systems" (Roman 1957), in the new series of IAU Symposia that started in 1953. Another prominent publication was that by Oort (1956) in *Scientific American*.

4.2.5 North and South Combined: The Galactic System as a Spiral Nebula

The surveys mentioned and results obtained applied, of course, only to the parts of the Galaxy visible from Kootwijk. Following the early work by Christiansen and Hindman (1952) discussed above, new surveys of the southern parts of the Milky Way were undertaken by Kerr and collaborators from the Division of Radiophysics, CSIRO, using an 11-meter reflector, movable in the meridian only, at Potts Hill near Sydney; its beamwidth was 1.5° at 21 cm. In a discussion of the large-scale structure of the Galaxy, Kerr et al. (1957) published a composite spiral diagram, combining Leiden and Sydney data. In the regions of overlap the profiles agreed quite well, although differences in approach were found to lead to differences in the hydrogen distribution in the two halves of the map. In the outer parts of the Galaxy, the gas layer showed a systematic distortion, twisting downward on the southern and upwards on the northern side. Kerr (1957) considered whether this twist might be due to a gravitational tide caused by the Magellanic Clouds, but noted that the observed effect was much too large for a simple gravitational explanation. The full results of the survey were published by Kerr et al. in 1959.

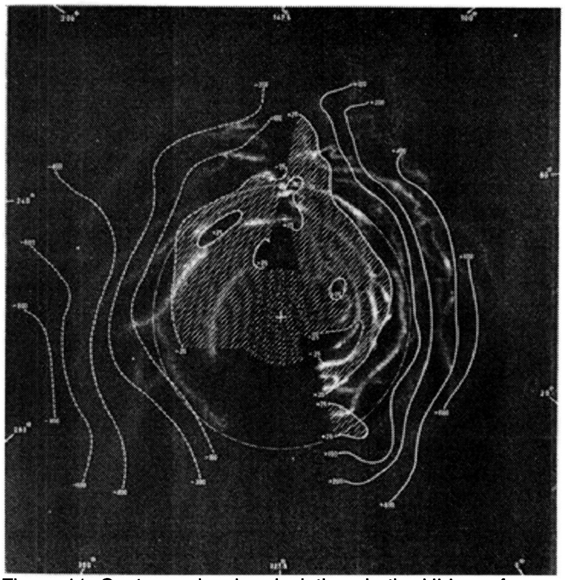

Figure 11: Contours showing deviations in the HI layer from a plane, the first evidence for a Milky Way warp. The HI distribution is shown as gray shading. The Galactic Centre is shown by +, and the location of the Sun by ⊙ (Oort et al., 1958: Plate 5).

In 1957, Kerr spent several months at Leiden working on a map that combined the northern and southern results. In a joint publication, with the title "The Galactic System as a Spiral Nebula", Oort, Kerr and Westerhout (1958) compared the rotation curves derived from both sets of data and found satisfactory agreement; the differences were less than 10 km/s, on average. They further emphasized the great flatness of the inner parts of the hydrogen disk. Figure 11 shows the systematic deformation of the disk in its outer parts: an upwards warp on one side, downwards on the other side. Figure 12 gives the combined hydrogen distribution projected on the Plane. Comparison with the results of Westerhout (1957) and Schmidt (1957) shows that the structures found from the Australian and from the Dutch observations differ in character. Oort et al. (1958: 382) have written about this:

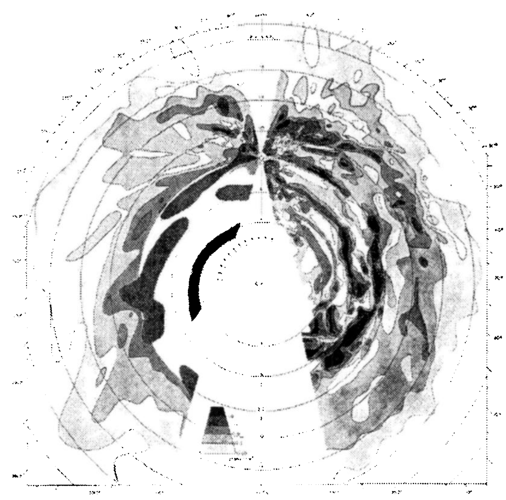

Figure 12: The complete map of HI distribution in the Galaxy, combining the northern (Kootwijk) and southern (Potts Hill) data. The maximum densities in the z-direction have been projected onto the Galactic Plane. The projection and symbols as in Figure 11 (after Oort et al., 1958: Figure 4).

> It should be emphasized that the distribution obtained depends considerably on the resolving power and on the particular assumption regarding the velocity dispersion, temperature of the gas, circularity of the average motion, etc. We believe that the diagram gives the general pattern fairly well, but the densities must be considered very uncertain, in some cases by a factor of two or more. The relatively wide beams efface the detail structure of the interstellar medium and are suitable for observing the large-scale features with which the present report is concerned.

However, there appears to be more to the difference. At an after-dinner speech in Penticton in 2001, Westerhout (2002) said:

> … the drastic correction for random cloud velocities really sharpened up the line profiles, and provided the considerable details in the final map. The difference is clear when you compare the Northern and Southern spiral structure in the Oort, Kerr and Westerhout review … There is much less detail in the Southern part. Kerr refused to correct for random cloud velocities, calling that "arbitrary". Of course it *was* a very rough treatment, but it certainly helped highlighting all the minute details in the line profiles.

Hence, the difference between North and South might have been largely due to different reduction procedures. Nevertheless, Kerr (1962), in a later detailed comparison of the Leiden and Sydney surveys, noted that the Leiden velocity model led to an implausible spiral structure diagram on the southern side, and considered alternative models in which the structure and motions of the Galaxy would be symmetrical on a large scale. He found that an outward velocity component of 7 km/s for the Sun and the Local Standard of Rest would reconcile the results on the two sides of the Galaxy.

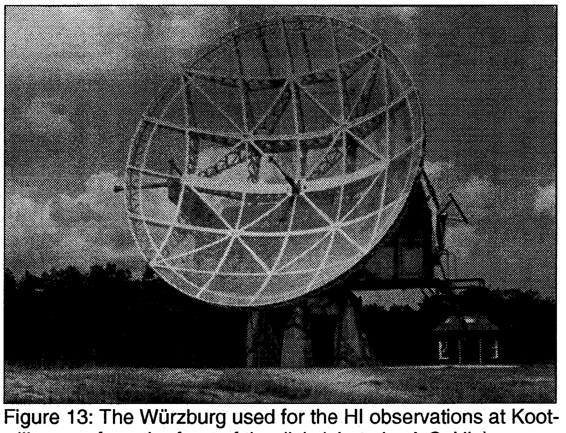

Figure 13: The Würzburg used for the HI observations at Kootwijk, seen from the front of the dish (photo by A.C. Hin).

4.2.6 New Galactic Coordinates

The systematic deviations of the hydrogen layer from the Galactic Equator defined by Ohlsson (1932) prompted the IAU to define a new Galactic Coordinate System. A Sub-Commission 33b, appointed by the Dublin General Assembly in 1955, investigated "… the desirability of a revision of the galactic pole and of the zero point of galactic longitude …", and reported to the Moscow General Assembly in 1958. This Assembly endorsed a resolution reproduced in the final report of the Sub-Commission (Blaauw et al., 1960). The main clauses of this resolution were: (a) adoption of a standard system of Galactic coordinates for which the Pole is based primarily on the distribution of neutral hydrogen in the inner parts of the Galactic System; (b) the zero of longitude to be chosen near the longitude of the Galactic nucleus; (c) authorization for Commission 33b to define the exact values of the coordinates of the Pole and of the zero of longitude. The paper by Blaauw et al. (1960) gives the precise definitions of the Galactic Pole and of the zero of longitude. The final report of the Sub-Commission included four papers (Gum et al., 1960; Gum and Pawsey, 1960; Blaauw, 1960; and Oort and Rougoor, 1960) which discussed various details relating to the main issue. It is clear that the definition of the Galactic Pole (and hence, of the Galactic Equator) was essentially based on the 21-cm line observations carried out at Kootwijk and Potts Hill.

4.2.7 Other Developments

One more paper based on Kootwijk HI observations deserves mention. Lindblad (1966) presented isophote maps in velocity-latitude planes, based on the observations published earlier by Muller and Westerhout (1957) and by Westerhout (1957). These isophote maps show the velocity distribution of atomic hydrogen in the outer parts of the Galactic System, without assuming a velocity-distance relation based on an uncertain model of Galactic rotation in the outer parts of the Galaxy.

At Harvard, after the initial detection of the 21-cm line by Ewen and Purcell, Ewen obtained his doctorate, and no further hydrogen-line work was done for a few years. Starting in 1953, Bok and his students undertook various studies of special regions such as dark clouds, stellar associations and star clusters. These studies, however, fall outside the scope of the present review.

5 WÜRZBURG ANTENNAS USED IN DUTCH RESEARCH AFTER 1945

5.1 The Situation in Europe just after the War

When the war ended in Europe in May 1945, there was considerable interest among radio engineers in German radar technology. Martin Ryle, for example, was sent to Germany in a Major's uniform to appropriate any equipment he thought might be useful (Robinson, 1999: 66). Among the items he collected was a pair of Würzburg antennas which were later used at Cambridge to determine source positions (Ryle and Smith, 1948). The Würzburg 7.5 m parabolic antenna, with its alt-azimuth mounting, was a legacy of the German war machine which would be employed in the nascent radio astronomy effort throughout Europe and even overseas. Used during hostilities as a 54 cm wavelength radar antenna for aircraft location, the reflecting surface and pointing accuracy were sufficient for 20 cm use. The 'Würzburg-Riese' (or '-giant' [FuMG65]; there was also a 3 m diameter version, the 'Dora' [FuMG39/62]) became a valuable instrument for radio astronomers in countries such as England, France, the Netherlands, even Sweden (which had been neutral in the war) and America (Robinson, 1999: 66).

The Dutch study of the 21 cm neutral hydrogen line in the first half of the 1950s amounted to what was arguably the greatest research achievement of any Würzburg antenna. (In this paper, 'Würzburg' is used to refer to the 7.5 m version of the reflector.) Its accomplishments would rightly earn the 'Kootwijk HI Würzburg' a unique place in astronomical history, and one might be unaware that it was not the only such instrument used in the Netherlands after the war. There may have been as many as eight (and probably at least six) 'Dutch' Würzburgs pressed into scientific service by a variety of research organizations. All came from the Zeppelin Factory in Friedrichshafen, where an estimated 2,000 or more were produced between 1941 and 1945, and they had seen service in the *Atlantikwall*, the German defence line which stretched along continental Europe's west coast from France to Norway. All but two of the appropriated 7.5 m reflectors had been abandoned in the Netherlands as the occupiers surrendered. Although most of the forty or so Würzburgs which were used in Holland during the war were scrapped after 1945, a handful was rescued. The rest of this paper will attempt to recontruct their history. A very useful source of information is an article which endeavours to locate the Kootwijk HI Würzburg (Beekman, 1999); it will be regularly cited below and referred to simply as 'B99'.

5.2 The TNO Würzburg near The Hague

The Würzburg with the best-documented history was acquired and used by the Netherlands Organisation for Applied Scientific Research (TNO) (B99). During the war it was part of the radar installation on the (Dutch) island of Rozenburg (German radar stations would have had a number of antennas for locating targets and guiding their own fighter aircraft, usually including two Würzburgs). In 1947 it was moved to the Vlakte van Waalsdorp on the northern outskirts of The Hague (and near the present TNO headquarters) for experimental use by the Physics Laboratory of the Netherlands State Defence Organisation (*Rijksverdedigingsorganisatie*, which later became a TNO division). At first the radar was used to study the propagation of radio waves in collaboration with SRZM (*Stichting Radiostraling van Zon en Melkweg*, the Netherlands Foundation for Radio Astronomy).

It seems to have only once been used for astronomical research, in June 1954, when a partial solar eclipse was observable from the Netherlands. The measurements were carried out and published by Seeger (1955), who observed the entire eclipse (three-quarters of the photosphere was occulted) at 400 MHz. The resulting occultation curve was smooth, and an observed asymmetry was discussed and interpreted. The antenna was later used for receiving signals from weather and communication satellites. In 1965, the Moon was used as a reflector to transmit telegraph signals between the TNO Würzburg and Puerto Rico (B99).

What finally happened to it has also been documented (B99). In 1977 the antenna was donated to the German Air Force (*Luftwaffen-*) Museum, then in Appen (north of Hamburg) where it was on display at the Marsielle-Kaserne. In 1994 it moved again when the Museum was rehoused at the General-Steinhoff-Kaserne near Berlin, though it first had to be restored at an airbase near Hannover. It should have gone on display in 1999.

5.3 The Würzburgs in Kootwijk, Nederhorst den Berg and Dwingeloo

The clear and well-documented story of the TNO Würzburg contrasts with the complex and in some respects uncertain saga of the remaining antennas operated by SRZM and the PTT. This is largely because most were moved at least once between the three observing stations, and records were either not kept, or later disappeared. About one fact there is general agreement: the initiative to acquire the PTT Würzburgs came from Ir A.H. de Voogt; see, for example, Muller (1980: 65-6). In his PTT function, De Voogt was in charge of the transmitting and receiving stations for communication with the Dutch colonies in particular. After the war he decided to launch a research programme to understand how the ionosphere influences radio propagation, and the effect which solar activity has on it (De Voogt, 1952; Muller, 1980: 65). This appears to have been his motivation for acquiring a number of Würzburgs in about 1947 and installing them at the PTT stations. A brief sketch of De Voogt's life is given in Appendix 10.2.

5.3.1 The Transmitting Station at Kootwijk

PTT radio transmissions to Indonesia and Surinam were broadcast from near Kootwijk (a village west of Apeldoorn) starting in the early 1920s. After 1945, wartime damage was repaired (several of the antenna masts had been blown up), and the transmissions resumed. It was about this time that, according to most former Kootwijk employees contacted (B99; based on interviews made in 1998), four Würzburgs arrived at the station. Three were complete, but the surface of one was damaged. It was replaced with a new reflector of 10 m diameter constructed by the PTT. The three unmodified Würzburgs were placed on concrete foundations at a location on the southern side of the original transmitter terrain. The easternmost of the trio was made available to the new astronomical organisation SRZM by De Voogt in 1948, and was used for the HI work (Figure 13). The antenna with the new 10 m dish was installed some 1,500 m to the southeast (B99). While this seems to be the most likely scenario, there are some former employees who can only remember two 7.5 m Würzburgs (in addition to the 10 m reconstructed one).

Whatever their exact number, the antennas were all used for research until at least 1955. In August of that year, the HI group (belonging to SRZM) moved to Dwingeloo, where the 25 m dish was nearing completion. Sometime in the following years (and probably before 1958; see next section), two 7.5 m Würzburgs and the 10 m one were moved from Kootwijk to the PTT receiving station at Nederhorst den Berg, where solar radio research had been actively pursued since 1951. The main reason for the move was almost certainly the hostile radio environment of a high-power transmitting station. The HI team had been more than happy with the transfer to the benign forest near Dwingeloo, Kootwijk being "... uncomfortably close to high-power transmitting antennas ..." (Muller, 1980: 66), and their departure may have triggered the more substantial removal of antennas. Certainly by 1963, the Kootwijk 'HI-Würzburg' had disappeared (B99: 155; a photograph taken by A.C. Hin shows a vacant concrete foundation).

In light of the interference climate, one might wonder why the Würzburgs were installed at Kootwijk in the first place. One reason may have simply been the large terrain available there, over which De Voogt had complete control. In addition, there was an electronics development workshop where antennas and receivers could be constructed and repaired. This infrastructure was also extremely useful to the SRZM team (Muller, 1980: 66). Finally, the severity of the problem on the one hand, and the exact nature of the research to be carried out on the other, may not have been clear when the original location was decided upon; the HI research would probably not have been anticipated, for example.

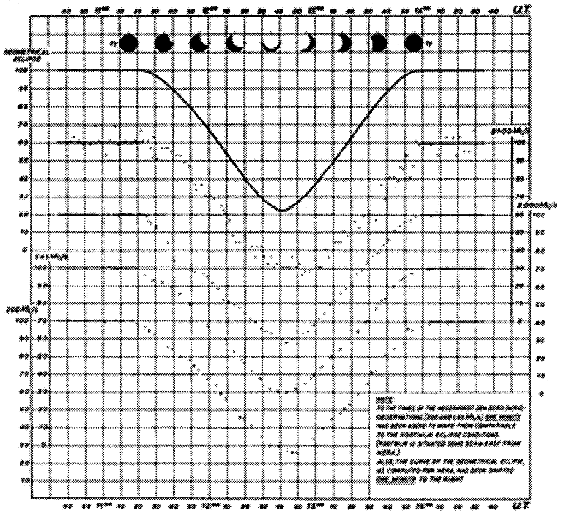

Figure 14: The solar eclipse of 30 June 1954, as observed at NERA (200 and 545 MHz) and Kootwijk (3 and 9.1 GHz) by Fokker et al. (1955). The four curves (dots) show the change in solar radiation as a function of time.

The results of the HI work at Kootwijk, published in a series of articles, have been discussed above (in Section 4.2). Very little seems to have come out of observations with the other Würzburgs there, and nothing appears to have been published. De Voogt (1952) does mention Kootwijk, but the only result shown, the intensity of background radiation as a function of RA at Dec = 41.5° for the wavelength 6 m, came from an entirely different antenna there. The solar results presented nearly all came from Nederhorst den Berg. It seems likely that experiments were done to monitor the Sun, and investigate ionospheric effects, but presumably the results were either compromised by the interference situation, or not of sufficient scientific interest.

5.3.2 The PTT Station at Nederhorst den Berg

Until 1950 the PTT operated a receiving station for overseas radio communication at Noordwijkerhout, near the coast north of the town of Leiden. It then moved to Nederhorst den Berg (southeast of Amsterdam), a facility also under the direction of De Voogt. This station would, like Kootwijk, be host to a number of Würzburg antennas, certainly with one from the start of operations. If it too was procured before 1948, as seems probable, it must have been stored somewhere for a couple of years. Perhaps it was simply moved from Kootwijk around 1950 (and this might explain the confusion of former employees as to the number of 7.5 m Würzburgs in Kootwijk). Nederhorst den Berg became the main radio observatory for solar research in Holland in the 1950s, and operated under the acronym NERA (NEderhorst den Berg RAdio). Among the references to the instruments at NERA, De Voogt (1952: 211) himself describes the 'Würzburger' of 7.5 m diameter, "… just as this is used at Nederhorst den Berg and Radio-Kootwijk."

There was certainly one Würzburg operating at NERA from as early as 1951. De Voogt (1952: 209) himself, describing observations with a parabola, writes, "… at Nederhorst den Berg there are two receivers in service, one at 200 megaherz and one at 140 megaherz." This most likely refers to two receiver systems mounted in a single Würzburg (and also used from 1952 by Fokker and De Feiter, 1954b). An independent source of information on the instruments used at NERA in the early 1950s is Table 1 in the doctoral thesis of Fokker (1960: 3), which lists a "7.5 m parabola" used for 200 MHz solar monitoring from 1952 until May 1957, and a "7.5/10 m parabola" used at 545 MHz from 1953 until December 1958 ("7.5/10 m" presumably means that separate antennas were used for monitoring at different times). This most likely refers to the same 7.5 m Würzburg rather than two separate ones. Another source of information comes from the radio monitoring published in the Quarterly Bulletin on Solar Activity (QB), which is also consistent with one Würzburg at NERA between 1951 and 1954. A more detailed discussion of all these facts, and reproduction of the relevant parts of Fokker's Table 1, can be found in Appendix 10.3.

As noted in the previous section, after 1955 most (if not all) of the parabolic antennas in Kootwijk were moved to NERA. Fokker (1960: 3) records the presence of two 7.5 m parabolas and a 10 m one for 200 MHz interferometry from February 1958. They were almost certainly the Kootwijk antennas, and they must have moved by 1957. By the late 1950s then, NERA was probably making use of three 7.5 m Würzburgs, three 10 m parabolas (partially) constructed by the PTT, as well as a number of smaller instruments for solar radio observations.

Most of the research done with the Würzburgs at NERA involved the Sun, and it was published in a variety of ways. Solar monitoring data appeared monthly in the QB, starting in July 1951 at 140 MHz (QB95). By August and September, bursts were also being reported at 73, 200, 255 and 545 MHz; being much stronger, they could be monitored with simple Yagi antennas. Daily monitoring continued throughout the 1950s and 60s, with peak activity during the International Geophysical Year (1957-1958). There were also research articles published in standard astronomical journals and conference proceedings.

De Voogt's department, the IRA, also issued its own reports in the years 1954 to 1958. The work published there included a 2-year study of the quiet Sun (Fokker and De Feiter, 1954b), a classification of solar storms (Fokker, 1954) and observations of polarized emission (Neubauer and Fokker, 1958). The June 1954 eclipse observed by Seeger (see Section 5.2) was also monitored with the NERA Würzburg at 200 and 545 MHz, and at Kootwijk with 1.2 m (3 GHz) and 60 cm (9.1 GHz) dishes (Fokker et al., 1955). The resulting eclipse curves (Figure 14) were all smooth, symmetrical and rather similar. There was also non-solar research, like a study of the scintillation of Cygnus A (Van 't Veer, 1956). Fokker and De Feiter (1954a) mapped the background radiation at 140 MHz (see Figure 15).

5.3.3 The Dwingeloo Radio Observatory

In addition to the 25 m parabolic dish, two Würzburgs were also used at Dwingeloo from its inception, but they were different from the others described above in several ways (B99; Hooghoudt, 1957). They were originally part of the *Atlantikwall* in Norway, located on one of the coastal islands. In 1952 the Norwegian Government sold them to the Netherlands for the symbolic price of 1 guilder each. They were transported in 1954, and the alt-azimuth mountings were replaced by equatorial ones. In 1955 they were installed at Dwingeloo, one to the east and the other to the west of the nearly-completed 25 m dish, where they were mainly used for solar research, notably a spectral study of solar bursts by De Groot (1966). In 1962 the eastern dish moved to NERA to strengthen the solar effort there, and in 1973 it was returned to Dwingeloo as the PTT receiving station was being wound down.

The Dwingeloo Würzburgs were mainly used for solar research, as a two-element interferometer, but one of them was also used as a single dish in early polarization studies. A photograph from the 1980s is reproduced in Figure 16.

5.4 What Finally Became of the 'Dutch' Würzburgs?

The fate of the TNO-Würzburg has already been noted above; it should now be on display at a museum near Berlin. Some of the remaining antennas which served at the PTT stations and Dwingeloo are also on display, but the others can no longer be located. Much of the information has been assembled by Beekman (B99), although his account has to be corrected in one respect: he was apparently unaware that NERA already had a number of paraboloids before the post-1955 move from Kootwijk.

Let us first consider the 10-m dishes, which were only partially Würzburg constructions. Besides the one which came from Kootwijk and was described above, Fokker (1960; and see Appendix 10.3) refers to two others. This agrees with an account in De Voogt (1952: 211) who says, after describing the Würzburgs in Nederhorst den Berg and Kootwijk, "Two other reflectors are coming to Nederhorst den Berg, constructed by the PTT with 10 m aperture and 2.5 m focal distance and destined for interferometer tests." There is no indication whether they also used a Würzburg mounting, or whether the entire construction was of PTT origin, although the former seems more likely. One of these 10 m PTT dishes (according to B99 this was the one originally in Kootwijk, but as Beekman was not aware of the others in NERA, it could have presumably been any of the three) was sold in 1981 to the *Volkssterrenwacht Drenthe* (an amateur observatory). It was set up in Emmercompascum in 1983, but when it was moved to a new planetarium (the Planetron) in Dwingeloo, the mounting was damaged. It was replaced with the equatorial system from one of the Würzburgs in Dwingeloo (see below).

Of the three (7.5 m) Würzburgs in NERA around 1960, the fate of only two is known. According to Beekman (B99: 157), these were the two which flanked the 10 m dish and were used as an interferometer, hence the two which had come from Kootwijk. The eastern one went to the National War and Resistance Museum in Overloon at the end of the 1970s, while the western one was donated to the *Volkssterrenwacht Simon Stevin* in Hoeven early in the seventies. Both are still on display, though they are not in the best of condition.

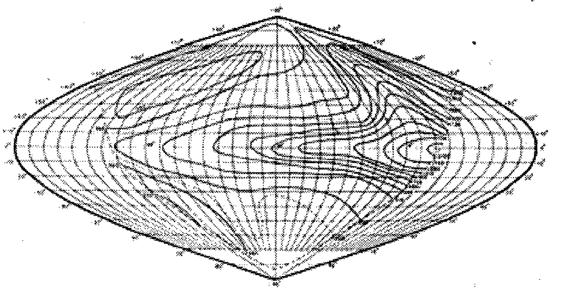

Figure 15: Map of the 140 MHz background radiation made with the NERA Würzburg by Fokker and De Feiter (1954a). The contours were 'corrected for the antenna pattern', and the bright sources Cas A and Cyg A were subtracted off.

Of the two Würzburgs used in Dwingeloo, one ended up in a German museum. It originally stood to the west of the 25 m telescope, and in 1991 was donated to the *Deutsches Museum für Naturwissenschaften und Technik* in Munich. After being restored by the Bundeswehr, it has been on display since 1997. The Technical University of Munich has provided it with a receiver, and it is still used for demonstrations and teaching (B99). The eastern Würzburg, after returning from NERA in 1973 (above), was dismantled in the late 1980s. The mounting was donated to the Planetron to replace the one damaged in moving the 10 m dish from Emmercompascum (above) in 1989 (B99). It can to this day be seen at the entrance to the Planetron.

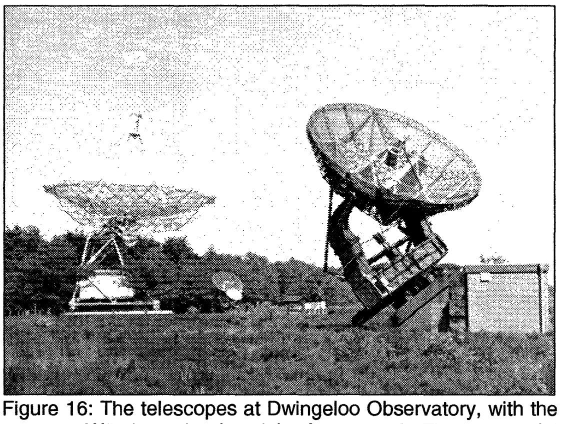

Figure 16: The telescopes at Dwingeloo Observatory, with the western Würzburg in the right foreground. The equatorial mounting can be seen clearly. The 25-m telescope is on the left, and the eastern Würzburg can be seen in the distance (photo by H. Schneider).

We are left with the question of what happened to the most famous Würzburg of all, the one used for the

HI studies at Kootwijk (Figures 3 and 13). If it should be any of those still in museums, then it would have to be either in Overloon or Hoeven, since neither of the other ones in Germany (near Berlin or Munich) was ever in Kootwijk. One of the few people still alive who worked regularly with the HI Würzburg, A.C. Hin, has examined the two candidates and is quite certain that they are not the missing one. As mentioned above, one of us (HvW) recalls hearing that it may have broken down in 1956. If this is correct, then it seems likely that it was scrapped about the time that the other Würzburgs moved to NERA.

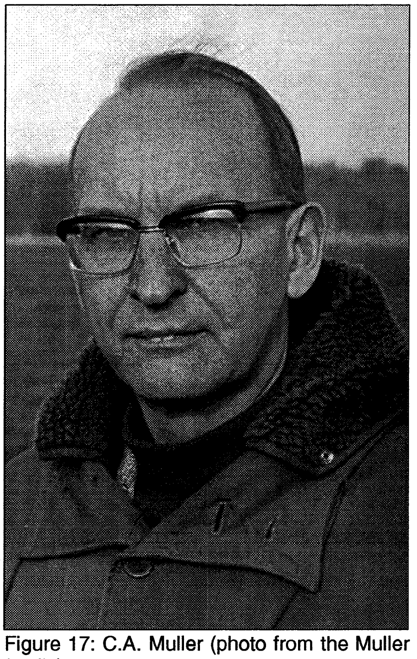

Figure 17: C.A. Muller (photo from the Muller family).

6 CONCLUSION

It is noteworthy that when Van de Hulst arrived in Leiden early in January 1944, the research he was to do had not yet been settled. He had known Oort for a year or so, and their collaboration up to that point concerned the formation and destruction of interstellar dust (or as they then called it, "smoke"). The suggestion from Oort to look into the unexplored potential of radio emission must have come early during his stay in Leiden; Van de Hulst completed the investigation (and prepared his talk) in just three months. An interesting, but unresolved, question is: when did the idea that there might be a radio line come to Oort? A few years had elapsed since he first saw Reber's paper, but it had been a difficult time and it must have often been filled with more pressing concerns. Moreover, Oort had also been busy with other astronomical research, such as the work on the progenitor of the Crab Nebula, SN1054.

The speed with which Oort decided to pursue the radio potential in a serious way was typical of him, as was his resolution in the face of adversity, be it financial or technical. The early prominent radio astronomers in Britain (like Lovell and Ryle) and Australia (Bolton and Pawsey) had been involved in radar; their Dutch counterparts—Oort and Van de Hulst—were astronomers with a strong astrophysical bent. Muller (Figure 17) was, to be sure, an engineer, but even he had not come from the radar fraternity. We do not know the exact sequence of events which motivated De Voogt (also an engineer with no radar connections) to initiate his group's radio investigations, and in particular to appropriate the abandoned Würzburgs. His amateur interest in both radio and astronomy (Section 10.2) probably played a role, but it is certainly possible that he had contacts with professional astronomers. The collaboration involving both Utrecht and the PTT reported at the end of Houtgast's (1946) paper suggests an early liaison with Utrecht astronomers.

The approach adopted in the HI effort, once the 1951 detection had been made, would make sense to most researchers: first get a global impression by sampling the Galactic Plane at a variety of locations. But it soon became apparent to Muller that the receiver could and should be improved. The year's delay this precipitated must have been frustrating to Oort, but he clearly had confidence in his young colleague, and that this was well-placed is demonstrated by the results of the survey which began in 1952. To finally be able to examine the kinematics of the entire Galaxy would have pleased no one more than Oort: the topic had fascinated him since his doctoral research, and had only been pushed to the 'back-burner' by optically impenetrable dust. The success of the HI detection, followed by the survey, provided the ammunition Oort needed to get funding for the large, 25 m radio telescope. Ironically, Kootwijk completed the survey which had been the main reason for building the new dish; fortunately, no one suggested that the project be terminated. However, the achievements of the Dwingeloo Telescope are a different story, one we plan to discuss in a separate paper.

7 ACKNOWLEDGEMENTS

We are grateful to Leiden Observatory, Stichting 'De Koepel', Kluwer Academic Publishers, and the Royal Astronomical Society for allowing the use of published figures. The Museum voor Communicatie, Den Haag, has given permission to reproduce Figure 18, and RGS wishes to thank Saskia Spiekman, the Librarian, for help in searching the Museum archives. HvW thanks Hilda Koster of the Faculty Library of Mathematics and Physical Sciences, University of Groningen, for bibliographical help. We also thank the staff of the Library of Leiden University for help with the consultation of the Oort Archives. We are very grateful to Jet Katgert for her excellent inventory of the *Letters and Papers of Jan Hendrik Oort*. RGS wishes to thank A.C. Hin for information provided in an interview in 2004, and for giving him access to photographs and other materials. He is also grateful to Aad Fokker for discussions on the work of NERA.

8 NOTES

1. The chronology of events described here was carefully checked by us in the original sources quoted. Some of the stories about it are not quite accurate, including that by Sullivan (1982: 299). Raimond (1996: 12) mistakenly places the line prediction by Van de Hulst later in 1944, after the correspondence between Oort and Bakker (in April-June 1944) about a large radio telescope and receiver. An excellent, detailed story is given by Sullivan (2000: 237-261), although the *Nederlandse Astronomen Club* was (and

still is) not a "... gathering of amateur and professional astronomers ..." (Sullivan, 2000: 237), but a society of professionals. In addition, Van de Hulst did not "... shift his studies informally to Leiden ..." (Sullivan, 2000: 238); rather, he remained Minnaert's student and an Assistant at Utrecht Observatory, visiting Leiden for only three months (cf. Section 2, above).

2. Oort was not only anxious to observe the 21-cm line; he was also interested in the radio continuum as a source of information about Galactic structure: witness his "Comparison of the intensity distribution of radio-frequency radiation with a model of the Galactic System" (Westerhout and Oort, 1951).

9 REFERENCES

Bakker, C.J., 1945. Radiogolven uit het wereldruim. I. Ontvangst der radiogolven. *Nederlands Tijdschrift voor Natuurkunde*, 11, 201-209.

Beekman, G., 1999. Een verjaardag zonder jarige. *Zenit*, 26 (April), 154-157 (B99).

Blaauw, A., 1960. Optical determinations of the Galactic Pole. *Monthly Notices of the Royal Astronomical Society*, 121, 164-170.

Blaauw, A., 1993. Jan Hendrik Oort 28 April 1900 - 5 November 1992. *Zenit*, 20 (5), 196-210.

Blaauw, A., Gum, C.S., Pawsey, J.L., and Westerhout, G., 1960. The new I.A.U. system of Galactic coordinates (1958 revision). *Monthly Notices of the Royal Astronomical Society*, 121, 123-131.

Blaauw, A., and Schmidt, M., 1993. Jan Hendrik Oort (1900-1992). *Publications of the Astronomical Society of the Pacific*, 105, 681-685.

Bowen, E.G., 1984. The origins of radio astronomy in Australia. In Sullivan, W.T. (ed.). *The Early Years of Radio Astronomy. Reflections Fifty Years after Jansky's Discovery*. Cambridge, Cambridge University Press. Pp. 85-111.

Christiansen, W.N., and Hindman, J.V., 1952. A preliminary survey of 1420Mc/s. line emission from Galactic hydrogen. *Australian Journal of Scientific Research*, A5, 437-455.

Dicke, R.H., 1946. The measurement of thermal radiation at microwave frequencies. *Review of Scientific Instruments*, 17, 268-275.

Ewen, H.I., and Purcell, E.M., 1951. Radiation from Galactic hydrogen at 1,420 Mc./sec. *Nature*, 168, 356.

Fokker, A.D., 1954. Classificatie van de stormachtige zonneruis. *IRA Report*, No. 5.

Fokker, A.D., and Feiter, L.D. de, 1954a. De intensiteits-verdeling over de hemel van radiostraling op frequentie 140 MHz. *IRA Report*, No. 1.

Fokker, A.D., and Feiter, L.D. de, 1954b. Radiostraling van de rustige zon op 140 en 200 MHz. *IRA Report*, No. 4.

Fokker, A.D., Munck, J.C. de, and Feiter, L.D. de, 1955. The influence of the solar eclipse of June 30th 1954. *IRA Report*, No. 7.

Fokker, A.D., Jr, 1960. Studies of enhanced solar radio emission at frequencies near 200 MHz. Doctoral thesis, Leiden University.

Groot, T. de, 1966. Weak solar radio bursts. Doctoral thesis, Utrecht University.

Gum, C.S., and Pawsey, J.L., 1960. Radio data relevant to the choice of a Galactic coordinate system. *Monthly Notices of the Royal Astronomical Society*, 121, 150-163.

Gum, C.S., Kerr, F.J., and Westerhout, G., 1960. A 21-cm determination of the principal plane of the Galaxy. *Monthly Notices of the Royal Astronomical Society*, 121, 132-149.

Haar, D. ter, Hulst, H.C. van de, Oort, J.H., Woerkom, A.J.J. van, 1943. De vorming van vaste deeltjes in het interstellaire gas. *Nederlands Tijdschrift voor Natuurkunde*, 10, 238-257.

Habing, H.J., 2001. Hendrik Christoffel van de Hulst, 1918-2000. *Astronomy & Geophysics*, 42, 1.33-1.35.

Henyey, L.G., and Keenan, P.C., 1940. Interstellar radiation from free electrons and hydrogen atoms. *Astrophysical Journal*, 91, 625-630.

Hooghoudt, B.G., 1957. Algemene gegevens van de Radiosterrenwacht te Dwingeloo. *De Ingenieur*, 69, O. 3-O. 7.

Houtgast, J., 1946. Zon en ionosfeer. *Hemel en Dampkring*, 44, 91-93.

Houtgast, J., 1949. De radiostraling van de Zon. *Hemel en Dampkring*, 47, 181-191; 210-214.

Hulst, H.C. van de, 1943a. Letter to J.H. Oort, dated 11 June. Oort Archives, Leiden University Library (file 158e).

Hulst, H.C. van de, 1943b. Letter to J.H. Oort, dated 21 October. Oort Archives, Leiden University Library (file 158e).

Hulst, H.C. van de, 1945. Radiostraling uit het wereldruim. II. Herkomst der radiogolven. *Nederlands Tijdschrift voor Natuurkunde*, 11, 210-221.

Hulst, H.C. van de, 1951. Observations of the interstellar hydrogen line of wave length 21 cm made at Kootwijk, Netherlands. *Astronomical Journal*, 56, 144.

Hulst, H.C. van de, 1953. The Galaxy explored by radio waves. *The Observatory*, 73, 129-139.

Hulst, H.C. van de (ed.), 1957a. *Radio Astronomy. Proceedings from 4th IAU Symposium.* Cambridge, Cambridge University Press.

Hulst, H.C. van de, 1957b. Studies of the 21-cm. line and their interpretation (Introductory Lecture). In Hulst, H.C. van de (ed.). *Radio Astronomy. Proceedings from 4th IAU Symposium.* Cambridge, Cambridge University Press. Pp. 3-13.

Hulst, H.C. van de, 1998. Roaming through astrophysics. *Annual Review of Astronomy and Astrophysics*, 36, 1-16.

Hulst, H.C. van de, Muller, C.A., and Oort, J.H., 1954. The spiral structure of the outer part of the Galactic system derived from the hydrogen emission at 21 cm wave length. *Bulletin of the Astronomical Institutes of the Netherlands*, 12, 117-149.

Katgert-Merkelijn, J.K., 1997. *The Letters and Papers of Jan Hendrik Oort, as Archived in the University Library, Leiden*. Dordrecht, Kluwer.

Kellermann, K.I., 2005. Grote Reber (1911-2002): a radio astronomy pioneer. In Orchiston: 43-70.

Kerr, F.J., 1957. A Magellanic effect on the Galaxy. *Astronomical Journal*, 62, 93.

Kerr, F.J., 1962. Galactic velocity models and the interpretation of 21-cm surveys. *Monthly Notices of the Royal Astronomical Society*, 123, 327-345.

Kerr, F.J., 1984. Early days in radio and radar astronomy in Australia. In Sullivan, W.T. (ed.). *The Early Years of Radio Astronomy. Reflections Fifty Years after Jansky's Discovery*. Cambridge, Cambridge University Press. Pp. 133-145.

Kerr, F.J., Hindman, J.V., and Carpenter, M.S., 1957. The large-scale structure of the Galaxy. *Nature*, 180, 677-679.

Kerr, F.J., Hindman, J.V., and Gum, C.S., 1959. A 21 cm survey of the southern Milky Way. *Australian Journal of Physics*, 12, 270-292.

Kleibrink, H., 1957. De bouw van een radiotelescoop (film).

Kwee, K.K., Muller, C.A., and Westerhout, G., 1954. The rotation of the inner parts of the Galactic system. *Bulletin of the Astronomical Institutes of the Netherlands*, 12, 211-222.

Lindblad, P.O., 1966. The velocity distribution of atomic hydrogen in the outer parts of the Galactic system according to the Kootwijk Survey 1953–55. *Bulletin of the Astronomical Institutes of the Netherlands, Supplement Series*, 1, 77-104.

Morgan, W.W., Sharpless, S., and Osterbrock, D., 1952. Some features of galactic structure in the neighborhood of the Sun. *Astronomical Journal*, 57, 3; with a plot in *Sky and Telescope*, 11, 134 (1952).

Muller, C.A., 1956a. Een ontvanger voor de radiostraling van interstellaire waterstof. I. Het onderzoek van de waterstofstraling. *Philips Technisch Tijdschrift*, 17, 249-259.

Muller, C.A., 1956b. Een ontvanger voor de radiostraling van interstellaire waterstof. II. Bouw van de ontvanger. *Philips Technisch Tijdschrift*, 17, 341-353.

Muller, C.A., 1980. Early galactic radio astronomy at Kootwijk. In Woerden, H. van, Brouw, W.N., Hulst, H.C. van de (eds.). *Oort and the Universe*. Dordrecht, Reidel. Pp. 65-69.

Muller, C.A., and Oort, J.H., 1951. The interstellar hydrogen line at 1.420 Mc/sec, and an estimate of Galactic rotation. *Nature*, 168, 357-358.

Muller, C.A., and Westerhout, G., 1957. A catalogue of 21-cm line profiles. *Bulletin of the Astronomical Institutes of the Netherlands*, 13, 151-195.

Neubauer, F.R., and Fokker, A.D., 1958. The polarization of solar radio emission at a frequency of 200 MHz. *IRA Report*, No. 15.

Ohlsson, J.B., 1932. *Lund Observatory Tables for the Conversion of Equatorial Coordinates into Galactic Coordinates Based on the Galactic Pole R.A.* 12^h40^m*, Decl.* $+28^o$ *(1900.0).* Lund, Lund Observatory.

Ollongren, A., and Hulst, H.C. van de, 1957. Corrections of 21-cm line profiles. *Bulletin of the Astronomical Institutes of the Netherlands*, 13, 196-200.

Oort, J.H., 1945. Letter to C.J. Bakker, dated 17 December. Oort Archives, Leiden University Library (file Oort 98a).

Oort, J.H., 1944-1948. Correspondence on radio telescopes. Oort Archives, Leiden University Library (file Oort 251).

Oort, J.H., 1947. Letter to H.C. van de Hulst, dated 6 March. Oort Archives, Leiden University Library (file Oort 100b).

Oort, J.H., Rinia, H., and Minnaert, M.G.J. 1951. Symposium over de werkzaamheid der Stichting "Radiostraling van Zon en Melkweg" en over de ontdekking van een emissie-lijn van interstellaire waterstof. *Verslagen Koninklijke Nederlandse Akademie van Wetenschappen*, 50, 53-62.

Oort, J.H., 1952. Radiostraling uit de wereldruimte: Inleiding. *Nederlands Tijdschrift voor Natuurkunde*, 18, 116-118.

Oort, J.H., 1956. The evolution of galaxies. *Scientific American*, 195, 101-108

Oort, J.H., Kerr, F.J., and Westerhout, G., 1958. The Galactic system as a spiral nebula. *Monthly Notices of the Royal Astronomical Society*, 118, 379-389.

Oort, J.H., and Rougoor, G.W. 1960. The position of the Galactic Centre. *Monthly Notices of the Royal Astronomical Society*, 121, 171-173.

Oort, J.H., 1970. Afscheidscollege. *Hemel en Dampkring*, 68, 257-261.

Orchiston, W. (ed.), 2005. *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth*. Dordrecht, Springer.

QB (*Quarterly Bulletin on Solar Activity*), published by Zürich Observatory.

Raimond, E., 1996. Historical Notes: four decades of Dutch radio astronomy, twenty-five years Westerbork Telescope. In Raimond, E., and Genee, R. (eds.). *The Westerbork Observatory, Continuing Adventure in Radio Astronomy*. Dordrecht, Kluwer. Pp. 11-51.

Raimond, J.J., 1952. Radiostraling van verre waterstofwolken. *Hemel en Dampkring*, 50, 141-152.

Reber, G., 1940. Cosmic static. *Astrophysical Journal*, 91, 621-624.

Robinson, B., 1999. Frequency allocation: the first forty years. *Annual Review of Astronomy and Astrophysics*, 37, 65-96.

Roman, N.G., 1957. *Comparison of the Large-scale Structure of the Galactic System with that of Other Stellar Systems. IAU Symposium No. 5*. Cambridge, Cambridge University Press.

Ryle, M., and Smith, F.G., 1948. A new intense source of radio frequency radiation in the constellation Cassiopeia. *Nature*, 162, 462.

Schmidt, M., 1956. A model of the distribution of mass in the Galactic system. *Bulletin of the Astronomical Institutes of the Netherlands*, 13, 15-41.

Schmidt, M., 1957. Spiral structure in the inner parts of the Galactic system derived from the hydrogen emission at 21-cm wavelength. *Bulletin of the Astronomical Institutes of the Netherlands*, 13, 247-268.

Seeger, C.L., 1955. 400 Mc/s partial eclipse observations on 30 June 1954. *Bulletin of the Astronomical Institutes of the Netherlands*, 12, 273-283.

Shklovsky, I.S., 1949. Монохроматическое радиоизлучение Галактики и возможность его наблюдения. *Astronomicheskii Zhurnal*, 26, 10-14.

Strom, R.G., 2005. Radio astronomy in Holland before 1960: just a bit more than HI. In Orchiston: 93-106.

Sullivan, W.T., 1982. *Classics in Radio Astronomy*. Dordrecht, Reidel.

Sullivan, W.T., 2000. Kapteyn's influence on the style and content of twentieth century Dutch astronomy. In Kruit, P.C. van der, and Berkel, K. van (eds.). *The Legacy of J.C. Kapteyn*. Dordrecht, Kluwer. Pp. 229-263.

Sullivan, W.T., 2005. The beginnings of Australian radio astronomy. *Journal of Astronomical History and Heritage*, 8, 11-32.

Veer, F. van 't , 1956. Scintillatie van de radiobron Cygnus A nabij onderculminatie. *IRA Report*, No. 8.

Voogt, A.H. de, 1952. Radio sterrenkunde in ons land. *Hemel en Dampkring*, 50, 209-214.

Welther, B.L., 2000. Hendrik Christoffel van de Hulst, 1918-2000. *Bulletin of the American Astronomical Society*, 32, 1688-1689.

Westerhout, G., 1956a. Search for polarization of the Crab Nebula and Cassiopeia A at 22 cm wavelength. *Bulletin of the Astronomical Institutes of the Netherlands*, 12, 309-311.

Westerhout, G., 1956b. Continuous radiation from the direction of the Galactic Centre at 22 cm. *Bulletin of the Astronomical Institutes of the Netherlands*, 13, 105-109.

Westerhout, G., 1957. The distribution of atomic hydrogen in the outer parts of the Galactic system. *Bulletin of the Astronomical Institutes of the Netherlands*, 13, 201-246.

Westerhout, G., 2002. The start of 21-cm line research: The early Dutch years. In Taylor, A.R., Landecker, T.L., and Willis, A.G. (eds.). *Seeing Through the Dust: The Detection of HI and the Exploration of the ISM in Galaxies*. San Francisco, Astronomical Society of the Pacific (ASP Conference Proceedings, Volume 276). Pp. 27-33.

Westerhout, G., and Oort, J.H., 1951. A comparison of the intensity distribution of radio-frequency radiation with a model of the Galactic system. *Bulletin of the Astronomical Institutes of the Netherlands*, 11, 323-333.

Woerden, H. van, Hin, A.C., Raimond, E., and Schipper, B.A.P., 2005. In Memoriam C.A. Muller. *Zenit*, 32 (nr 1), 27-28.

10 APPENDICES

10.1 Obituaries of the pioneers

We briefly refer to a few obituaries of the leading persons mentioned in this paper. Obituaries of Henk van de Hulst have been written by Habing (2001) and by Welther (2000). Many obituaries of Jan Oort have been published; we mention an extensive one (in Dutch) by Blaauw (1993), and one in English by Blaauw and Schmidt (1993). For Lex Muller the only obituary we know is by Van Woerden et al. (2005), in Dutch.

10.2 Brief Sketch of the Life of Ir A.H. de Voogt

Anthonet Hugo de Voogt (Strom, 2005) was born on 1 May, 1892. While still a teenager he became one of the first radio amateurs in the Netherlands, having constructed his own station in 1909. As a student he earned the radio-telegrapher's diploma (and studied electrical engineering at the Delft Institute of Technology). He completed his studies, earning the engineer's (Ir) title, in 1916, and was almost immediately mobilized. Until the 1920s he was active in amateur radio, meteorological and astronomical clubs, giving talks and contributing to various specialist magazines. In 1919, after his discharge from the army, he became a telegraph engineer with the PTT, soon moving from wireless to cable-linked communication. He had several inventions in this period which were patented, and also served in a number of Governmental advisory committees. During the war-time occupation (1940-1945), he was head of the telephone district of Breda.

Immediately after the war, De Voogt (Figure 18) became Head of the PTT's Radio Service, and undertook initiatives to study the ionosphere, and the effects of solar activity upon it. The acquisition of a number of abandoned German radar antennas formed part of this activity. In 1948 he loaned one of the Würzburgs at Kootwijk to the newly-established SRZM to search for and study the 21 cm neutral hydrogen line, and also joined the board of the organization. He established a department (IRA) within the PTT to study the Ionosphere and Radio Astronomy, and helped set up and coordinate a world-wide survey of solar radio emission at the behest of URSI. He is credited with having pointed out the need to protect the 21 cm band from harmful transmissions, and was active in the international effort of radio astronomers to secure frequency allocations for passive radio services. In 1953 the PTT promoted him to Deputy Chief-Director of General Affairs and Radio, and in 1957 he was awarded a Dutch knighthood. He continued his work with the IRA past the usual retirement age to see out the International Geophysical Year, and retired in 1960. A.H. de Voogt died in 1969 at the age of 77.

10.3 Parabolic Antennas at NERA in the 1950s

The best source of information comes from Fokker's (1960) doctoral thesis, in fact from a single table. For the reader's reference, relevant parts of this table are reproduced below in Table 1. (What have been left out are entries for smaller antennas, and columns relating to recording speed and normal observing times.) The first column—"Label"—has been added in an attempt to identify the different antennas, and for ease of the discussion. It should perhaps be noted from the outset that there are errors—or in any event omissions—in the Table. Reference was made above to solar monitoring at 140 and 200 MHz in 1952 (De Voogt, 1952: 209), but the former frequency is not mentioned anywhere in the Table. That 140 MHz was regularly used is confirmed by entries in the QB (see below), and Fokker himself published a map (Figure 15) of the background emission made with a NERA Würzburg at 140 MHz (Fokker and De Feiter, 1954a). In addition, regular monitoring began before 1952, as reported in the QB: at 140 MHz, in July 1951 (QB95); and at 200 MHz, in October 1951 (QB96). In a discussion which one of us (RGS) had with Aad Fokker, he was unable to provide additional information concerning the Table.

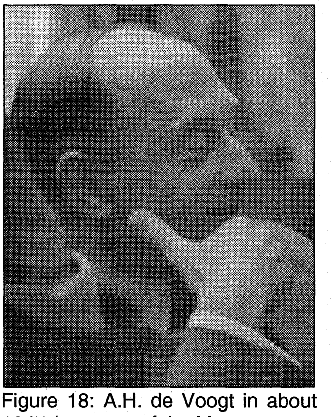

Figure 18: A.H. de Voogt in about 1947 (courtesy of the Museum voor Communicatie, Den Haag).

Let us first consider the three elements used for interferometry, labeled C, D and E. The fact that they are labeled by location means that we can be pretty certain that the following two entries were indeed C and E, as indicated. As noted above, the trio C, D, E almost certainly arrived from Kootwijk after 1955. In addition to D there should be two more 10 m reflectors if we accept De Voogt's (1952: 211) account that they were then on their way to NERA. They are labeled B and F. Although we cannot be certain that the two instruments in the third line ("A/B") were the same as A and B, this is the most likely identification. The frequency used is the same, polarization could be added to total flux determinations, and Fokker uses a similar format in repeating C and E for the total flux measurements. For the last entry, it is clear from other sources that a 7.5 m Würzburg was outfitted with dual 545/200 MHz receivers, so identification with A is the most likely. As for the 10 m parabola, it could be identified with B or D, but F has been chosen since other evidence suggests that there should have been three of the larger dishes. If this analysis is correct, then a total of three 7.5 m and three 10 m parabolas passed through NERA before 1960. There could have been more 7.5 m dishes – if the identification with 'A' in line 3 and/or 9 of the Table is incorrect – but it is unlikely that there were more than three of the 10 m type.

Table 1: Parabolic reflectors at NERA to 1960 (after Fokker, 1960: 3).

Label	Instrument	Frequency	Use	Period of observation
A	7.5 m parabola	200 MHz	total flux	1952–May 1957
B	10 m parabola	200	total flux	May 1957–now
A/B	7.5/10 m parabola	200	polarimetry	December 1955–now
C	7.5 m parabola, east }		large –	
D	10 m parabola, centre }	200	spacing –	February 1958–now
E	7.5 m parabola, west }		interferometry	
C	7.5 m parabola, east	198.5	total flux	October 1958–now
E	7.5 m parabola, west	203	total flux	October 1958–now
A/F	7.5/10 m parabola	545	total flux	1953–December 1958

Hugo van Woerden was born in 1926, and studied at Leiden with J.H. Oort and H.C. van de Hulst. After his graduation in 1955 he did extensive research with the Dwingeloo Radio Telescope, was appointed at the Kapteyn Institute in Groningen, and obtained his doctorate there in 1962 from A. Blaauw. He was Professor of Radio Astronomy at Groningen, and was Department Chairman from 1985 to 1991. After his retirement in 1991 he continued his research on the properties of interstellar clouds, and on the structure and kinematics of galaxies, and he did much work on popularizing astronomy. He has edited several books, including *Oort and the Universe* (Reidel, 1980) and *High-Velocity Clouds* (Kluwer, 2004). He served on the Board of the Netherlands Foundation for Radio Astronomy from 1965 to 1991, and as President of IAU Commission 34 (Interstellar Matter) from 1973 to 1976. He is currently a Committee Member of the IAU Working Group on Historic Radio Astronomy.

Richard Strom was born in New York City, USA, in 1944. While living in New York, he gained entrance to and attended the Bronx High School of Science. He earned a B.A. degree in Physics from Tufts University, and M.Sc. and Ph.D. degrees in Radio Astronomy from the University of Manchester (Jodrell Bank), UK. He is currently a Senior Research Astronomer with ASTRON (the Netherlands Foundation for Research in Astronomy) in Dwingeloo, and Adjunct Professor at the University of Amsterdam. Richard is a past Secretary and member of the SOC of IAU Commission 40 and has been on the SOC of several conferences, including 'Woodfest' and IAU Colloquium 182 (of which he was co-Chair). He is a member of IAU Commissions 28, 34, 40 and 41, and has been on a number of time allocation panels for radio, infra-red and X-ray telescopes. His research interests include supernova remnants (especially those associated with historical supernovae), pulsars, large radio galaxies, radio polarimetry and interferometry, new telescopes, Chinese historical records and the history of radio astronomy in the Netherlands.