HOW WAS ATOMIC HI ($\lambda = 21$ CM LINE) IN SPACE DISCOVERED?

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The discovery of neutral atomic hydrogen (HI) in the interstellar medium was based on a prediction by H. C. van de Hulst. The story of how Jan Oort suggested that the student Van de Hulst might investigate the question, who then reported his results at a wartime colloquium in Leiden, is well known. Recent archival research has turned up letters and other documents which, while not changing the basic storyline, do throw new light on certain details. From letters to Oort, it is now possible to determine when he first heard about Reber's observations of radio emission from the Milky Way, and what his immediate reaction was. After the 1944 colloquium, Oort began his quest to detect and study the HI line, despite technical and financial limitations, and the lack of radar know-how in the Netherlands. The Dutch effort achieved success in 1951, but not before the Harvard team of Ewen and Purcell had detected the line some six weeks before.

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1. Introduction

In 1926 a man who was young as the century earned a doctoral degree from the university in the northern Dutch city of Groningen. The degree was awarded *cum laude*; on the day, he and his family undoubtedly would have felt proud of this achievement. His thesis¹ was a study of high-velocity stars and the patterns of their motion, which at the time he was unable to explain. He would later express his disappointment at the result and in the fact that he hadn't then realized what it implied.² The following year Bertil Lindblad³ suggested that motion in the solar neighborhood is the result of differential rotation about the distant Milky Way nucleus. It was then that Jan Oort realized the patterns left unexplained in his thesis resulted from Lindblad's differential rotation, and provided proof for his model.

Oort developed a mathematical description of Milky Way kinematics,⁴ but would have quickly realized that it could only be tested within a few kpc of the sun. Light from the distant parts of the Galaxy, especially the all-important nuclear region, is heavily absorbed by dust particles. Visually, the study of disk kinematics was

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limited and what happened in the center was shrouded in mystery. By 1940, Oort had turned to investigating the interstellar medium. Even before then, he must have wondered whether it might somehow be possible to see through the dust.

2. The Origins of Radio Astronomy and First Dutch Awareness of It

In the early 1930s, Karl Jansky⁵ discovered that the central part of the Milky Way emits radio waves. Up to that moment, observational astronomy was a discipline based upon visual measurements (though invisible infrared radiation from the sun had been observed by William Herschel⁶ in 1800). Jansky's discovery was unexpected ("serendipitous" in the sense coined by Horace Walpole) and while not ignored, its significance was unappreciated at first. For a variety of reasons (not least of which was the 1930s Depression), there was no immediate follow up. Only late in the decade would the radio engineer and amateur Grote Reber begin a series of observations which confirmed Jansky's results and significantly extended them.

When did Dutch astronomers first become aware of radio emission from space? There is no evidence that it was known about before 1940, while it is now clear that it was being discussed by early 1941. Reber's first astronomical article⁷ was published in June 1940. However, German occupation of the Netherlands the month before halted the delivery of scientific journals until late in the year. In letters between Oort and Bart Bok at Harvard (Ref. 2, 151b^a), the problem was discussed, and it is mentioned that the June issue of the *Astrophysical Journal* only reached the Netherlands in December.

In a letter (Ref. 2, 94) from the Philips engineer (and technical advisor of Oort and Leiden Observatory) Herre Rinia to Oort, he mentions the Reber paper which Oort had lent him, having "read [it] with great interest." Moreover, the Amsterdam University astronomer David Koelbloed wrote a popular Dutch article⁸ on Reber's work in 1941. Although it is unclear who took the initiative to write something about radio astronomy for the general public, it is known that Oort was a close friend of the popular magazine's editor (and director of the Planetarium in The Hague) Jean Jacques Raimond, Jr. One suspects that Oort may have had a hand in the matter.

2.1. Oort and Van de Hulst

Henk van de Hulst⁹ was a student of Marcel Minnaert, director of the Utrecht University Observatory. In 1941, Minnaert initiated a national astronomical conference (an on-going annual event), which was held over a three-day period in June. Both Oort and Van de Hulst attended (Fig. 1), so if they hadn't met earlier, they certainly would have there. Later that year, Leiden University organized a prize-essay

^aReference 2 gives a catalogue of documents in the Oort Archive at Leiden University; the reference number (151b) can be used to locate the letters in question.

Fig. 1. Group photo of the attendees of the June 1941 astronomy conference, which includes several players in the Dutch radio astronomy effort. They are Oort (far left), Van de Hulst (sitting, in shirt sleeves), Koelbloed (far right), Minnaert (third from left) and Houtgast (center rear, with beard), who did solar radio work with Minnaert.

contest on the topic of dust in interstellar space (Oort was the main instigator). Minnaert urged Van de Hulst to enter, which he did, and this marked the beginning of his serious scientific contact with Oort. Together they began a study of interstellar dust, its origin and destruction. Oort also arranged for Van de Hulst to visit Leiden Observatory from January–April 1944, and during this visit the question of radio emission from the Milky Way first arose.

2.2. The 1944 colloquium in Leiden

The idea of organizing a colloquium on radio astronomy apparently only came up during Van de Hulst's visit to Leiden: "In the spring of 1944 Oort said to me: '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.'"¹⁰ The 1944 colloquium in Leiden had as its title *Radiogolven uit het Wereldruim* (Radio waves from space), and Oort had arranged for two speakers to discuss Reber's results. Cornelis Bakker (a physicist with the Philips NatLab.) reviewed radio technique. Van de Hulst considered the origin of continuum radio emission, then possible lines: recombination, and that of neutral hydrogen at 21 cm.¹¹

The existence of a hyperfine transition in atomic hydrogen was already known, but its physical properties were rather uncertain. Moreover, the conditions in interstellar space were unclear: the line might appear in absorption or in emission. On top of that, the hydrogen might all be in molecular form (H_2), rendering it undetectable by radio. In view of all these uncertainties, Van de Hulst was cautious in what he said. (Note that the hyperfine transition problem was first solved by Hendrik Casimir, a good friend of Oort. Had Oort thought of this he might have asked Casimir to give the talk, not Van de Hulst.)

3. The Search for $\lambda = 21$ cm HI After the War

Oort, never one to let things stagnate, wrote Bakker just four days after the Leiden Colloquium, thanking him for his contribution, but also asking whether Philips could build a receiver for the radio antenna reflector which was already taking shape in his mind. In his reply Bakker said that while there was interest at Philips, little could be done before the end of the war (Ref. 2, 158a).

What was needed to look for the 21 cm HI line? The antenna, which was only the most visible component required (it was pictured in Reber's article⁷), would in Oort's original plan be constructed by the Observatory workshop. This was rather optimistic, and a year later he was in contact with a civil engineering firm. Oort may not have realized that it would be almost as difficult to acquire a sufficiently low-noise receiver: 21 cm was an extremely short wavelength at the time (Bakker indicated that Philips could build low-noise amplifiers only for wavelengths of 30 cm and longer). Finally, there was the problem of finding an excellent radio engineer, as Reber had strongly advised in correspondence (see Ref. 12 for more details).

3.1. *The Dutch effort begins to take shape*

Despite the challenges, Oort and others began serious efforts to carry out radio astronomical research from the Netherlands. In 1946 or 1947, Ir A. H. de Voogt, head of the Post Office Radio Division, appropriated a number of abandoned German Würzburg radar dishes and set up the country's first radio astronomy observatory near Kootwijk.¹³ He, Minnaert and Jaap Houtgast helped form a workgroup to study the ionosphere and radio emission from the sun; by 1947 Oort was also involved in the discussions.

The Leiden physicist Cornelis Gorter, who had done laboratory experiments with microwaves, was also interested in detecting the 21 cm line, and apparently began an independent project in 1946. By 1948 he had an engineering student from Delft, H. Ho, working on the problem. Meanwhile, De Voogt had suggested that Oort might use one of the Würzburg antennas for the 21 cm line search, and the Gorter and Oort efforts were merged. Oort and Minnaert set up a Foundation for Radio Astronomy, which included representatives from Philips and the Post Office, and Ho became its first employee.

By 1949 test observations were being made on a borrowed Würzburg at Kootwijk using Gorter's amplifier. Progress was steady, but slow. Then, on 10 March 1950, disaster struck. A fire destroyed the receiver hut and all the equipment. Some personal items were also lost. The total loss was estimated at f 8000, about 50% of the annual budget, and nothing was insured. Fortunately no one was hurt, but Gorter's amplifier and a new Brown recorder worth f 3500 had to be written off.

3.2. *Meanwhile, across the Pond...*

By 1950, another team was also looking for the line. Harold Ewen and Edward Purcell at Harvard had heard about Van de Hulst's prediction at a conference in 1949. Both had radar experience and came up with a simple solution to the antenna problem: a horn. Their equipment was similar to that of the Dutch, based upon a super heterodyne receiver, with one important innovation: frequency switching was used to remove amplifier drift. In addition, certain electronic components which Ewen had access to were probably of higher quality. The line was detected on Easter weekend, 1951. (For the full story, see Ref. 14.)

4. Finally, Dutch Success Some 6 Weeks Later

With the newly employed engineer Lex Muller, the Dutch team detected the line just 6 weeks after Ewen and Purcell, and both results were published simultaneously.^{15,16} For Ewen it meant the completion of his Ph. D. thesis; he and Purcell did not follow up their detection. For Oort and his team, it was only the beginning of systematic studies, first of the Milky Way, and later of other galaxies.

What has it meant for (astro)physics? The 21 cm line became widely used for studies of the structure and kinematics of galaxies, more than realizing Oort's original vision. It has also revealed much about the physical properties of the interstellar medium, and provided evidence for the presence of dark matter in galaxies.

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