Chaotic Phenomena in Near-Earth Plasma

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1) Near Earth plasma (NEP) is the inhomogeneous, nonstationary and nonlinear medium disturbed by a number of external forces, for example, the solar wind, cosmic rays, solar flares, the Earth gravity field, interplanetary magnetic field variations. The NEP nonstationarity is conditioned, in particular, by daily and annual variations of perturbations, solar activity cycles and so on. In the near Earth plasma, electromagnetic emission are observed in the wide frequency range from mHz up to X-rays frequencies and γ ones.

Temporal fluctuations in the solar wind are conditioned by the Sun's inhomogeneous atmosphere rotation and by fractal structures generation which are registered in the Earth vicinity. The spectrum of low frequency fluctuations in the solar wind corresponds to spatial scales ~ $(10^5 \div 10^{10})$ cm and it is a very anisotropic one. Its appearance is connected with nonlinear cascade processes of waves interaction and the main components are alfvenic waves and magnetosonic ones. In the inertial interval of plasma turbulence, the power-law degree spectra P(f) are observed. For example, magnetic fluctuations in the frequency band $3 \cdot (10^{-4} \div 10^{-1})$ Hz have $P(f) \sim 1 / f^{\alpha}$ where $\alpha = (1.5 \div 2)$ in the Earth vicinity.

2) Cosmic rays penetrating into the Earth atmosphere promote the growth of thunder-storm clouds due to the formation of water vapour condensation centres and the resulting thundery discharges. The solar wind gathering on the Earth is separated from the magnetosphere by the magnetosheet (see the fig.1 below) which is the transition region. In the magnetosheet, ions fluxes are of the order of $(1 \div 4)\ 10^8$ ions / $cm^2 \cdot s$, the magnetic field variations are large ones up to $\delta B / B \sim 50\ \%$. In the magnetopause near the magnetosheet the ion gyroradius magnitude is $r_{Hi} \sim (40 \div 80)$ km. In the magnetosphere tail, the magnetic field lines reconnection causes a strong nonadiabatic charged particles acceleration. The typical size of the reconnection region is $\sim 10^3$ km.

3) There are also electric fields of the order of $E \sim 8$ mV / m and due to their nonstationarity, the polarization drift of charges appears with following velocity $v_d = (Ze / M\ \omega_H)\ \partial E / \partial t \sim (80 \div 170)$ km / s. Due to the plasma nonlinearity and its turbulence, the current sheets are forming. In the magnetopause at the distance from the Earth about $r \sim 10\ R_E$ (R_E is the Earth radius) there are boundary layers having the thickness $\sim R_E$. In the turbulent boundary layer, the strong nonlinear fluctuations exist with frequency $f \sim 1.5$ mHz and higher.

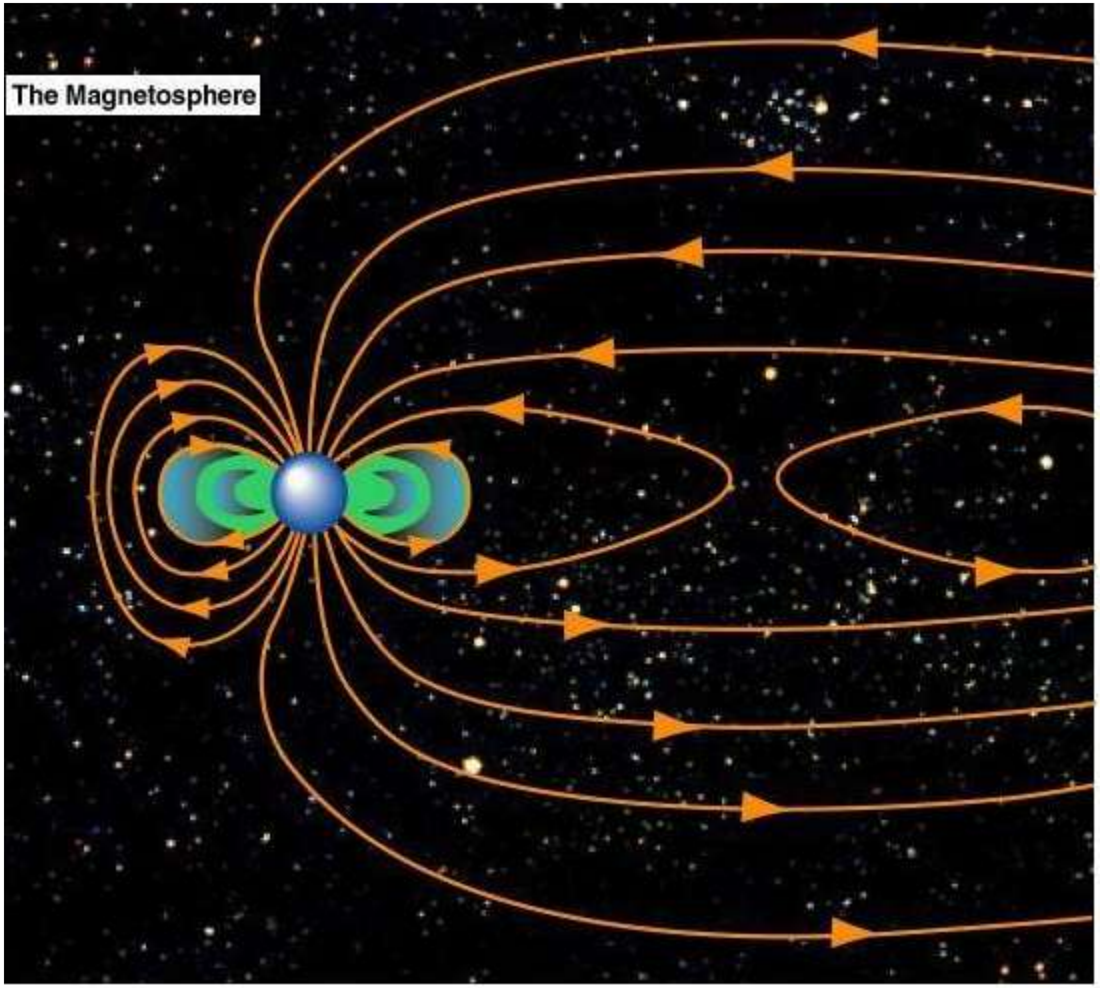

Fig.1. The Earth magnetosphere structure

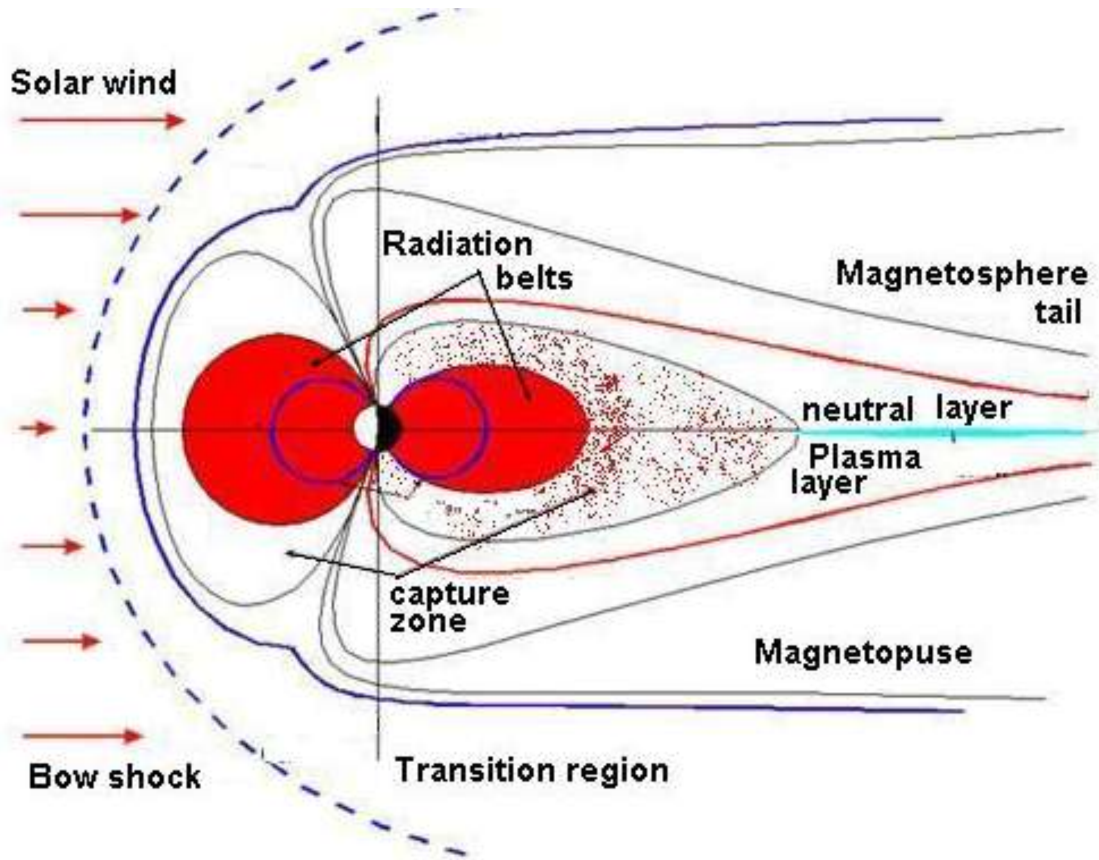

Fig.2. The solar wind gathering on the Earth.

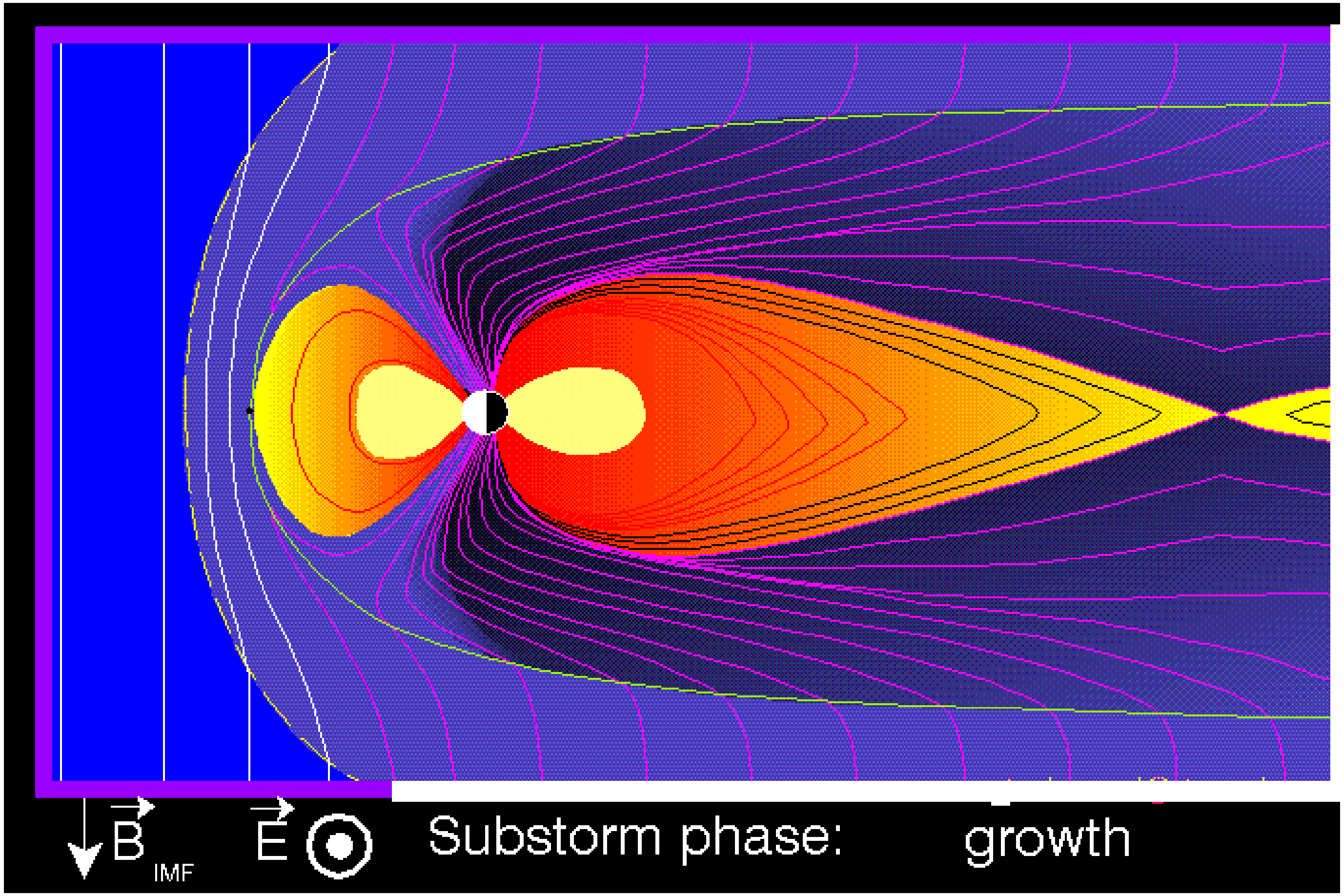

Fig.2. The Earth magnetosphere tail.

At the frequency $f_L \sim 1.5$ mHz the typical scale of oscillations in the turbulent boundary layer is $v_A / f_L \sim (3 \div 7) R_E$ where v_A is the alfvenic velocity. The magnetospheric filling up by the solar wind plasma takes place with the turbulent diffusion coefficient

$$D_f \sim (5 \div 10)\, 10^9 \text{ m}^2/\text{s}.$$

So the plasma flux of the order of $(1 \div 2)\, 10^{27}$ particles / s is provided through the Northern boundary layer and the Southern one. The ion-cyclotron waves are generated having their amplitudes from $(3 \div 10)$ mV / m up to 25 mV /m of electric field which results in the electrons acceleration. Low-hybrid waves are also observed at the frequencies $(1 \div 30)$ Hz.

4) The magnetosphere dynamics are characterized by both the multiscale mixing of plasma and the magnetic field lines reconnection. The plasma flux due to the action of alfvenic and magnetosonic waves is tending to the thermal equilibrium at scales from the ion larmor radius r_{Hi} up to 10^3 km .

Turbulent fields cause particles acceleration : electrons are accelerated up to ~ 40 keV and ions up to 400 keV near the Earth poles. It is necessary to note that the magnetopause is serving as a barrier for the in-coming solar wind.

In the near Earth plasma there occurs a ring current of ions having an energy about ~ (1 ÷ 300) keV and moving at the distance $r \sim (3 \div 6)\ R_E$ from the Earth in the equatorial plane vicinity. On magnetic field **B** lines the parallel currents connected with the auroral zone are of the order of 10^6 A. The flow of solar wind around the Earth results in the formation of the elongated magnetospheric tail. The fluxes of hot ionized particles from Sun travel to the Earth with velocities in the order of ~ (300 ÷ 1000) km /s, with temperatures T ~ (10 ÷ 50) eV and having a plasma density of the order of n ~ (1 ÷ 10) / cm^3.

5) The reconnection of magnetic field lines in the magnetospheric tail takes place at distances up to $r \sim 60\ R_E$. In quiet magnetosphere conditions, both electrons and ions in the tail are magnetized, but during substorms their motion becomes quite chaotic. At the night time side of the magnetosphere there are laminar and turbulent current layers. The strong perturbations in the near Earth plasma (like substorms) have a typical preparation time (the energy accumulation) of about (30 min ÷ 2 hours). During this processes, the plasma energy increases up to the very high level. As a result, the system becomes unstable. Then the turbulent current layer is quickly destroyed in the explosive process.

At this stage there are intense plasma fluxes and electromagnetic radiation. Strong geomagnetic field variations (MFV) also appear. These MFV have a significant influence on the human organism as medical data are showing. The plasma fluxes in the ionosphere create northern lights. Typical parameters of turbulent current sheets in the magnetosphere are as follows: their thickness is of the order of $r_{Hi} \sim (250 \div 1000)$ km, the electric current density is high enough $\sim 10\ \mu A / m^2$. There are also strong elongations of geomagnetic field lines.

6) The modeling of nonlinear dynamics of current sheets is performed by the usage of fractal topology methods. It is important to note here that the slow energy storage in the laminar zone of the magnetosphere tail is ending through the fast breakup. At the breakup stage, the scattering of ions by magnetic fluctuations results in the appearance of a complex chaotic structure of the magnetospheric tail up to distances $\sim 100\ R_E$. Among important processes in the near Earth plasma there are geomagnetic storms – global decreasing of magnetic field **B** magnitude at the equator vicinity during time intervals of a few hours with intensity $\delta B / B \sim 100$ nT. The following renewal of magnetic field **B** level is occurring more slowly on time scales of about a few days.

The generation of large currents $\sim 10^8$ A takes place, which then during the magnetic field renewal stage are dissipating into plasma.

7) The continuation of the ionosphere in the altitudes $z > 1000$ km is the plasmasphere, which is the internal part of the magnetosphere. In this region, there is the solar wind plasma captured by the Earth magnetic field **B** and having the following parameters: its temperature is $\sim (1 \div 2)$ eV (cold plasma), the density is $n \sim (10^2 \div 10^3) / cm^3$ and the mean part of the ions are protons. There is a wide spectrum of electromagnetic waves generated in the plasmasphere, namely in the VLF-range with $f \sim (3 \div 30)$ kHz, then ELF-one with $f \sim (5$ Hz $\div 3$ kHz), and also whistlers with $\omega > \omega_{Hi}$. Besides, there are geomagnetic pulsations with frequencies $f \sim (1$ mHz $\div 5$ Hz $)$ – low frequency oscillations of **B**.

8) The near Earth plasma contains radiation belts (RB). Ions RB are mainly made of protons (95 %). They are at magnetic shells with $L \in (1.5 \div 6)$ where $L = r / R_E$, r is the distance from Earth in equatorial plane. RB have proton fluxes $J \sim (10^2 \div 3 \cdot 10^4)$ ions/ $cm^2 \cdot s$. At the day side of RB the ions have a maximum energy > 30 MeV but for the night side of RB it is less: ≥ 1 MeV.

The ions motion in RB includes the Larmor rotation and the longitudinal drift under quiet magnetospheric conditions. The maximum proton current in RB is registered at the shell $L = 5$. Under the RB ion energy growth, their position becomes closer to the Earth.

In the case of captured electrons, there are the external RB and the internal one separated during the quiet magnetospheric conditions by the deep decrease of particle density at $L \approx (2.2 \div 3.5)$. In quiet magnetosphere conditions near the equatorial plane, typical values of electron RB current are about 10^8 electrons / $cm^2 \cdot s$. During the magnetic storms, the external electron radiation belt disappears practically, but after the storms ending it restores itself again.

The main part of RB particles is of solar origin. A other source of their production is conditioned by the interaction of galactic cosmic rays with the Earth atmosphere when some part of reaction products go up. Channels of particles loss from RB are as follows: the neutral atoms ionization and the cyclotron instability result in RB particles deceleration and in their scattering into the loss cone. An additional channel of proton loss from RB is electron capture by RB proton from neutral atoms leading to protons neutralization.

The thunderclouds discharges in the atmosphere produce electromagnetic waves which lead to the precipitation of RB electrons with energies ~ (50 ÷ 150) keV from magnetic shells L = (2 ÷ 2.4). At the heights $z < 1500$ km the particles precipitation from RB is conditioned by the influence of geomagnetic field anomalies like the Brazilian one. In the vicinity of the geomagnetic equator, there is an interesting phenomenon - the appearance of bubbles which are intense depletions of electron density n_e . After sundown, the density n_e (below F2 region) quickly decreases. The reason for the bubbles formation is the Raylei-Taylor instability development in the ionospheric plasma in the presence of plasma drift in the magnetic meridional plane, due to an electric field action. The drift velocity is about $v_d \sim 20$ m/s. This instability may be initiated frequently by the internal gravity waves (IGW) coming below, for example, from the troposphere. The bubbles are forming and then rise up above maximum F-region. Simultaneously, bubbles increase their horizontal size due to spreading along the geomagnetic field **B**. In a given region, there may exist simultaneously a number of bubbles of different sizes and intensities $\delta n_e / n_e$. The typical horizontal size of a bubble is about 50 km, the vertical scale is $l_z < 200$ km. In bubbles, the electron density observed is min $n_e \sim 10^3 / cm^3$ against the background one $\sim 10^6 / cm^3$

The vertical drift velocity of bubbles is less 1 km / s. The range of heights where bubbles are registered is $250\ km < z < 830\ km$. Bubbles are observed more frequently over the Atlantic ocean. Large bubbles may contain small-scales structures with size $l_s \geq$ cm. Along the geomagnetic field lines, the bubbles' horizontal size sometimes may reach a value of up to 1000 km.

Solar flares are accompanied by short-time X-rays emissions having enhanced power. Their typical wavelength are $(0.1 \div 10)$ nm. Besides X-rays, high energy protons fluxes are observed. Both these fluxes create ionosphere perturbations, namely plasma density growth during time intervals of $(10 \div 20)$ min. For the D-region, these plasma density enhancements may be one order of background magnitude or more, in the E-layer they will be $\delta n_e / n_e \sim (50 \div 100)\ \%$ and for the F-region we have minimal value $\delta n_e / n_e \sim (10 \div 30)\ \%$.

Substorms in the ionosphere (ISS) are a changing of the ionosphere parameters due to the magnetosphere substorms development. During ISS-events, the acoustic waves and internal gravity ones are excited in the auroral zone by the actions of ponderomotive force and by joule heating of plasma. In the middle latitude regions, the large-scale IGW may propagate only with $\lambda_h \sim$ tens km but other IGW are damping.

The duration of ionosphere perturbations is of the order of 40 min, their intensity corresponds to $\delta n_e / n_e \sim 50\,\%$ and their horizontal displacement is $\delta x \leq 4500$ km with a typical velocity of $v_x \sim 1400$ m/s.

The plasma density n in the geomagnetic equator vicinity is very sensitive to electric field variations δE occurring in the magnetosphere tail (at very large distances). These δE variations are conditioned by the changes in interplanetary magnetic field **B** direction and the field **B** is frozen into solar wind plasma.

The fast particle generation during ionosphere perturbations is conditioned, for example, by charges acceleration under interactions with cyclotron electromagnetic waves.

Thus we see that the near Earth plasma is characterized by a number of effects due to electric and magnetic fields variations, the wave-particle interaction mechanism and the nonstationarity of the background situation.

Owing to these effects, the near Earth plasma demonstrates the complicated dynamics and chaotic behaviour of its parameters.

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