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CONJUGATE ROCKET-SATELLITE EXPERIMENT AT THE SAMA REGION WITH ARTIFICIAL PLASMA INJECTION

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Preliminary results of synchronized rocket-satellite active experiment "KOMBI-P" are presented. The aim of the experiment was investigation of the complex plasma and wave disturbances, stimulated by artificial plasma beam injection into the ionosphere. The main idea was to inject a plasma beam in the magnetic field line which crosses the satellite COSMOS-1809 orbit. The launch of two meteorological rockets with separable plasma gun was made from scientific research vessel "Professor Zubov" in August 1987 in the Brazilian anomaly region ($\rho_s \approx 30^o$, $\lambda_w \approx 30^o$).
Enhancement of ELF emission at satellite height and its modulation with characteristic period of plasma gun operation indicates that observed ELF emissions were stimulated by plasma beam injection. These ELF waves were identified as ion-cyclotron waves. Synchronized rocket-satellite experiment permitted to trace geomagnetic field tube. Noticeable divergence of magnetic conjugacy of the satellite and plasma beam generator give by the magnetic field model IGRF-75 was found.

EXPERIÊNCIA CONJUGADA FOGUETE-SATÉLITE NA REGIÃO SAMA COM INJEÇÃO ARTIFICIAL DE PLASMA – São apresentados resultados preliminares de experiências sincronizadas de foguetes-satélites "KOMBI-P". O objetivo do experimento foi investigar o plasma complexo e as perturbações de ordem, estimuladas pela injeção de um feixe de plasma artificial na ionosfera. A idéia principal foi de injetar um feixe de plasma na linha de campo magnético que cruza a órbita do satélite COSMOS 1809. O lançamento de dois foguetes meteorológicos com disparador de plasma separável ocorreu a bordo do navio "Professor Zubov" em agosto de 1987 na região da anomalia brasileira ($\rho_s \approx 30^o$, $\lambda_w \approx 30^o$).
O aumento da emissão ELF a altura do satélite e sua modulação com período característico da operação de disparo do plasma indica que as emissões ELF observadas foram estimuladas pelo feixe de plasma injetado. Essas ondas ELF foram identificadas como ondas conciclotron. Experiências sincronizadas de foguete-satélite permitiram traçar o canal do campo geomagnético. Foi encontrada sensível divergência na conjugância magnética do satélite e do feixe gerador e plasma dada pelo modelo de campo magnético IGRF-75.

1. INTRODUCTION

One of the important tasks of conducting active experiments with plasma injection is the investigation of interaction of artificial energetic particles with magnetized ionospheric plasmas. The most interesting in such experiments are the diagnostics of beam dynamics and disturbance of background plasma, and excitation and propagation of plasma waves in the magnetic field tubes especially in magnetic anomaly regions.

Some of the experiments with plasma beam injections allowed to draw a general picture of the beam dynamics, and interaction with background plasmas (Haerendel & Sagdeev, 1981; Hausler et al., 1986; Oraevsky et al., 1989; Sagdeev et al., 1986). In

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these experiments diagnostics were conducted on rockets themselves and on separated containers. It should be noticed that the distance between the diagnostic complex and injection region was small.

To obtain more details of the interaction picture at greater distances it is necessary to launch additional rockets. More convenient is to use satellites with diagnostic apparatus. Difficulties that arise in achieving simultaneity in conjugate measurements can be avoided by making launches in predetermined regions, for example by lauching meteorological rockets from research vessels like "Professor Zubov". By synchronizing rocket launch with satellite flight we can reach a very preferable situation: the satellite crosses a magnetic field tube at the same time as the experiment is conducted by the apparatus installed on the rocket.

In this paper we present the preliminary results of two conjugate rocket-satellite active plasma experiments conducted in the South Atlantic magnetic anomaly region when measurements were made on the rocket as well as on the satellite crossing the same magnetic field tube where injection was done.

2. SCHEME OF EXPERIMENTS AND RESULTS

In August 1987 at the SAMA region (L = 1.25) two rocket experiments were conducted; "KOMBI-P" with quasineutral plasma beam injections at the height interval 100-240 km. A remarkable feature of the experiments was that the beam injection was synchronized with a flight of the diagnostic satellite COSMOS-1809.

The launching time of the rocket was so determined that plasma injection was at the time when the satellite passed as close to the injection region as possible and crossed the magnetic field tube where injection was performed. For this reason the first launch on 5 August was at 07h56'50,2" UT and the second on 6 August at 08h16'50,4" UT.

Cone-like caesium plasma beam was injected during 300 s along the rocket axis from a plasma generator separated forward from the payload with a velocity of ≈ 1,2 m/s at an angle of ≃ 45° to the local magnetic field lines. The density distribution of the beam with respect to the apex angle θ and the distance to anode according to laboratory chamber investigations is given in Fig. 1 (Oraevsky et al., 1989). Full beam angle of the injection was ≤ 60°. Parameters of the beam were the following: integrated beam ion flux $N_i \sim 5.10^{19}$-10^{20} ion/s, mean ion energy ~ 1.7-1.8 ev, jet plasma density near the gun nozzle ~ 10^{12}-10^{13} sm^{-3} and its velocity ~ 1-3 km/s. The jet intensity was pulse modulated with the repetition period of 5 s (4 s - injection and 1 s - pause). Measurement of plasma density, electric field variations in frequency interval 0.9-11 kHz, energetic particle flux variations, and optical emissions were made by the diagnostic rocket payload, placed below the plasma gun container.

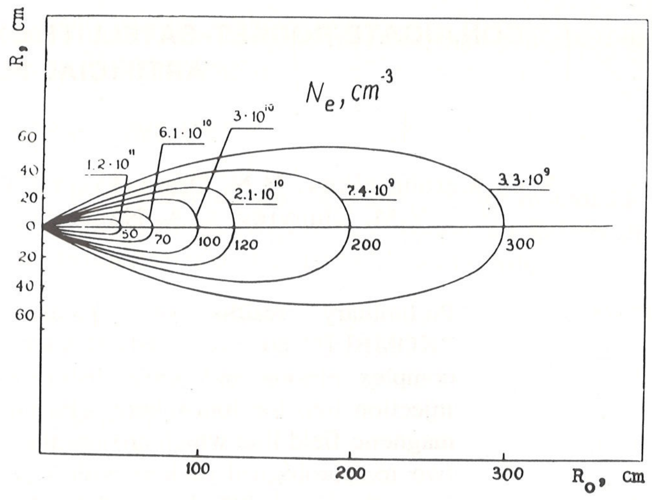


Figure 1. The density distribution of the beam according to laboratory testing.

Figura 1. Distribuição de densidade do feixe de acordo com testes de laboratório.

Response of the upper ionosphere was controlled with particle and electromagnetic field detectors on board the satellite COSMOS-1809 operating at the near circular orbit with an altitude of 960 km and an inclination of 81.3°. Geometry of the experiment is shown in Fig. 2, where rocket and satellite trajectory projections on the earth surface are shown. Also shown on the picture are the geomagnetic field line projections in different models: solid lines - geomagnetic model IGRF-75 and dotted lines - model ADR (from Space Research Institute, USSR). Distance between the satellite and the magnetic field tube of injection was minimum (100-150 km) at the time: 08h23'00" UT. Density distribution in the plasma beam near payload obtained in the experiments agreed with the laboratory data. Energetic particle flux variations were measurements by two types of Geiger-counters at energies > 40 keV. On the rocket distinct modulation of energetic electron flux with the frequency of the plasma gun operation (f ≃ 0.2 Hz) from 120 s (start of plasma beam injectors) to 245 s of the flight was registered. Pitch-angle distribution of the electron flux was strictly anisotropic so that even slight variation of rocket axis due to precession with the period of 27-30 s brought deep modulation of the particle flux.

The diagnostics satellite COSMOS-1809 was at shortest distance from injection region (800-860 km) at

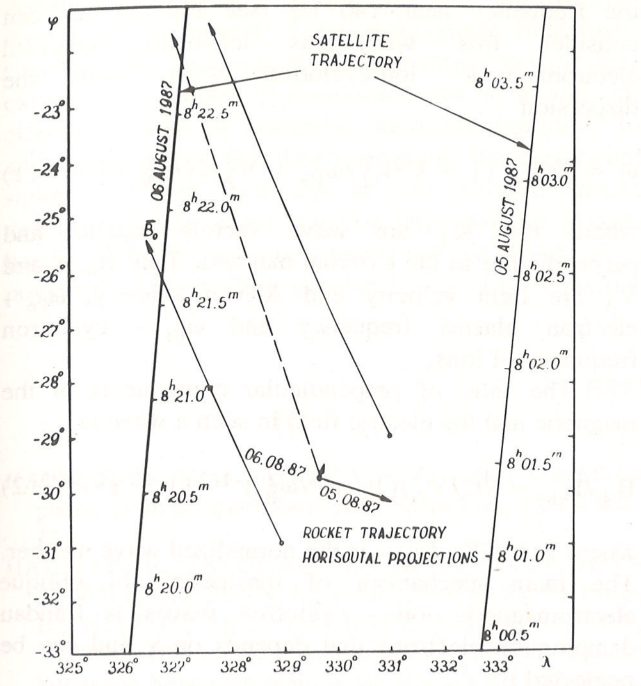
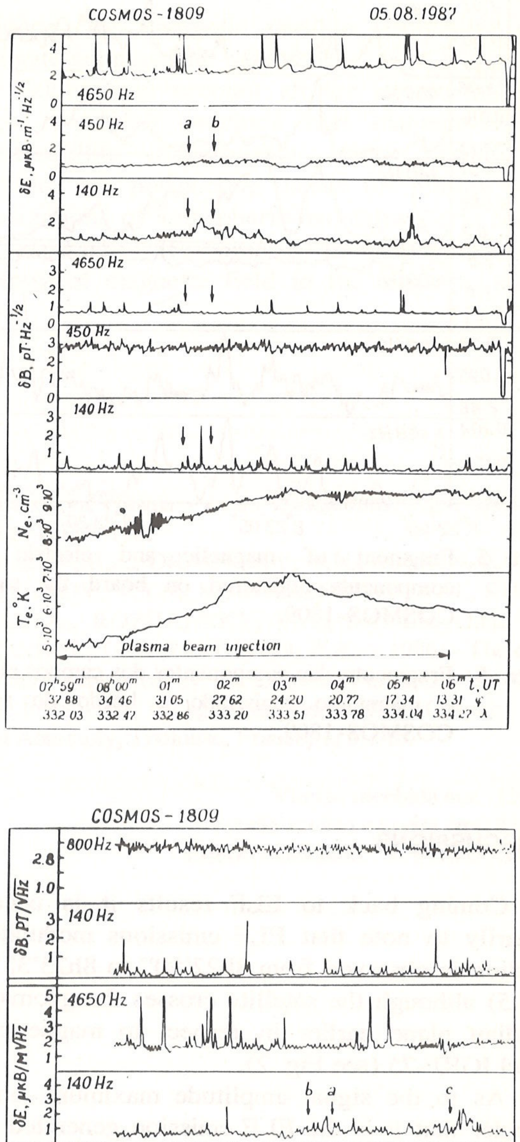


Figure 2. Experiment geometry.

Figura 2. Geometria do experimento.

times 8h01'18'' UT and 8h20'41'' UT (indicated by letter ''a'' on Figs. 3 and 4) in the first and second experiment respectively. Enhancement of the wave intensity of electric field at the frequency of 140 Hz was observed in sector indicated by letters "a" and "b", where "b" is the intersection of plasma injection L - shell by satellite trajectory (Figs. 3 and 4). Temperature variations of background electrons correlate with their density variations.

In the second experiment (6 August) during a period when the satellite passed near the magnetic field tube (indicated by letter "c" on Fig. 4), where the plasma injection was performed, a significant enhancement of electric (up to 2.5 mkV/m $\sqrt{Hz}$) and magnetic component at frequencies of 140 Hz and 450 Hz was observed. As can be seen from Fig. 5, at the same time electromagnetic wave amplitudes were modulated by the frequency of gun operation (~ 0.17-0.2 Hz). Sharp increase in the energetic electron (E > 40 keV) precipitation flux registered on the rocket preceded by 20-30 s by an enhancement in ELF waves registered on satellite at 8h22'50''. On the contrary during the satellite pass near the same trajectory on 9 August 1987 when there were no injections, no enhancements in ELF waves were observed.



Figures 3 and 4. Plasma and wave data registered on board the satellite COSMOS-1809 on 5 and 6 August respectively.

Figuras 3 e 4. Dados de plasma e onda registrados a bordo do satélite COSMOS-1809 nos dias 5 e 6 de agosto respectivamente.

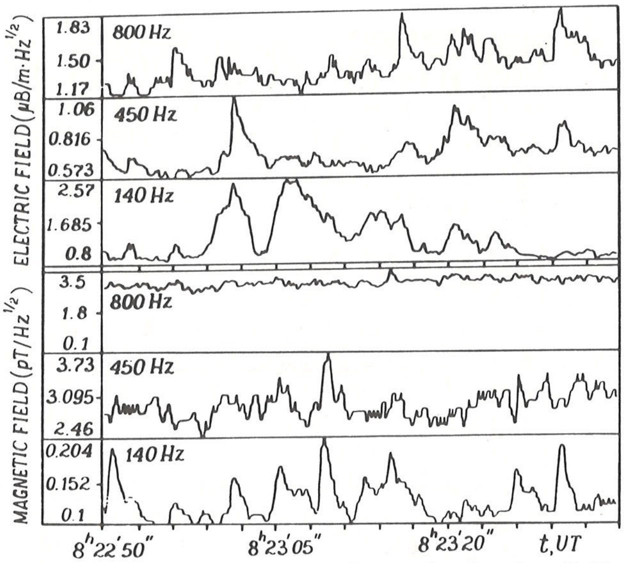


Figure 5. Fragment of magnetic and electric field components registered on board the satellite COSMOS-1809.

Figura 5. Fragmento das componentes dos campos elétrico e magnético registrado a bordo do satélite COSMOS-1809.

3. DISCUSSIONS

Coming back to ELF results it is necessary primarily to note that ELF emissions modulated by injection is observed from 8h22'50" to 8h23'32" (see Fig. 5) although the satellite crosses the geomagnetic meridian plane earlier in respect to magnetic field model IGRF-75 (see Fig. 2).

As to the signal amplitude maximum, one can consider that it is the ELF emission generated in the injection region and guided along the magnetic line to the conjugate point. The zone of ELF emission generation must to be more than several kilometers in the plane perpendicular to the magnetic force lines in the injection region. Then it is natural that the signal registered at the satellite should be intensive at minimum distance from the satellite to the magnetic force line where injection was done. The difference of maximum signal zone with the calculated geomagnetic meridian position signifies that the magnetic field model in the anomaly region is unrealistic at the satellite trajectory height (~ 1000 km). From the figure we can concluded that the magnetic field model KADR is more realistic.

Returning to the discussion of observed ELF signal nature, it should be noted that in a process of ion jet injection into the ionosphere the most reasonable is to expect excitation of one of the branches of plasma waves. Considering that the most significant by order was magnetic field component at the frequency near 140 Hz (see Fig. 5) one can consider this wave as left-hand polarized electromagnetic ion-cyclotron wave with the dispersion

$$\omega = k_{\|} V_A \left(1 + C^2 k_{\perp}^2/\omega_{Pe}^2 + V_A^2 K_{\|}^2/\omega_{Bi}^2\right)^{-1/2} \qquad (1)$$

where $K_{\|}$, $K_{\perp}$ are wave vectors parallel and perpendicular to the external magnetic field B_o, C and V_A are light velocity and Alfvén velocity, ω_{Pe} - electron plasma frequency and ω_{Bi} - cyclotron frequency of ions.

The ratio of perpendicular components of the magnetic and the electric field in such a wave is

$$B_{\perp}/E_{\perp} \approx (C/V_A)(1 - \omega^2/\omega_{Bi}^2)^{-1/2}(1 + \chi^2)^{-1/2} \qquad (2)$$

where $\chi = CK_{\perp}/\omega_{Pe}$ - is the normalized wave number. The main mechanism of dissipation of oblique electromagnetic ion - cyclotron waves is Landau damping on electrons that depends on χ and can be neglected if:

$$\chi^2 \ll (V_A^2/2V_{Te}^2)(1 - \omega_{Bi}^2)^{-1} \qquad (3)$$

Using the plasma parameters measured on board the satellite ($\omega_{Pe} \approx 10^6$ Hz, $\omega_{Bi} \approx 250$ Hz, $V_A \approx 4.10^8$ cm/s, $V_{te} \approx 2.10^7$ cm/s) one can find that Landau damping is small for $\chi^2 \ll 130$. For ELF waves of frequency $\omega \approx 140$ Hz and χ satisfing to eq. (3) we get according to eq. (2) the ratio $B_{\perp}/E_{\perp} > 8$ that is in accordance the experiment ($B_{\perp}/E_{\perp} \approx 30$ for $\omega = 140$ Hz). Perpendicular wave length ($\sim K_{\perp}^{-1}$) in this case should be > 30 m, that is of the order of the depth of the ion jet front in the ionosphere.

So we can come to the conclusion that the mechanism of the wave generation of ELF waves at the frequency $\geqslant 140$ Hz can be related to the drift instability of oblique electromagnetic ion-cyclotron waves at the edge of plasma jet. More detailed analysis of this process will be a subject of a separate paper.

4. CONCLUSION

The first results obtained by a diagnostic satellite of artificial plasma beam injection in the ionosphere of the magnetic anomaly region at a significant distance from the injection point (~ 1000 km) indicates that observed increase of ELF emissions and its deep modulation with the characteristic period of plasma gun operation depend on the satellite position with respect to the geomagnetic field line where injection was made. The observed ELF emission propagates dominantly in quasiperpendicular and quasiparallel direction with respect to the geomagnetic field lines. Consequently on conducting future magneto-conjugate experiments, guided ELF emission can be used as an effective tracer of magnetic field configuration in anomaly regions. On the other hand the significant signal level of emission at the satellite height generated by the beam injection indicates that plasma beam injection in ionosphere can be used as a powerful ELF emission generator. Also ELF emission influences the energetic particle population in the conjugate geomagnetic field tube.

Taking into account all the aspects mentioned above, one can conclude that magneto-conjugate rocket-satellite experiments with plasma beam injections are perspective means for plasma process investigations of ionospheric-magnetospheric coupling and especially for precise investigations of the topology of magnetic field in the magnetic anomaly region.

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