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Some Type of Broad-Band Emission in the Hectometric Frequency Range Observed Within the Ionosphere*

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Abstract

A unique set of ionospheric radioemissions in the frequency range of 0.6–6.0 MHz has been registered on board of Intercosmos-19 satellite launched in 1979, i.e., during the peak of the last solar activity period. Many new characteristics of ionospheric radioemissions have been discovered in this set. In the above spectral range of emission the Intercosmos-19 data show the following features: if $f_p \lesssim 3$ MHz and foF2 $\gtrsim 5.5$ MHz, there exists a broadband enhancement centred on 4 MHz, reaching the level of about -82 dB; the shape of this enhancement shows minor variation of the order of 3 dBm along the satellite orbit in spite of broad variations of f_p and foF2, if the mentioned relations between frequencies are fulfilled; usually if foF2 drops even to 3 MHz, the man made radionoises add independently to this enhancement – the enhancement is strongly modified when f_p increases above 5 MHz and its shape is related to the changes of f_p. These characteristics suggest the hypothesis on nonglobal origin of the observed broad-band emission. The aim of the present paper is to discuss this question.

1. Introduction

Radio noise levels observable at a satellite in the ionosphere manifest various features depending on frequency range. As has already been reported by Hartz on the basis of the Alouette I and II records [1], in general the upper end of the frequency range shows a large rapidly fluctuating signal that is characteristic of interference from ground transmissions. Down, in the frequency from f_0F2 to approximately local f_T the Alouette I and II records show a slowly varying amplitude which – according to Hartz – represents the galactic noise level observed through an antenna network with a nonuniform response.

A similar type of emission in the hectometric frequency range has also been registered recently on board of the EXOS-C satellite [2]. Here, too, the upper frequency edge of this spectrum was identified as coinciding with the maximum plasma frequency f_0F2 in the ionosphere below the satellite, the lower edge located about the local satellite plasma frequency. The EXOS-C experimenters have named this emission Terrestrial Hectometric Radiation [2].

We have also observed this broad-band emission on board of the Intercosmos-19 satellite (IK-19) launched in 1979, i.e., during the peak of the last solar activity period. A superheterodyne receiver with double frequency conversion and sweeping frequency in the band 0.6–6.0 MHz, which operated with a dipole antenna 15 m long from tip-to-tip, was used as spectrometer. The IK-19 satellite was stabilized with respect to the vertical axis and the velocity vector, the receiver dipole antenna was oriented along the satellite vellocity vector with one monopole ahead of, and the other behind the satellite. The dipole antenna swings around the vertical axis with the period of about twenty minutes and with maximum amplitude 12°. So, one monopole was always located in the plasma wake, and the other in the satellite plasma front. The apogeum and perigeum of the IK-19 were 980 and 490 km, respectively [3, 4].

These observations bring a unique set of ionospheric radioemission whose features suggest the hypothesis that the source of this broad-band emission should be located close to the satellite. We present the results of measurements below discussing their features, with some tentative conclusions.

2. Observation results

The typical spectrum observed by the IK-19 is presented in Fig. 1. The band in question from frequency equal f_0F2 below the satellite down to the local satellite plasma frequency is manifested clearly. The gap between the lower frequency edge of the band and local plasma frequency, observed also by the EXOS-C experimenters, is due to the attenuation of the band by the noncompatibility of the antenna network [5, 6].

The sequence of these spectra along the satellite orbit is presented in Fig. 2: here the local plasma frequency at the satellite is located below the considered band. It can be seen that the intensity of this broad-band emission is almost constant along the orbit. Fig. 3 presents the sequence of spectra for the case when at some part of the orbit the local plasma frequency becomes higher than the considered band. It can be

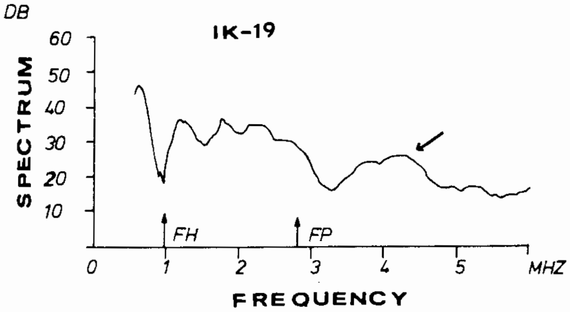

Fig. 1. Typical spectrum observed on board of IK-19 on 1979, 05, 31; UT 13h31′18″; at LAT 48.3°N; LONG 173.7°; L = 2.0; ALT = 687 km. The electron gyrofrequency FH, electron plasma frequency FP, as well as the enhanced band of emission are indicated.

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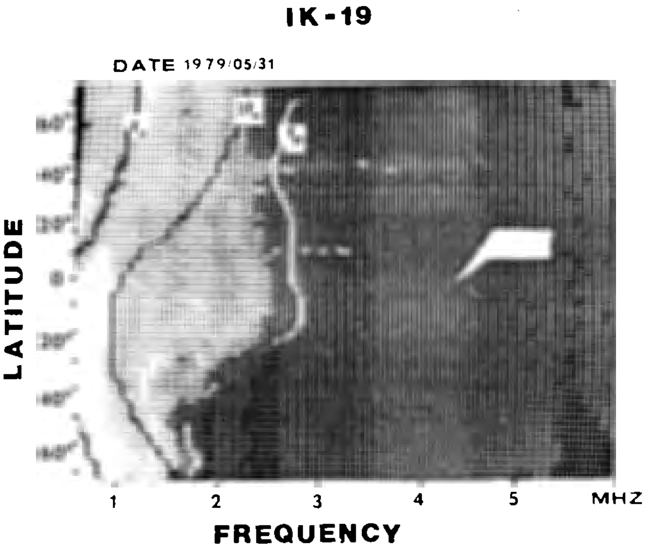

Fig. 2. Sequence of spectra observed along the IK-19 satellite orbit (dynamic spectra) obtained on 1979, 05, 31 for UT 15h26′48″ to 16h06′48″. Emission intensity increases from the black colour (background level) 8 dB/1 μV to the white colour (max. 40 dB/1 μV) between which seven different levels of intensity are located. The local – at the satellite – electron plasma frequency determined from the IK-19 top-side sounder, electron gyrofrequency determined from the board magnetometer and its second harmonic are also indicated. Here the broad band emission is above the local electron plasma frequency.

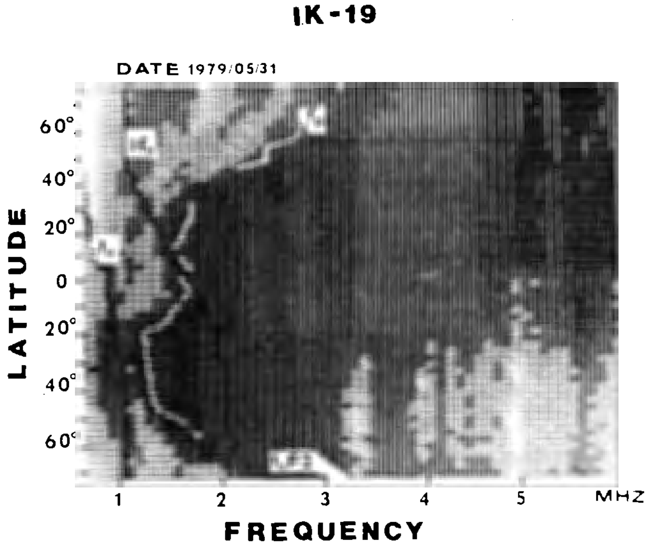

Fig. 4. Dynamic spectra observed on board of IK-19 on 1979, 05, 31 for UT 17h29′06″ to 18h09′06″. The details of this figure are the same as in Fig. 2. Here for some part of the orbit frequency f_0F2 below the satellite is lower than the upper edge of the broad band emission in question. Interference lines from ground based stations are clearly manifested.

observed that here the emission in question not only does not disappear, but increase its intensity. This happens always when the local plasma frequency exceeds the considered emission band. As can be seen in Figs. 2 and 4 below the local plasma frequency two resonances (the white traces) determined by the coupling between the antenna network and the surrounding plasma are manifested: one (higher in frequency) is related to the front monpoloe, and the other at lower frequency to the monopole in the wake. When the local plasma frequency increases to a large extent, and the front monopole resonance is superposed with the considered emission band, the spectrum becomes torn out.

The case when the frequency f_0F2 below the satellite is lower than the upper edge of the observed broad band emission in question is illustrated in Fig. 4. Thus it is evident that the emission can be created in the frequency range above the F-layer maximum.

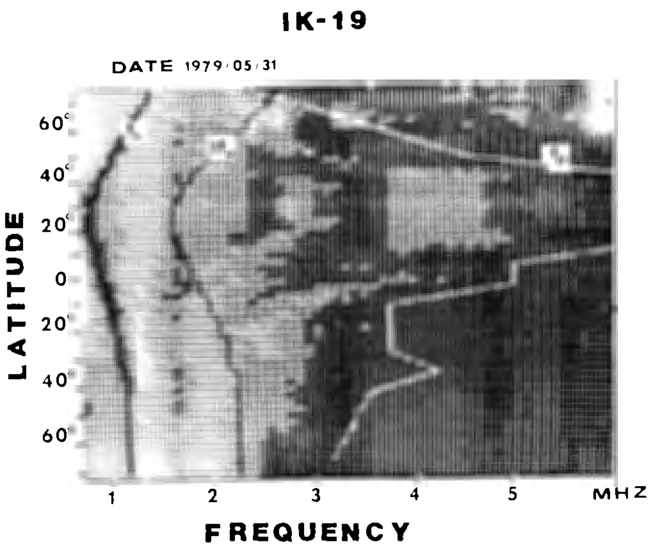

Fig. 3. Dynamic spectra observed on board of IK-19 on 1979, 05, 31 for UT 14h46′48″ to 15h26′48″. The details of this picture are the same as in Fig. 2. Here at some part of the orbit the local plasma frequency becomes higher than the considered emission band. In that situation the emission in question increases its intensity.

The dependence of intensity of the broad-band emission on magnetic local time in the polar region is illustrated in Fig. 5. The enhancement of intensity in evening hours follows mainly from ground based transmitters.

Figure 6, in turn presents the intensity in dependence on geographic latitude. The enhancement in high latitude can again be related to ground based transmitters.

3. Discussion

From the presented observation results the following features of the considered broad-band emission can be concluded:

– the broad-band emission occurs not only in the frequency range $f_p < f < f_0$F2, but also in the case when $f < f_p$ and $f > f_0$F2;

– the case when $f > f_0$F2 shows that the emission cannot be generated in the F2 region of the ionosphere;

– when $f < f_p$, the intensity of the emission increases, which suggests that its source should be located very close to the satellite.

Thus following the above IK-19 experiment data, it is difficult to interpret the considered emission as of extrater-

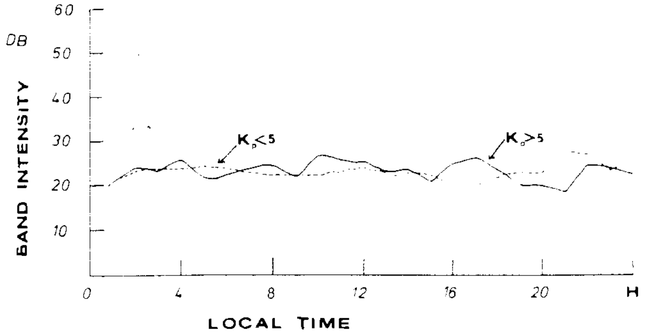

Fig. 5. Intensity of emission integrated over the observed frequency band and selected for the polar region in dependence on magnetic local time for low ($K_p < 5$) and high ($K_p > 5$) magnetic activity.

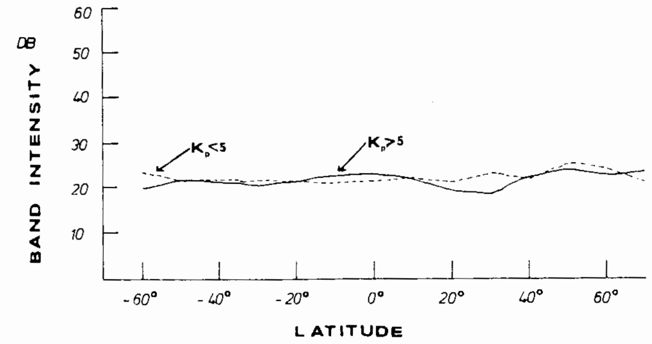

Fig. 6. intensity of emission integrated over the observed frequency band in dependence on geographic latitude for low ($K_p < 5$) and high ($K_p > 5$) magnetic activity.

restrial origin (cosmic noise), or of global origin natural ionospheric emission. It should rather be approached as locally generated Satellite Hectometric Noise (SHN). The question is what kind of mechanism is responsible for its generation. It is highly unlikely that such a broad-band emission registered on board of different satellites is caused by an artificial generator of the satellite equipment. The satellite–plasma interaction seems to be a more probable source of generation. The problem of plasma waves excitation by a body moving in plasma with high velocity was already considered in literature [7]. The existing models can explain the low frequency oscillation, also registered on satellite board, but the problem of wave generation in the hectometric frequency range remains open. We attempt the following tentative hypothesis.

As has already been mentioned by Al'Pert [7] the interaction of energetic particles with satellite created nonuniform plasma structures can be one of the probable mechanisms of wave generation.

Plasma irregularities are created particularly behind the body, i.e., in the plasma wake. This problem was already analyzed by Liu [8] for particles trapped in the potential well behind the satellite. Such negative potential well (with respect to the satellite) has the depth with an absolute value of the order $\phi_1 = (kT_e/e)\ \ln (R/d)^2$, and is located at a distance of about $2R$ in the case of a spherical satellite with radius, R, from the centre of the satellite. Here kT_e, d, and e are electron thermal energy, electron Debeye radius, and electron charge, respectively. The half-width of the well is approximately R.

This negative potential well is filled with an electron rich plasma whose ions are trapped and oscillate between the ridge and the valley of the well. So, the ion-sound fluctuations are created in the plasma well. It can be expected that the steady state of ion-sound turbulence can be created in the well by nonlinear interaction. For ion-sound turbulence generated in some band of scale the spectrum has a narrow shape [9]. The intensity changes as $k^{-1}\ln (k/k_0)$, where k_0 is related to the scale at which the turbulence energy becomes zero (in our case it is determined by the width of the well). The spectrum reaches its maximum at $\sim 1.6\,k_0$, and is strongly damped for $k \sim 3.5\,k_0$.

Thus behind the satellite in the near wake region strong irregular structure can be created. The spatial scales of these irregularities depend on the potential well parameters. The hot electrons of the surrounding plasma with energies $E > e(\phi_0 + \phi_1)$ – where ϕ_0 is the satellite potential with respect to the plasma – can cross the potential well and interact with the existing irregularities.

It is known [9, 10] that in such case transition or scattering radiation can be created whose frequency ω is determined by the superthermal electron velocity V_0, and spatial scale of irregularity l, namely

$$\omega \;=\; \omega_s(k) + \boldsymbol{k}\cdot \boldsymbol{V}_0 \approx \boldsymbol{k}V_0 \tag{1}$$

Here $k = 2\pi/l$ and ω_s-frequency of ion-sound pulsation. The scales of turbulent structures are limited from $k_{\min}$ to $k_{\max}$. Hence the emission can be expected in some frequency band. The conversion coefficient for the case of anisotropic distribution of superthermal electrons and isotropic ion-sound turbulence is [10]:

$$\mu(\omega) \;=\; \pm\,\frac{2\pi\omega_{pe}W_s^{T}}{n_e^2 m_e v_s}\left[\frac{\omega_s}{\omega_{pe}}\right]^2\left[\frac{\omega_{pe}}{\omega}\right]^5 n\left(V > \frac{\omega}{\omega_s}v_s\right) \tag{2}$$

Here $n[V > (\omega/\omega_s)v_s]$ – concentration of superthermal electrons with velocities higher than $v = \omega v_s/\omega_s$; v_s – ion-sound velocity; ω_{pe} – electron plasma frequency; m_e – mass of electron, and W_s^{T} – average energy of the ion-sound pulsations.

The observed spectrum density is determined by the factor of eq. (2). It is evident that with increase of electron plasma frequency the intensity of emission should also increase. How the potential of the satellite can control the above phenomena is not obvious. In the first place with decrease of ϕ_0 with respect to the nondisturbed plasma, the population of superthermal particles which pass the well decreases. At the same time the depth of the potential well with respect to the nondisturbed plasma potential increases, and more particles are trapped, i.e., the average density of energy of the excited ion-sound turbulence W_T can increase. Thus, according to eq. (2) the dependence of intensity of broad-band emission on satellite potential ϕ_0 should be weak. The IK-19's potential with respect to the ionospheric plasma changed from -1 V in the equator region to -6 V in the polar region. As it can be seen in Fig. 6 the observed intensity of broad-band emission remains almost constant. Here we can perform some rough estimations. If we take the following plasma parameters: $kT_e = 0.3$ eV, $d = 0.9$ cm, and satellite radius $R = 50$ cm, we have $e\phi_1 = 2.4$ eV. Thus the electrons with velocity

$$v > v_0 \;=\; \left[\frac{2e}{m_e}(\phi_0 + \phi_1)\right]^{1/2}$$

$$= \;5.93 \times 10^7[(\phi_0 + \phi_1)(V)]^{1/2}\mathrm{cm/s}$$

can pass the well. Taking into account that the largest scale of ion-sound fluctuations inside the well is of the order of the well width, i.e., $2R$ for turbulence wave numbers we have: $k_{\min} = (2\pi/2R)$, and $k_{\max} = 3.5\,k_{\min}$. The frequency range in which the transition radiation will be created is according to eq. (1) $f \approx 1.15$–3.8 MHz for the equatorial region ($\phi_0 \approx -1$ V), $f \approx 1.7$–6 MHz for the polar region ($\phi_0 \approx -6$ V). As particles with velocity $v > v_0$ also contribute to the generation in spite of exponential decrease of their concentration the total spectrum should shift to higher frequency.

If it happened that some voltage existed (for instance, power supply ~ 27 V) between the receiving antenna and the solar battery, the plasma electrons could be accelerated to rather high energy. So, the population of superthermal particles could be drastically modified. In that case electron plasma oscillation in the near satellite region can be created, which also modifies the observed phenomena. The model presented here is very tentative. A serious calculation of the ion-sound turbulence generated in the potential well permeated by the geomagnetic field and superthermal particles is needed. We expect to perform it in future publications.

4. Conclusions

Summing up we can conclude the following. The broad-band emission in hectometric frequency range observed on board of different satellites is difficult to interpret as of natural origin. As the IK-19 satellite observations show, its features are controlled by the near satellite plasma properties. We suggest that the emission in question is locally generated close to the satellite. We have proposed a model in which the particles trapped in the potential well behind the satellite created turbulent structures with which the superthermal particles interact. As the result transition or scattered radiation is generated. In the model the phenomenon is controlled mainly by the satellite radius R, parameters of plasma close to the saltellite (f_p, T_e, d), and the environment of superthermal particles. Although the model is only tentative it renders the main features of the observed emission. As this radiation is created in the hectometric frequency range we propose to call it locally generated Satellite Hectometric Noise (SHN).

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