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THE SOLAR WIND AND POLAR AURORAE

by

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# UNEDITED ROUGH DRAFT TRANSLATION

THE SOLAR WIND AND POLAR AURORAE

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**ABSTRACT :** The author analyzes some similarities in the origin of comets and aurorae, with emphasis on light radiation and solar corpuscular radiation, compare the tails of comets with that of the earth, and finds similarities in their formation. Still unexplained factors in the tails of comets will probably be understood after observations of the interaction of the solar wind with the magnetic field and the earth's atmosphere. It is quite possible that strongly magnetized comets may be found. Aurorae are of special interest because the interaction and combined flow of plasma of charged particles of the solar wind with the earth's "electromagnetosphere", as the author calls the matter closest to the earth's surface boundary layer, may be observed in them. In his discussion of the origin of aurorae, the author emphasizes the importance of the phenomenon of dissipation of the earth's atmosphere. He also discusses the complex interaction of solar wind with the magnetic field and the small increase of solar-wind energy even during the strongest aurorae, as compared to the extremely frequent changes in aurorae intensity. The importance of finding out how the magnetic field of interplanetary space is related to the solar-wind matter is stressed. The author adds that the confirmation of a recent American discovery of helium ions in the solar wind will also confirm the magnetohydrodynamic action as at least a complimentary cause of the discharge of solar particles. The fine composition of aurorae may be related to the existence, in the earth's surface boundary layer, not only of the extremely variable magnetic fields of the solar wind, but also of electric fields related to the circulation of the ionosphere, which may account for the extreme variation in aurorae intensity. The author does not believe in the existence of a third, outermost, terrestrial radiation belt, and adds that the more descriptive word, "sponge" should be used instead of "trap" when discussing charged-particle traps in the geomagnetic field. Orig. art. has: 4 figures. English translation: 14 pages.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й я	<i>Й я</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

\* ye initially, after vowels, and after ъ, ь; e elsewhere.  
 When written as ѣ in Russian, transliterate as yě or ě.  
 The use of diacritical marks is preferred, but such marks  
 may be omitted when expediency dictates.

## THE SOLAR WIND AND POLAR AURORAE

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At first glance there is nothing in common between comets and polar aurorae. But with more through examination it is explained that they have many common traits, mainly, that both phenomena are formed during the participation of radiant and corpuscular radiation of the Sun. A comparison of data about comets and polar aurorae and also about the radiation exciting them allows a better comprehension of their nature.

### Comet Tails and the Gas Tail of the Earth

Comets are small bodies of the solar system. They are much smaller than the smallest satellites of the solar planets. But in contrast to meteorites, which consist basically of solid material, comets contain considerably more volatile components. When approaching the Sun tails appear in them; these disappear again when they leave the Sun. Properly speaking, comets are mostly known by the bright tails of some form or other (Fig. 1). These tails are formed as a result of the interaction of neutral and ionized gases and dust particles that fly off from the comets with radiant radiation and ionized gasses emitted by the Sun, streams of which are called solar wind. Comet tails are subject to

observation because of the glow of the vaporizing material under the effect of solar radiation.

It is interesting that even about twenty years ago it was established that the Earth also has a tail, similar to a comet tail. We see it as a night glow close to the antisolar point - gegenschein (Fig. 2). This treatise belongs to Academician V. G. Fesenkov and Professors I. S. Astapovich and N. N. Pariyskiy. The gegenschein brightness increases during the polar aurorae.

The tail of the Earth is somewhat different from that of a comet, since it has a greater mass, it is strongly magnetized, and it is surrounded by a dense atmosphere. In the earth's tail the predominant component is gas, not dust. Ions and electrons fly off from the terrestrial ionosphere, and their streams are blown off and compressed by the solar wind. Initial evaluations have shown that on the boundary of the earth's umbra in the terrestrial tail are contained several hundred pairs of ions per cubic centimeter. Such an intensive stream of plasma, i.e., a mixture of electrons and ions, should distort and delay the penetration of the geomagnetic field into the central regions of the tail. That is why the geomagnetic field should be more extensive in the antihelion direction (Fig. 3).

#### The Cause of Polar Aurorae

Recently American scientists with the aid of satellites discovered namely such a deformation of the geomagnetic field and interpreted it as the tail of the earth. But they considered it, in our opinion, as too simplified only as a result of the flow of the solar wind around the geomagnetic field. Many years of investigations of aurorae have enabled us to accumulate vast

material that confirm a physically richer physical concept which takes into account scattering (dissipation) of the terrestrial atmosphere. It has been reliably established that around the geomagnetic poles there often appear very intense streams of energetic electrons, protons, and, possibly, even helium ions. Their collisions with atmospheric atoms and molecules lead to the glow called the polar aurorae. It is very characteristic that regions of proton invasion do not coincide with regions of the invasion of the densest stream of electrons in the so-called radiant formations of aurorae. In places with an excess of protons there is created an electrical field, which not only compensated for the power of terrestrial gravitation, but can also intensively eject positive terrestrial ions beyond the boundaries of the geomagnetic field. This process of dissipation of the terrestrial atmosphere is accelerated by its heating at the time of polar aurorae by the energetic ally charged particles which come from without and the rapid vibrations of the geomagnetic field, the so-called magnetohydrodynamic waves. A substantial rise in temperature of the upper atmosphere and its expansion at the time of aurorae is presently well known. The upwards rise in that period of even such heavy ions as ions of molecular nitrogen is well observed by their fluorescence in solar radiation (Fig. 4). In this way, invasion of foreign material into the terrestrial atmosphere during aurorae is accompanied by dissipation of the atmosphere. The now reliably established low relative content of hydrogen in the upper atmosphere compared with the surface region is the results of its intensive dissipation. This scattering of the lightest atmospheric element is the most intense the greater the

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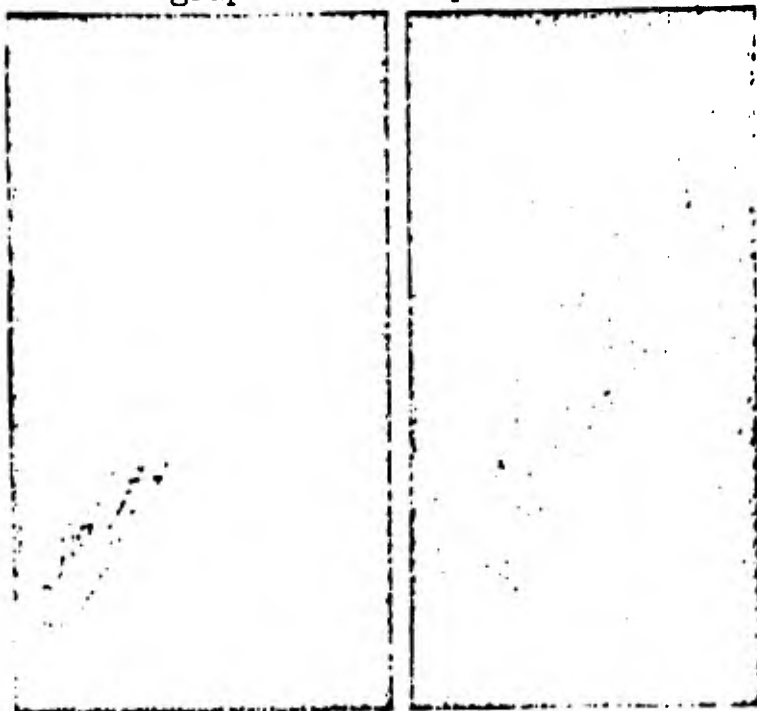


Fig. 1. The Morehouse comet: October 23, 1908 (left); October 30, 1908 (right). Gaseous tails of comets sometimes sharply change their configuration and brightness. The most rapid and grandiose changes observed in the Morehouse comet 1908 - in the years of maximum solar activity.

ions streams invading from without and the stronger the heating of the upper atmosphere.

#### The Solar Wind and the Geomagnetic Field

On the basis of what has been said it was possible to represent the anticipated picture of solar wind interaction with the geomagnetic field (see Fig. 3). The incident stream of particles first creates at a certain distance from the earth a magnetohydrodynamic shock wave. As a result there is a redistribution of energy between the protons and electrons of the solar wind. One part of such deformed streams penterates into the ionosphere of the earth, the other flows around the geomagnetic field. Simultaneously

terrestrial ions dissipate from the polar regions of the atmosphere. As result of blowoff by the solar wind they form the central part of earth's tail.

But in reality everything takes place considerably more complexly. A number of circumstances connected with aurorae and solar wind require additional explanations. Up until the time of rocket investigations it was assumed that the solar wind is a constantly acting phenomenon. Voluminous contemporary materi confirmed this initial assumption. It was especially remarkable, however, that the energy of the solar wind even during the strongest polar aurorae is not much greater than its energy under ordinary undisturbed conditions. The intensity of polar aurorae changes sometimes by a factor of more than ten thousand. Each of them, in spite of certain general traits, is nonrecurrent. The energy of individual protons of the solar wind is low (usually several kiloelectronvolts), and the energy of its electrons is generally insignificant (several electronvolts). After the shock wave the energy of the basic mass of invading electrons is the same as for protons. But the energy of both is insufficient to overcome an ordinary geomagnetic field and to penetrate into those latitudes for which polar aurorae are characteristic.

How can we explain all these remarkable features? At the present time it is still impossible to answer this question finally, since it is in a stage of experimental and theoretical investigation. It can only be mentioned that the attentions of investigators are concentrated on two causes that possibly accompany each other.

#### Interplanetary Magnetic Fields

First of all it is necessary to turn our attention to the

magnetic field of interplanetary space and the solar wind. It is absolutely possible that the changing structure of such a field exerts an effect on the scale of the interaction of the solar wind with the geomagnetic field and regulates the penetration of its particles into polar regions. Although the existence of such a field has been at present absolutely reliably established, nonetheless the necessary details of its fine structure and its variation in time and space are still unknown.

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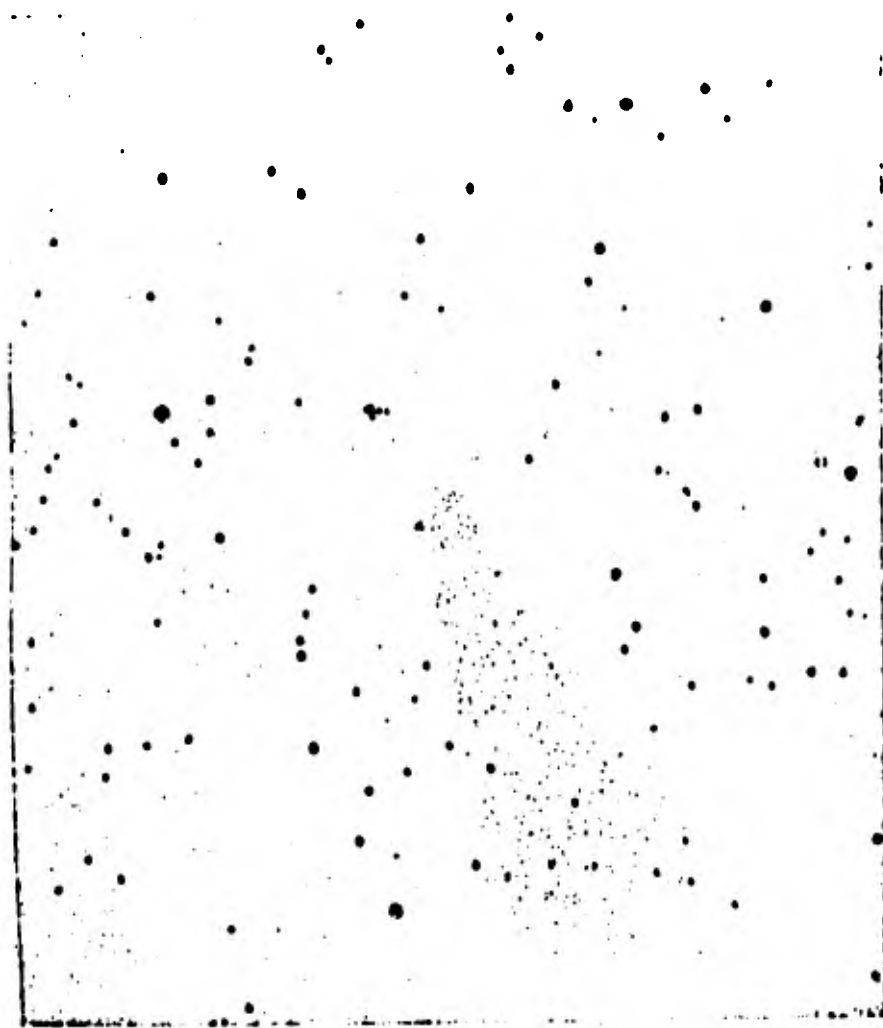


Fig. 2. Negative depiction of gegenschein area (earth's tail). Reproduction from photo made by Academician F. G. Fesenkov in the USSR in the Sara-Ishikotrau desert in October 1948. Dark spots in the center of the photo-negative depiction of gegenschein.

It is especially important to know in what form this field is connected with the coordinates of the material making up the solar wind. Ejection of charged particles from the Sun is possible in principal, first of all, as a result of the thermal evaporation of

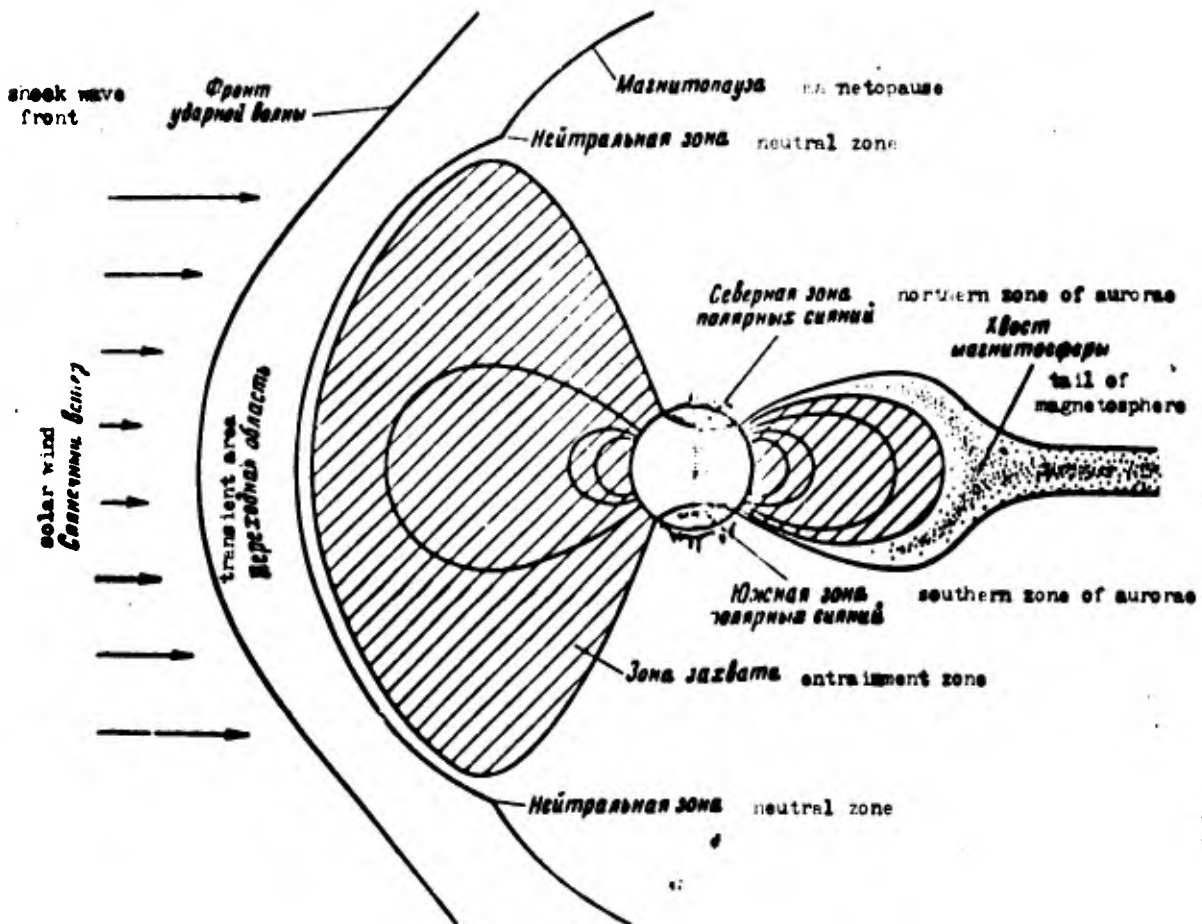


Fig. 3. Diagram of the interaction of solar wind with geomagnetic field. Streams of solar wind when approaching the geomagnetic field form a shock wave. Beginning from the so-called magnetopause there are detected magnetic lines of force of the earth (cross-hatching). In the neutral zone between the magnetopause and the area designated by points, the magnetic lines of force coming from the poles are elongated here, not closing along the tail of the magnetosphere. The position of the aurorae is designated by oval lines. In the entrainment zone the magnetic lines of force extend from one hemisphere and enter into the other. In this zone radiation belts exist. When an electric field appears perpendicular to the meridional planes depending on its sign the charged particles, situated in the entrainment zone will drift toward the center of the earth or in the opposite direction. In the drawing is depicted only the central part of the tail, limited by the magnetopause and having the approximate form of a cylinder.

charged particles. During such a process, first of all the lightest hydrogen ions protons will dissipate. Secondly, ejection of ions is possible on account of magnetohydrodynamic processes. In this case the magnetic fields of the ejected plasma can also carry off from the Sun heavier ions than protons. Speaking descriptively, the magnetic field serves as cement, fastening together charged particles of various signs and masses. American scientists recently announced that they have discovered helium ions in the solar wind. If this is confirmed in the future, it will be difficult to find a more solid argument in favor of the magnetohydrodynamic mechanism, at least, as an additional cause for the ejection of charged particles from the Sun. It is very interesting that energy helium ions have also been detected within the geomagnetic field.

#### Value of the Electrical Field

We also assume that the fine structure of aurorae can be connected with the existence, in the space around the earth, of an electric field in addition to the magnetic field. These fields penetrate into the space around the earth from the lower ionospheric layers as a result of its high electrical conductivity along the geomagnetic lines of force. Below, the electrical fields are generated as a result of the circulation of certain ionized layers of the atmosphere in the geomagnetic field, i.e., descriptively speaking, thanks to the natural dynamomachine. Electrical fields substantially change the movement of charged particles in the geomagnetic field.

With definite directions of the ionospheric winds and the electrical fields corresponding to them, charged particles even with very low individual energy can penetrate from without into the region of a

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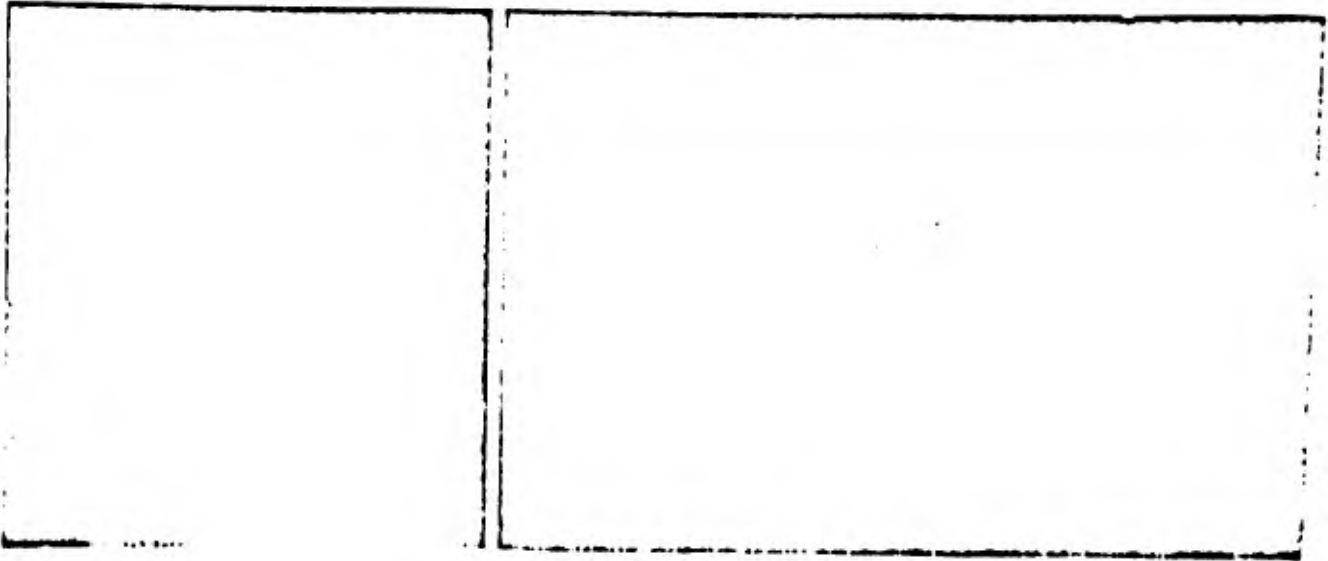


Fig. 4. Radiant arcs of aurorae close to the zone of their maximum appearance in Loparskaya on the Kola Peninsula. Photos were made in the blue part of the spectrum in the radiation of ionization molecules of nitrogen. Photo taken at local midnight on 25-26 November 1958 (left). The aurorae area is fully situated in the earth's umbra. The abrupt increase in brightness in the lower parts of the rays is well noticeable. This is explained by the fact that in the upper part of the atmosphere there are few nitrogen molecules. It consists basically of atomic oxygen. Photo taken at 20 hrs 30 min local standard time of 28 August 1958 (right). The aurorae area is fully situated outside of the earth. Rays have a greater dimension and their brightness changes little with an increase in altitude. The luminescence of rays is basically due to the fluorescence of ionized nitrogen molecules in solar radiation. With the development of the aurorae the altitude of the rays increases, which indicates the upwards penetration of larger amounts of ionized nitrogen molecules.

strong geomagnetic field and spread into the dense part of the atmosphere. With other winds, the charged particles situated in geomagnetic field are ejected beyond its limits. Since the intensity and direction of ionospheric winds are very changeable, then also the effect which they exert on the interaction of the geomagnetic field with solar wind cannot be constant. It is also necessary to mention that with an increase in streams of solar wind the heating of polar atmospheres is intensified and, consequently changes, of the atmosphere also with a certain delay the circulation. Our satellite of charged particle movements in the geomagnetic field

confirm the simultaneous existence of magnetic and electrical fields.

Thus, enormous variations in the intensities of aurorae and their slightly recurring fine morphology are possibly explained by the very changeable structure of the magnetic fields of the solar wind and electrical fields in the space near the earth, connected with ionospheric circulation.

#### The Role of Radiation Belts

When the so-called radiation belts were detected several years ago assumptions began to be expressed to the effect that aurorae originate as a result of spreading of charged particles entrapped by the geomagnetic field into the atmosphere. It was considered in this case that these particles are the product of the decay of neutrons forming during the irradiation of the atmosphere by cosmic rays. But now there is no doubt that the energy released during aurorae substantially exceeds that remaining in the radiation belts. Streams of cosmic rays are insufficient even for the creation of any substantial reserve of particles in the radiation belts. During very strong aurorae energy is released which would be sufficient to form tens and hundreds of thousands of terrestrial radiation belts. Furthermore, the basic mass of particles penetrating into the atmosphere in the time of aurorae has a considerably lower individual energy than the particles of the radiation belts. Efforts to explain the aurorae by the acceleration of ionospheric ions and electrons remain so far unsuccessful.

Since during aurorae in the geomagnetic field there are

situated charged particles of the same assortment as in radiation belts<sup>1</sup>, it is natural to assume that radiation belts consist of a small residue of the mass of particles which penetrated the atmosphere during the aurorae. It should be mentioned in this case that the entire geomagnetic field, as has now been established, is filled with charged particles of various signs and energies. Each kind of particle has its special characteristic distribution in space. In the so-called internal belt electrons of low energies prevail, not protons with energy of several tens of millions of electronvolts, as was first assumed. Beginning with distances of approximately two earth radii from the center of the earth, i.e., between those internal and external belts where, according to previous opinions, there were practically no energetic charged particles, it was possible to detect protons with energies of hundreds of thousands of electronvolts. Some authors assumed that there exists a third, outermost radiation belt of charged particles. But the area in which this belt was assumed to be could not be, in my opinion, the carrier of a single formation. In it there are no entrained charged particles. Instead of them, at various azimuths relative to the Sun there are charged particles of entirely different origin. As already stated, on the solar side of the magnetosphere there is formed a shock wave; one part of the solar wind streams invades the polar areas of the atmosphere, the other one flows around the geomagnetic field. From the nocturnal side in the antisolar

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<sup>1</sup>At the time of aurorae the ionosphere absorbs radio waves; this is caused by ionization of the atmosphere below the 100-km level. That ionization is created by more energetic particles than the ones which cause a visible aurora. But there are always fewer hard particles than less energetic ones.

direction flow streams of ionized gas dissipated by the terrestrial atmosphere.

The above mentioned electrical fields in the space near the earth are small (about ten microvolts per centimeter) and they exert a strong influence only on low-energy charged particles (with energy up to several kiloelectronvolts), i.e., on those short lived particles with which is associated the basic energy of aurorae. The higher the energy of the charged particles, the less they are subject to the effect of electrical fields. Considerably more time is needed to change the trajectory of motion of these particles. Therefore the position of regions occupied by hard particles is more stable than in the case of low-energy particles, which usually perish, not having completed even a considerable part of the drift around the earth. Short lived low-energy particles basically form not belts but fibrous formations along certain meridional planes<sup>1</sup>.

#### Not a Particle "trap", but a "jaw"

During aurorae there take place variations of intensity in the magnetic field with various periods. Such changes in the magnetic field are the results of movement of charged particles of various signs in opposite directions. It takes place either as the result

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<sup>1</sup>Charged particles in a geomagnetic field execute three kinds of movements: rotational, around geomagnetic force lines with very small radius, vibrational along these force lines, and rotational around the earth. The latter is the faster, the greater the energy of the particles. High-energy charged particles entrained by the geomagnetic field at the time of their existence in dense areas of the atmosphere execute an enormous number of turns around the earth and create therefore a uniform belt of the given type of particles. Charged particles of low energies cannot execute a considerable number of turns around the earth since they perish rapidly, causing an aurora. Their spatial configuration is therefore associated basically with the vibrational movement along definite geomagnetic lines.

of the appearance of electrical fields, or during the movement of a neutral stream of charged particles in the magnetic field. Since the basic mass of charged particles in the geomagnetic field has low energies, it is the disruption of movement of such particles which appears to be the basic cause of changing geomagnetic fields, and not vice-versa. Of course, the additional magnetic fields originating in this case exert an additional effect also on the movement of less numerous particles with much higher energy.

It appears to me that the usually applied descriptive expressions, such as "trap of charged particles in a geomagnetic fields," are not fully successful. If it is a trap, it is a poor one, one full of holes. I like better the descriptive name "jaw", which can absorb and squeezes out its content. But all this of course, is more a matter of taste. From the scientific viewpoint for the closest near-earth space, the material of which moves together with the earth, the most appropriate name is "electromagnetosphere of the earth."

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The investigation of comet tails enabled to predict and to find at the earth an analogous formation. But the many still unexplained details of comet tails apparently will be able to be understood on the basis of the fact that observation is made during the interaction of solar wind with the magnetic field and the terrestrial atmosphere. It is absolutely possible that it will become possible to detect strongly magnetized comets.

The phenomenon of polar aurorae is very interesting not only from the geophysical viewpoint it is, in addition, of general scientific interest, since in it can be observed the reaction of

charged particles of solar wind with the "electromagnetosphere of the Earth" on those scales which are nonrealizable under laboratory conditions, and with such details which are impossible to notice in distant astronomical objects.