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ALBRECHT UNSÖLD: HIS ROLE IN THE INTERPRETATION OF THE ORIGIN OF COSMIC RADIO EMISSION AND IN THE BEGINNING OF RADIO ASTRONOMY IN GERMANY

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Abstract: Albrecht Unsöld's career spanned over 50 years at the beginning of the 20th century. In this period atomic physics made great advances and Unsöld applied this to astrophysical questions. He came in contact with the early radio astronomy observations and devoted part of his career to the interpretation of the origin of cosmic radio waves. Although hampered by the post-war situation, Unsöld's contributions to the interpretation of cosmic radio waves were important.

Keywords: Albrecht Unsöld, radio astronomy, emission processes, Germany

1 INTRODUCTION

Albrecht Unsöld (Figure 1) was born on 20 April 1905 in Bohlheim (Württenberg), and died on 23 September 1995 in Kiel. Already as a 14-year-old, Unsöld began correspondence with Arnold Sommerfeld (1868–1951; Figure 2), the Professor of Physics in Munich, after reading his book *Atombau und Spektrallinien.* Unsöld studied first in Tübingen and later went on to complete his doctoral degree under Sommerfeld in Munich. This was an exciting time in physics with Schrödinger's wave mechanics, the Bohr-Sommerfeld atomic model and Heisenberg's quantum mechanics making great advances in the development of physics. Unsöld was awarded his doctorate in 1927 (at the age of 21) for a dissertation titled *Beiträge zur Quantenmechan-ik der Atome*.

The earliest papers by Unsöld deal with the interpretation of spectral lines observed in the Sun. Following his doctoral thesis Unsöld received a Rockefeller Foundation Fellowship and carried out spectral work at Mount Wilson Observatory using the 100-in telescope. Unsöld returned to Munich to complete his 'Habilitation' thesis, that was needed for an appointment in a German university. He spent a brief period from 1930 to 1932 at Hamburg Observatory (Figure 3) where he came in contact with Walter Baade (1893–1960).

In 1932 Unsöld was appointed to the Chair of Theoretical Physics at the University of Kiel, at the age of only 26. With this appointment he initiated a very successful study of stellar atmospheres in Kiel, which continued under his lifelong direction. His seminal book *Physik der Sternatmosphären (mit besonderer Berücksichtigung der Sonne)* (Unsöld, 1938) dealt with stellar atmospheres and became a classic in this research area. Unsöld developed good contacts with colleagues in the USA, that led to a Visiting Professorship in Chicago in 1939. While at the Yerkes Observatory and working with Otto

Figure 1: Albrecht Unsöld (techniklexikon.net).

Figure 2: Arnold Sommerfeld (en.wikipedia.org).

Figure 3: Hamburg Observatory (eso.org).

Struve (1897–1963), Unsöld took spectra of the BO star τ Scorpii at the McDonald Observatory.

During his visit to the Yerkes Observatory Unsöld became aware of the radio observations of Karl Jansky (1905–1950). He also received information about the early radio observations of Grote Reber (1911–2002), and immediately realised the close connection between the observed radio waves and his research on stellar atmospheres.

The origin of the radio emission observed by Jansky and Reber at first eluded interpretation. The few theoretical discussions at this time centred on a possible thermal (free-free) interpretation. This was also the interpretation that Unsöld first took. Unsöld concentrated his attention on the questions of intensity calibration of the observed cosmic radio waves, which led to the realisation that very high thermal temperatures would be necessary for the thermal interpretation. Soon the idea was born that an 'Ultrastrahlung' (ultra radiation) was needed to explain the observational radio results.

This 'Ultrastrahlung' was proposed by Unsöld to be emitted by energetic particles in magnetic fields. Unsöld did not become involved in details of emission theories, instead accepting the classical work of George Adolphus Schott (1868–1937) as a basis for the interpretation of emission from relativistic particles in magnetic fields (Schott, 1912). Unsöld worried instead for a long time about the origin of energetic particles. He knew that magnetic fields were present in sunspots as a result of the Zeeman Effect that was detected in 1908 by George Ellery Hale (1868–1938). Unsöld proposed that the origin of the cosmic radio emission was by the 'magnetic bremsstrahlung' process, and was similar to the emission seen in 'betatrons'. This later became the standard interpretation, under the name of 'synchrotron emission'.

Figure 4: The 100-in Hooker Telescope at Mt Wilson Observatory (www.mtwilson.edu).

Some historical details of Unsöld's work have been discussed by Jesse Greenstein in Sullivan (1984). Also Sullivan (2009) investigates the impact of Unsöld's work in detail. In a monograph recently edited by Gudrun Wolfschmidt two related contributions are found: one about the life and letters of Albrecht Unsöld, by Weidemann (2011), and a second one about his research on stellar atmospheres, by Baschek (2011). In the present paper my investigation will cover Unsöld's published papers that deal with the origin of cosmic radio waves. But first, a short description of Unsöld's early work on stellar atmospheres, which led to his interest in radio astronomy, will be presented. The work of other 'players', astrophysicists and physicists, who were involved in the hunt for an interpretation of cosmic radio waves only will be included if they affected the development of Unsöld's research. Unsöld's venture into observational radio astronomy at Kiel University also will be described since this had a significant impact on the establishment of observational radio astronomy in Germany.

2 THE EARLY WORK

Unsöld's earliest work concentrated on the application of the new atomic theory to the interpretation of spectral emission lines in stars. Early papers (e.g. Unsöld, 1926; 1927) concentrate on the derivation of the spectrum of hydrogen, based on atomic theory. During a Rockefeller Foundation Fellowship, following completion of his doctoral thesis, Unsöld used the Mount Wilson 100-in telescope (Figure 4) for spectral line observations. He then returned to Munich to complete his Habilitation thesis, a 'must' for a future university appointment in Germany. The thesis, *Über die Balmer-Serie des Wasserstoffs im Sonnenspektrum*, was a masterpiece that combined atomic theory and observational details. In the following years Unsöld expanded this work by taking into consideration radiation transfer and quantum mechanical line width broadening due to collisional damping and electric fields (the Stark Effect). In this era Unsöld laid the basis for the quantitative analysis of stellar spectra, in particular the determination of the abundance of elements in stellar atmospheres.

Starting his investigations with the hydrogen line spectrum, Unsöld developed similar procedures for other elements, e.g. calcium (Unsöld et al., 1930) and helium (Unsöld, 1931). At this time Unsöld's (1936) interests shifted to the theory of solar emission, and to the abundance of elements in stars. Unsöld was also involved in writing his seminal book *Physik der Sternatmosphären (mit besonderer Berücksichtigung der Sonne)* (Unsöld, 1938). This book saw several editions (e.g. 1955, 1968) and became a standard work, with over 1000 citations. In 1939 Unsöld was invited by Otto Struve (Figure 5) to accept a Visiting Professorship at the University of Chicago. He spent most of the time taking spectra of the B0 star τ Scorpii at the recently-completed McDonald Observatory. Upon his return to Germany WWII broke out and Unsöld was required to work in a weather office, but he continued to analyse his observations, which led to several important publications (Unsöld, 1942a; 1942b; 1942c; 1944). As a result of his visit to Yerkes Observatory, and with his background in stellar atmospheres research, Unsöld became involved in the quest to interpret the origin of the recently-discovered cosmic radio waves.

Figure 5: Otto Struve (astron.kharkov.ua).

3 CONNECTIONS TO EARLY RADIO ASTRONOMY

The serendipitous discovery of cosmic radio waves by Karl Jansky (1932; 1933; Figure 6) was made at a low radio frequency, around 20 MHz. In the USA Fred Lawrence Whipple (1906–2004) and Jesse Leonard Greenstein (1909–2002) became interested in this monumental discovery. A paper by Whipple and Greenstein (1937) discussed 'interstellar radio disturbances' from the physicist's point of view, and gave arguments about what the cosmic radiation could *not* be. Stellar origin was excluded as well as secondary radiation in the Earth's atmosphere. Later in this paper an attempt was made to interpret the observed radio waves as thermal emission from interstellar dust. Their major conclusion was that *"...* the black-body radiation theory failed to account for Jansky's observations by a factor of 10^4 in the most favourable case." (Whipple and Greenstein, 1937: 181).

Following Jansky, a publication by Grote Reber (1940; Figure 7) reported observations at the much higher frequency of 162 MHz. Reber also made test observations at 3300 MHz but failed to detect any emission.

The next discussion about the possible origin of cosmic radio waves was by Louis G. Henyey (1910–1970) and Philip C. Keenan (1908–2000), who gave an account of the intensities expected from free-free emission of hydrogen. Although they suggested that this may be the process responsible for the observed radio waves, Henyey and Keenan (1940) thought that the intensity values published by Jansky were too high. At that time interest in cosmic radio waves was not very great within the astronomical community, so Henyey and Keenan's 1940 paper was only cited 19 times (see ADS) while a 1941 paper by Henyey and Greenstein, about diffuse optical emission in our Galaxy, received 743 citations.

Unsöld started his investigations based on the data available to him in 1940, and at first tried to use the free-free emission process to explain the radio observations. In 1944 he submitted a paper to the German journal *Die Naturwissenschaften*, but this only was published after the war. In this paper Unsöld (1946) recalculated in detail the free-free emission mechanism that was dealt with by Henyey and Keenan, proved their physical arguments to be correct and agreed that this may explain cosmic radio emission.

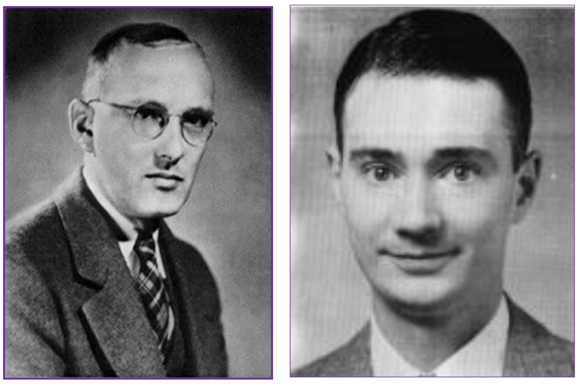

Figure 6 (left): Karl Jansky (members.westnet.com.au).
Figure 7 (right): Grote Reber (nrao.edu).

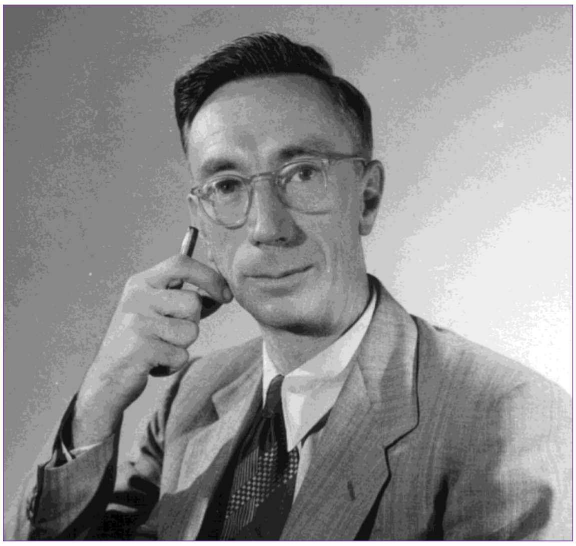

Figure 8: Joseph Pawsey (courtesy: CSIRO Astronomy and Space Sciences).

One of the problems that Unsöld discovered in Reber's 1940 paper was that the beam (hence the intensity calibration) was based on "... a cone of acceptance of 3°." (Unsöld, 1946: 37; my English translation). This obviously was wrong for a 31.4-ft dish operating at 160 MHz. Unsöld had contacts with Kurt Fränz (1912–2002), an engineer with the Telefunken Company, who actually repeated some of the Jansky observations at 30 MHz in Germany (Fränz, 1942). Unsöld and Fränz discussed the intensity definitions for radio emission used by Reber and Jansky, and Unsöld became worried about the differing intensity units used by the various authors: microvolt/meter by the engineers and ergs/sec/cm^2/kc by the physicists. Unsöld suggested that using the Rayleigh-Jeans approximation would lead to 'Rauschtemperatur *T*' (the effective temperature), as used in radio astronomy today. This was an important step forward, allowing clear spectral derivations. Fränz also suggested that Reber's beamwidth should have been ~12°, which was in agreement with antenna theory. Hence the intensity calibration may have been in error. The beamwidth was actually corrected by Reber in his important 1944 survey paper to 6° × 8°, still an over-estimate, but this information did not reach Unsöld at the time.

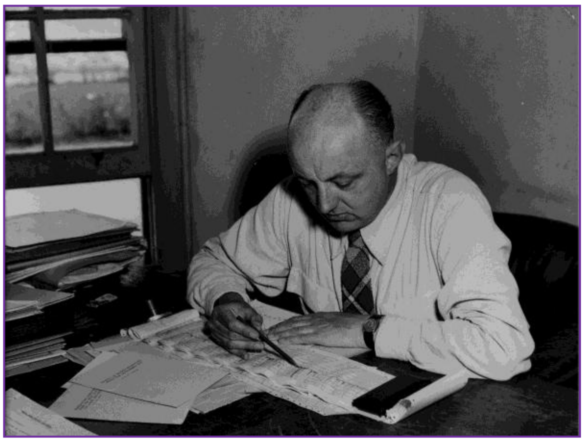

Figure 9: David Martyn (courtesy: CSIRO Astronomy and Space Sciences).

In his 1946 paper Unsöld also suggested that Reber's claim to have detected the Andromeda Nebula was plausible, given its basic similarity to our own Galaxy. However Unsöld was unaware that solar radio emission had already been recorded (see Sullivan, 2009: 79-99), and he pointed out that it should exist, although the editor of the journal added a note stating that solar radio emission had by then been detected. The final paragraph in Unsöld's paper is devoted to suggesting that this may "... for some people be the fulfilment of a dream of interstellar communication while for the physicists it is a love game of electrons and protons." (Unsöld, 1946: 40; my English translation).

During the war the Kiel University astronomical observatory and Unsöld's home was destroyed by bombs, so Unsöld found accommodation with Werner Kroebel (1904–2001), who later became the Professor of Experimental Physics at Kiel and Unsöld's close associate in developing radio astronomical observations (see Weidemann, 2011). After the war Unsöld was appointed by the British military administration as the Dean of the Faculty of Arts and Humanities at Kiel University and entrusted with the reconstruction of the 'Institute for Theoretical Physics and Astronomical Observation'. In spite of his administrative work Unsöld continued active research, but at first he did not have access to recent journals—an unfortunate result of the post-war destruction. Also, the papers written by Unsöld at this time did not reach the wider astrophysical community since they were available only in the German language.

A claim that German radar units in northern Denmark and elsewhere in Europe detected solar radio emission at 125 and 175 MHz and at other frequencies between 1939 and 1945 (inclusive) was made by E. Schott (1947) after the war, but no detailed proof of this was provided. However, given the sensitivity of the various German radar systems this claim seems plausible.

The detection of solar radio emission between 1942 and 1945 (inclusive) was definitely made by Allied radar operators, and the names of George Clark Southworth (1890–1972; Sullivan, 2009: 91-99), James Stanley Hey (1909–2000; Sullivan, 2009: 80-83), Elizabeth Alexander (1908–1958; Orchiston, 2005; Sullivan, 2009: 84-85) and Bruce Slee (b. 1924; Orchiston and Slee, 2002; Orchiston et al., 2006) are associated with these different independent discoveries. Hey's (1946) 1942 observations in England were made at frequencies between 55 and 85 MHz, while in 1945 Alexander (1946) in New Zealand and Slee in Australia observed at 200 MHz. Meanwhile, in 1942 Southworth (1945) in the USA observed at the much higher frequency of 9370 MHz. In addition to these radar-based discoveries, Reber (1946) was successful in detecting solar radio emission at 160 MHz in 1943 (Sullivan, 2009: 65-66).

In October 1945, following Alexander's successful research in New Zealand, an Australian group at the CSIR's Division of Radiophysics began an intensive programme of solar radio research at 200 MHz using ex-WWII radar equipment located in and near Sydney (e.g. see Pawsey, Payne-Scott and McCready, 1946; cf. Orchiston, 2005; Orchiston et al., 2006). Leading this dynamic group was Joseph Lade Pawsey (1908–1962; Figure 8), and in a paper published in *Nature* in 1946 he claimed a temperature of one million Kelvin for the solar corona. This certainly aroused Unsöld's attention.

At this time another, much smaller, group based at Mt Stromlo Observatory near the Australian capital, Canberra, was also observing solar emission at 200 MHz (Orchiston et al., 2006). A member of this team was David Forbes Martyn (1906–1970; Figure 9), who played an important role in the observation and interpretation of solar radio waves. On theoretical grounds he postulated a temperature of one million Kelvin for the corona in a paper that was published end-to-end with Pawsey's (1946) paper in *Nature* (see Martyn, 1946b). Martyn (1946a) also was the first to determine that solar bursts were polarised, and he predicted that limb-brightening would occur at longer radio wavelengths (Martyn, 1946b), a topic that Unsöld later would study in detail.

When news of these British and Australian research programs finally reached Unsöld he began anew to search for an interpretation of solar and galactic radio emission.

The interpretation of galactic radio emission posed greater problems. All astrophysicists working in this field attempted to explain the radio observations in terms of thermal (free-free) emission theory. Charles H. Townes (b. 1915) critically discussed the existing free-free emission theory and the observations in 1946, concluding that only temperatures of 100,000K to 200,000K could explain the radio intensities.

The results of the radio observations of the Galaxy, the Sun and the Moon were reviewed in a major paper by Unsöld in 1947. By then Unsöld had access to recent publications. The detection of the Moon by Robert H. Dicke (1916–1997) and E. Robert Beringer (1946; 1917–2000) at a frequency of 24,000 MHz and all the other new observations published in 1946 impressed Unsöld (1947: 194; my English translation) as "The enormous possibilities for astronomy as a result of opening the spectral range from λ1cm to λ15m … allow the author … to return once more to this subject and discuss it." Unsöld continued to use the 'effective temperature' (T_e) definition obtained from the Rayleigh-Jeans approximation that he had proposed in 1946 (Unsöld, 1946). He examined the results of solar observations and concluded that the chromosphere must have an effective temperature ~6000K while the solar corona can have T_e >500,000K. Still much higher intensities of the solar bursts (the Sun was particularly active in 1946) led him to the conclusion that an 'Ultrastrahlung' (ultra-radiation) must be present, in addition to thermal free-free emission (from the quiet Sun).

Unsöld (1947) also computed the expected disc-limb variation for solar radio emission at lower frequencies. These early computations pointed out that the solar limb emission would be higher than the disc, contradicting the optical situation where limb-darking was well established. Considering the observed radio emission, Unsöld pointed out that a thermal interpretation would require the temperature of the interstellar gas to be ~100,000K or more.

Unsöld then discussed the publication by L.A. Moxon (1946) that showed that galactic radio emission had a non-thermal spectrum. As a result of this, the measurement of the spectrum of the radio emission became an important observational result in Unsöld's thinking. Concerning the nature of the 'Ultrastrahlung', Unsöld (1947: 201; my English translation) suggested that this could be due to energetic particles emitting in "... time variable magnetic fields ..." and that this emission would be similar to the situation found in 'betatrons'. In the final sentence of this 1947 paper Unsöld pointed out that this may be the first time that a viable interpretation of the cosmic radio waves has been given. It must be noted that at this time most astrophysicists interested in galactic radio astronomy still favoured the thermal emission interpretation. For example, the paper by G. Burkhardt, G. Elwert and Unsöld (1948) begins with a clear statement that cosmic radio emission can be interpreted only as 'bremsstrahlung' of free electrons.

Other European theoreticians (Hannes Alfvén, 1908–1995; Karl-Otto Kiepenheuer, 1910–1975), as well as Soviet researchers (e.g. Josif Shklovskii, 1916–1985; Vitaly Ginzburg, 1916–2009; and others), became active in this field. The Soviet results were not widely disseminated internationally since they were published in rarely-available journals and written in Russian. Also, the Soviet researchers were subject to a rigid censorship that prevented them from openly publishing their results, and in addition there

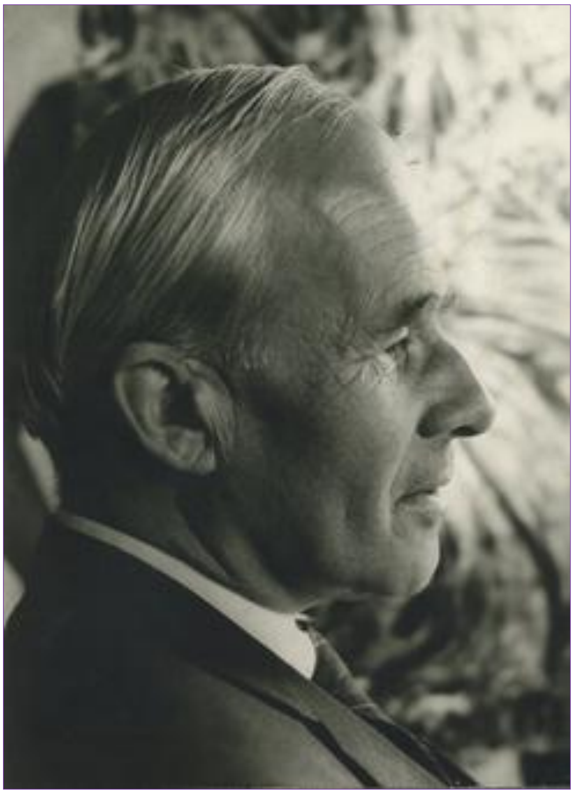

Figure 10: Karl-Otto Kiepenheuer (kis.uni-freiburg.de).

were long delays before approval was granted for publication. As a result, the papers by the Soviet researchers did not reach Unsöld (or other Western colleagues) for a long time, which he pointed out in one of his papers. Even today, most of the early Soviet papers (in Russian) are not available via the Astrophysics Data System. On the other hand, papers by Unsöld were cited by the Soviet astrophysicists.

The German solar astrophysicist Karl-Otto Kiepenheuer (Figure 10) fortunately lived in Freiburg, which at the end of the war ended up in the French Zone of Germany. Although some of his astronomical equipment was taken away by the French navy, Kiepenheuer received support from some of his French colleagues and hence had immediate access to recently-published papers. Details of Kiepenheuer's life have been discussed by Seiler (2005). In 1946 Kiepenheuer suggested that intense solar emission may be related to sunspots, where strong magnetic fields were known to be present. This was indeed an important step in the quest for the interpretation of the emission mechanisms of cosmic radio waves. Also Martyn (1946a) and McCready, Pawsey and Payne-Scott (1947) observed enhanced solar radio emission when large sunspots were visible. Ginzburg (1946; Figure 11) made his first contribution to radio astronomy by discussing the possible reasons for the million degree temperature of the solar corona. Then, the following year, Shklovskii (1947; Figure 12) managed to publish a paper in English in *Nature*, where he discussed various alternative emission mechanisms for solar radio emission (e.g. plasma oscillations), and tried to associate high-intensity solar burst emission with magnetic storms. In this paper Shklovskii follows the general assumption that thermal emission at high temperatures could be responsible for the radio waves (see also Ginzburg, in Sullivan, 1984).

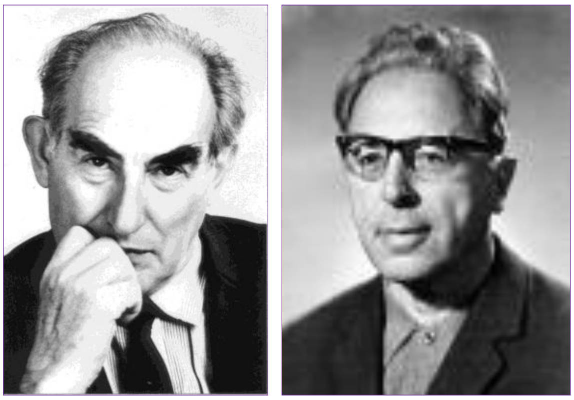

Figure 11 (left): Vitaly Ginzburg (en.wikipedia.org).
Figure 12 (right): Josif Shklovskii (courtesy: H. Friedman).

4 THE PARALLEL WORK OF THE PHYSICISTS

It also is necessary to go back and look at the work of theoretical physicists in this period. The basic work on the emission from relativistic electrons in magnetic fields was already given by Schott (1912). The development of energetic particle accelerators led to several configurations: the betatron, synchrotron, microtron, linear wave guide accelerator, and others (e.g. see Schiff, 1946). Dmitri Iwanenko (1904–1994) and Isaak Pomeranchuk (1944; 1913–1966) described the performance of a betatron. In a publication describing the General Electric synchrotron F.R. Elder et al. (1948) stated that blue light was seen when the synchrotron beam was observed in the accelerator tube (hence in the Earth's magnetic field). Furthermore, the blue light was found to be polarised. Julian Schwinger (1949; 1918–1994) described the classical radiation of accelerated electrons emitting in magnetic fields, as observed in synchrotrons. There was no theoretical investigation of the polarisation properties of the synchrotron emission at this time. In the Soviet Union numerous theoretical physicists also worked on similar problems, but at first they did not see the connection to astrophysical emission processes.

The question of the origin of cosmic rays was discussed right from the time of their detection by Victor Francis Hess (1883–1964). One of the early discussions was by Alfvén (1937; Figure 13). He investigated cosmic ray energies and suggested that the higher-energy particles could be produced by acceleration in magnetic fields. Observations of massive increases in the intensity of cosmic rays correlated with solar storms were reported by Scott E. Forbush (1946; 1904–1984). Another important contribution came from Enrico Fermi (1901–1954; Figure 14), who realised that cosmic rays may possess the energy to generate radio emission in magnetic fields. Fermi (1949) discussed the existence of an inverse power spectral law for the spectral distribution of the cosmic rays. In a way, the physicists provided all that was needed for the interpretation of cosmic radio waves. An early paper by German G. Getmantsev (1926–1980) published in 1952, presumably discussed earlier in a seminar, examines the possibility that cosmic electrons produce galactic radio waves.

The presence of magnetic fields in sunspots and in Ap stars was observed by George Ellery Hale and by Horace W. Babcock (1912–2003) respectively. The existence of a magnetic field in our Galaxy was first established by the optical polarisation observations of William Albert Hiltner (1949; 1914–1991), followed by their interpretation by Leverett Davis (1914–2003) and Greenstein (1951) in terms of alignment of dust particles in magnetic fields. Additional support for the existence of galactic magnetic fields came from Subrahmanyan Chandrasekhar (1910–1995), Fermi (1953) and Biermann and Schlüter (1951). Hence a discussion of the emission mechanisms in which energetic cosmic rays emit in galactic magnetic fields could take place.

5 THE RAPID DEVELOPMENT OF RADIO ASTRONOMY 1946-1949

In addition to the solar observations several new directions of research were initiated (see Sullivan, 2009). After Reber's (1944) pioneering work surveying the radio sky at 160 MHz, a whole bonanza of new results was published. J. Stanley Hey (1909–2000), James W. Phillips, and S. John Parsons surveyed the northern sky at 60 MHz (see Hey, Phillips and Parsons, 1946). In these observations the scintillation of strong radio emission from a position in Cygnus led Hey, Parsons and Phillips (1946) to suggest the existence of compact radio sources. The results of these radio astronomical observations were reviewed by Reber and Greenstein in 1947.

At the same time, interferometry was adopted in Australia by John G. Bolton (1922–1993), Gordon J. Stanley (1921–2001) and O. Bruce Slee (b. 1924) in a bid to dramatically increase the angular resolution of the equipment used (see Bolton and Stanley, 1948; Bolton, Stanley and Slee, 1949). Observing at 100 MHz, they quickly confirmed the existence of the discrete source in Cygnus, and by the end of January 1948 had discovered five more discrete sources (see Orchiston, 1993; 1994). Meanwhile, Martin Ryle (1918–1984) and F. Graham Smith (b. 1923) discovered a strong new radio source in the constellation of Cassiopeia, also using an interferometer (Ryle and Smith, 1948). A short discussion between Marcel G.J. Minnaert (1948; 1893–1970) and Ryle and Smith (1948) led to the suggestion that the observed radio sources were 'radio stars', and this idea was followed for quite some time even though Bolton et al. (1949) showed that stars were not responsible for the emission when they demonstrated two of the radio sources (Virgo A and Centaurus A) were associated with active galaxies and a third (Taurus A) with the Crab Nebula (the remnant of a supernova whose eruption in AD 1054 was recorded by Chinese, Japanese and Korean astronomers—see Stephenson and Green, 2002). Observations by Moxon (1946) of galactic radio emission at four frequencies—already discussed by Unsöld—indicated a (non-thermal) inverse power law spectrum that pointed to a magnetic bremsstrahlung process.

Figure 13: Hannes Alfén (en.wikipedia.org).

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Figure 14: Enrico Fermi (solmagazine.wordpress.com).

6 INTERPRETATION ATTEMPTS BY UNSÖLD IN VIEW OF THE NEW OBSERVATIONAL DATA

In a major paper entitled "Über den Ursprung der Radiofrequenzstrahlung und der Ultrastrahlung in der Milchstraße*"* ("The origin of the radio frequency emission and the ultra-emission in the Milky Way") Unsöld (1949a) dealt first with solar radio emission. He agreed with the free-free mechanism for the 'quiet Sun', with temperatures of ~6000 K in the chromospheres and ~500,000K in the corona He stated categorically that the free-free emission interpretation could not hold for solar bursts, and he suggested once more that the 'ultra-radiation' was generated by energetic particles in magnetic fields, "… a sort of plasma oscillations." (Unsöld, 1949a: 197; my English translation). Since then, the origin of solar radio emission has filled books, and is still the subject of detailed research.

When it came to galactic radio emission Unsöld (1949a: 183; my English translation) decisively stated: "The radio emission from our Galaxy cannot be considered to be due to free-free emissions of the interstellar gas." Unsöld did, however, consider the possibility that the galactic radio emission came from numerous 'radio stars'. He suggested that this non-thermal 'radio star' emission, similar to solar bursts, could be responsible for the radio emission from our Galaxy. The main worry that is seen in all of Unsöld's papers is connected to the origin of energetic particles—he simply could not imagine that such particles could come from stellar processes. On the other hand, Ryle (1949) claimed that there was observational evidence for the stellar origin of cosmic rays. After all, just a short time before this publication, Babcock showed that magnetic fields exist in Ap stars. In a shorter paper, his first written in English, Unsöld (1949b) admitted that he had for a long time adhered to the thermal interpretation, yet this could not be upheld in view of the recent discovery of discrete sources ('radio stars'). He pointed out that while solar magnetic fields could produce 10^9 to 10^{10} eV, the radio stars had to produce energies of up to 10^{15} eV, possibly in "… much larger spots." (Unsöld, 1949b: 491).

6.1 Interpretation of the Origin of Cosmic Radio Emission

Although solar research was a driving force in the development of early radio astronomy, the interpretation of radio waves from our Galaxy and from extragalactic discrete radio sources was important for the further development of the subject. The interpretation of cosmic radio emission is usually dated to 1950 when H. Alfvén and N. Herlofson (1950) suggested that radio emission from 'radio stars' was a result of energetic electrons emitting in magnetic fields. In this paper the problem of energetic particles was discussed, and a reference to the paper by Fermi (1949) is made—suggesting that cosmic rays may have sufficient energy to produce cosmic radio emission. A reference also is made to a paper by F.R. Elder et al. (1948) where it is suggested that emission like in the synchrotron machine may be the source of cosmic radio waves. Kiepenheuer (1950a; 1950b) took up this idea and argued that this emission mechanism also can be responsible for the radio waves from our Galaxy.

The acceptance of the idea that cosmic rays may possess enough energy to be responsible for radio and optical emissions in magnetic fields was the break-through point in this discussion. This step was initiated by a brilliant suggestion from Shklovskii (1953), who proposed that the optical and radio emission from the Crab Nebula could be a result of relativistic electrons emitting in a magnetic field. From then on, his proposed interpretation influenced the theoretical discussions. The importance of the Crab Nebula in the interpretation of astrophysical emission processes was realised by Soviet astronomers. The energy of a supernova explosion was obviously sufficient for the generation of relativistic particles. Soviet optical astronomers V.A. Dombrovskii and Mikhail A. Vashakidze studied the Crab Nebula, and in 1954 both published papers that reported the detection of polarised optical emission. In particular, Dombrowskii (1954) pointed out that this emission could be the same sort of radiation as suggested by Shklovskii. This statement was made although Shklovskii did not point out that the radio emission would be polarised. The connection between the polarisation of the radio continuum and bremsstrahlung emission was realised later by Isaak M. Gordon, in 1954. Ginzburg (1984: 296) says that he "... supported the proposed polarisation observations in 1953/54 while Shklovskii felt in 1954 that such measurements would have insufficient sensitivity." Possibly, as early as 1952, there was discussion in seminars about this polarisation aspect, but it took time for a relevant publication to appear. The observation of linear polarisation of radio waves became a major method to study cosmic magnetic fields, but details of the polarisation properties of synchrotron emission were not dealt with until much later.

In his later publications, Unsöld slowly comes to terms with the theoretical advances. In 1951 he still favoured the 'radio star' model, but his argument hinged on the possibility of cosmic rays due to "... activity qualitatively similar to that of the Sun but several billion times stronger." (Unsöld, 1951: 859). Another publication (Unsöld, 1955) reiterated the radio star model and discussed the need for strong galactic magnetic fields to allow energies of up to 10^{17} eV. In his 1955 paper Unsöld was fascinated by cosmology, and he asked if "... the origin of the ultra-radiation could come from the creation of the universe". (Unsöld, 1955: 71; my English translation). He even suggested that the 'Ultrastrahlung' could be a result of the 'Urknall' (Big Bang)! By 1957, Unsöld reluctantly agreed with the interpretation that supernova remnants could be the source of the energetic particles, but he still suggested the alternative view, that cool dwarf stars may be a source of these particles. Note that in none of these papers did Unsöld refer to the work of the Soviet researchers. In a way, Unsöld was on the right track in his interpretation of cosmic radio waves, but he did not coin the term 'synchrotron emission', using instead 'Ultrastrahlung' or 'betatron emission'. He still hoped for a stellar process as the basis of the cosmic radio emissiond.

It is interesting to note that the term 'synchrotron emission' was not used for a long time in astronomical papers. In the work of the Soviet researchers (e.g. Shklovskii and Ginzburg) the term was 'emission from energetic particles in magnetic fields' or 'magnetic bremsstrahlung'. Ginzburg and Syrovatskii title their important 1965 review paper "Cosmic magnetobremsstrahlung (synchrotron radiation)". The first thorough discussion of the emission process using the term 'synchrotron radiation' was published by Jan Oort (1900–1992) and Theodore Walraven (1916–2008) in 1956, possibly as a result of Oort's visit to Russia to attend the reinauguration of the Pulkovo Observatory in 1955.

7 OBSERVATIONAL RADIO ASTRONOMY IN KIEL

Professor Unsöld developed close ties with Werner Kroebel, who became Professor of Applied Physics at Kiel University (see Figure 15). Unsöld recognised the need for observational radio astronomy in Germany and he proposed to Kroebel that they develop a suitable antenna. At that time radio (and particularly radar) research was forbidden by the West German Allied authorities, but a way around this was to build a steerable dipole array rather than a parabolic reflector. A thesis by H.J. Loose, submitted in 1951, describes an antenna intended for radio astronomical observations. Unsöld decided to observe at 198 MHz (a wavelength of 1.5 metre), so that he could derive the spectral index of galactic continuum emission. The resulting instrument, a 5m x 5m array with three rows of seven full-wave dipoles, was described by Franz Dröge (b. 1925) in 1955. Subsequent observations led to the publication of a radio map by Dröge and Wolfgang Priester (1924–2005) in 1956. The authors also used the southern sky-data from Clabon W. Allen (1904–1987) and Colin Gum (1924–1960), originally published in 1950, to make the first all-sky radio continuum map at this frequency. In this map the North Polar Spur at *l* = 30°, and other spurs, were clearly delineated for the first time (see Figure 16).

The full-wave dipole array posed some calibration problems, and these were investigated by Bernd-Harald Grahl (b. 1930) in 1958. The array antenna then was dismounted and a corner reflector was placed on the stand to determine the absolute temperature of the radio emission. The spectrum of the galactic radio emission could be determined by comparing the German observations with those made by John E. Baldwin (1931–2010) at 81.5 MHz and published in 1955. A definite non-thermal spectrum was found.

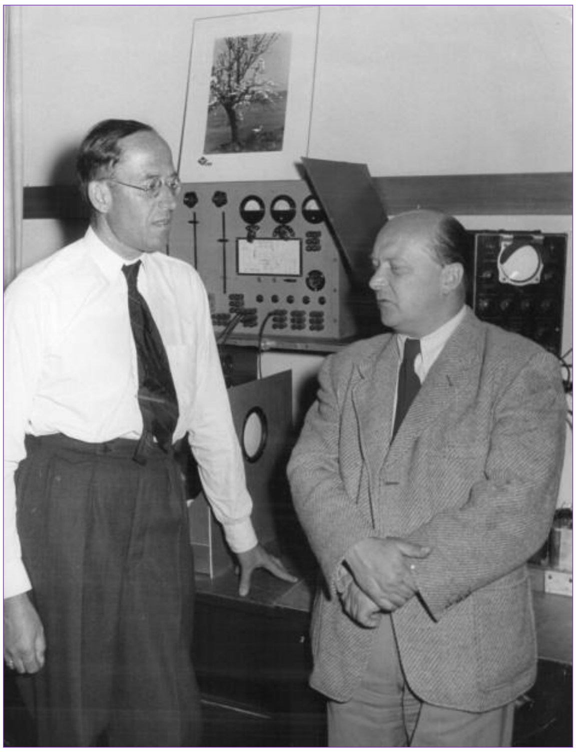

Figure 15: Professor Albrecht Unsöld (left) and Professor Werner Kroebel (right) photographed in a laboratory at the Institute for Applied Physics by Hans Hinkelmann.

Around the time when the survey was finished the prohibition on radar research in Germany was lifted and a 25m dish was under construction at Stockert Mountain for the Astronomy Department of Bonn University. Subsequently, the major investigators (Priester and Grahl) left Kiel University for the larger radio telescope. Unsöld continued to support observational radio astronomy, securing funds for a 7.5m dish that was dedicated to solar research. This antenna was used for many years, first for regular solar patrol observations (e.g. see Dröge et al., 1961) and later for high-resolution solar burst observations (e.g. see Dröge, 1977; Zimmermann, 1971). The

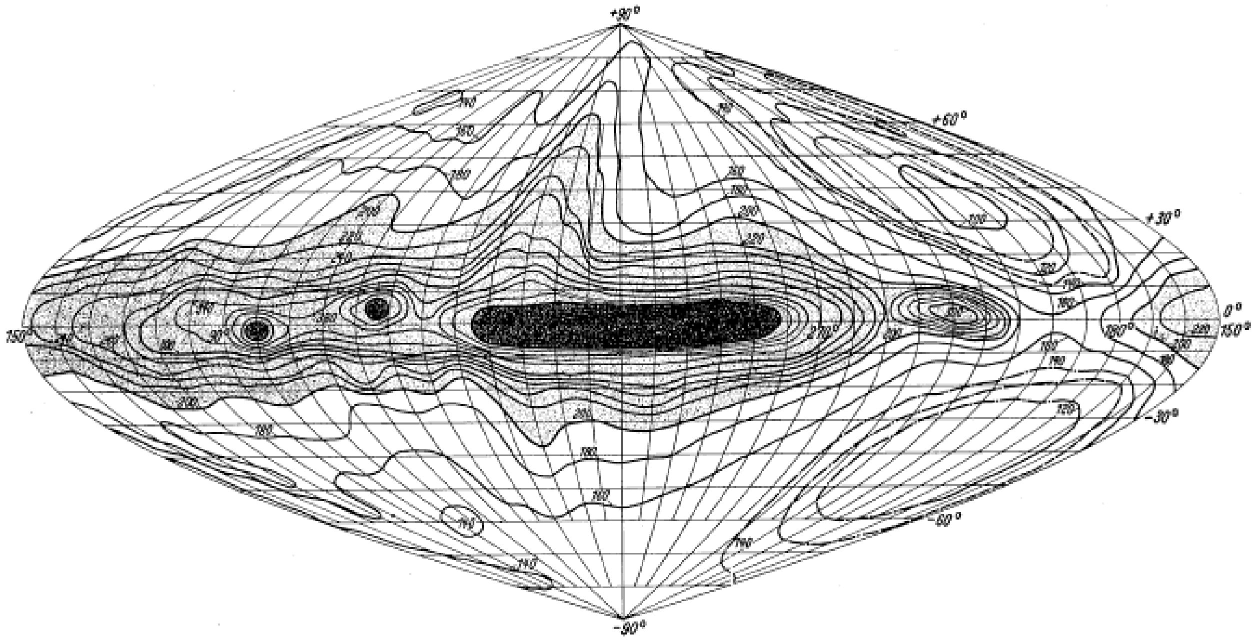

Figure 16: Isophotes of 198 MHz all-sky emission (after Dröge and Priester, 1956: 245).

development of observational radio astronomy in Kiel University is discussed in more detail by Wielebinski and Grahl (2013).

8 THE LATER YEARS

Even during the time when Unsöld was involved in the interpretation of cosmic radio waves he published many additional papers on various theoretical topics in astrophysics, but the main direction of his research—the physics of stellar atmospheres—never changed. He studied the Fraunhofer lines of the Sun, and derived a solution for the centre-limb variation (Unsöld, 1948a). He also ventured into cosmology (see Unsöld, 1948b). The second edition of *Physik der Sternatmosphären (mit besonderer Berücksichtigung der Sonne)* was published in 1955. Then Unsöld was asked by the Royal Astronomical Society to give the George Darwin Lecture, and this was published in 1958. A series of papers, published between 1960 and 1963, dealt in detail with the solar chromosphere. In 1967 Unsöld's next major book, *Der neue Kosmos*, appeared; this book was primarily intended to accompany his lectures at Kiel University, and through several different editions it became a standard work for a whole generation of students.

The theory of solar flares (Unsöld, 1968) was in a way Unsöld's farewell to radio astronomy, and his retirement in 1973 led ultimately to the closure of the radio astronomy observatory at Kiel University on 31 December 1976. This brought to an end two decades of pioneering research in German radio astronomy.

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10 REFERENCES

Alexander, F.E.S., 1946. The Sun's radio energy. *Radio & Electronics*, 1(1), 16-17, 20.

Alfvén, H., 1937. Versuch zu einer Theorie über die Entstehung der kosmischen Strahlung. *Zeitschrift für Physik*, 105, 319-333 (in German).

Alfvén, H., and Herlofson, N., 1950. Cosmic radiation and radio stars. *Physical Review*, 78, 616.

Allen, C.W., and Gum, C.S., 1950. Survey of galactic radio-noise at 200 MHz. *Australian Journal of Scientific Research*, 3, 224-233.

Baldwin, J.E., 1955. A survey of the integrated emission at a wavelength of 3.7m. *Monthly Notices of the Royal Astronomical Society*, 115, 684-689.

Baschek, B., 2011. Physics of stellar atmospheres – new aspects and old problems. In Wolfschmidt, G (ed.). *Entwicklung der theoretischen Astrophysik Nuncius Hamburgensis.* Hamburg, Tredition. Pp. 383-397.

Biermann, L., and Schlüter, A., 1951. Cosmic radiation and cosmic magnetic fields. II. Origin of cosmic magnetic fields. *Physical Review*, 82, 863-868.

Bolton, J.G., and Stanley, G.J., 1948. Variable source of radio frequency radiation in the constellation of Cygnus. *Nature*, 161, 312-313.

Bolton, J.G., Stanley, G.J., and Slee, O.B., 1949. Positions of three discrete sources of galactic radio frequency radiation. *Nature*, 164, 101-102.

Burkhardt, G., Elwert, G., and Unsöld, A., 1948. Über das langwellige Ende des kontinuierlichen Röntgenspektrums und die Theorie der Radiofrequenzstrahlung der Milchstraße und der Sonne. *Zeitschrift für Astrophysik*, 25, 310-314 (in German).

Chandrasekhar, S., and Fermi, E., 1953. Magnetic fields in spiral arms. *Astrophysical Journal*, 118, 113-115.

Davis, L., and Greenstein, J.L., 1951. The polarisation of stardust by aligned dust grains. *Astrophysical Journal*, 114, 206-240.

Dicke, R.H., and Beringer, R., 1946. Microwave radiation from the Sun and Moon. *Astrophysical Journal*, 103, 375-376.

Dombrowsky, V.A., 1954. On the nature of the radiation from the Crab Nebula. *Doklady Akad. Nauk SSSR*, 94, 1021-1024 (in Russian).

Dröge, F., 1955. Die Radiosternwarte Kiel. *Zeitschrift für Astrophysik,* 37, 125-131 (in German).

Dröge, F., 1977. Millisecond fine-structures of solar radio bursts in the range 0.2-1.4 GHz. *Astronomy and Astrophysics*, 57, 285-290.

Dröge, F., and Priester, W., 1956. Durchmusterung der allgemeinen Radiofrequenz-Strahlung bei 200 MHz. *Zeitschrift für Astrophysik*, 40, 236-248 (in German).

Dröge, F., Howeger, F., and Unsöld, A., 1961. Information Bulletin of Solar Radio-Observatories, 6. *Contributions of the Radiosternwarte Kiel.*

Elder, F.R., Langmuir, R.V., and Pollock, H.C., 1948. Radiation from electrons accelerated in a synchrotron. *Physical Review*, 74, 52-58.

Fermi, E., 1949. On the origin of cosmic radiation. *Physical Review*, 75, 1169-1174.

Forbush, S.E., 1946. Three unusual cosmic ray increases possibly due to charged particles from the Sun. *Physical Review*, 70, 9-10.

Fränz, K., 1942. Messung der Empfängerempfindlichkeit bei kurzen elektrischen Wellen. *Hochfrequenztechnik und Elektroakustik*, 59, 143-144 (in German).

Getmantsev, G.G., 1952, Cosmic electrons produce galactic radio waves. *Doklady Akad. Nauk SSSR*, 83, 557-560 (in Russian).

Ginzburg, V.L., 1946. On solar radiation in the radio spectrum. *Doklady Akad. Nauk SSSR.*, 52, 491 (in Russian).

Ginzburg, V.L., 1984. Remarks on my work on radio astronomy. In Sullivan, W.T. III (ed.). *The Early History of Radio Astronomy.* Cambridge, Cambridge University Press. Pp. 289-302.

Ginzburg, V.L., and Syrovatskii, S.I., 1965. Cosmic magnetobremsstrahlung (synchrotron radiation). *Annual Reviews of Astronomy and Astrophysics*, 3, 297-349.

Gordon, I.M., 1954. New theory of chromospheric eruptions. *Doklady Akad. Nauk Ukrain-SRS*, 1, 13-16 (in Russian).

Grahl, B.-H., 1958. Absolutmessung radioastronomischer Flächenhelligkeiten bei 198 MHz mit einer 90°-Winkelantenne. *Zeitschrift für Astrophysik*, 45, 49-67 (in German).

Greenstein, J.L., 1984. Optical and radio astronomers in the early years. In Sullivan, W.T. III (ed.). *The Early Years of Radio Astronomy: Reflections Fifty Years After Jansky's Discovery.* Cambridge, Cambridge University Press. Pp. 67-81.

Henyey, L.G., and Greenstein, J.L., 1941. Diffuse radiation in the galaxy. *Astrophysical Journal*, 93, 70-83.

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

Hey, J.S., 1946. Solar radiation in the 4-6 metre radio wavelength band. *Nature*, 157, 4.

Hey, J.S., Phillips, J.W., and Parsons, S.J., 1946. Cosmic radiation at 5 metres wavelength. *Nature*, 157, 296-297.

Hey, J.S., Parsons, S.J., and Phillips, J.W., 1946. Fluctuations in cosmic radiation at radio frequencies. *Nature*, 158, 234.

Hiltner, W.A., 1949. On the presence of polarisation in the continuous radiation of stars. *Astrophysical Journal*, 109, 471-481.

Iwanenko, D., and Pomeranchuk, I., 1944. On the maximal energy attainable in a betatron. *Physical Review*, 65, 343.

Jansky, K.G., 1932. Radio waves from outside the Solar System. *Nature*, 132, 66.

Jansky, K.G., 1933. Electrical disturbances apparently of extraterrestrial origin. *Proceedings of the Institute of Radio Engineers*, 21, 1387-1389.

Kiepenheuer, K.O., 1946. Origin of solar radiation in the 1-4 metre radio wavelength band. *Nature*, 158, 340.

Kiepenheuer, K.O., 1950a. Cosmic rays as the source of general galactic radio emission. *Physical Review*, 79, 738-773.

Kiepenheuer, K.O., 1950b. Cosmic rays and radio astronomy. *Astronomical Journal*, 55, 172-173.

Loose, H.J., 1951. Entwurf einer scharf bündelnden Antenne für Schmalbandbetrieb bei 200 MHz *Diplomarbeit*, *Institut für angewandte Physik der Universität Kiel* (in German)

McCready, L.L., Pawsey, J.L., and Payne-Scott, R., 1947. Solar radiation at radio frequencies and its relation to sunspots. *Proceedings of the*

Royal Society, *A.* 190, 357-775.

Martyn, D.F., 1946a. Polarisation of solar radio-frequency emission. *Nature*, 158, 308-309.

Martyn, D.F., 1946b. Temperature radiation from the quiet Sun in the radio spectrum. *Nature*, 158, 632-633.

Minnaert, M., 1948. Origin of fluctuating galactic noise. *Nature*, 162, 858.

Moxon, L.A., 1946. Variation of cosmic radiation with frequency. *Nature*, 158, 758-759.

Oort, J.H., and Walraven, Th., 1956. Polarization and composition of the Crab Nebula. *Bulletin of the astronomical institutes of the Netherlands*, *12, 285-308.*

Orchiston, W., 1993. New Zealand's role in the identification of the first "radio stars". *Southern Stars*, 35, 46-52.

Orchiston, W., 1994. John Bolton, discrete sources and the New Zealand field trip of 1948. *Australian Journal of Physics*, 47, 541-547.

Orchiston, W., 2005. Dr Elizabeth Alexander: first female radio astronomer. In Orchiston, W. (ed.). *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth*. New York, Springer. Pp. 71-92.

Orchiston, W., and Slee, B., 2002. The Australasian discovery of solar radio emission. *AAO Newsletter*, 101, 25-27.

Orchiston, W., Slee, B., and Burman, R., 2006. The genesis of solar radio astronomy in Australia. *Journal of Astronomical History and Heritage*, 9, 35-56.

Pawsey, J.L., 1946. Observation of million degree thermal radiation from the Sun at a wavelength of 1.5 metres. *Nature*, 158, 633-634.

Pawsey, J.L., Payne-Scott, R., and McCready, L.L., 1946. Radio-frequency energy from the Sun. *Nature*, 157, 158-159.

Reber, G., 1940. Cosmic static. *Astrophysical Journal*, 91, 621-623.

Reber, G., 1944, Cosmic static. *Astrophysical Journal*, 100, 279-287.

Reber, G., 1946, Solar radiation at 480 MHz, *Nature*, 158, 945.

Reber, G., and Greenstein, J.L., 1947. Radio-frequency investigations of astronomical interest. *The Observatory*, 67, 15-26.

Ryle, M., 1949. Evidence for the stellar origin of cosmic rays. *Proceedings of the Physical Society*, *A* 62, 491-499.

Ryle, M., and Smith, F.G., 1948. A new intense source of radio frequency radiation in the constellation of Cassiopeia. *Nature*, 162, 462-463.

Schiff, L.I., 1946. Production of particle energies beyond 200 MeV. *Reviews of Scientific Instruments*, 17, 6-10.

Schott, E., 1947. 175 MHz Strahlung der Sonne. *Physikalische Blätter*, 2,159-160 (in German).

Schott, G.A., 1912, *Electromagnetic Radiation: and the Mechanical Reactions Arising From It*. Cambridge, Cambridge University Press.

Schwinger, J., 1949. On the classical radiation of accelerated electrons. *Physical Review*, 73, 1912-1925.

Seiler, M.P., 2005. Solar research in the Third Reich. In Wittmann, A.D., Wolfschmidt, G., and Duerbeck, H. (eds.). *Development of Solar Research.* Frankfurt am Main Harri Deutsch. Pp. 199-228.

Shklovskii, I.S., 1947. Emission of radio waves by the Galaxy and the Sun. *Nature*, 159, 752-753.

Shklovskii, I.S., 1953. On the nature of Crab Nebula's optical emission. *Doklady Akad. Nauk SSSR.*, 90, 983-986 (in Russian).

Southworth, J., 1945. Microwave radiation from the Sun. *Journal Franklin Institute*, 239, 285-297.

Stephenson, F.R., and Green, D.A., 2002. *Historical Supernovae and their Remnants*. Oxford, Oxford University Press.

Sullivan, W.T. III., 1984. *The Early Years of Radio Astronomy*. Cambridge, Cambridge University Press.

Sullivan, W.T. III., 2009. *Cosmic Noise: A History of Early Radio Astronomy.* Cambridge, Cambridge University Press.

Townes, C.H., 1946. Interpretation of radio radiation from the Milky Way. *Astrophysical Journal*, 105, 235-240.

Unsöld, A., 1926. Über das Spektrum des Wasserstoffs. *Zeitschrift für Physik*, 38, 237-241 (in German).

Unsöld, A., 1927. Quantentheorie des Wasserstoffmoleküls und der Born-Landéschen Kräfte. *Zeitschrift für Physik*, 43, 563-574 (in German).

Unsöld, A., 1931. Die Kontur der Heliumlinie λ 5976 (D_3) im Spektrum der Sonnenchromosphäre. *Zeitschrift für Astrophysik*, 3, 77-80 (in German).

Unsöld, A., 1936. Stoßdämpfung in der Sonnenatmosphäre. *Zeitschrift für Astrophysik*, 12, 56-64 (in German).

Unsöld, A., 1938. *Physik der Sternatmosphären*, *mit besonderer Berücksichtigung der Sonne.* Berlin, Julius Springer Verlag (Later editions: 1955; 1968) (in German).

Unsöld, A., 1942a. Quantitative Spektralanalyse des BO-Sternes τ Scorpii I. Messung der Linienintensitäten. *Zeitschrift für Astrophysik*, 21, 1-21 (in German).

Unsöld, A., 1942b. Quantitative Analyse des BO-Sternes τ Scorpii II. Deutung des Linienspektrums. Kosmische Häufigkeit der Leichten Elemente. *Zeitschrift für Astrophysik*, 21, 21-71 (in German).

Unsöld, A., 1942c. Quantitative Analyse des BO-Sternes τ Scorpii III. Theorie des kontinuierlichen Spektrums. *Zeitschrift für Astrophysik*, 21, 229-248 (in German).

Unsöld, A., 1944. Quantitative Analyse des BO-

Sternes τ Scorpii IV. Druckverbreiterung der He und He^+ Linien. Eine neue Methode zur Bestimmung des Häufigkeitsverhältnisses von Wasserstoff und Helium. *Zeitschrift für Astrophysik*, 23, 75-97 (in German).

Unsöld, A., 1946. Die kosmische Kurzwellenstrahlung. *Die Naturwissenschaften*, 33, 37-40 (in German).

Unsöld, A., 1947. Die Kurzwellenstrahlung der Milchstraße, der Sonne und des Mondes. *Die Naturwissenschaften*, 34, 194-201 (in German).

Unsöld, A., 1948a. Über die Fraunhoferschen Linien und ihre Mitte-Rand-Variation auf der Sonnenscheibe. *Annalen der Physik*, 438, 124-138 (in German).

Unsöld, A., 1948b. Kernphysik und Kosmologie. *Zeitschrift für* Astrophysik, 24, 278-305 (in German).

Unsöld, A., 1949a. Über den Ursprung der Radiofrequenzstrahlung und der Ultrastrahlung in der Milchstraße. *Zeitschrift für Astrophysik*, 26, 176-199 (in German).

Unsöld, A., 1949b. Origin of the radio frequency emission and the cosmic radiation in the Milky Way. *Nature*, 489-49.

Unsöld, A., 1951. Cosmic radiation and cosmic magnetic fields I. Origin and propagation of cosmic rays in our Galaxy. *Physical Review*, 82, 857-863.

Unsöld, A., 1955. Astrophysikalische Bemerkungen zur Entstehung der kosmischen Ultrastrahlung. *Zeitschrift für Physik*, 141, 70-82 (in German).

Unsöld, A., 1957. Radio astronomy and the origin of cosmic rays. In Van der Hulst, H.C. (ed.). *Radio Astronomy* (Proceedings of the 4th IAU Symposium). Cambridge, Cambridge University Press. Pp. 238-240.

Unsöld, A., 1958. On the quantitative analysis of stellar spectra (George Darwin Lecture). *Monthly Notices of the Royal Astronomical Society*, 118, 3-13.

Unsöld, A., 1967. *Der Neue Kosmos*. Berlin, Springer-Verlag (in German).

Unsöld, A., 1968. On the theory of flares and some related solar phenomena. *Quarterly Journal of the Royal Astronomical Society*, 9, 294-301.

Unsöld, A., Struve, O., and Elvey, C.T., 1930. Zur Deutung der interstellaren Calciumlinien. *Zeitschrift für Astrophysik*, 1, 314-325 (in German).

Vashakidze, M.A.. 1954. On the degree of polarisation of the light near extragalactic nebulae. *Astronomicki Cirkular*, 147, 11-13 (in Russian).

Weidemann, V., 2011. Albrecht Unsöld – Biographie und Briefwechsel. In Wolfschmidt, G. (ed.). *Entwicklung der theoretischen Astrophysik Nuncius Hamburgensis.* Hamburg, Tredition. Pp. 357-378 (in German).

Whipple, F.L., and Greenstein, J.L., 1937. On the origin of interstellar radio disturbances. *Publications of the National Academy of Sciences*, 23, 177-191.

Wielebinski, R., and Grahl, B-H., 2013. Radio astronomy at Kiel University. In Wolfschmidt, G. (ed.). *Nuncius Hambugensis* (in press).

Zimmermann, G., 1971. Statistical investigation of the time-dependent fine structure of solar bursts. *Astronomy and Astrophysics*, 15, 433-443.

Richard Wielebinski was born in Pleszew, Poland on 12 February 1936. The family was evicted from their home in 1939 and after a ten year odyssey settled in Hobart, Tasmania. Richard studied Electrical Engineering at the University of Tasmania, completing B.E (Hons.) and M.Eng. Sc. degrees. In his student days Richard met Grote Reber, and was involved in the construction of a long-wavelength antenna at Kempton, Tasmania. For two years he worked for the Postmaster General's Department in Hobart, as the engineer in charge of the construction of the television transmitter ABT2 on Mt. Wellington. After being awarded a Shell Scholarship Richard studied at the Cavendish Laboratory, Cambridge, in Martin Ryle's radio astronomy group. His 1963 Ph.D. thesis discussed the detection and nature of polarised galactic radio emission. From 1963 to 1969 Richard worked with Professor W.N. (Chris) Christiansen in the Department of Electrical Engineering at the University of Sydney, and he made absolute calibrations of galactic emission with the Fleurs Synthesis Telescope, mapped the southern sky at 150 MHz with the Parkes Radio Telescope, and became involved in the early Australian pulsar detections. At the Molonglo Radio Observatory the detection of some 20 pulsars established the galactic distribution of these objects. In 1970 Richard was invited to accept the Directorship of the Max-Planck-Institute für Radioastronomie in Bonn, where he was responsible for the instrumentation of the 100m radio telescope at Effelsberg. In addition, he built up a research group that became involved in mapping the sky in the radio continuum, studying the magnetic fields of galaxies, and pulsar research. Further developments were the French-German-Spanish institute for mm-wave astronomy, IRAM, and co-operation with the Steward Observatory, University of Arizona, in the Heinrich-Hertz Telescope Project. Richard has been active in many international co-operations, in Australia, Poland, Russia (Soviet Union), India and China. He holds Honorary Professorships in Bonn and Beijing, and until recently in Townsville (Australia). He is a member of several academies, and has been awarded honorary doctorates by three universities. After retirement in 2004 Richard became involved in history of radio astronomy research. He is currently the Vice-Chairman of the IAU Working Group on Historic Radio Astronomy.