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STIMULATED PLASMA RESONANCES AS AN INDICATOR OF NEAR-SATELLITE PLASMA MODIFICATION BY POWERFUL RADIO EMISSION

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ABSTRACT

The plasma resonances stimulated by topside sounder radioemission were additional means for near satellite plasma diagnostics from the very beginning of topside sounding experiments. The wide-band receiver data on-board IK-19 satellite, as well as the discovery of sounder accelerated particle effects have shown that those phenomena do not keep within weak turbulence frames. It was shown that considerable modification of the ambient plasma in the 100-200 m vicinity takes place: the strictional extrusion, the development of modulational instability, remarkable heating of electrons and ions. On the normalized stimulated resonance distribution which is represented, the different resonance regions are discussed as a function of Langmuire and gyrofrequency, the different mechanisms of resonance excitation and wave-particle interaction are identified.

Stimulated topside plasma resonances have been discovered in the 60-s /1/ and were always considered as a most reliable mean for ambient plasma diagnostics. One can find in /2/ the table of integrated plasma parameters which could be determined "in situ" by measuring the topside plasma resonance parameters. The Plasma probe gives a single point measurement which depends strongly on the position of the point on the satellite body and on the relation to the satellite velocity vector due to plasma flow round the spacecraft. At the same time the wave measurements integrate over the volume with linear scale from centimeters to several kilometers, and in this case we deal with the real integrated plasma characteristics.

For a long period of time all diagnostics with the help of topside resonances was based on the linear approximation. So, they played the role of the probe waves and their interaction with the ambient plasma was taken into consideration only through the tensor of dielectric permeability of the undisturbed plasma. The more detailed analysis led to weak turbulence approximation /3,4/ when the nonlinear effects like parametric decay instability and nonlinear Landau damping were considered /8/. But all these theories work under assumption of a practically undisturbed plasma with very small deviations from the mean values. Measurements on-board the Interkosmos-19 satellite, particularly, the high frequency wide-band receiver and soft particle detector data, have shown that the waves emitted by the sounder transmitter modify the near-satellite plasma to great extent /5,6/. Here changes of electron temperature and density of ambient plasma may be mentioned, the small scale density irregularities appearance, acceleration of electrons and ions up to 1 keV and 100 eV respectively. Obviously, these effects are accompanied by optical emissions /7/ not fixed yet due to the absence of special optical photometers on-board the satellite. This assurance is based on the results of /7/, where estimations are made for ground-based HF transmitter, having 100 MW effective power, which will give at the reflection point at 250 km height 0.25 mW. At the same time the topside sounder antennas immersed immediately into the ambient plasma, will exude nearly 200 W. In this case we have right to expect the strong nonlinear effects which are essentially stronger than during the ground-based heating. At this point we must remark the dual role of resonances - as a result of modification processes development and as a means of modification diagnostics.

The evidence of nonlinear nature of the plasma resonances is shown in Fig.1; simultaneous excitation of several resonances by single pulse of topside transmitter. As can be seen from the Figure the picture is changed in dependence on the relation between the pumping frequency and the main plasma frequencies.

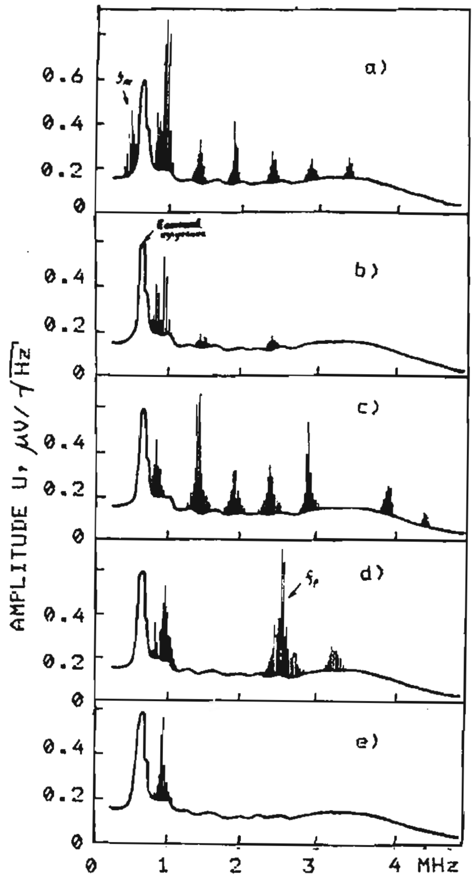

Fig.1. Spectra of waves excited by single radio pulse of frequency Fo a)Fo<Fhe, b)Fhe<Fo<Fpe, c)Fo=2Fhe, d)Fo=Fpe, e)Fo≫Fpe (26.04.1979)

If we turn to Fig.2, which format was proposed first by Oya /3/, where the horizontal axis q represents the ratio Fpe/Fhe and the vertical axis p = Fsound/Fhe, we can move along any axis. The vertical direction corresponds to changing of pumping frequency under fixed Fpe/Fhe (such moving corresponds to Fig.1). It is a real situation of measuring in selected point during obtaining of ionogram by transmitter frequency sweeping. The moving along the horizontal axis is more physical because it gives a possibility to track the development of processes with changing of plasma parameters and corresponds to moving of satellite in changing Earth ionosphere. The building up of three dimentional picture would be the best and it is a real task with the help of modern computer technique. We'll try to combine both ways and extract the characteristic areas in Fig.2. We'll compare simultaneously the wave measurements with the accelerated particles data, obtained during topside sounding. First let us try to move along p axis under fixed q. The most effective interaction and hence the most developed turbulence is in the $p < q$ region. Indeed, for $q > 1$ in the region $1 < p < q$ the electromagnetic waves couldn't propagate and hence the energy emitted by the sounder transmitter has to dissipate in near-satellite region. The wave carrier of this energy might be Bernstein modes and electron cyclotron waves. In addition there must exist an effective mechanism to transfer energy to particles. We would like to mention two of them which are effective in the $p < q$ region. The First is connected with 2Fhe resonance and is described in /8/ as nonlinear Landau damping for $p < q$, and the second is modulational instability for $p \sim q$ /5/. The main criteria of transition from one mechanism to another are the resonance duration and appearance of strong bursts of accelerated particles (Fig.3). Especially important is a duration of ion fluxes. Long duration of ion fluxes indicate the ion acoustic wave excitation with the collapse of Langmuir solitons.

After crossing $p = q$ value to $p > q$ the intensity of interaction falls because the main part of the energy is taken away by the electromagnetic waves. One can observe this effect on the resonance duration (Fig.3) as well as on the duration of accelerated particles fluxes. In the $q < p < 2q$ area the main source of information about accelerated particles is the Q - resonances. After crossing $p = 2q$ relation to $p > 2q$ region the main role is played by the parametric decay instability. One of its products always is a plasma resonance which leads to parallel acceleration of electrons registered by the soft particle detector. Thus, moving along the p-parameter we have the chain of instabilities: cyclotron heating (D-resonances and electron cyclotron waves), modulational instability (collapse of Langmuir solitons), cyclotron heating (Q-resonances and electron cyclotron waves), parametric decay instability (heating of electrons through the Landau damping mechanism).

Now it is necessary to turn to exposing of the q-param. role. The situation described above is typical for 1 < q < 3.5. Under q < 1 the plasma is magnetised and the picture near q ~ p is changed. As it is seen from particle measurements under q < 1 conditions, in the vicinity of q ~ p the long duration fluxes of accelerated ions are absent, which permits us to say that the modulational instability does not lead to collaps of cavitons. Indeed, it is shown in /9/, that in a magnetized plasma Fhe > Fpe the solitons are stable and collapse takes no place. At the same time one can see the enhancement near Fhe/2. This can be explained by the peculiarity, which whistler dispersion has near Fhe/2 /10/. In the vicinity of p~1/2 the intensive exchange of energy could take place between LF emission and ambient electrons. A very interesting feature of the Fig.2 is the changing of picture after crossing the q ~ 3.5 value. These changes are noticeable both for resonances and for accelerated particles. As one can see from Fig.1, practically all wave effects move to the lower half plane which is limited by the p = q line. Q-resonances practically disappear. Something like this was mentioned in /8/. The branches of the resonance acceleration of particles change their nature too and deviate more from the p ~ q line towards the smaller p values. We can say that more densed plasma prevents by development of long-lived longitudinal oscillations and the cyclotron heating prevails. Maybe the absence of waves in the upper half plane is due to the fact that these frequencies fall into a frequency band higher than the critical frequency of the F2 layer and are shadowed by the interference from the ground.

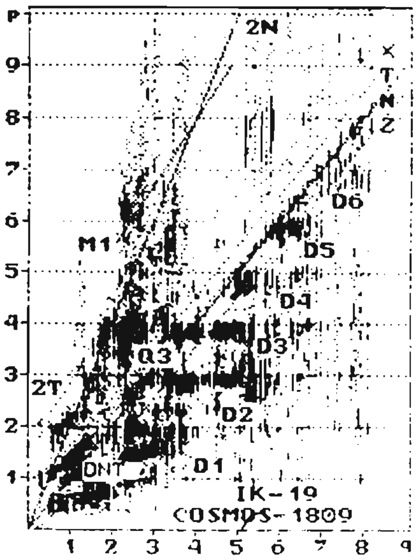

Fig.2. The normalised stimulated resonances distribution

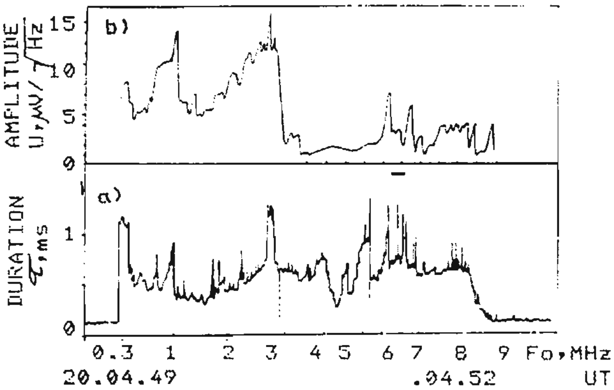

Fig.3.The excitation of Fpe resonance by the ionosond pulses (26.04.1979)

It is necessary to mention one more effect observed very rarely. Sometimes when the sounding frequency coincides with the local plasma frequency or with some of harmonics of the local electron gyrofrequency, the intensive wide-band noise is observed in the whole frequency band of the wide-band receiver 0.1 - 5.0 MHz. This effect could be explained in the following way. Taking into account that the frequency step of sounder in the vicinity of Fpe is 50 kHz it is difficult to expect the exact coincidence (within 10^{-4}) of sounder frequency with the local plasma frequency or another characteristic frequency of the ambient plasma. But when it nevertheless takes place, the exponential growth of the effectiveness of wave pumping appears. In this case the effect observed may be explained either by overloading of the input circuits of the wide-band amplifier during the sharp increasing of the input signal level, or by so large turbulization of the ambient plasma that it is no sence to speak about resonance frequencies but only about the wide-band turbulent emission. The main indicators of the near-satellite region modificatin are the frequency, bandwidth, duration and number of resonances observed simultaneously (excited by the single sounding pulse). For example, the long duration (>5 ms) and wide-band (>100 kHz) resonance indicate the modulational instability development. The relation between the frequency band of the resonances and the main frequencies of the ambient plasma permits to determine the prevailing type of instability. Very wide-band emission indicates the strong plasma turbulization. Basing on the results of latest investigations /11/ the presence of DNT /2,3/ resonance on the ionogram indicates the effective transformation of ordinary wave to the slow extraordinary wave (z-wave), which in term indicates the presence of small scale irregularities. The frequency of the maximum of this resonance is determined by formula (1):

$$F_m^2 = F_{uhr}^2/2 + \sqrt{F_{uhr}^4/4 - (F_{he} * F_{pe} * \cos\theta)^2} \qquad (1)$$

θ – the angle between density gradient and $\vec{H}$. So, using the information on the DNT resonances it is possible to make the global diagnosis of ionospheric smallscale irregularities at the satellite heights. The natural noise registered on the ionograms are adjoined to this subject. Sometimes (mainly in the high latitudes) instead of usual image of plasma and upper hybrid resonances the wide-band noises appear (Fig.4). It is clearly seen in the picture that the switching off the sounder transmitter does not change the picture /12/. These natural noises which we believe to have the turbulent nature witness the turbulent state of ambient plasma connected with the particle precipitation in the high latitudes, and may be used for ionosphere diagnostics too.

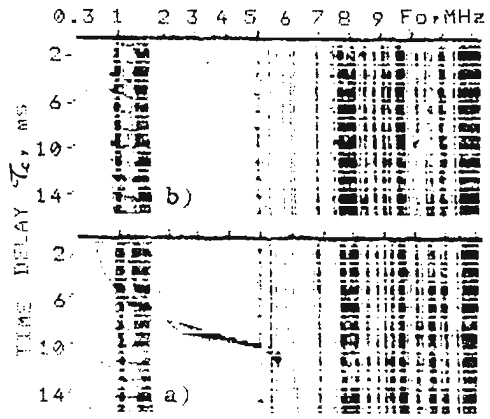

Fig.4. KOSMOS-1809 ionograms a) with and b) without transmitter

R E F E R E N C E S

1. Nelms G.L., Lockwood G.E. Early Results From the Topside Sounder in the Alouette-2 Satellite. Space Res., v.7, p.604, (1966).
2. Benson R.F. Stimulated Plasma Waves in the Ionosphere. Radio Sci., v.12, ≠ 6, pp.861-878, (1977).
3. Oya H. Verification of Theory on Weak Turbulence Relating to the Sequence of Diffuse Plasma Resonances in Space. Phys.Fluids., v.14, ≠ 11, pp.2487-2499, (1971).
4. Benson R.F. Stimulated Plasma Instability and Nonlinear Phenomena in the Ionosphere. Radio Sci., v.12, ≠ 14, pp.1637-1659, (1982).
5. Pulinets S.A., Selegey V.V. Ionospheric Plasma Modification in the Vicinity of a Spacecraft by Powerful Radio Pulses in Topside Sounding. J. Atm. and Terr. Phys., v.48, ≠ 2, pp. 149-157, (1986).
6. Shuiskaya F.K., Galperin Yu.I., Serov A.A., Baranetz N.V., Kushnerevsky Yu.V., Vasiliev G.V., Pulinets S.A., Phligel M.D., Selegey V.V. Rezonant Heating of the Ionospheric Plasma by Radiopulses Aboard the Intercosmos-19 and Cosmos-1809 Satellites. Preprint IKI AN SSSR, ≠ 1304. (1987), Plan. and Space Sci., in press.
7. Vaskov B.B., Milih G.M. Artifisial Emission and Additional Ionization of the Upper Ionosphere on Pouarefull Radiowave Field, Geom. and Aeronom., v.23, ≠ 3, pp.196 - 201, (1983).
8. Kivamoto Y., Benson R.F. Nonlinear Landau Damping in the Ionosphere. J. Geoph. Res., v.84, ≠ A8, pp.4165-4172, (1979).
9. Nezlin M.V. Stream Dinamices in Plasma. Moscow:Energoizdat, (1982).
10. Izhovkina N.I., Pulinets S.A. On the Electrostatic VLF Emission by Rokcets and Satellites Experiments Data. Geom. and Aeronom., v.27, ≠ 2, pp.270-273, (1987)
11. Denisenko P.F., Zabotin N.A., Pulinets S.A., Selegey V.V. The Ordinary Wave Transformation Into Extraordinary Wave by Upper Sounding ionosphere Data. Geom. and Aeronom., v.2, ≠ 4, pp.544-549, (1987).
12. Danilkin N.P., Pulinets S.A. On the Wide Band High Frequency Noises During Topside Sounding in High Latitudes. The Results of the First Scientific Expedition on the Atomic Icebreaker 'Sibir' in Near-pole Vicinity, AANII, in press.