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Auroral research at the Tromsø Northern Lights Observatory: the Harang directorship, 1928–1946

Alv Egeland[1] **and William J. Burke**[2]

[1]Department of Physics, University of Oslo, Blindern, Oslo, Norway
[2]Boston College, Institute for Scientific Research, Chestnut Hill, MA, USA

Correspondence to: Alv Egeland (alv.egeland@fys.uio.no)

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Abstract. The Northern Lights Observatory in Tromsø began as Professor Lars Vegard's dream for a permanent facility in northern Norway, dedicated to the continuous study of auroral phenomenology and dynamics. Fortunately, not only was Vegard an internationally recognized spectroscopist, he was a great salesman and persuaded the Rockefeller Foundation that such an observatory represented an important long-term investment. A shrewd judge of talent, Vegard recognized the scientific and managerial skills of Leiv Harang, a recent graduate from the University of Oslo, and recommended that he become the observatory's first director. In 1929, subsequent to receiving the Rockefeller Foundation grant, the University of Oslo established a low temperature laboratory to support Vegard's spectroscopic investigations.

This paper follows the scientific accomplishments of observatory personnel during the 18 years of Harang's directorship. These include: identifying the chemical sources of auroral emissions, discovering the Vegard–Kaplan bands, quantifying height distributions of different auroral forms, interpreting patterns of magnetic field variations, remotely probing auroral electron distribution profiles in the polar ionosphere, and monitoring the evolving states of the ozone layer. The Rockefeller Foundation judges got it right: the Tromsø *Nordlysobservatoriet* was, and for decades remained, an outstanding scientific investment.

1 Introduction

Shortly after the death of Kristian Birkeland (1867–1917), Lars Vegard (1880–1963) was appointed to succeed him as professor of physics at University of Kristiania (renamed Oslo in 1925). Vegard had established outstanding credentials as a spectroscopist while studying at the universities of Leeds, UK and Würzburg, Germany under the guidance of Nobel laureates, William H. Bragg and Wilhelm Wien, respectively. Inspired by Birkeland's laboratory simulations of aurorae and campaigns in the Arctic wilderness (Birkeland, 1901, 1908, 1913), Vegard, together with the staff of the Northern Lights Observatory at Haldde, saw the need to establish a new observatory within the auroral zone that had a permanent staff, was located at a place with reasonable communications and living quarters, and equipped with the most modern sensors available to help uncover the inner secrets of the northern lights.

In February of 1925, Vegard and four other young Norwegian auroral scientists applied for a grant from the Rockefeller Foundation's International Education Board to build the *Nordlysobservatoriet* (Northern Lights Observatory) near Tromsø in northern Norway. Their proposal was accepted 15 October 1925. The foundation agreed to allocate USD 75 000 (∼ USD 2 million in current US dollars) for the acquisition of new buildings and instrumentation that would be owned and administered by the Norwegian government. The Department of Education exercised financial responsibility for its daily operations and maintained a minimum, permanent staff of four that included two scientists. Vegard remained deeply involved in the observatory's practical operations and served as its first chairman for the board of directors for more than 20 years.

The observatory (Fig. 1) was constructed on top of a smooth hill on Tromsø Island (Fig. 2), just north of Lake Prestvannet, about 2 km from the town's center. The approx-

Figure 1. Photograph of the Northern Lights Observatory in Tromsø (geographic coordinates 69°36″ N, 18°54″ E, geomagnetic latitude 67.1° N) taken in the early 1930s. The observatory is on the left. The building on the right acted as living quarters for its staff and visiting scientists. A stable auroral observing platform was constructed close to the observatory. To minimize contamination from man-made sources, two small huts for making geomagnetic recordings were built about 400 m from the observatory.

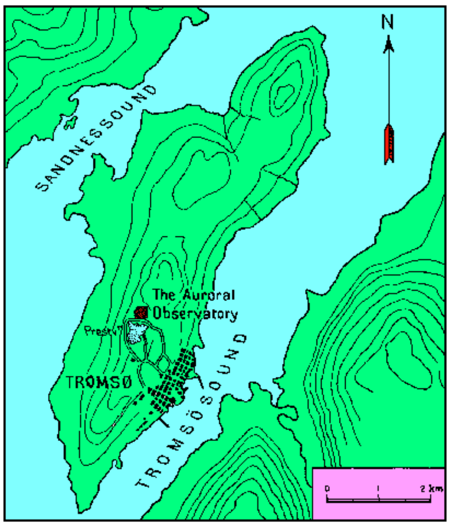

Figure 2. The Northern Lights Observatory is located on Tromsø Island on a hilltop about 110 m a.s.l. (above sea level). This 1930 map was drawn long before bridges connecting Tromsø to the mainland and a modern airport were constructed.

imately 51 000 m^2 site was donated by the town of Tromsø and Tromsøsund municipality. When construction was completed in 1928, Norway obtained a modern auroral observatory. The same year, Vegard (Fig. 3a) nominated Leiv Harang (Fig. 3b), who had recently completed his *Candidatus Realimus (Cand. Real.)* degree in physics at the University of Oslo, to become its first director. Harang took up residence in the summer of 1928, about 2 years prior to the observatory's official opening. He and *Cand. Real*. Einar Tønsberg (1900–1970) worked cooperatively with Vegard along with mathematics professor and auroral investigator Carl Størmer (1874–1957) to establish and implement the research program.

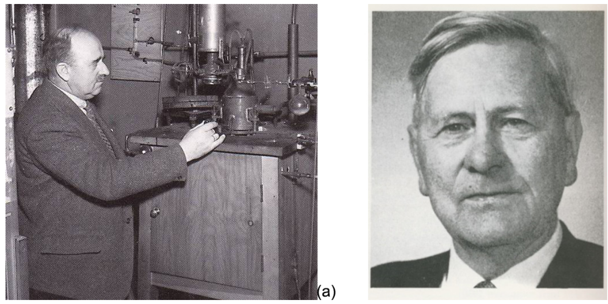

Figure 3. **(a)** Lars Vegard (1880–1963) was professor of physics at the University of Oslo. His greatest contributions came in the form of spectroscopic remote sensing to identify the photochemical sources of auroral emissions. **(b)** The first director, Leiv Harang (1902–1970), worked at the Northern Lights Observatory from 1928 to 1946 when he was appointed superintendent for Norway's newly formed Division for Telecommunication within the Norwegian Defense Research Establishment. In 1952, Harang was appointed an adjunct professor at University of Oslo, a position he held for the rest of his life. There he remained an active supporter of the research program at the Tromsø Northern Lights Observatory which he frequently visited to conduct auroral observations.

2 Research conducted at the Northern Lights Observatory prior to 1946

The first priority at the new observatory was to conduct investigations of aurorae and related phenomena. The main research topics during Harang's directorship concerned:

1. continuously recording the Earth's magnetic field: standard observations, rapid run recordings, and absolute calibrations;
2. optical measurements of wavelengths, occurrence frequencies, and height distributions of auroral spectral emissions;
3. explorations of the upper atmosphere using high-frequency sounding radio waves, starting in 1932;
4. vertical mapping the ozone layer using a Dobson spectrophotometer, starting in 1934; and
5. atmospheric electricity.

Harang proved to be very efficient at obtaining research support from multiple sources. As the observatory's leader he focused on obtaining the most sensitive instruments and data recording methods available at the time. To support optical-spectroscopy and radio-sounding investigations, new techniques and instrumentation were introduced. While studying at the University of Oslo, Harang's research had focused on X-ray spectroscopy under Vegard's supervision. Later at Tromsø (Fig. 4), they collaborated to expand the range of observed auroral wavelengths beyond the visible range into the infrared portion of the spectrum (Vegard and Harang, 1933;

Harang, 1951). In addition, during the 1930s they conducted simultaneous observations of northern lights in southern Norway and Tromsø, separated by about 1000 km. Throughout Harang's 18-year tenure as director, cutting-edge auroral research was conducted at the Tromsø Northern Lights Observatory.

In April 1940, German forces invaded Norway and continued to occupy it throughout the remainder of World War II. During the war years, ionospheric studies at Tromsø using radio-echo methods were taken over by German scientists. Harang was arrested in January 1945 and sent to Berlin where he was imprisoned until the war ended in May. Understandably, relatively few research papers were published by observatory scientists during these years.

3 Discoveries at the Tromsø Northern Lights Observatory during Harang's directorship

The Second Polar Year (1932–1933) occurred shortly after the observatory's opening. Its strategic location in the auroral zone attracted many eminent scientists, such as Nobel laureate Sir Edward V. Appleton (1892–1965) and his assistant Robert Watson-Watt (1892–1973), as well as Professor Karl W. Wagner (1883–1953) from the Heinrich Hertz Gesellschaft in Berlin, to conduct collaborative radio experiments (Brekke and Egeland, 1994; Larsen and Berger, 2000; Schlegel and Lühr, 2014). Wagner was accompanied by a young electrical engineer, Willy Stoffregen (1909–1987), who struck up a friendship with Harang during his stay. Soon after returning to Germany, both he and Wagner fell out of favor with Nazi authorities, causing Stoffregen to emigrate to Norway. With Harang's assistance he was able to obtain an industrial position. Starting in 1937, Stoffregen worked directly for the observatory where he contributed significantly, introducing high-frequency radio wave techniques to probe the auroral ionosphere (Schlegel and Lühr, 2014).

Most of the discoveries reported here were based on observations acquired during Solar Cycle 17 that covered the interval 1933 to 1946. During this cycle the levels of geomagnetic activity ranged between moderate and high. With their new and more sensitive auroral sensors, Tromsø investigators were able to detect weak but important auroral emissions that previously had been inaccessible.

3.1 Optical characteristics of aurorae

Occurrence and height distributions of different types of auroral forms, as well as their optical spectra, were recorded every clear winter night at the observatory. An important part of the studies concerned the height distributions of aurorae utilizing parallactic, photographic methods developed by Carl Størmer, and their relationships to Earth-magnetic disturbances. The techniques are described in Chapter 5 and 1, respectively of The Polar Aurora (Størmer, 1955) and The Aurorae (Harang, 1951). Harang concluded that annual variations of auroral occurrences observed at Arctic stations are significantly lower than those observed at sub-auroral latitudes. He also found that the average heights of different auroral forms were lower at lower latitudes than those observed within the normal auroral zone. From a Space Age perspective, these lowered auroral heights probably reflect the fact that precipitating electrons are more energetic during storms than quiet times and thus penetrate deeper into the atmosphere.

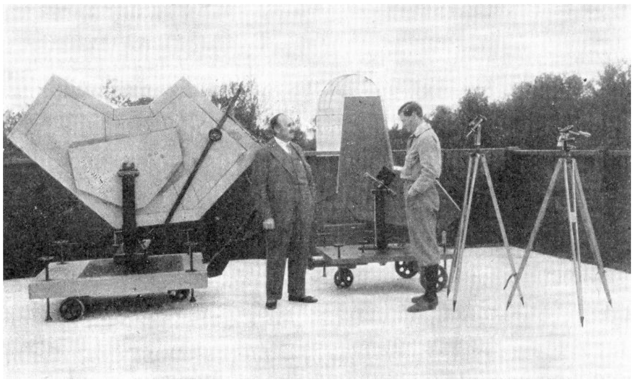

Figure 4. Lars Vegard (left) standing with Leiv Harang beside his large spectrographs at the Tromsø Northern Lights Observatory. This picture, taken in 1930, also shows a part of the observation platform. Vegard's instruments had greater dispersion and light gathering power than those at any other existing station at the time. The spectrographs were enclosed in wooden containers with heaters to control their temperature ranges.

Statistical studies of the height distributions of luminosity from auroral arcs and draperies, conducted at the observatory in 1928 and 1929, showed that E-region altitudes actually had two electron density maxima separated by ∼ 6 km (see Fig. 58 of Harang, 1951). Egedal (1929) suggested that double maxima were atmospheric tidal effects. Harang (1941, 1951) referred to the higher peaks as flood-tide and the lower peaks as ebb-tide distributions. Radio backscatter experiments conducted by Appleton and Weekes (1938) confirmed this explanation. Backscatter from the E layer also showed two electron density maxima at the same altitudes as those of auroral luminosity.

3.2 Auroral spectra

Vegard contributed to understanding auroral dynamics by simultaneously conducting spectroscopic experiments at the new Low Temperature Laboratory at the University of Oslo and field measurements at Tromsø. He was mainly responsible for the design of his own instrumentation. These sensors changed little over the discussed interval, but they allowed Vegard and his assistants to identify the sources of more than 500 lines and bands in the auroral spectrum. The observatory's unique location was clearly a critical element responsible for this outstanding scientific productivity.

Figure 4 shows Vegard with his large-prism spectrographs on the observatory platform. These instruments had greater dispersion and light gathering power than any earlier sensors. To maintain the highly sensitive detectors in near constant thermal environments, the observation platform included a heating facility. The instruments were continuous in operations during auroral occurrences. Simultaneous with their auroral observations, during this period Vegard also conducted laboratory experiments at the University of Oslo that measured emission spectra of nitrogen when bombarded with cathode rays of varying energies. While working at Birkeland's Northern Lights Observatory at Haldde, prior to the construction of the one in Tromsø, Vegard had identified the first negative band system of ionized nitrogen at 391.4, 427.8, and 470.9 nm in the aurorae (Vegard, 1913).

Vegard's life-long research interest concerned the spectral colors light emitted by the northern lights. Before his work started at the observatory, little was known about auroral spectra, and several of the observed emissions were mysterious, in the sense they could not be replicated in laboratory experiments. This was especially true of the commonly observed green (557.7 nm) and red (630.0 nm) auroral emission lines that we now know come from atomic oxygen. The latter is largely responsible for the blood red color of aurorae seen at middle latitudes during large magnetic storms during sunspot maximum years. Anders Jonas Ångström (1814–1874) was first to measure the wavelengths of green-line emissions from aurorae, albeit without great accuracy. He was unable to identify their chemical source. The mystery generated bitter disputes and deterred progress for understanding auroral processes (Kragh, 2009). Vegard (1932a) was the first to measure the wavelength of the auroral green line accurately (557.7 ± 0.1 nm) using a Fabry–Perrot interferometer. Based on laboratory experiments, Vegard (1924) and Vegard and Harang (1936) argued (wrongly) that the emissions came from frozen nitrogen dust particles in the upper atmosphere. Two Canadian scientists, McLennan and Shrum (1925), offered the correct solution, namely that 557.7 nm emissions were due to "forbidden transition" between metastable states of excited atomic oxygen. With some reluctance, Vegard (1938a, b) eventually conceded.

Some of the first observations at the new observatory included for the first time infrared plates which led to the first new auroral identification at the N_2 first positive group emissions in the aurora (Vegard, 1930a, 1932a, b). Several new auroral emissions were discovered. According to Vegard, the list of newly identified lines and bands in aurorae doubled by 1932 (Egeland et al., 2008). He also did pioneering work on the more rarely observed type B red aurorae which normally occur at the lowest altitudes. He and Harang also identified a number of other neutral oxygen (OI) emission lines in the red end of the spectrum (Vegard and Harang, 1936). More forbidden lines due to transitions between metastable excited states of oxygen to ground were detected (Harang, 1944; Vegard and Kvifte, 1945).

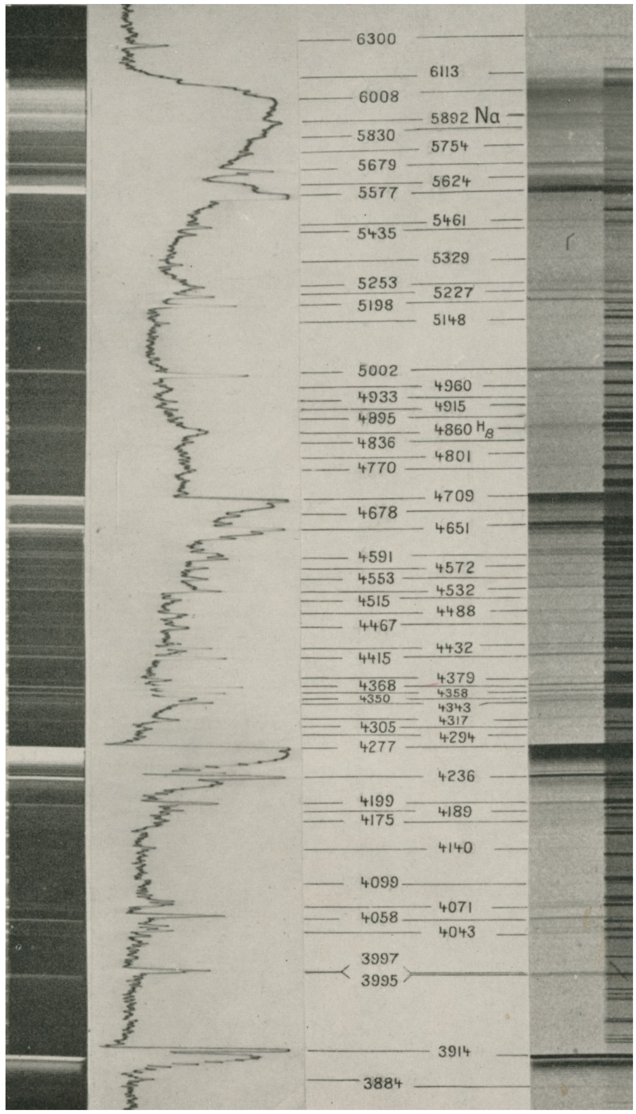

Figure 5. Auroral spectrum measured by Vegard on 23 February 1950 and published as Fig. 101 by Størmer (1955). Wavelengths of emission lines and bands are marked. By 1950, Vegard had identified the chemical sources of more than 500 different auroral emissions.

Vegard (1930a) considered the spectra of frozen gases to show that molecules radiate at many more wavelengths than atoms. He concluded: "The molecular bandspectra draw their energy from changes in: (1) electron orbits, (2) vibrational energy, and (3) rotational energy." The total energy is the sum of the three contributions. Figure 5 shows that a large number of auroral discrete lines and band emissions may occur during a single display.

3.3 Vegard–Kaplan bands

Simultaneous measurements at Tromsø and Oslo were used to document variations in the latitudes and altitudes of dif-

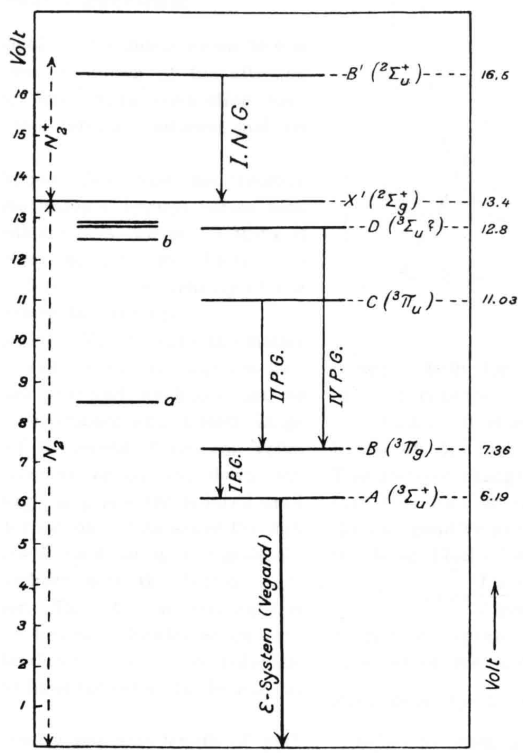

Figure 6. Vegard's energy level diagram showing the first positive nitrogen bands supplying the *A* state (often quenched in laboratory spectra, but not in the upper atmosphere) which lead to the Vegard–Kaplan bands.

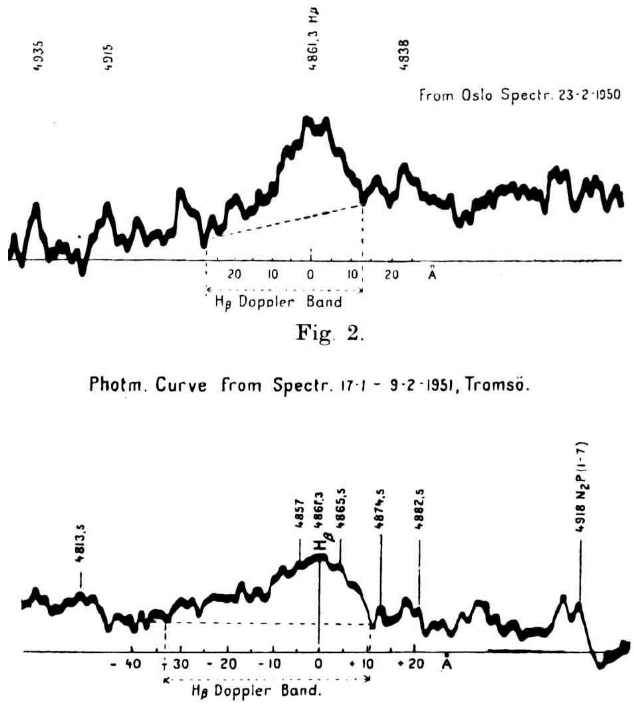

Figure 7. Simultaneous observations from Tromsø and Oslo (Vegard, 1950). Note that spectra from Oslo were more symmetric than those from Tromsø. Spectral difference reflects the fact that emitting particles were traveling toward observers in Tromsø, resulting in a Doppler shift towards the blue. Great credit is due to Vegard for this discovery.

ferent spectral emissions. Most important among these was the band system that Vegard first identified in the laboratory when layers of solid neon mixed with diatomic nitrogen molecules at the temperature of liquid helium were bombarded with cathode rays. He observed a new series in aurora that he called the epsilon bands (Fig. 6).

Vegard (1930b) postulated that epsilon-band emissions came from N_2 molecules in the excited *A* state. Kaplan (1934) reported higher dispersion measurements that confirmed Vegard's identification of this band system. He disagreed with his contention that the *A* state was the upper one. Vegard's interpretation of diatomic molecular spectra eventually prevailed. A full interpretation of N_2 spectra awaited broad applications of developing quantum mechanical theory within the spectroscopic community. Since 1935, this new system has been referred to as the Vegard–Kaplan band system. Figure 6 shows an energy-level diagram of the Vegard–Kaplan bands.

3.4 Hydrogen emissions

Probably Vegard's most famous discovery in auroral spectroscopy was his detection of the H_α, H_β, and H_γ lines in the Balmer series (Vegard, 1939). One reason that the H_α line at 656.3 nm, the strongest proton emission, had not been detected previously in auroral emissions was that its wavelength location is nearly covered by the first positive band of N_2. The H_β and H_γ emission lines of the Balmer series were too weak to detect reliably with available sensors. More characteristic were the significant Doppler broadenings and shifts of the lines. Their details were not detectable in either the previous or the following solar cycle which was even more active. Simultaneous observations from both Tromsø and Oslo of the proton emission spectra are reproduced in Fig. 7.

In the years after 1940, auroral scientists began to give greater attention to these newly detected hydrogen emissions, and soon realized that their occurrence was sporadic. This finding led them to postulate that hydrogen was not a constituent of the atmosphere. Rather, the emissions resulted from proton "showers" of solar origin. Based on precision spectrographic measurements made at Cornell University after 1939, Gartlein (1950) showed that the hydrogen line emissions were most easily identified as auroral activity increased during magnetic storms. During the following years, Vegard (1950) recorded a significant shift toward the blue in hydrogen line emissions, as seen in Fig. 7. By comparing simultaneous spectrographic observations from both zenith and horizon perspectives, it was possible to extract information about the pitch angle distributions of precipitating protons.

3.5 Temperatures of the auroral atmosphere

Vegard (1932b) was the first to measure the mean temperatures in the auroral atmosphere using recordings of the nitrogen-band spectra. Based on Doppler broadening of emission lines, he estimated a mean temperature between 95 and 125 km of $\sim 240°$ K, which agrees reasonably well with in situ observations carried out decades later in the Space Age. During the observatory period up to 1940, Vegard published nine papers on this subject. Vegard and Tønsberg (1938) included an overview of a large amount of previous observations. The average temperature for the region 95–125 km was later determined to be 240.5 °K with a variation of $\pm 7°$. After Vegard's initial measurements were published, similar observations were carried out at many stations around the world.

3.6 Magnetic field measurements

Using standard techniques, the three components of the geomagnetic field and their spatial–temporal variations were recorded continuously to support research that would address questions that had vexed European scientists for centuries.

- Why do the northern lights appear overhead when the Earth's magnetic field is disturbed and large irregularities are observed in the ionosphere?
- How are magnetic storms connected to disturbances on the Sun?

Harang (1936) summarized conclusions about magnetic pulsations that were reached during the course of his doctoral dissertation research.

Shortly after the conclusion of World War II, Harang (1946) published two studies on high-latitude magnetic disturbances that, in the assessment of Heppner (1972), rank alongside the classical works of Chapman and Bartels (1940) and Vestine et al. (1947). High-latitude magnetic disturbances and auroral displays are never found to be completely identical at a given location from one day to the next. Connections between observed magnetic perturbations and their sources are therefore very variable and complex.

As illustrated in Fig. 8, Harang analyzed diurnal patterns of magnetic variations as functions of latitude and local time as observed at 11 stations spread across the Scandinavian longitude sector. The figure shows magnetic perturbations typically found as functions of latitude and local time. The three diagrams show the typical senses of magnetic perturbations in the horizontal (ΔH) (top), declination (ΔD) (lower left), and vertical (ΔZ) superposed on magnetic latitude-versus-local time grids. Harang was the first to recognize a distinct pattern that was marked by reversals in the signs of the three field components in the nightside auroral belt. The local times where reversals occur depend on the latitude of observations.

Causative ionospheric currents responsible for observed reversals in perturbation field directions are now called the "Harang discontinuity". These ionospheric currents flow at altitudes near 120 km, changing from eastward to westward across a narrow span in local time, as marked by a dash line in the ΔH plot. The polarity reversal generally occurs between 22:00 and 23:00 MLT. In the northern hemisphere, ΔH traces change sign abruptly from positive (northward) to negative (southward) as recording stations rotate under the Harang discontinuity. Space Age observations and modeling show that the Harang discontinuity is marked by intense sheets of upward Birkeland currents that couple the auroral ionosphere to the nightside magnetosphere (Erickson et al., 1991).

As the sensitivity of magnetometers and data recording devices grew in the late 19th century it became possible to detect perturbations with relatively long (0.2–600 s) periods and amplitudes of a few nanotesla (nT). Eschenhagen (1896) was first to describe such regular oscillations in the three components of the Earth's magnetic field at middle latitudes which he called "elementary waves". During the winter of 1899–1900, Birkeland (1901) observed similar, sinusoidal magnetic oscillations with large amplitude at his auroral observatory at Haldde in northern Norway. Rolf (1931) and Harang (1932) reported similar oscillations at auroral stations in Abisko (Sweden) and Tromsø, respectively. Harang referred to them as "micro-pulsations" a name that continues to be used into the 21st century. A few years later, Harang (1936) published back-to-back reports describing a class of rapid micro-pulsations, observed at the Tromsø and Sodankylä (Finland) observatories, that are now referred to as continuous pulsations of the first kind (PC-1). Shortly after the German invasion of Norway, Harang (1941) published a review paper summarizing the characteristics of 97 micro-pulsation events that had been observed at Tromsø between 1929 and 1940. In this report, Harang listed the Greenwich mean times, the amplitudes of magnetic components, the durations of events and the periods of the oscillations. By comparing them with observations at other auroral stations, he established the local time dependence of micro-pulsation phenomena. It is interesting to note that after the development of magnetohydrodynamic theory in the 1950s, micro-pulsations would be seen as tools for the remote sensing of dynamics in the magnetosphere and the interplanetary medium.

3.7 Probing the upper polar atmosphere using radio waves

Prior to 1932, only optical sensors and magnetometers were used at the observatory to study the polar atmosphere at high altitudes. During The Second Polar Year Appleton's

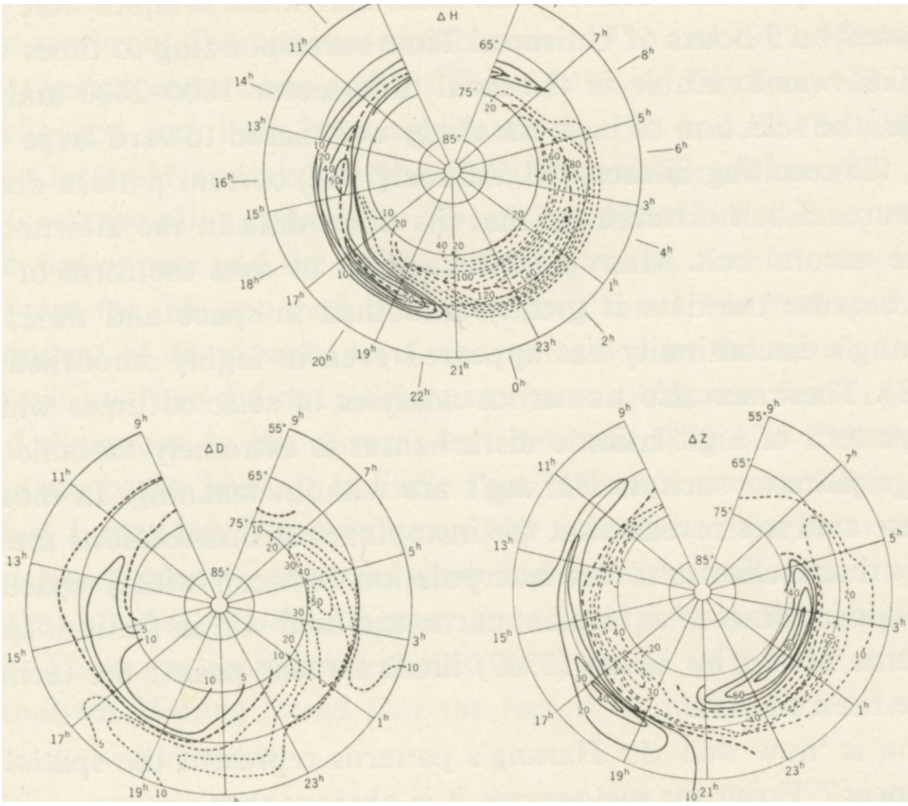

Figure 8. Typical distributions of ionospheric currents responsible for perturbations in the magnetic field's horizontal (ΔH), declination (ΔD), and vertical (ΔZ) components plotted on magnetic latitude-versus-local time grids (Heppner, 1972). The Harang discontinuity location is highlighted by a dashed line.

group inspired investigations at Tromsø using radio waves. Pulsed transmitters were used as ionospheric sounders. Systematic radio measurements started in the fall of 1932 and grew in importance during the following years. After the radio echo technique was introduced, observatory investigators soon discovered that the E region often splits with two electron density maxima separated by approximately a few kilometers and that the F region normally divides into the F_1 and F_2 layers (Harang, 1938). As mentioned above, it was during this time that Willy Stoffregen first became an observatory staff member. A major portion of our knowledge about the upper atmosphere between about 70 and 400 km has been obtained using the radio echo techniques, first systematically applied during the Second Polar Year.

In 1934, Harang and his coworkers began to study the ionospheric E and F layers above the observatory. Changes in critical frequencies and reflection heights between quiet and disturbed days and their relationships to geomagnetic perturbations and auroral occurrences were Harang's main interests. Several discoveries were made regarding the formation of the ionosphere at polar latitudes. Harang's studies provided the main material for the first doctoral dissertation written at the observatory (Harang, 1938).

Figure 9 provides an example of how quickly observatory scientists mastered the radio wave technology, now referred to as ionosondes, needed to probe the dynamics of the ionospheric layers as they transitioned between periods of magnetic quite and disturbance. The top traces show measurements of terrestrial magnetic fields' declination (D), horizontal (H), and vertical (V) components on 15 (left) and 16 (right) May 1935. Perturbations seen on 16 May indicate the presence of overhead currents in the ionosphere that were not present at the same time on the previous quiet day. Below are plots of the virtual heights of the reflection layers in the ionosphere. These are the heights calculated from the times radio signals would take to reach their reflection heights and return to the ground, if they had been traveling the whole way at the speed of light. The bottom traces show inferred height profiles of electrons in the E and F layers that account for the slowing down of radio waves while they were traversing the ionosphere.

Note that the measurements were made while Tromsø was in sunlight when auroral light used to estimate ionospheric height distribution cannot be seen. While Harang's main focus was to understand how ionospheric electrons are redistributed at afternoon local times between quiet and disturbed conditions, we cannot help but be impressed with the sophis-

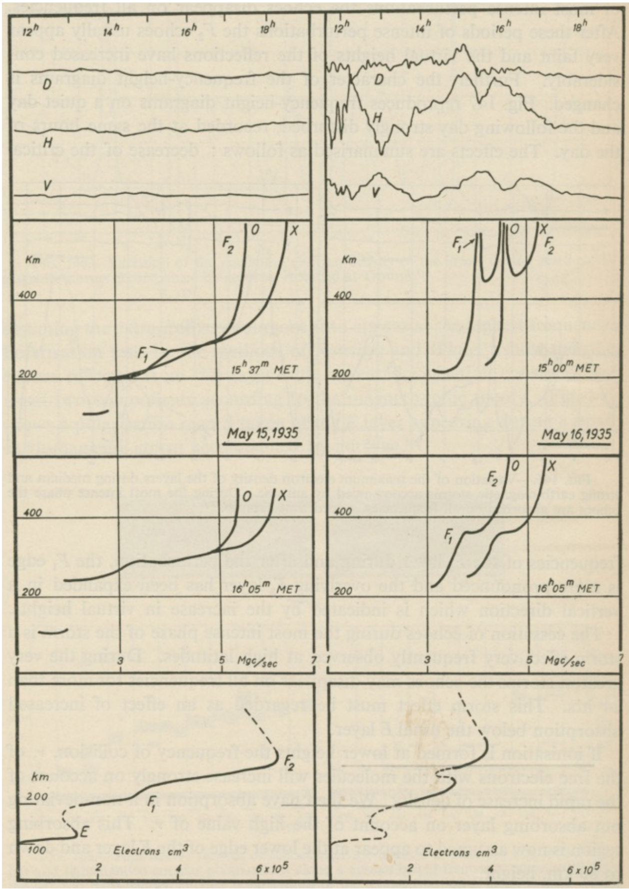

Figure 9. Example of magnetometer and ionosonde data acquired at Tromsø over the same time intervals on the consecutive quiet and disturbed days, 15 and 16 May 1935. The top traces show the three components of the Earth's field. The second and third traces show virtual reflection heights of O- and X-mode waves at two different times. Traces in the bottom panels show the height distributions of electron densities inferred after corrections for radio wave travel times (Harang, 1951).

tication of his quick mastering of a very new remote sensing tool.

3.8 Radio aurora

Scattering of high-frequency radio waves from auroral ionization is known as radio aurora or coherent auroral backscattering. Thus, the occurrence of aurorae can be detected by radio waves even if optical viewing is not possible. The first scientific studies of radio aurora were carried out by Harang and Stoffregen in Tromsø in 1939, with a pulsed transmitter operated at 9 MHz (Harang and Stoffregen, 1938, 1940). Unfortunately, they misinterpreted their results by claiming echoes were received through the main lobe of their antenna from heights between 850 and 1300 km, instead of via side lobes. For the first time these echoes were connected to overhead aurorae. As these pioneer observations have recently been summarized by Schlegel and Lühr (2014), we will just refer here to their paper.

3.9 Ozone measurements

Stratospheric ozone (O_3) is a form of oxygen that protects the biosphere from deadly UV rays from the Sun and is thus essential for the survival of most life forms on the Earth. Its spatial distribution over the planet is highly variable. George M. Dobson, a British scientist, pioneered measurements of atmospheric ozone. With his Dobson spectrophotometer, he visited the observatory in 1934 and left behind one instrument for future studies. Subsequently, height profiles of O_3 were recorded by E. Tønsberg and other coworkers. In 1939, the group acquired a new and upgraded Dobson instrument. Thus, the first sustained measurements of O_3 at polar latitudes were conducted by the observatory's staff. A summary of all ozone observations was published in Investigations on Atmospheric Ozone at *Nordlysobservatoriet*, Tromsø (Langlo, 1951). The many years of observations conducted at the observatory has provided an invaluable resource for assessing long-term trends in the ozone layer. For example, results of ozone recordings at the observatory contribute significantly to material in the textbook by Henriksen and Larsen (1989) used in the course on environmental science at the University of Oslo.

4 Concluding remarks

This brief summary of the many auroral discoveries made in the early years of the Northern Lights Observatory in Tromsø clearly demonstrates the brilliant work carried out by Lars Vegard and Leiv Harang and their staff during Solar Cycle 17. The observatory's working scientific staff was small. However, both Vegard and Harang were adept in making the most of their talents in solving the cutting-edge problems of the 1930s. Equally impressive was their openness to foreign visitors and the new technologies they brought with them. The occurrence of the Second Polar Year soon after the observatory's official opening was serendipitous. It drew Sir Edward V. Appleton and Professor Karl W. Wagner to Tromsø to conduct radio wave experiments' probing of the auroral ionosphere. With Wagner came Willy Stoffregen who, due to tragic circumstances in Germany, returned to the observatory where, in modern parlance, he transferred radio wave technology and practical knowledge to his Norwegian hosts.

Nothing in this world remains the same forever. It either evolves or dies out. Such is the case of the Tromsø Northern Lights Observatory. Over the intervening years, many of the original problems associated with the aurorae were solved, especially after regular access to space was achieved through sounding-rocket and satellite-borne sensors. The city of Tromsø grew and electrical lighting degraded auroral monitoring. Today, the *Nordlysobservatoriet* lives on, but as part of the University of Tromsø's Geophysical Observatory. It is now located about 30 km south of Tromsø in Ramfjordmoen where ground-based monitoring of the auroral ionosphere's dynamics continues. Today's technology at the observatory's site includes all-sky imagers, ionosondes, and incoherent scatter radars that provide information with temporal and spatial resolution undreamed of in the 1930s. Vegard and Harang would be proud of how their pioneering work continues to flourish. Research conducted at the observatory in the Harang years provided a secure platform for Norwegian scientists to enter the subsequent Space Age.

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