

The aurora is probably the most fascinating and mysterious of the many spectacles that Nature produces. It has stirred man's imagination and curiosity as long as earth has been inhabited.

Only direct observations can reveal the three-dimensional grandeur of the aurora. The most conspicuous emission in the spectrum is the auroral green line (557,7 nm) which is responsible for the typical auroral colour. This emission line was first discovered by Ångström in 1868, who measured its wavelength as 556,7 nm.

At the end of the 19th and early in the 20th century several Nordic expeditions were carried out in the arctic regions. In 1912 Vegard correctly attributed another part of the emission spectrum to N_2 and in 1939 he detected the auroral hydrogen lines and interpreted them as due to showers of protons being neutralized in the earth's atmosphere. Størmer and colleagues, with the aid of photographic observations, placed our knowledge of the location and height of the aurora on a firm base.

In 1896 Birkeland had suggested that auroras occur as a result of solar electrons being bent towards the polar regions by the earth's magnetic field. He performed laboratory (terrella) experiments to demonstrate that the motion of electrons towards a magnetized sphere causes the observed auroral zones. Intrigued by these experiments, Størmer, in 1904, began his studies of the motion of charged particles in a magnetic dipole field. He verified Birkeland's interpretation of the experiments and found also the forbidden regions of trapped particles in a dipole field.

Birkeland demonstrated that strong electric currents (due to the energetic particle precipitation) flow near the auroral zone; i.e. now called electrojets. He also discussed polar elementary storms which are similar to the substorm picture now adopted. Birkeland explained the magnetic perturbations by a system of two vertical currents parallel to the earth's magnetic field, in opposite directions, connected by a horizontal section in the ionosphere. He also suggested that some worldwide magnetic disturbances could be produced by a ring current encircling the earth in the equatorial plane.

From about 1930 up to 1960 the height of the ionosphere was mainly

explored by ground-based radio waves (see accompanying article). Several ionosondes have been and are still operated in the Nordic countries, together with VLF propagation, partial reflection, cross-modulation, and coherent scatter observations. The basic ideas concerning the formation and the dynamics of the ionosphere have slowly emerged during this period.

In the years around 1940, Alfvén advanced a number of theories in fields related to cosmic physics. He suggested theories for aurora and magnetic storms, which, although controversial, stressed the necessity for electric fields in the space surrounding earth. In order to compute the motion of charged particles in electromagnetic fields, he developed a perturbation technique, and introduced the guiding centre concept together with the first adiabatic invariant, the magnetic moment of charged particles. The prediction of magnetohydrodynamic waves and the introduction of «frozen in» magnetic fields in matter of high conductivity are attributed to him.

Outstanding Problems in Cosmical Geophysics

A large number of significant new observations from satellites rockets and balloons have been combined with ongoing ground observations to provide a basis for advanced models and theories for the sun-earth system, during the last decade. Even though substantial progress in our knowledge has resulted, many fundamental problems remain. These can all be grouped into the area of the coupling and interaction between the interplanetary space, the magnetospheric-ionospheric regions, and the neutral atmosphere. The main aim of Nordic research in this area is to understand the characteristics of the polar ionosphere (i.e. poleward of 60° mag. lat.) and to explain the basic interaction processes in this region.

It is now well established that the main part of the energetic particles (of solar and magnetospheric origin) impinge on the polar ionosphere along an oval and cause the luminous auroral belt as illustrated in Fig. 1. The auroral ionosphere undergoes more

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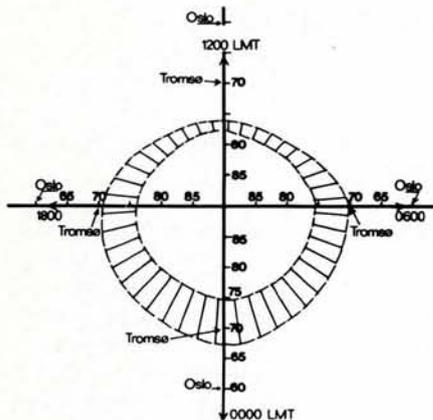


Fig. 1. An idealized representation of the auroral oval vs. geomagnetic latitude and time. The location of Tromsø and Oslo relative to the oval is indicated.

or less continuous, unpredictable structural changes of almost all scales of size and time. A latitudinal profile of the night time aurora can in general be characterized as a single broad (order of 100 km) maximum (diffuse aurora) together with one or more narrow strips on the poleward side (discrete aurora). The exact location of this oval with respect to time, magnetospheric-boundaries and solar-terrestrial activity is not known.

The daytime auroras are considerably different from those in the night sector. They are caused by energetic particles with the characteristics of the magnetosheath plasma penetrating the magnetospheric cleft regions (Fig. 2). Because the average energy of these particles is well below 1 keV, the auroral emissions are produced above 200 km. The midday aurora is therefore relatively rich in atomic emissions particularly in the red part of the spectrum. The auroras at night are much richer in the green and blue part of the spectrum and their average

altitude is around 110 km. Thus, the night time auroral particles are typically a factor of 10 to 100 more energetic than those precipitating during the day. Another striking feature of the auroral displays is the fact that the proton rich auroras occur on the equatorward side of the oval in the evening while in the morning sector they dominate on the poleward side. Furthermore, protons contribute very little to the discrete auroral luminosity. Understanding the space-time morphology of the proton aurora as it contrasts with that of electron aurora is a major unsolved problem. Large temporal and spatial variations of particle precipitation occur at night and the main energy sources for discrete and diffuse auroras are probably different. The conversion factors between net downward particle energy and auroral emissions have been studied in fairly great detail, but this problem is not solved yet.

Another fundamental and permanent feature of the polar ionosphere seems to be a dynamic system of currents. This consists of an inward field-aligned (Birkeland) current from the dawnside magnetopause to the forenoon sector of the auroral oval (positively charged) and an outward Birkeland current from the afternoon sector of the oval (negatively charged) to the duskside magnetopause, bound together with the ionospheric (Pedersen and Hall) electrojet currents. The resulting ionospheric charge distribution causes a discontinuity in the electric and magnetic field, with reversals of the ionospheric current and fields near magnetic midnight. However, the ionospheric distribution of the electric field is asymmetric with respect to the earth-sun line. Geomagnetic gradients and curvatures as well as

electric fields, with superimposed temporal and spatial variation, cause large scale circulation in the magnetosphere and the ionosphere. In this way the disturbances are spread all along the oval.

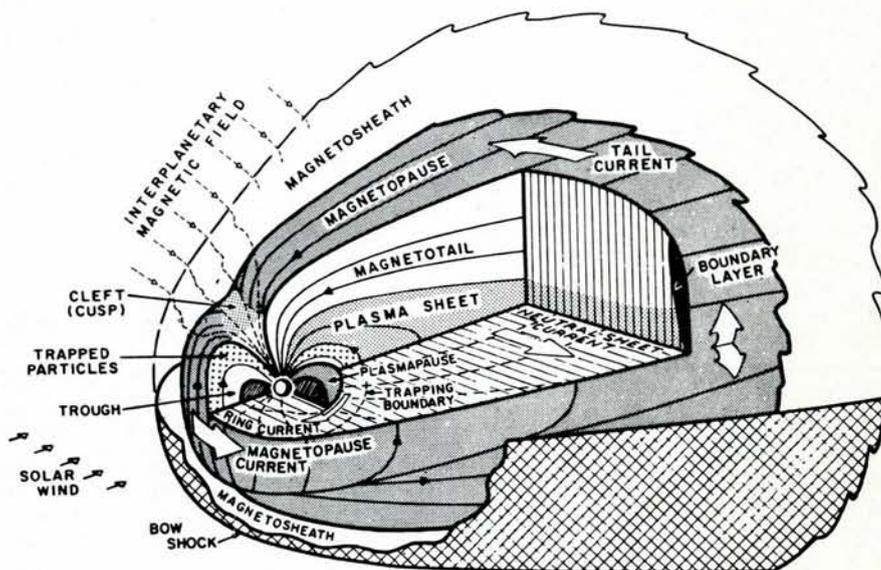
The central part of the plasma sheet, the main reservoir for night time auroras (Fig. 2) contains the hottest plasma, while a substantial cooling occurs towards the boundaries. These spectral characteristics may explain in a general sense the different types of auroras vs. latitude; i.e. a fairly uniform flux across the diffuse aurora from the inner part of the plasma sheet, irregular variations in the discrete region from the outer sections. Considerable acceleration either in the equatorial plane and/or along the field lines must occur in order to produce the night time aurora and the ionospheric disturbances. The energy reservoir in the plasma sheet is large enough to provide a few auroral displays and magnetic storms without new supply from the solar wind.

The plasma sheet particles are probably injected or scattered into the atmosphere by some type of wave-particle interaction. When the Birkeland current density reaches a critical value, a wave instability or a double layer may rise which can accelerate the precipitating particles sufficiently to start the auroral disturbances. There may, however, well be other types of mechanisms which «start» the activity. The main requirement is that a sufficient amount of hot electrons are lost in the polar ionosphere.

Main Research Projects

The most interesting, but also the most complex phenomena in cosmic geophysics occur within the auro-

Fig. 2. The effect of the solar wind low-energy electrons and protons flowing past the earth is to produce a bow shock and a transition region called the magnetosheath around the magnetosphere. It is beginning to appear that the solar wind particles gain access into the magnetosphere through the clefts in the dayside magnetopause where the high-latitude magnetic field lines are swept back into the magnetotail and from there into the plasma sheet, which is the immediate source of the auroral particles.



ral region and nowhere else in the world is the climate at auroral latitudes so hospitable as in Northern Scandinavia. Cosmical geophysics, as a result, has been and still is an important field of research in these countries.

Eight permanent, well equipped observatories exist more or less along the auroral oval from Finland to Greenland, a longitudinal span of more than 60° (Fig. 3). Furthermore, a chain of nine stations from Southern Scandinavia to Spitzbergen covers more than 20° in latitude, across the oval, at about the same longitude. Several temporary stations are operated within this area on an ad hoc basis, as well as the advanced incoherent scatter radar discussed later.

In addition, three modern ranges for sounding rockets are in operation. Research groups from the USA, Canada, and several European countries have launched more than 200 rockets from these ranges during the past decade. Also, instrumented balloons, at 30 to 40 km altitude, are frequently used for ionospheric research in this part of the world.

In the following, the parameters studied by the different groups are listed :

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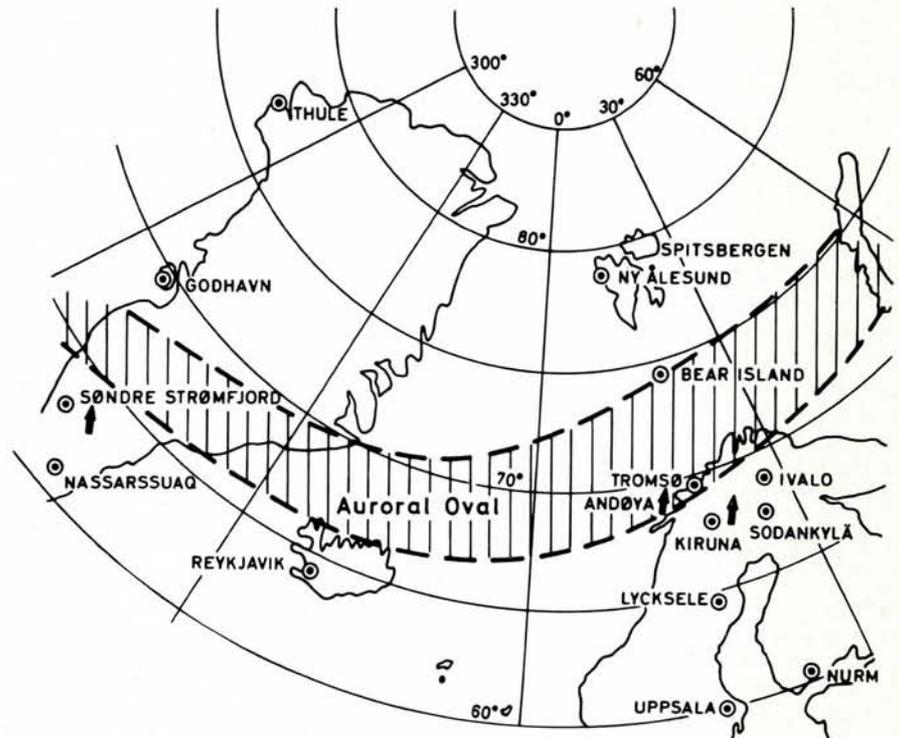


Fig. 3. A map showing several permanent observatories in the polar region relative to the evening auroral oval. The 3 arrows indicate the location of rocket ranges.

Ground observations : The morphology and the spectral characteristics of the auroral emissions are mapped out by the use of all-sky cameras, meridian scanning and fixed photometers, spectrometers and TV-cameras. Different radio instrumentation covering the wavelength range from several km to less than one m are used to obtain continuous information on the ionospheric layers and their temporal and spatial variations. Variations in the geomagnetic field from DC to approximately 10 Hz, and their relation to ionospheric currents are recorded simultaneously at more than 10 different observatories. In addition, naturally occurring electromagnetic emissions in the range 10 Hz to about 1 MHz generated by the energetic particles in the magnetosphere, are recorded. The different parameters are analyzed vs. time, location, and solar-terrestrial activity and the results are compared with similar recordings from different parts of the world.

Satellite observations: A few groups in Denmark, Norway, and Sweden have constructed instruments for satellite observations. Their analyses of high- and low-energy electron and proton fluxes in different directions relative to the geomagnetic field lines, the luminosities of electron and proton auroras, and the AC and DC electric and magnetic fields have contributed significantly to our knowledge of processes occurring in the near-earth magnetosphere.

Rocket observations : By the use of rockets it is possible to obtain in situ measurements of the auroral parameters during day and night for different kinds of ionospheric disturbances. The most frequent parameters observed are energetic particles of all energies, AC and DC electric and magnetic fields, light emissions, plasma and neutral composition and densities. Active release and radio experiments as well as accelerators are also used in rockets. Roughly the same type of instrumentation can be used as for the balloons.

Both vertical and low elevation rockets, different payload configurations such as mother-daughter as well as pairs of rockets have been utilized. From these kinds of measurements it is possible to obtain information about the intensities and net downward particle energies, investigate different kinds of plasma instabilities and particle acceleration mechanisms.

It is necessary to understand the physical and chemical processes in the polar ionosphere in order to establish the energy balance, and explain the coupling between the different regions from the neutral atmosphere close to the ground up to interplanetary space. These scientific goals can only be realized by further investigations (both experimental and theoretical) of the magnetosphere, the interplanetary space, and in particular the polar ionosphere.