The processes of eruption and spreading of a cloud of hot plasma in the magnetosphere is clearly reflected in the expansion towards the pole and in longitude of such forms of auroral glows during the substorm time[21,22]

The energies of the substorm is determined in this case by the depth of modulation of the energy flux carried by the solar-wind particles drifting across the tail of the magnetosphere, i.e., essentially by the energy of the plasma-layer particles. The role of the electric field produced in the substorm is analogous in this case to the role of the grid voltage that controls the plate current in a vacuum tube.

The appearance of intense local (so-called discrete) forms of auroras excited by the electrons and protons (ions) with average energies $\sim 1-5$ keV does not follow directly from the described picture, and their interpretation calls apparently for a detailed analysis of the vibrational and other collective processes in the magnetospheric plasma.

It is interesting that for Jupiter, which also has a magnetosphere and belts of captured particles, owing to the large magnetic moment M_Ψ and the rapid rotation ω_Ψ, the resonant energy may be the particle energy E_Ψ:

$$E_\Psi \approx E_0 \frac{\omega_\Psi}{\omega_E} \frac{R_E}{R_\Psi} \frac{M_\Psi}{M_E} \approx 0.22\, E_0 \frac{M_\Psi}{M_E},$$

i.e., higher by at least one and a half or two orders of magnitude than the value $E_0 \sim 10$ keV which is typical for the earth. In this case, if the conclusion that Jupiter's magnetic moment has a direction opposite that of the earth is correct, then the resonant particles there are relativistic electrons, which appear relatively rarely in the solar wind, but are effectively generated in Jupiter's magnetosphere.

The purpose of this communication was to emphasize the presently unclear aspects in the planetary physical picture of the phenomenon of magnetospheric substorm and auroras, and to present a working hypothesis that is presently being verified and compared with the experimental data obtained in recent comprehensive earth-based and outer-space experiments with the satellites "Kosmos-264" and "Kosmos-348," and are also further analyzed theoretically.

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Cosmic Radioastronomy

The present paper discusses the prospects of investigations in the ordinary radioastronomical band, without discussing the region where the earth's atmosphere and ionosphere are not fully transparent.

The recent major discoveries in the field of radioastronomy (observation and investigation of quasars, pulsars, residual background, discovery of numerous interstellar molecules) are due, on the one hand, to the expansion of the spectral band of the research, and on the other to the increased size of the radio telescopes and the sharp reduction of the receiver noise. Of tremendous significance is also the use of computer both during the course of radioastronomical observations and during the time of their reduction.

The most important parameters characterizing the capabilities of experimental radioastronomy is the minimum observable spectral flux density min F [W/m^{2}Hz] and the minimum angular resolution min θ["].

The F_ν band covers in modern radioastronomy about 10 orders, and the weakest among the observed sources have approximate fluxes of 10^{-28} W/m^{2}Hz. The angular resolution is attained with the aid of interferometers, and the highest attainable resolution is $\sim 3 \times 10^{-4}$ seconds of arc[1]. For comparison, in the optical band astronomical observations cover about 20 orders in F_ν and the attained angular resolution (also with the aid of interferometry) is $\sim 10^{-4}$ second of arc[2]. It is important to note that by methods of radio and optical observations we usually obtain information on different physical processes, and therefore one type of investigation does not supersede the other. At the same time, from the given comparison of the sensitivity and angular resolution in optics and in radio it can be seen that it is highly desirable to extend the capabilities of radio astronomy. We have $\min F_\nu = 10kT_n/A\sqrt{\Delta\nu t}$, where $k = 1.4 \times 10^{-23}$ W/Hz is Boltzmann's constant, T_n the effective noise temperature of the radio telescope, A the effective antenna area, $\Delta\nu$ the receiver bandwidth, and t the signal accumulation time. At the present time, for good receivers we have $T_n \gtrsim 100°K$ (in individual cases even $\lesssim 10°K$[3], $\Delta\nu \lesssim 0.1\ \nu$, and $t \lesssim 24$ hours. Recognizing that the minimum value of T_n is determined by the brightness temperature of the background (~3°K in the short-wave part of the radio-astronomical band), further improvement of the apparatus will increase the sensitivity by 1–2 more orders of magnitude. The increase of sensitivity by increasing the antenna area A is practically unlimited. The largest parabolic antennas with mirror diameter ~100 m have $A = 4 \times 10^3$ m^2.

Figure 1 demonstrates the limitations that hinder the construction of larger antennas on earth. The main limitation is the presence of gravity, which causes deformation of the structure. At the same time calculations that employ the elastic and strength parameters of ordinary materials demonstrate the possibility of constructing in outer space of structures of arbitrarily large size[4].

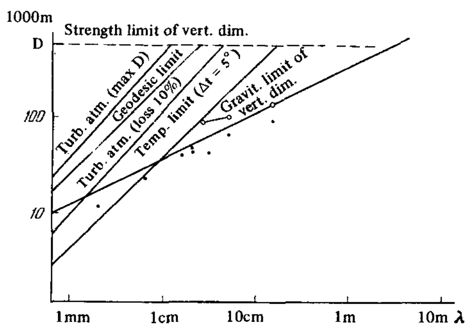

FIG. 1

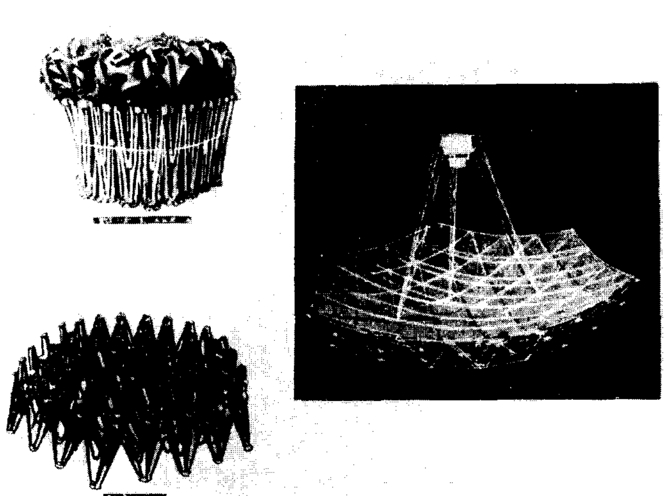

FIG. 2

Figure 2 shows one of the possible constructions of large outer-space antennas (developed in the USA) and the principle of its development after reaching the orbit[5]. This antenna has a diameter of 30 m and can operate at a wavelength up to 30 cm. The main forces acting on the outer-space antenna is the light pressure, the earth's tidal force, and the centrifugal force due to rotation. These forces are smaller by many orders of magnitude than the force of gravity. An important role in the calculation of the antenna deformation is played by the local temperature changes at different orientations relative to the sun. The calculations show that it is possible to produce continuous parabolic mirrors in outer space with dimensions on the order of 1 km and more. The "confusion effect" is no longer of importance for large mirrors. It should be noted in addition, as one of the important advantages of outer-space telescopes, the possibility of greatly reducing the radio noise level. Another important trend in cosmic radioastronomy is further increase of the angular resolution. Modern intercontinental interferometers with bases exceeding 10 000 km, i.e., on the order of the earth's radius, show the presence of finer details in the radio sources. An investigation of these details, and particularly the study of the rapid changes observed recently in quasars and galactic cores, is one of the most important problems of radioastronomy[6]. An investigation of the structures of such objects is possible only if one of the antennas of the interferometer is taken outside the earth to a large distance. An analysis of the use of an earth–outer space interferometer indicates a number of very interesting possibilities, such as the possibility of synthesizing the image of a radio source (by using the motion of the earth-based antenna together with the earth's rotation and an outer-space antenna on an orbit). For very large bases, it is also possible to construct a three-dimensional image of a source, to determine the trigonometric distances up to the most remote sources, and to investigate the cosmological curvature of space[7]. An important prospect for the development of cosmic interferometers may be the recently observed scattering of radio waves in interstellar space. Scattering by clouds of interstellar plasma leads to finite values of the angular dimensions even for an ideally pointlike remote source. According to scattering theory[8] we should observe a source with unchanged angular dimensions, attenuated by a factor $\exp(\beta z)$, around which there is also seen a halo of scattered radiation with a Gaussian intensity distribution and with angular dimensions $\theta_S = \theta_0 = \lambda/2\pi r_0$ for $\beta z \ll 1$ and $\theta_S = \theta_0(\beta z)^{1/2}$ for $\beta z \gg 1$. Here the scattering coefficient is $\beta = \sqrt{\pi} b^2 \Delta^2 r_0 \lambda^2$, the electron radius is $b = 2.82 \times 10^{-13}$ cm, Δ is the rms excess of electron density in interstellar-plasma clouds of radius r_0, λ is the wavelength, and z is the path length in the scattering medium. It is estimated from observations of the flicker of pulsars[8] that the angular dimension of the halo is $\theta_S = 10^{-3}(408/\nu\text{MHz})^2(z_{\text{kps}})^{1/2}$ second of arc, which yields $\theta_S = 10^{-5}$ second arc for observations across the galactic plane with z = 0.2 kps (1 kps = 3×10^{21} cm) and ν = 3000 MHz (λ = 10 cm). On the other hand, for the same parameters and for $r_0 \approx 10^{11}$ cm the exponent $\beta z = 1$ and the non-equilibrium part of the source flux is sufficiently large.

Although the effect of interstellar scattering requires further study, it can nevertheless be stated on the basis of the available data that there are no significant limitations on cosmic interferometry in the decimeter and shorter-wave bands.

In conclusion, we list the main advantages of radio-astronomical investigations in outer space, which in our opinion will cause all the major radio telescopes of the future to be constructed outside the earth:

1. Possibility of producing very large mirrors, ensuring an unlimited increase of sensitivity.
2. Realization of very large bases, ensuring a high angular resolution.
3. A sharp decrease of the level of natural and artificial noise and of the influence of the earth's atmosphere.
4. The feasibility of a very prolonged continuous investigation and accumulation of the signal.

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V. L. Indebom and F. N. Chukhovskiĭ. X-ray Optics

X-ray optics of almost perfect crystals, based on the dynamic theory of x-rays, has seen a rapid development in recent years in connection with the appearance of new methods of using crystals in science and engineering, in which more and more perfect single crystals are required. X-ray diffraction study has proceeded from the analysis, in the kinematic approximation, of line shapes on Debye patterns or spots on Laue patterns, to x-ray topographic methods that give a dynamic image of the internal structure of the crystal in one Laue reflection, with a resolution that ensures the display and identification of individual dislocations.

A specific feature of the x-ray diffraction image, unlike the optical or electron-microscope image, is the ratio of the radiation wavelength λ to the interatomic distance d. Whereas in optics $\lambda \gg d$ and in electron microscopy $\lambda \ll d$, for x-rays we have $\lambda/d \lesssim 1$ and accordingly the diffraction angle is of the order of unity. As a result the crystal regions that take part in the formation of each detail of the x-ray image have large dimensions not only in the transmission direction but also in the transverse direction. Whereas an electron-microscope image can be regarded as consisting of points, each of which depicts the structure of the sample along the transmission direction (the column approximation), in x-ray topography the image should more readily be regarded as made up of lines, and to each point in the crystal there corresponds a small strip of length on the order of the sample thickness. Overlap of the geometric and diffraction images, rarely encountered in optics and in electron microscopy, is a general rule in x-ray topography.

The paper considers the dynamic theory of formation of the x-ray image, based on the representation of the x-ray field in the form of spatially-inhomogeneous wave packets. The homogeneous and inhomogeneous fields in an ideal crystal are investigated, the contribution of the Bloch waves of different types are separated (including waves with large free path lengths, causing anomalous transmission of x-rays), influence functions describing the propagation of the local perturbation are constructed, and the images of slits, screens, and various volume inclusions are analyzed. It is shown that the influence function makes it possible to construct directly the wave field for an arbitrary distribution of the incident radiation on the crystal surface, and also to reveal the main details of the image of volume defects of the crystal. In many cases these details are due to the character of the influence functions, and not to the character of the object whose image is produced. A general theory is constructed for the image of a crystal with a known distortion field, and in particular cases are indicated in which simple analytic estimates can be obtained. The geometrical optics of x-rays is discussed. An analogy is established between the ray trajectories and the motion of charged particles in an electric field. The constant field corresponds to homogeneous bending of the crystal, and the vibrational motion of particles in a potential well corresponds to motion of x-rays in waveguides. Conditions are derived for reflection and refraction of rays on going through an interface. A general method is developed for the construction of an analytic solution of the equation for the wave field in a crystal in the geometrical optics approximation. For weakly distorted crystals, the solution of the image problem is given in explicit form. A method is proposed for investigating the asymptotic behavior of the wave field for a two-dimensional distortion field; this method facilitates the analysis of the image for a thick crystal and makes it possible to take directly into account effects of the type of total internal reflection, appearance of waveguides or shadows, etc.

Compared with the theory of the electron-microscope diffraction image, the theory of the x-ray image has made only the first steps. Many devices for the analysis of the image, used in electron microscopy, still have no analogs in x-ray topography. The variety of possible cases and the complexity of the numerical methods for calculating the image make it difficult to compile charts of images of typical lattice defects. Most problems, however, as shown in the paper, admit of effective qualitative and even quantitative investigation leading to a solution of the image-analysis problem in practical cases.

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