Planet. Space Sci., Vol. 38, No. 2, pp. 173–180, 1990
Printed in Great Britain.

0032-0633/90 $3.00+0.00
Pergamon Press plc

RESONANT HEATING OF THE IONOSPHERIC PLASMA BY POWERFUL RADIOPULSES ABOARD THE *INTERCOSMOS*-19 AND *COSMOS*-1809 SATELLITES

F. K. SHUISKAYA, YU. I. GALPERIN, A. A. SEROV and N. V. BARANETS
Institute of Space Research, U.S.S.R. Academy of Sciences, 117810 Moscow, GSP-7, Profsojuznaya str., 84/32, U.S.S.R.

and

YU. V. KUSHNEREVSKY, G. V. VASIL'EV, S. A. PULINETS, M. D. FLIGEL and V. V. SELEGEY
Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation, U.S.S.R. Academy of Sciences, 142092 Troitzk, Moscow Region, U.S.S.R.

(*Received in final form* 31 *May* 1989)

Abstract—Local heating/acceleration of the ionospheric plasma particles near the satellite by RF pulses of the powerful topside sounder transmitter was detected by the soft electron spectrometer on board the *Intercosmos*-19 satellite and was first described in 1981 (Galperin *et al.*, 1981, *Cosmic Res.* **19**, 22). The acceleration of the electrons occurs primarily perpendicular to the external magnetic field for 0.3–3 ms. The energy spectrum of the accelerated electrons is close to Maxwellian with a mean temperature of the order of 100 eV. The electrons are accelerated at frequencies mainly near the first harmonics of the electron plasma and the gyrofrequency, but also in the frequency region of the plasma diffuse resonances and between the second and third harmonics of the plasma frequency. These investigations were continued on board the recent *Cosmos*-1809 satellite. Intensities of the sounder accelerated particles (SAP) were time-resolved on a millisecond scale. Different mechanisms of wave–particle interactions which could be responsible for SAP are discussed.

1. INTRODUCTION

The local heating/acceleration of near-satellite plasma electrons during the pulses of radioemission of the powerful (140–300 W) topside sounder IS-338 transmitter was detected on board the *Intercosmos*-19 satellite by the soft electron spectrometer (Galperin *et al.*, 1981). The heating/acceleration investigations were continued on board the *Cosmos*-1809 satellite (1986).

The *Intercosmos*-19 measurements always detected for superthermal electrons with energies from 10 up to 150 eV, sometimes to 500–1000 eV. The burst's duration was 0.3–3 ms. It was noticed that the most intensive spikes of electron intensity were registered when the pumping frequencies corresponded to the resonance frequencies of the surrounding plasma.

The *Cosmos*-1809 spectrometer (an electrostatic analyser of special form) provided the means of measuring the intensity of the electron and ion fluxes and estimating their anisotropy distribution. The analysis of the spectrometer data collected during the sounder radioemission, has shown that simultaneously with the efficient electron acceleration there also occurs some acceleration of the surrounding plasma ions. The stimulated ion intensity bursts were observed with energies up to 80 eV.

The particle measurements were supported by high frequency wave measurements with the help of a wide-band receiver HFA-2 (Pulinets and Selegey, 1986) and by studying the stimulated plasma wave resonances' distribution registered by a topside sounder receiver (Pulinets and Selegey, 1988).

All these effects are considered in the paper and possible mechanisms relating to local particle acceleration by powerful HF emission are discussed.

2. THE EXPERIMENTAL FRAMEWORK

The *Intercosmos*-19 satellite was launched on 27 February 1979, with inclination 74°, perigee at 500 km and apogee at 1000 km. The *Cosmos*-1809 satellite was launched on 18 December 1986, with inclination 82.5°, in an almost circular orbit at a height of about 960 km. *Intercosmos*-19 and *Cosmos*-1809 satellites have a three-axis stabilization with orientation (z-axis) to the Earth.

The topside ionospheric sounder IS-338 was mounted aboard both the *Intercosmos*-19 and *Cosmos*-1809 satellites. The sounder operates at 338 fixed frequencies within the range of 0.3–15.95 MHz. A pulse of 0.133 ms duration was emitted once at each frequency; the pulse repetition frequency is 58.60 Hz. The power supplied to the antenna was 140–300 W. The emission and reception of signals reflected from the ionosphere were carried out by the antenna system consisting of two mutually perpendicular dipole antenna pairs, positioned in the plane nearly parallel to the Earth's surface and making an angle of $\sim 45°$ to the direction of the satellite velocity vector. The dipole of 50 m length tip-to-tip operated within the range from approx. 0.3 to 5 MHz; the other dipole of 15 m length tip-to-tip operates within the range from 5 to 15.95 MHz.

For the detection of auroral particles, superthermal photoelectrons and sounder accelerated particles (SAP), the electrostatic analysers were used aboard both satellites.

Electrostatic analyser SF-3 on board the *Intercosmos*-19 registered electrons in the energy range from 10 eV to 15 keV with an energy resolution $\Delta E/E = 0.19$ and a geometric factor $1.4 \cdot 10^{-2}$ cm^2 sr. The view angle was conical with the full aperture of 10° directed upwards at an angle of 30° to the vertical axis of the satellite. The time resolution depended on the telemetry mode. We present here results from direct transmission data through the ETMS telemetry system where the time resolution of our particle measurements was 20 ms. The cycle of the electron energy scanning was 24 s with continuous scanning from 10 to 150 eV, also 24 s continuously from 150 to 10 eV, then eight energy steps followed successively with energies 0, 50, 120, 500, 1000, 5000, 15,000 and 0 eV. The duration of each step was 6 s.

On the *Cosmos*-1809 satellite the SF-3M particle spectrometer consisted of two toroidal electrostatic analysers for recording electrons and ions with energies from 10 to 10,000 eV in 16 energy steps. The energy scanning cycle was of the sawtooth type, so there were two measurements on each energy step per one full cycle. The accumulation interval at each of the steps for auroral particles and photoelectrons was determined by the telemetry mode and could be chosen by command from 80 ms to 2.5 s in the memory mode. It was 10 ms for electrons and 40 ms for ions in the direct transmission mode of the STO telemetry. In the SF-3M spectrometer the special 4-bin swift-sweep memory controlled by sounder pulses was provided for the SAP recording which consisted of memory counters for four bursts. The accumulation time for each bin, Δt, could be chosen from 0.5 to 3 ms by command. The burst memory counters counted particle pulses in such a sequence that the first bin was opened by the trailing edge of the sounder pulse and accumulated counts during a time interval Δt, then the second bin operated during the next interval Δt, and so on. Thus a four-point time evolution of particle fluxes on a millisecond time scale was recorded with the SF-3M spectrometer. The particles were recorded from four angular sectors of 42 degrees each in the satellite's vertical plane. The sectors' central axis made angles with the satellite vertical axis of 22, 67, 112 and 157 degrees, respectively. The energy resolution for the electrons $\Delta E/E$ was 0.21, while for the protons it was 0.28.

When the wave analyser HFA-2 was simply a wide-band amplifier in the frequency band 0.1–5 MHz, its output voltage was transmitted to Earth by the wide-band telemetry FM transmitter and recorded using a video-taperecorder. The main advantages of this device were: (a) unlike the sounder receiver, the HFA-2 could record the signals stimulated by sounder on the frequencies different from the emitted frequency; (b) the HFA-2 could record the whole power spectrum and the waveform in the 5 MHz band of signals stimulated by every single pulse of the sounder.

3. ELECTRON HEATING IN THE NEAR-SATELLITE PLASMA

According to the observations made during the on board sounder operation on the *Intercosmos*-19 satellite the bursts of intensity of soft electrons (SAP) appeared with energies up to 1 keV (Galperin *et al.*, 1981). Figure 1 gives an example of a stimulated burst of electrons for energy 130 eV during one frequency scan of the topside sounder (see Galperin *et al.*, 1981). High intensity spikes during emissions near local electron gyro- and plasma frequencies (f_{ce} and f_{pe}, respectively) are prominent features of the spectrometer output as seen from 20 ms time resolution for the ETMS telemetry. Sounder frequency is normalized to the local electron plasma frequency f_{pe} and the intensity to the maximal amplitude in the scan. Fast mode telemetry analysis of the data obtained by the *Intercosmos*-19 satellite (Galperin *et al.*, 1981) made it possible to conclude that the duration τ_e of a single burst of the electron intensity which corresponds to one pumping radiopulse of the sounder lasted not more than 3 ms, which was considerably longer than the pumping radiopulse (0.133 ms). Thus the range of $0.3 \leqslant \tau_e \leqslant 3$ ms was deduced indirectly (Galperin *et al.*, 1981) and later substantiated (Serov *et al.*, 1985).

The data of the *Cosmos*-1809 allowed direct measurement of the duration of the soft electron stimulated burst with the use of burst memory counters. After the end of a radiopulse the increased electron (and ion) intensities usually lasted about 0.5–3 ms.

From the data of the *Intercosmos*-19 satellite

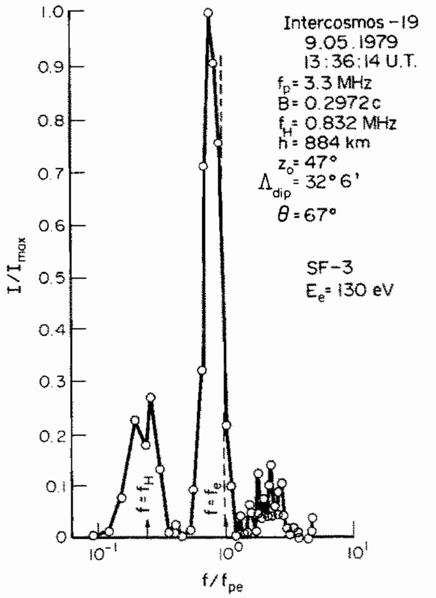

FIG. 1. AN EXAMPLE OF THE OBSERVED STIMULATED BURST OF ELECTRONS OF THE ENERGY $E_e = 130$ eV.

The horizontal axis is the ratio of the sounder emitted frequency (f) to the local plasma frequency (f_{pe}). I/I_{max}, normalized intensity; f_H, local gyrofrequency; h, satellite's altitude; B, Earth's magnetic field along the satellite's orbit; Z_0, solar zenith angle; Λ_{dip}, magnetic dip latitude; and θ, pitch angle for electrons measured during a stimulated burst.

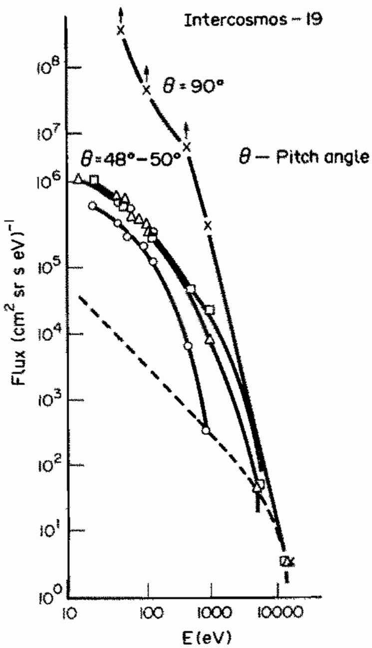

FIG. 2. ELECTRON ENERGY SPECTRA ACCUMULATED DURING A PASS FOR SEVERAL SUCCESSIVE STIMULATED INTENSITY BURSTS, NEAR LOCAL PLASMA FREQUENCY OBSERVED AT MIDDLE LATITUDES (○, □, △) FOR PITCH ANGLES OF 40–50°, AND AT THE EQUATORIAL LATITUDES (×) FOR THE PITCH ANGLE CLOSE TO 90°.

Below (dashed line), an intensity threshold (noise level) is shown.

(maximum solar activity, upper *F*-region at 500–1000 km altitude) the stimulated bursts of electrons were usually observed within the range of energies from 10 eV (low-energy threshold of the SF-3 instrument) to 150 eV, sometimes also at the energy step 500 eV, but only very seldom at 1000 eV and never at 5000 and 15,000 eV. From the data of the *Cosmos*-1809 satellite (minimum solar activity with 960 km altitude and consequently much lower local plasma frequency along the orbit) the SAP bursts of electrons were generally observed at energies of less than 100 eV.

Figure 2 demonstrates energy spectra of electrons accumulated from several stimulated bursts for the main "electron resonance" just below the local electron plasma frequency during a pass of the *Intercosmos*-19. The electrons' intensity increased sharply for pitch angles of about 90° which shows the predominant electron acceleration in the plane perpendicular to the magnetic field.

The results of the local plasma heating/acceleration and the SAP particular characteristics were fully confirmed by James (1983) in his study of the particles' intensity bursts observed by the *ISIS* topside sounder satellites.

From the data of *Intercosmos*-19 it was also noted that the sounder emission frequency interval corresponding to the main peak of the SAP electrons increases with the local plasma frequency. The dependence of the bursts' characteristics on the local plasma parameters has led to the proposal (Galperin *et al.*, 1981) that the SAP electrons' acceleration processes, similarly to sounder wave resonances, are predominant at some resonance frequencies of the near-satellite ionospheric plasma.

To study in more detail the bursts' dependencies on the local plasma parameters, Serov *et al.* (1985) considered the *Intercosmos*-19 data at middle and low latitudes (where there are no contaminating auroral electrons). A representative set of 332 intensive bursts of electrons was selected when the electron energy was in the range 100–150 eV. In each case the data were subjected to analysis according to the full frequency scanning cycle of the sounder. The precision of the frequency determination was 0.3 MHz. All prominent intensity bursts' locations from each of the 332 scans were plotted in Fig. 3 on the coordinate plane *p*, *q*, where parameter $q = f_{pe}/f_{ce}$ (ratio of the local electron plasma frequency and the electron gyrofrequency) and $p = f/f_{ce}$ (f is the sounder frequency). The f_{pe} values in each case were scaled from the data ionograms of the IS-338 sounder obtained simultaneously and the f_{ce} values from model calculations of the Earth's magnetic field for corresponding satellite positions.

In Fig. 3 the following three main groups of resonance frequencies can be distinguished corresponding to maximum intensity of SAP electrons in the stimulated bursts:

—the first group (branch H)—at the local electron gyrofrequency (the first harmonic);
—the second group—a wide band overlapping the region of several resonance branches lying near (for $q < 3.5$), and less than (for $q > 3.5$), the local plasma frequency. The corresponding "electron resonance branches" were called (by Serov *et al.*, 1985) DN2e, D2e, D3e, D3e$^-$, D3e$^+$ and D4e. This name was chosen by analogy with "diffuse wave resonances" in the topside ionograms discovered by Oya (1970) and also studied by Benson (1982). These two types of resonances partially overlap in the p, q-plane.
—The third group is situated mainly between the second and the third harmonics of the electron plasma frequency. There appears some regular structure which was denoted as M1 by Serov *et al.* (1985). The intensity ratios for these three groups can be evaluated from the sample shown in Fig. 1.

4. ACCELERATION OF IONS

The first measurements of the SAP ions were presented by James (1983) and were later discussed by James (1987).

Preliminary analysis of the *Cosmos*-1809 satellite measurements of the SAP ions shows that some of the acceleration of ions was observed on every frequency scan during the on-board sounder operation. The bursts of ion intensity were observed on energies up to 80 eV. Figure 4 shows the dependence of intensity of accelerated ions for $E = 10$ eV on the frequency of the IS-338 sounder (data accumulated for several frequency scans). For the SAP ions the noticeable intensity was observed at frequencies which were less than the local electron plasma frequency (f_{pe}). The

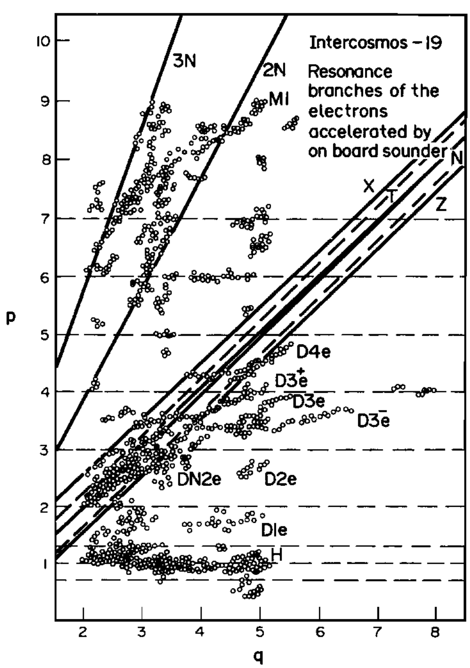

FIG. 3. p, q—REPRESENTATION LOCATIONS OF MAXIMUM ELECTRON INTENSITY ACCUMULATED FOR 332 SELECTED SOUNDER FREQUENCY SCANS SHOWING THE RESONANCE BRANCHES OF THE ELECTRONS ACCELERATED BY AN ON-BOARD SOUNDER.

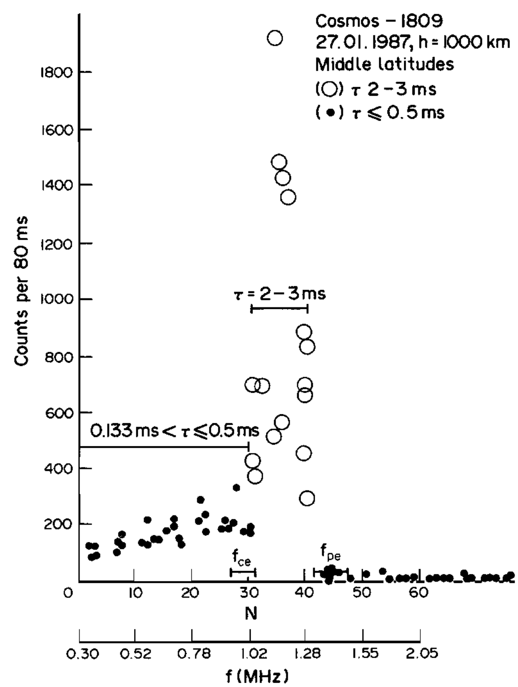

FIG. 4. DEPENDENCE OF THE INTENSITY OF SOUNDER ACCELERATED IONS ($E_i = 10$ eV) ON THE ON-BOARD RADIOTRANSMITTER FREQUENCY; N IS THE NUMBER OF RF PULSES IN THE SCAN.

most important increase of the SAP ions' intensity was observed for the emission in the range between gyro- and plasma frequencies (for $f_{pe} > f_{ce}$) and at the lowest energies.

For frequencies lower than the local gyrofrequency the duration τ_i of the ion intensity burst after the end of the radiopulse was $\tau_i \leqslant 0.5$ ms, and no significant dependence of intensity on pitch angle was noted. In the frequency range between f_{ce} and f_{pe} ($f_{pe} > f_{ce}$) the burst duration was much longer, i.e. of 2–3 ms, and the maximum intensity at the lowest energies occurred at pitch angles of about 35–40 degrees in the Northern Hemisphere.

The short-period isotropic bursts of low intensity agree quite well with those described by James (1983). According to James (1987) their acceleration occurs due to the antenna negative potential relative to the plasma during HF-radioemission; but the much more intensive, long duration ($\geqslant 2$ ms) anisotropic bursts of ion intensity observed at low energies in the limited range of frequencies are apparently due to a kind of resonance acceleration. This could be ion acceleration by intensive ion-acoustic waves, which can be excited in the course of intensive plasma oscillations around the satellite during the sounder emission in the non-propagating frequency band. One of the possibilities consistent with the observed anisotropic angular distribution is the ion heating inside the ion cavity in the wave of the satellite.

Figure 5 demonstrates energy spectra of ions accumulated from several sequential stimulated bursts for some resonance frequencies. It can be seen that low energy ions experience additional heating/acceleration and last for a longer time in the range of sounder frequencies f when $f_{ce} \leqslant f \leqslant f_{pe}$.

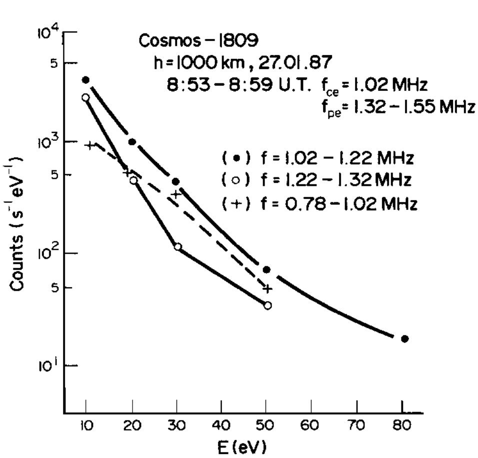

FIG. 5. ENERGY SPECTRA OF IONS ACCUMULATED FROM SEVERAL STIMULATED BURSTS AT DIFFERENT SOUNDER FREQUENCIES.

5. POSSIBLE MECHANISMS OF SAP ACCELERATION

To determine mechanisms responsible for the particle acceleration it is necessary to understand how the powerful RF electric field oscillations on the antenna dipoles, fed by the on-board sounder, interact with the near-satellite ionospheric plasma. A qualitative model of ionospheric plasma modification by powerful radiopulses was described by Pulinets and Selegey (1986). From the long duration of bursts of the accelerated particles (from 1 to 3 ms) one can conclude that the acceleration takes place mainly through the wave–particle interactions as the antenna potential is discharged for no more than 0.5 ms (Pulinets and Selegey, 1986). The p, q representation of the SAP maxima accumulated positions as shown in Fig. 3, appears to be very similar to the analogous distribution for plasma wave resonances from the *Intercosmos*-19 and *Cosmos*-1809 accumulated data shown in Fig. 6. This striking similarity in details gives important evidence of wave–particle interactions relating wave and particle resonances of the near-satellite plasma. The data on plasma resonances shown in Fig. 6 were accumulated from almost the same set of the *Intercosmos*-19 ionograms (near 400) as for the par-

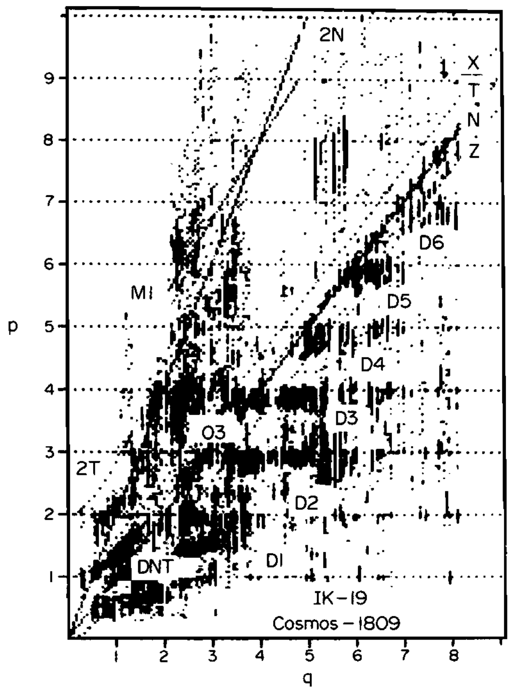

FIG. 6. p, q—REPRESENTATION OF THE DISTRIBUTION FOR PLASMA WAVE RESONANCES, ACCUMULATED FROM THE *Intercosmos*-19 (TAKEN ALMOST SIMULTANEOUSLY WITH DATA IN FIG. 3).

ticle data shown in Fig. 3, without any specific filtration. The picture was supplemented by the *Cosmos*-1809 data, mainly for the range $q < 1$.

From a comparison of Figs 3 and 6 one can see that the main resonance branches on both p, q representations are the same. It is most obvious for the "diffuse resonance branches" deviated from the N resonance to the frequencies lower than electron cyclotron harmonics. The form of the branches on the wave p, q distribution corresponds to a dispersive curve of electron cyclotron waves which are presumably stimulated by sounder emission. The electric field of these stimulated waves provides for the perpendicular heating of electrons (Galeev *et al.*, 1975). In fact, heating of electrons through the Harris instability was invoked by Oya (1970) to explain the diffuse wave resonances.

We would like to mention the M1 branch which can most probably be attributed to the three-wave decay parametric instability process. One can see this branch is faint, but quite noticeable for "electron resonances" in Fig. 3 and on the wave picture as well. It is important to note, though, that it is the resulting decay Langmuir waves and not the pumping waves of the M1 branch which must be responsible for the observed acceleration of electrons.

The most dramatic phenomena during a sounder frequency scan take place at frequencies slightly lower than local plasma frequency for $f_{pe} > f_{ce}$ when the RF energy emitted from the antenna dipoles cannot escape from the near-satellite region in the form of propagating electromagnetic waves. Due to high density of the emitted RF energy ($w/n_e T_e \gtrsim 1$, see Galperin *et al.*, 1981) the modulational instability develops which leads to the formation of plasma cavities where the wave energy condenses. The collapse of these cavities leads to a dissipation of the RF field by the Landau damping mechanism. As is known, the collapse in the magnetic field causes acceleration of the electrons predominantly perpendicular to the field. This is consistent with the SAP characteristics as evaluated by all soft particle spectrometer measurements on the *Intercosmos*-19, *ISIS* and *Cosmos*-1809 satellites.

To obtain a more complete picture of the wave–particle interactions in these conditions it is important to use an independent on-board high resolution wave receiver (or a wide-band receiver), to analyse the full frequency range of the near-satellite plasma oscillations. Such instruments were also installed on the *Intercosmos*-19 and *Cosmos*-1809 satellites (Gusev *et al.*, 1980).

Figure 7 gives an example of such a RF wide-band spectrum analysis for the case when SAP and wave resonances were prominent (from the *Intercosmos*-19). It is evident that the plasma oscillations took

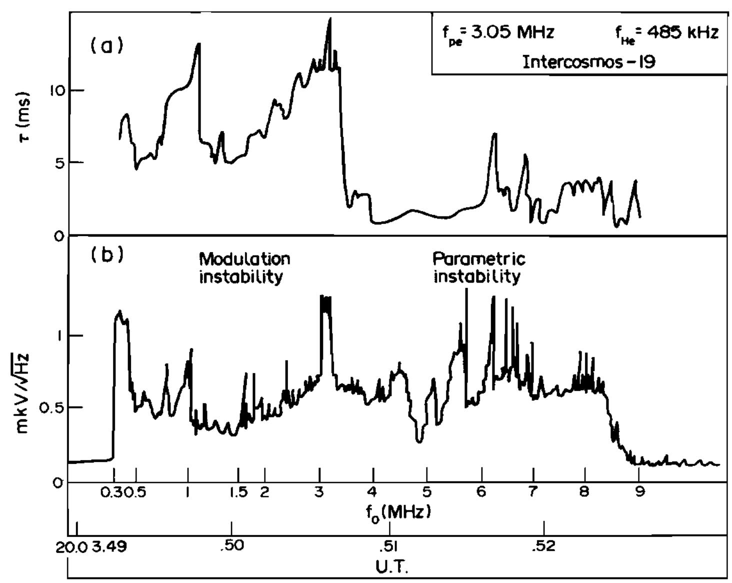

FIG. 7. ENVELOPE OF DURATION (a) AND MAXIMA (b) OF PLASMA FREQUENCY (f_{pe}) RESPONSE ON TOPSIDE SOUNDER PULSES DURING ONE SWEEP OF THE SOUNDER ON THE *Intercosmos*-19 AT THE ALTITUDE h = 930 km, MEASURED BY THE WIDE-BAND RADIORECEIVER.

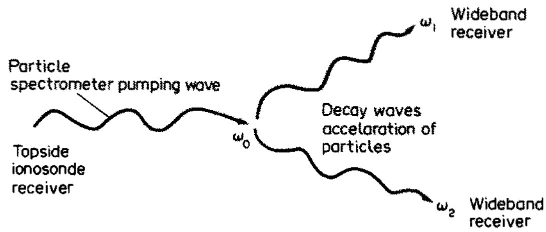

FIG. 8. SCHEMATICS OF THE HF PUMPING WAVE EFFECTS REGISTRATION FROM AN EMITTING SATELLITE.

place in all the frequency ranges where the SAP phenomena, or "electron resonances", were observed. The combination of the particle spectrometer data for electron resonances and the ionosonde receiver data for wave resonances can help to determine the frequency of the pumping wave producing the resonance where the effect of electron acceleration takes place together with the spectrum of the accompanying waves in the plasma. Yet these measurements may still be unable to indicate the particular waves with which the plasma electrons and ions actually interacted. From the data of the on-board wide-band receiver it was established that some plasma resonances (through which some particles' acceleration could occur) were stimulated by every pulse of the sounder when the frequency was emitted in the range from 0.3 MHz (the lowest sounder frequency) up to about $3 \cdot f_{pe}$ (Fig. 7b). Thus the proper study of the heating/acceleration mechanisms of the wave–particle interactions in the strongly turbulent near-satellite plasma excited by powerful RF electric field oscillations needs further experimentation specially designed for this purpose.

Meanwhile, from Fig. 7 one can probably understand why we see acceleration of ions only on frequencies lower than local plasma frequency (when $f_{pe} > f_{ce}$). It has already been mentioned that modulational instability is stimulated on frequencies lower than the electron plasma frequency. During this process the ion acoustic waves are emitted (Fig. 8) and the ions are accelerated in the electric field of these waves. This process is rather slow, which is consistent with the fact that the duration of the respective plasma resonance (Fig. 7a) on frequencies lower than the plasma frequency is relatively long. After passing the plasma frequency in the sounder scan, the duration of plasma resonance abruptly falls, which indicates that the ion acoustic waves are no longer excited and ions are no

TABLE 1. MECHANISMS OF PLASMA HEATING/ACCELERATION BY POWERFUL RF ELECTRIC FIELD PULSES

Branches of the maximal intensity of electrons and ions	Proposed mechanisms
Gyroresonance, branch H ($p \approx 1$; $q > 1$)	Cyclotron heating of electrons as a result of the Landau damping of electromagnetic RF oscillation near the emitting antenna (James, 1983; Serov *et al.*, 1985)
Plasma resonance, branch P ($p = q$; $0.7 < q < 3.5$)	Heating of electrons during the collapse of the Langmuir cavitons appearing as a result of the modulational instability in the near-satellite plasma (Serov *et al.*, 1985; Pulinets and Selegey, 1986)
Diffuse resonances between the electron gyrofrequency harmonics. Branches D1e, D2e, D3e, D3$^+$e, D3$^-$e, D4e	Cyclotron heating by the Landau non-linear damping of electron-cyclotron waves excited in the near-satellite plasma by antenna RF emission (Serov *et al.*, 1985; Oya, 1970; Kiwamoto and Benson, 1979; Benson, 1982)
Parametric resonance from $\sim 2f_{pe}$ up to $3f_{pe}$. Branch M1 ($6.4 < p < 9.2$; $2 < q < 5$)	Heating of electrons in the collapse of Langmuir caviton appearing during the excitation of Langmuir waves under the conditions of parametric resonance in the near-satellite plasma under the effect of the antenna RF emission (Serov *et al.*, 1985)
Ion heating/acceleration on f, $f_{ce} < f < f_{pe}$	Acceleration of ions in the electric field of ion-acoustic waves stimulated by the modulational instability (this paper)
Wide-band ion acceleration on $f < f_{ce}, f_{pe}$	Acceleration of ions in the negative satellite d.c.-potential region around the satellite formed during the transmitter pulse (James, 1983, 1987)

longer heated. It can be supposed that we observe here the transition from the modulational instability mechanism to the HF parametric decay instability, where the ions do not take part. Thus the observed characteristics of the ion heating/acceleration are also consistent with the mechanism of the modulational instability.

Mechanisms of particle heating/acceleration by powerful RF electric field oscillations in the near-satellite plasma according to the data from the *Intercosmos*-19 and *Cosmos*-1809 satellites considered above are summarized in Table 1.

Acknowledgement—The authors are grateful to Dr V. A. Gladyshev for the development of the instrument SF-3M and successful preparation of the experiment on board *Cosmos*-1809.

REFERENCES

Benson, R. F. (1982) Stimulated plasma instability and nonlinear phenomena in the ionosphere. *Radio Sci.* **17**, 1637.

Galeev, A. A., Sagdeev, R. Z., Shapiro, V. D. and Shevchenko, V. I. (1975) Dissipation of a strong electromagnetic wave at the point of plasma resonance. *Lett. Soviet JETR* **21**, 539.

Galperin, Yu. I., Sagdeev, R. Z., Shuiskaya, F. K., Lissakov, Yu. V., Migulin, V. V., Kushnerevskii, Yu. V., Fligel, M. D. and Vasilev, G. V. (1981) Detection of electron acceleration in the ionospheric plasma under the influence of high-power radio emission near the local plasma frequency aboard the space vehicle *Intercosmos*-19. *Cosmic Res.* **19**, 22.

Gusev, G. A., Zateev, O. G., Kushnerevskii, Yu. V., Malkov, B. M., Prostov, M. I., Pulinets, S. A., Selegey, V. V., Terletskii, N. A. and Tsyurupa, L. A. (1980) *Instruments for Investigation of the Upper Ionosphere*, p. 151. IZMIR AN SSSR, Moscow.

James, H. G. (1983) Sounder accelerated particles observed on *ISIS*. *J. geophys. Res.* **88**, 27.

James, H. G. (1987) Discharge of RF-induced spacecraft dc potential by positive ions. *Planet. Space Sci.* **35**, 105.

Kiwamoto, J. and Benson, R. F. (1979) Nonlinear Landau damping in the ionosphere. *J. geophys. Res.* **84**, 4165.

Oya, H. (1970) Sequence of diffuse plasma resonances observed on Alouette-2 ionograms. *J. geophys. Res.* **75**, 4279.

Pulinets, S. A. and Selegey, V. V. (1986) Ionospheric plasma modification in the vicinity of a spacecraft by powerful radio pulses in topside sounding. *J. atmos. terr. Phys.* **48**, 149.

Pulinets, S. A. and Selegey, V. V. (1989) Stimulated plasma resonances as indicator of near satellite plasma modification by powerful radioemission. *Adv. Space Res.* **10**, N7, 546.

Serov, A. A., Galperin, Yu. I., Lissakov, Yu. V. and Shuiskaya, F. K. (1985) Local acceleration of electrons of the near-satellite plasma by the radio emission of a powerful on board transmitter. *Cosmic Res.* **23**, 361.