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# DISTURBANCES IN THE UPPER IONOSPHERE DURING HEATING EXPERIMENTS ACCORDING TO THE COSMOS-1809 SATELLITE

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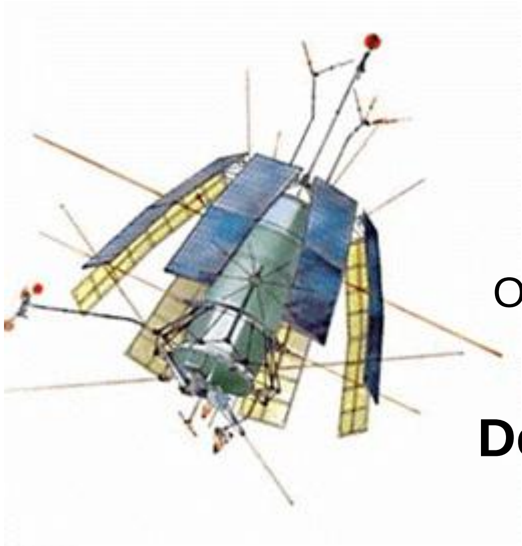
Abstract -- **The results of several series of experiments on ionosphere heating with high-frequency radiation at the Sura and the Research Institute of Radio stands in 1991–93 for the Cosmos-1809 satellite flights are presented [1]. Three zones of artificial electrostatic turbulence were identified above the Sura stand [2]. The first zone has a radius of 100 km, its creation is explained by the expansion of metastable oxygen and nitrogen atoms from the heating region. The second one has a radius of 400 km, its creation is explained by the expansion of metastable helium atoms. The radius of the third zone is 1000 km; its presence is explained by the expansion of metastable hydrogen atoms. It is shown that the Sura heating stand modifies the impact on the ionosphere with long-range navigation systems located on the European territory of the Russian Federation. It was found that the development of bubbles in the equatorial ionosphere west of the magnetic meridian of the Sura stand is suppressed during its operation. In the conjugated ionosphere of the southern hemisphere, a region of strong ELF turbulence was identified during the operation of the Sura stand, which is consistent with the Shklovsky effect. Neutral hydrogen intruding into the magnetosphere either ionizes or becomes neutral and a strong disturbance should be observed in the magnetic force tube. With the joint work of the Sura and the Research Institute of Radio stands in the area $2 < L < 3.2$, a canalized passage of whistlers was observed. After the eruption of the super volcanoes Pinatubo and Hudson, a change in ionospheric disturbances recorded on the coincident trajectories of the Cosmos-1809 satellite with the same operating conditions of the Sura stand was noted.**



# Satellite COSMOS - 1809

**Worked: December 18, 1986 – may 23, 1993**

Orbit: apogee - 980 km, perigee 950 km, inclination 82, T=104 min.

## Devices of passive diagnostics

| № | Device | Purpose | Elaborate | Processing |
|---|---|---|---|---|
| 1 | **АНЧ-2МЕ** | **Analyzer low frequency e/m fluctuations in the band of 20 Hz – 20 kHz and channels 140, 450, 850, 4600 Hz and 15 kHz [15]** | Mikhailov Yu.<br>Sobolev Ya. | Sobolev Ya.<br>Ovcharenko O. |
| 2 | **ИЗ-2** | **Impedance probe measurements for Ne and dNe [16]** | Komrakov G. | Trushkina E. |
| 3 | **ДЭП** | **Measurement of two components of the electric field** | Pushaev P.<br>Isaev N. | Trushkina E. |
| 4 | **КМ-9** | **The temperature of electrons in the range of 600 – 5000 [17]** | Afonin V. | Trushkina E. |
| 5 | **АВЧ-2Ф** | **High-frequency radio spectrometer measurement at frequency of 4.6 MHz** | Pulinets S. | Selegej V. |

# Effects of HF heating of the ionosphere recorded by the satellite Cosmos-1809

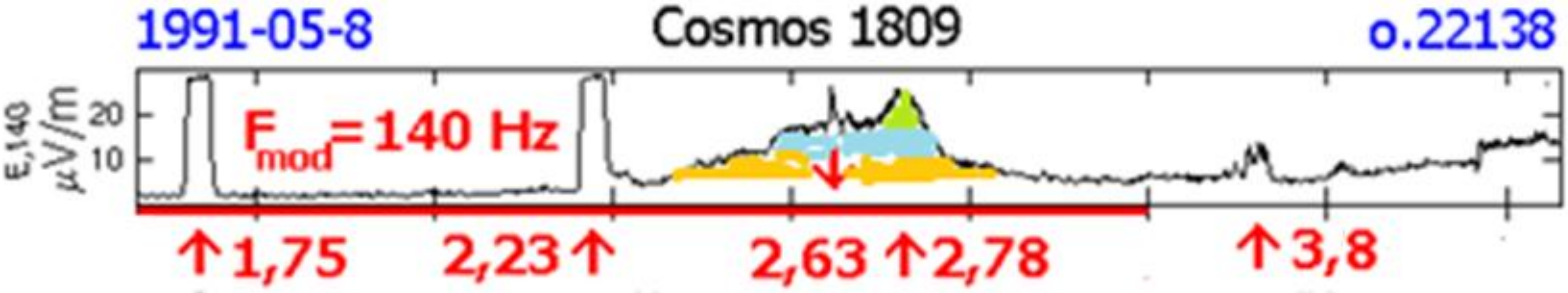
The works was carried out in the program of the "Active experiments and anthropogenic effects in the ionosphere“ [17].

**Avdyushin, S. (IPG) – the head of the Program**
**Migulin V. (IZMIRAN) – scientific program Manager of the satellite Cosmos-1809**
**Romanovsky Yu. (IPG) – the organizer of the Project SURA - Cosmos-1809**
**Zuzin V., Komrakov G. (FGBNU RRI) – the organizers of SURA in the Project**
**Petrov M. (Institute of Radio) – the organizer of work of the Moscow stand**
**Chmyrev V. (IZMIRAN) – the head of the works from IZMIRAN in the Project**
**Kostin V. (IZMIRAN) – the coordinator of the Cosmos-1809 and heating stands**

| Year | Month | day / number of activations stand |
|---|---|---|
| 1991 | Feb-March<br>April<br>May | 18/2, 19/2, 20/6, 21/3, 22/6, 25/6, 26/3, 27/3, 28/3 – 1/1<br>8/2, 9/1, 10/3, 11/1, 12/3, 14/3, 16/2, 17/4, 18/2, 19/2<br>5/1, 6/2, 7/3, 8/2, 12/3, 13/3, 15/3, 16/3 |
| 1992 | Nov-Dec | 21/5, 26/2 – 10/3, 17/6 |
| 1993 | May | 19/2, 20/4, 21/3 |

**Radio Institute stand worked in conjunction with SURA stand in April 1991.**

## Features of disturbances of the midday ionosphere modulation of the HF radiation cyclotron frequency of helium near the stand SURA [1, 2]

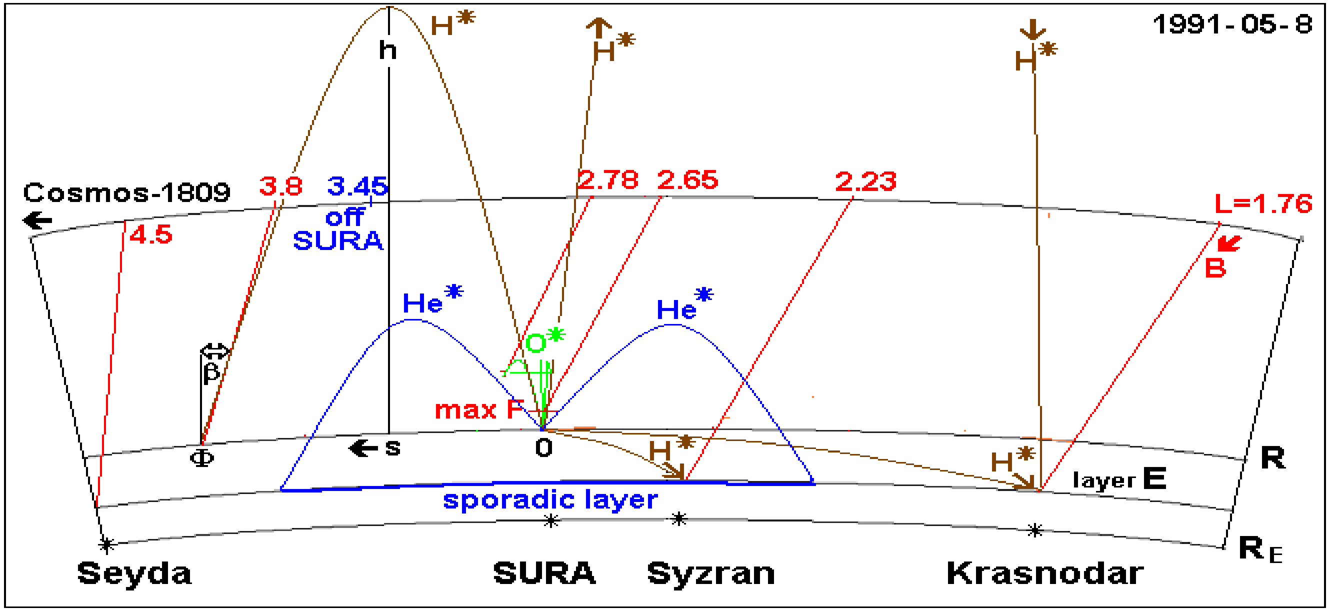



**Three areas of turbulence stand out :**

1. **With the centre L=2.63, length +/- 180 km where there is a whistler. Appears to be associated with the scattering atoms He∗ (blue).**
2. **With the centre L=2.78, held at an altitude of 100 km above the region of heating and length of +/- 70 km. Appears to be associated with the scattering of atoms O∗ (green).**
3. **With the center L=2.64 in the field of heating, but with a length of +/- 700 km presumably associated with the scattering of atoms H (braun).**

**"Tails" of pulsating flows atoms H, which arise under illumination by the Sun, travels more than 10000 km. Falling in the zone of influence of VLF transmitters are easily ionized ~3,4 eV and cause the e/m radiation with frequency modulation (Krasnodar, Syzran and Seyda).**

# Scheme of ballistic expansion of neutral atoms projected on the magnetic Meridian of the stand SURA




Particles, flying at a speed **V** and the incident angle β, will fly along the arc of a sphere of radius **R** distance **s**

$$\mathbf{s} = \Delta\Phi \cdot \mathbf{R} = \frac{R^2V^2\sin 2\beta}{gR_E^2}$$ , where $\mathbf{R_E}$ = 6370 km, ΔΦ – central angle

$$\mathbf{h} = \frac{R^2V^2\cos^2\beta}{\left|2gR_E^2 - RV^2\cos^2\beta\right|}$$ vertex of a parabola

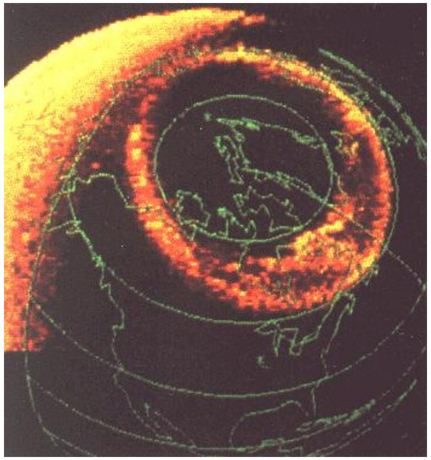
# Oxygen meta stable atoms

**The glow of oxygen due to the radiation of excited atoms in meta stable States with wavelengths 557,7 nm (green line, the life time of 0.74 s) and a doublet 630 and 636,4 nm (red region, the life time of 110 s). As a result, the red doublet is emitted at altitudes of 150-400 km, where due to the high sparsity of the atmosphere is low speed damping of the excited States in collisions.**

**The surface of the Earth is not the best place to observe auroras: first, almost always they have to be monitored at night, when the sun does not interfere; secondly, the observations may interfere with the clouds. These difficulties can be avoided if you follow the auroras from Space.**

**Both the 557.7 and 630.0 nm wavelengths correspond to forbidden transitions of atomic oxygen. In a situation where, according to usual approximations (electric-dipole approximation for the interaction with light), the process cannot happen, but at a higher level of approximation (magnetic dipole, or, electric quadrupole) the process is allowed but at a much lower rate.**

| Atom | Status | Transfer | λ, nm | J | Process |
|---|---|---|---|---|---|
| OI | $2p^4$ | 1S → 1D | 557.7 | 2 →0 | e |
| | | 1D → 3P | 630 | 2 →2 | m |
| | | 1D → 3P | 636.4 | 1→2 | m |

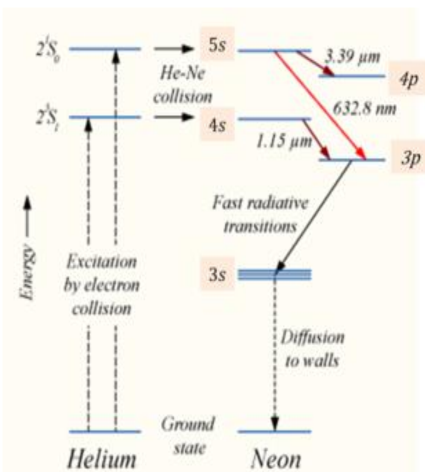


**Diffuse aurora observed by DE-1 satellite**

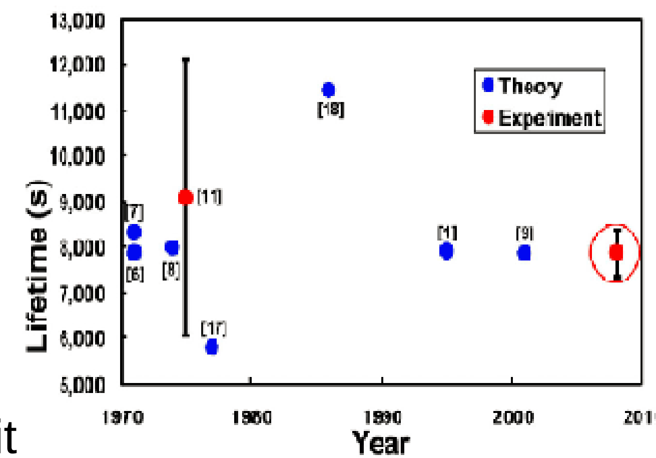
Region of HF heating: **T** electron = 3500 K; $\mathbf{V_o}$ = 1970 m/s; β =45; $\mathbf{s_o}$ = 150 km
Injection region by TC Harry: **T** neutral =1170 K; $\mathbf{V_o}$ =1100 m/s; β =20; $\mathbf{s_o}$ = 86 km

# Helium meta stable atoms

- **The mechanism producing [population inversion]() and [light amplification]() in a HeNe laser plasma originates with inelastic collision of energetic electrons with ground state helium atoms in the gas mixture. As shown in the accompanying energy level diagram, these collisions excite helium atoms from the ground state to higher energy excited states, among them the $2^3S_1$ and $2^1S_0$ long-lived meta stable states.**
- **Collisions between these helium meta stable atoms and ground state neon atoms results in a selective and efficient transfer of excitation energy from the helium to neon.**



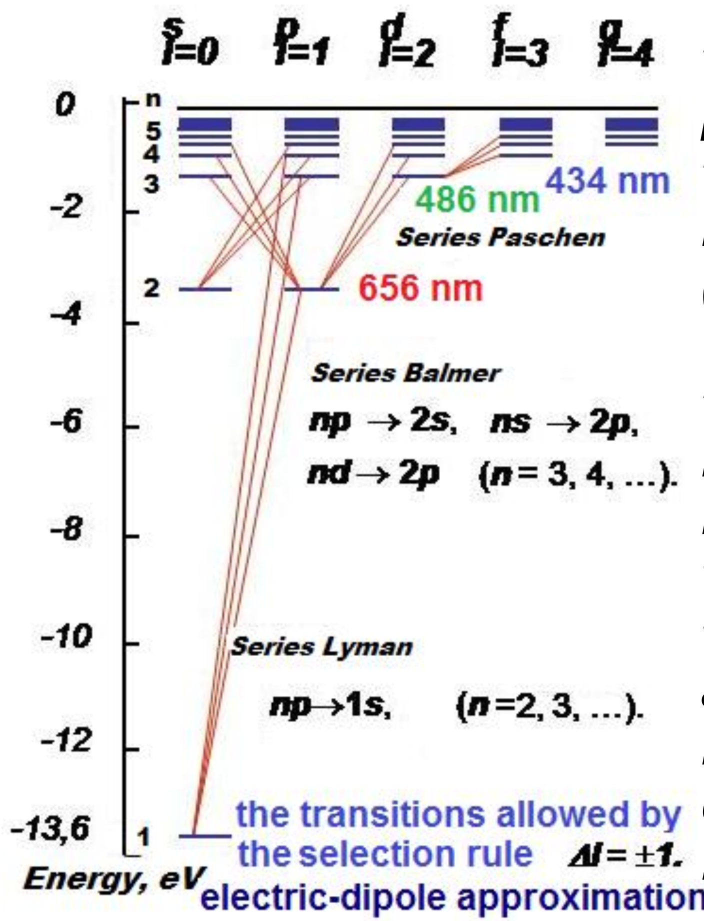

In the helium atom two electrons are sitting, and this extra work causes that prevent the decay of the excited state. The first measurements were taken in the 70-ies with very large errors, and only recently it was measured with acceptable precision: 131 ± 9 minutes.




Hodgman et al., 2009. Metastable Helium: A New Determination of the Longest Atomic Excited-State Lifetime

Region of HF heating: **T** electron = 3500 K; $\mathbf{V_{He}}$ = 3940 m/s; β =45; $\mathbf{s_{He}}$ = 1700 km
Injection region by TC Harry: **T** neutral =1170 K; $\mathbf{V_{He}}$ =2200 m/s; β =20; $\mathbf{s_{He}}$ =345 km

# Hydrogen emission spectrum

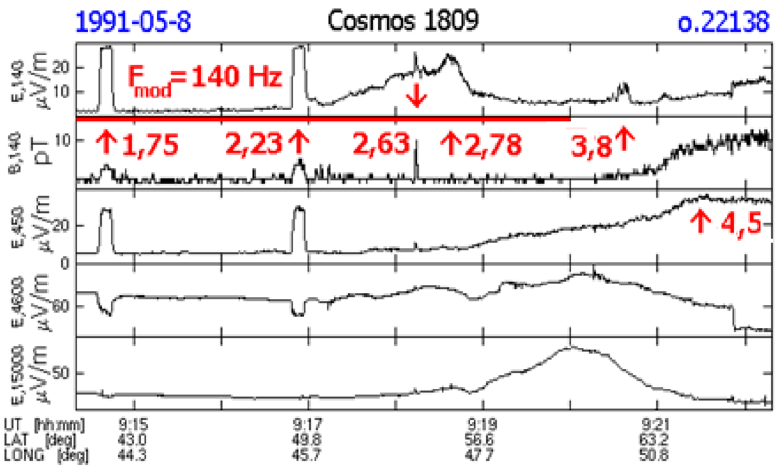


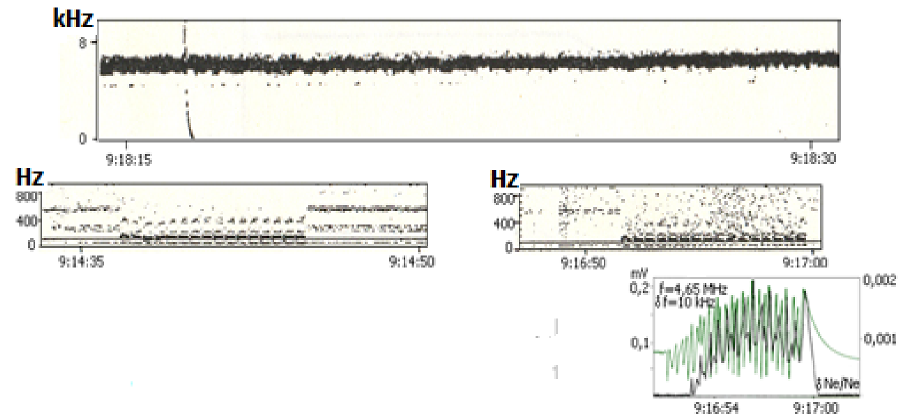

***The transformation of the 2S → 1S occurs through the simultaneous emission of two photons. This is a very rare process, and therefore the lifetime of the 2S state in the hydrogen atom is obtained already 2 ms (0,122 s ?), compared to τ*** **(2P → 1S) ≈ 1,6** ***ns***.

***I. S. Shklovsky suggested in 1951, the hypothesis of deep penetration of protons into the atmosphere - the mechanism of recharge. It occurs up to 100 times on the way to the Ground. A hydrogen atom, while in the ionized state, experiences the focusing action of the magnetic field. If this mechanism operates in the heating experiments, the conjugate ionosphere will be observed strong fluctuations in the cyclotron frequency of hydrogen.***

Region of HF heating: **T** electron = 3500 K; **V**$_H$ = 7880 m/s; β =45; **s**$_H$ = 6000 km
Injection region by TC Harry: **T** neutral =1170 K; **V**$_H$=4400 m/s; β =20; **s**$_H$=1380 km

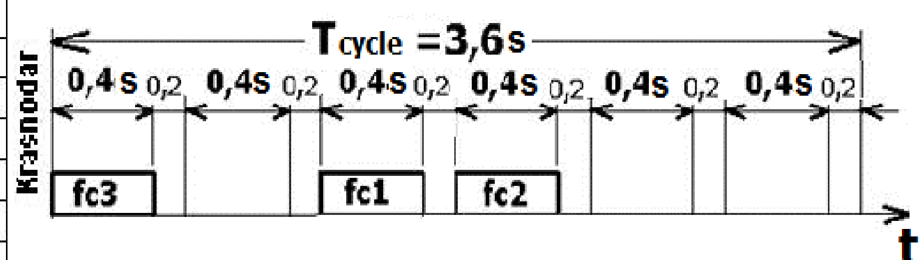
# Fine structure of ELF oscillations in the ionosphere created by the modulation of the HF stand SURA




*NEW RSDN-20 transmission sequence by frequency*

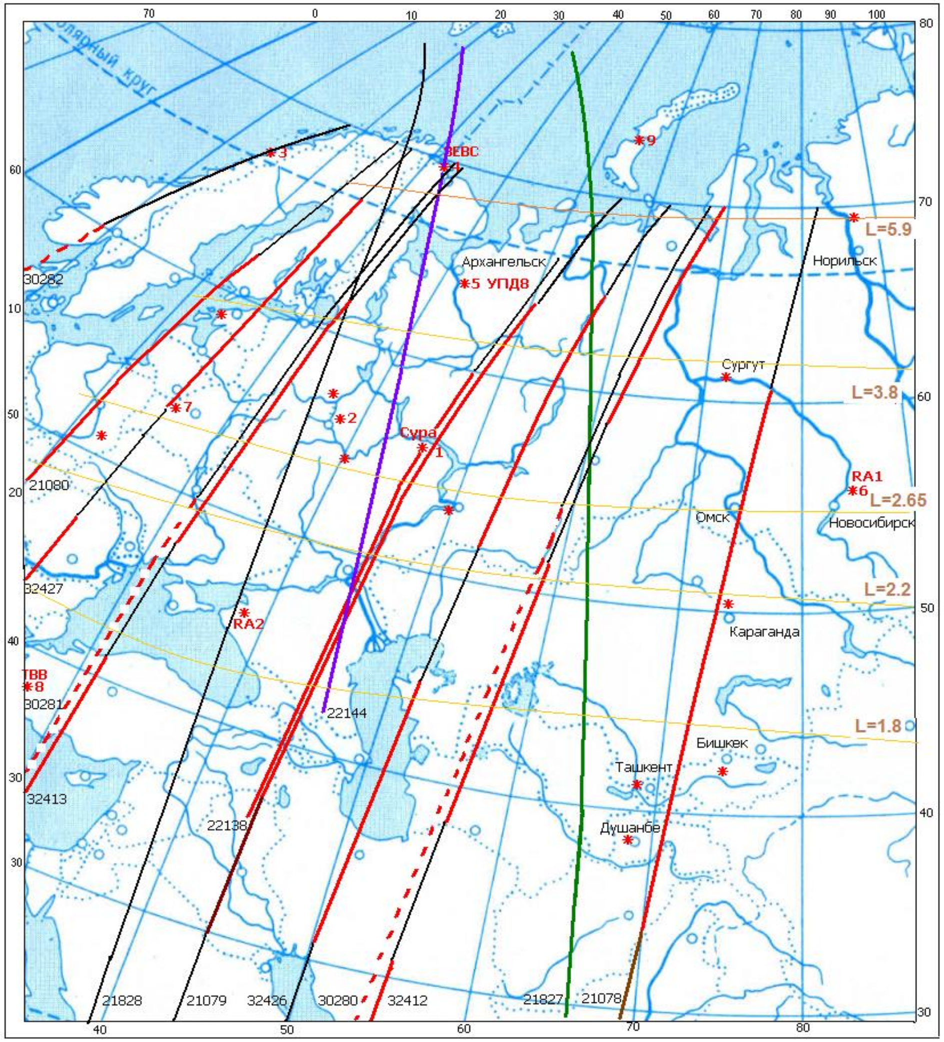
| Segment nr. station<br>Frequency kHz | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| F3p 14.881091 kHz | | | | Revda, Seyda | | |
| F3 14.880952 kHz | Krasnodar | | | | Seyda | Revda |
| F2 12.648809 kHz | Revda | | | Krasnodar | | Seyda |
| F4 12.090773 kHz | | Revda | | | | |
| F5 12.044270 kHz | | | Seyda | | | |
| F1 11.904761 kHz | | Seyda | Krasnodar | | Revda | |



# Separate VLF radio transmitters in the neighborhood of ~ 2000 km from the stand SURA

| N | Region | RSDN – Alpha (navigation) | | | Radio communication | | |
|---|---|---|---|---|---|---|---|
| | | Name | Lat | Long | Name | Lat | Long |
| 1 | Novaya Zemlya | Isle Pankratiev | 76.1 | 60.1 | Matochkin Spar | 73.3 | 54.4 |
| 2 | Taimyr | Dudinka | 69.4 | 86.3 | Norilsk | 69.3 | 88.2 |
| 3 | Kola Peninsula | Revda | 68.0 | 34.7 | Zeus | 68.8 | 34.5 |
| 4 | Northern Urals | Seyda | 67.1 | 63.7 | | | |
| 5 | North West | Petrozavodsk | 61.8 | 34.5 | Arkhangelsk | 64.4 | 41.6 |
| 6 | Moscow | | | | SRI Radio stand | 56.1 | 37.9 |
| 7 | Belarus | Slonim | 53.1 | 25.4 | Molodchenko | 54.5 | 26.8 |
| 8 | Center of Russia | Karachev | 53.1 | 35.0 | Taldom | 56.7 | 37.7 |
| 9 | Samara Region | Syzran | 53.3 | 48.1 | Novosemeykino | 53.3 | 50.3 |
| 10 | Crimea | Plovdiv | 44.9 | 33.9 | | | |
| 11 | Caucasus | Krasnodar | 45.4 | 38.2 | RJH-63 | 44.8 | 39.6 |
| 12 | Turkmenistan | Seyda-TKM | 39.5 | 62.7 | Tashkent | 41.3 | 69.3 |

# The orbits of the satellite Cosmos-1809 projected on the surface of the Earth




**Marked the work of the heatable stands:**

**Black - stands were not working**
**Red - HF emission of the stand SURA modulated 140 Hz**
**Red dotted line - stand SURA 5 s radiated with 10 s pause + modulation 140 Hz**
**Purple - HF radiation stand SURA modulated 400 Hz**
**Brown - continuous radiation of the stand SURA**
**Green - SRI Radio stand worked meanders for 3 s**

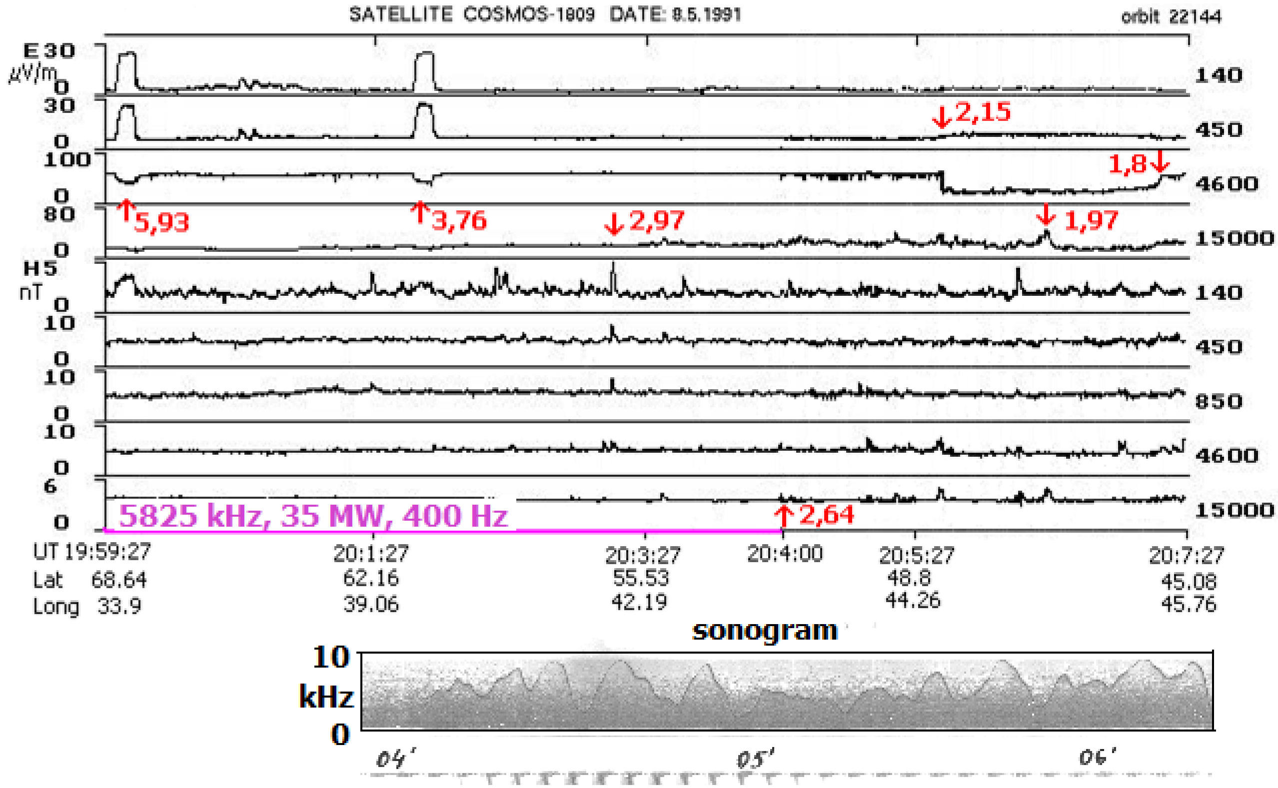
**Asterisks denote VLF transmitters and:**
**1. Stand SURA**
**2. Stand NII Radio**
**3. Stand Tromsø**

# These works stand SURA under the flight of the satellite Cosmos-1809

| No | Date | Time, UT | f, kHz | P, MW | Mode | Fкр | ∑Кр | Orbit |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.2.91 | 15:58-16:06<br>18:13-18:15<br>18:15-18:23 | 9310<br>7815 | 140<br>80 | modulation140 Hz<br>without modulation<br>modulation140 Hz | 6,4 | 18 | 21077*<br>21079 |
| 2 | 15.4.91 | 23:40-23:50 | 4785 | 150 | without modulation | 6,8 | 17 | 21828* |
| 3 | 7.05.91 | 19.35-19.50 | 5828 | 3x120 | modulation75 Hz | 7.8 | 20 | 22130 |
| 4 | 8.05.91 | 9:05-9:10<br>9:10-9:20<br>19:30-20:05 | 9310<br>5828 | 2x250<br>2x200<br>2x120 | without modulation<br>modulation140 Hz<br>modulation 400 Hz | 11<br>8.5 | 22 | 22138<br>22144 |
| 5 | 15.05.91 | 18:15-18:45 | 7815 | 3x240 | without modulation | 9.0 | 18 | 22240 |
| 6 | 17.12.92 | 10:23-10:35<br>12:05-12:18 | 9050 | 140 | radiation 5 s - pause 10 s<br>+ modulation 140 Hz | | | 30280<br>30281 |
| 7 | 20.05.93 | 15:27-15:46<br>15:56-16:18<br>17:08-17:27<br>17:37-17:59 | 5828 | 150 | 140 Hz, rad.5 - pause 2 min<br>140 Hz, 4-2-4-2-4-2-4 min<br>140 Hz, 5-2-5-2-5 min<br>140 Hz, 4-2-4-2-4-2-4 min | | | 32411*<br>32412<br>32412*<br>32413 |
| 8 | 21.05.93 | 15:43-16:02<br>16:12-16:34<br>17:57-18:19 | 5828 | 150 | 140 Hz, rad.5 - pause 2 min<br>140 Hz, 4-2-4-2-4-2-4 min<br>140 Hz, 4-2-4-2-4-2-4 min | | | 32425*<br>32426<br>32427 |

**Orbit with star - satellite in the southern hemisphere**

# Intensity of ELF-VLF fluctuations of evening ionosphere to the West of stand SURA modulation of the HF radiation 400 Hz



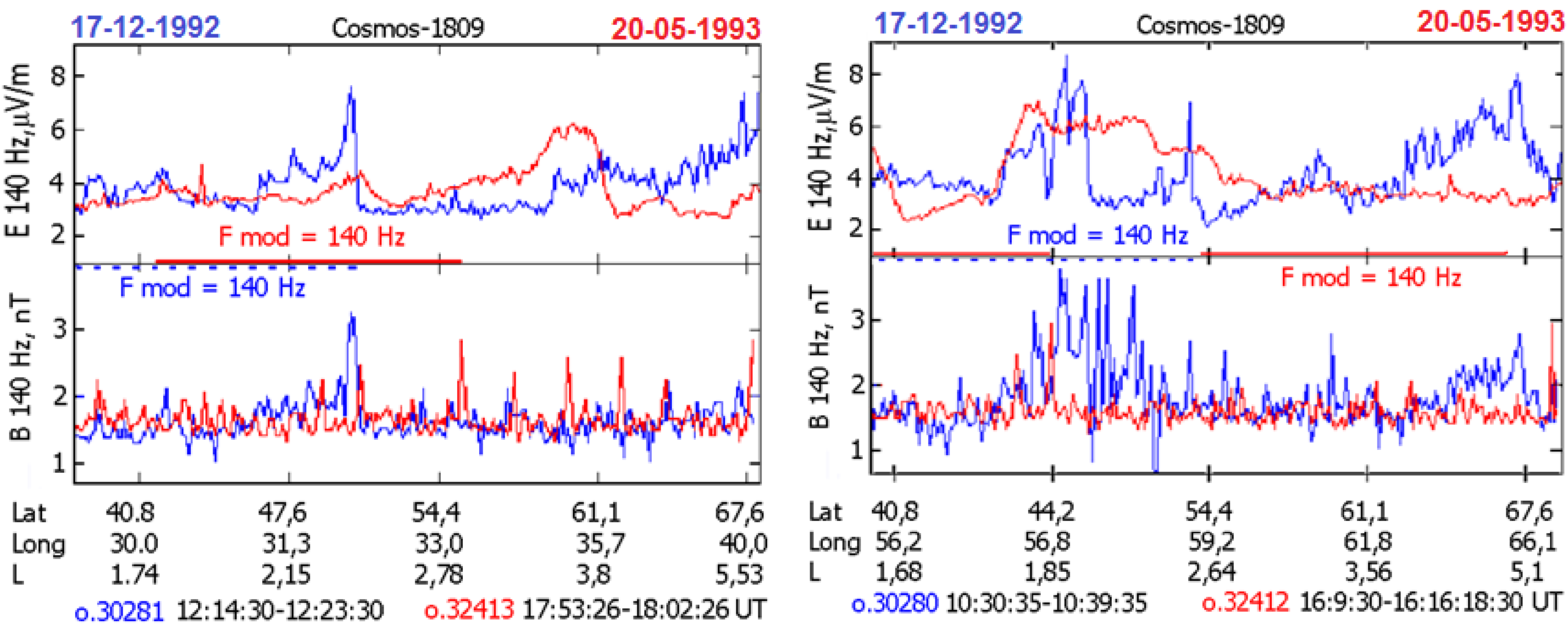

1. For L= 5.93 – identified with the area of impact transmitter Revda, noted a sharp increase in the e/m fluctuations in frequency ~ 140 Hz and electrostatic waves in the frequency range ~ 450 Hz. This region increases the concentration of light ion component of the plasma, which leads to an increase of the lower hybrid frequency, which becomes more than 4600 Hz. Accordingly, in the channel 4600 Hz the signal intensity drops.

2. For L=3,76 – identified with the area of the impact of RSDN “Petrozavodsk” observed the same pattern. But the magnetic component in the channel 140 Hz is slightly less.

3. From L=2,97 to L=2,64 change in the VLF data is not detected. It should be noted that at this time the sun's shadow rose above the heating area. Removal of the orbital plane of the satellite from the booth ≥ 300 km.

4. There are more than3 min, the change in the spectrum of lower hybrid waves (channel E4600 Hz) from L=2.15 to L=1.8 between the areas of influence of two RSDN transmitters.

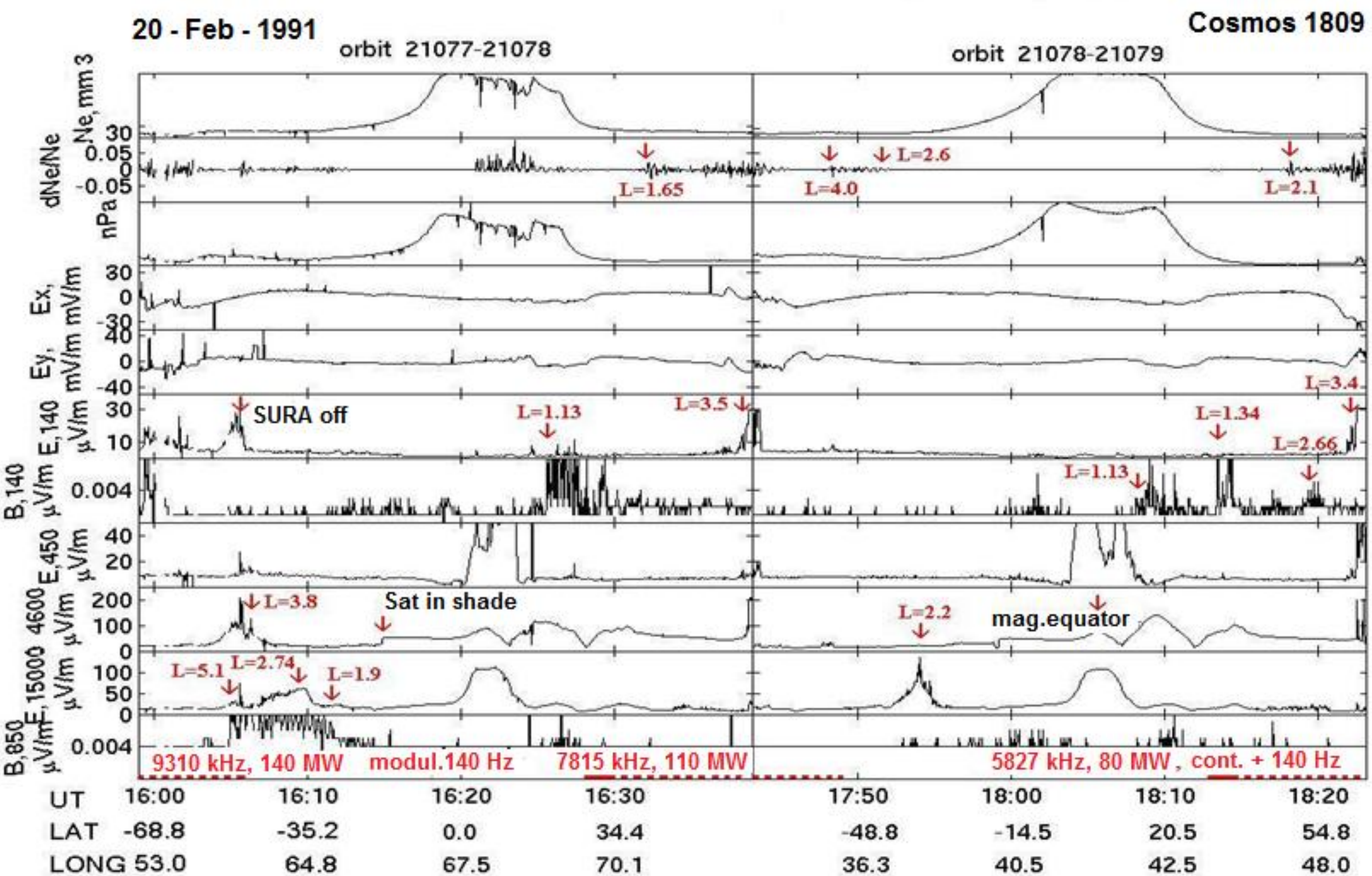
# The reaction of ELF-VLF artificial turbulence in zones of VLF transmitters influence when the stand SURA on/off



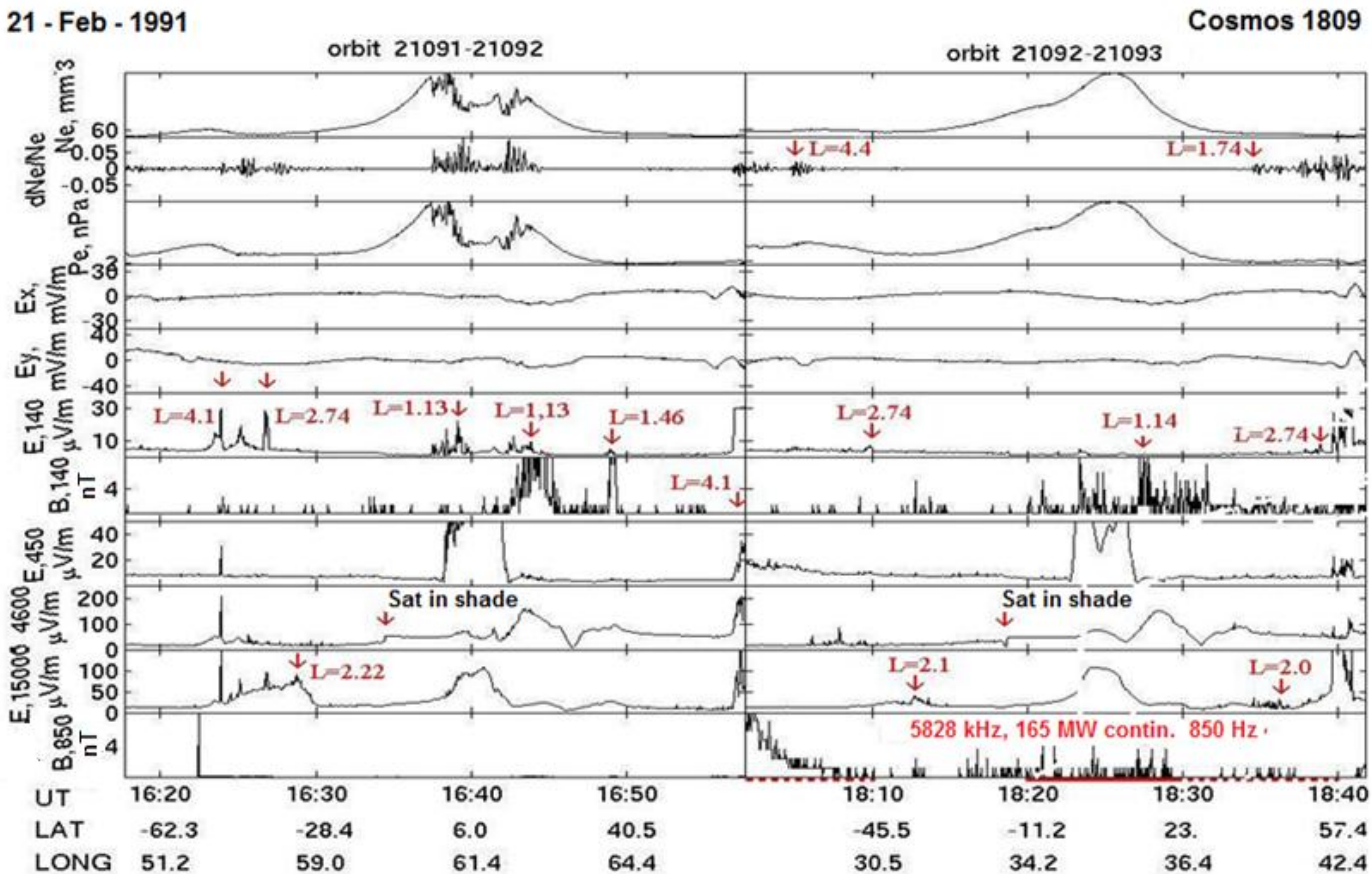

**The reaction of the ionosphere in the same areas on and off the stand SURA with an average (F10.7~200, December 1992) and low (F10.7~100, May 1993) the Sun's activity shows that:**

**1. E / m waves (140 Hz) in the areas of RSDN transmitters influence are increasing to 2-4 s when the stand is turned on and fall with 5-10 s when the stand is turned off.**
**2. Depressed area 140 Hz noise occurs when the stand is completely turned off. This zone is located west of the stand, has a length of about 500 km and a lifetime of more than 2 minutes.**

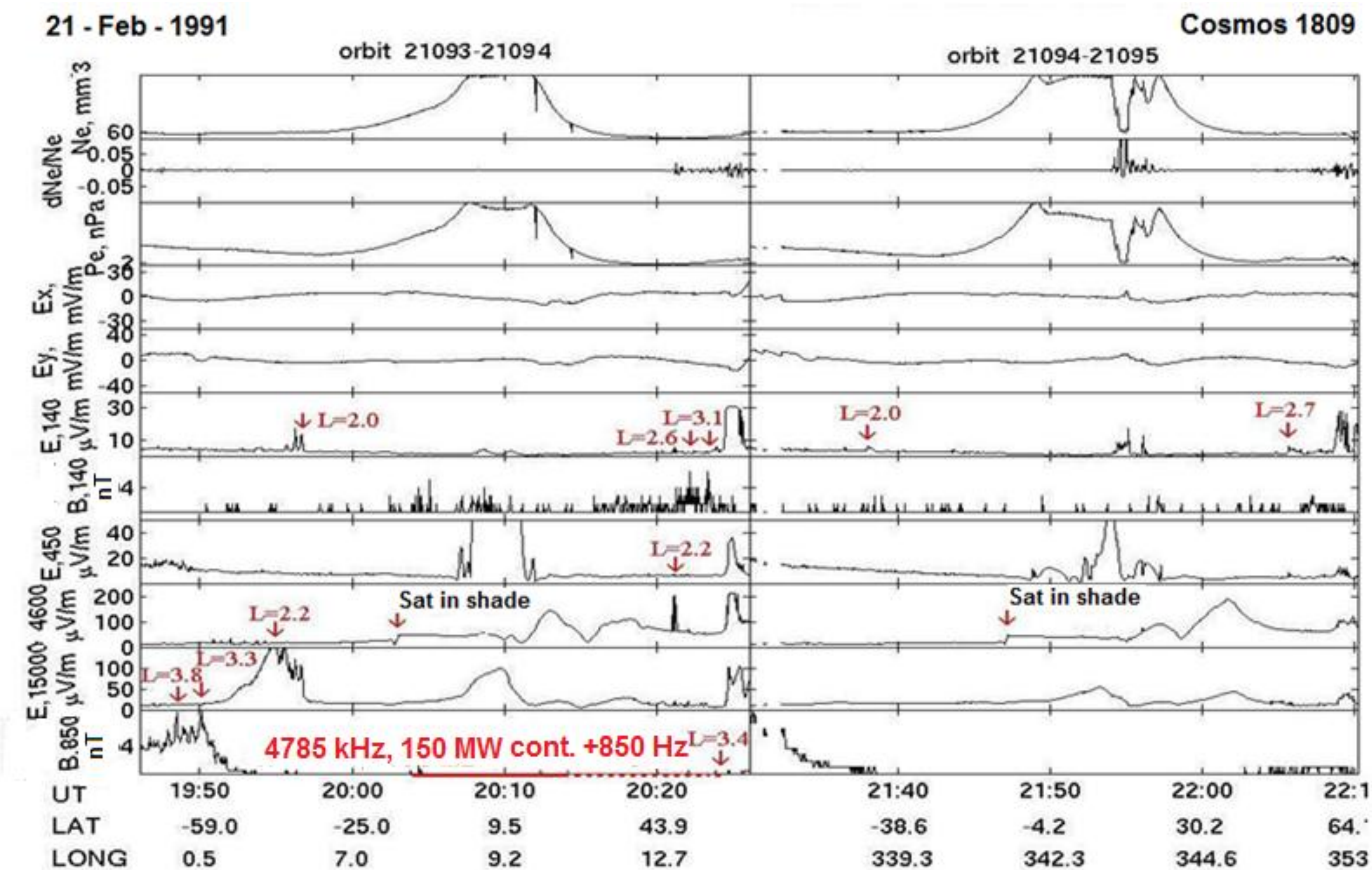
# Nighttime ionosphere parameters east stand SURA at high solar activity when HF radiation is modulated by 140 Hz



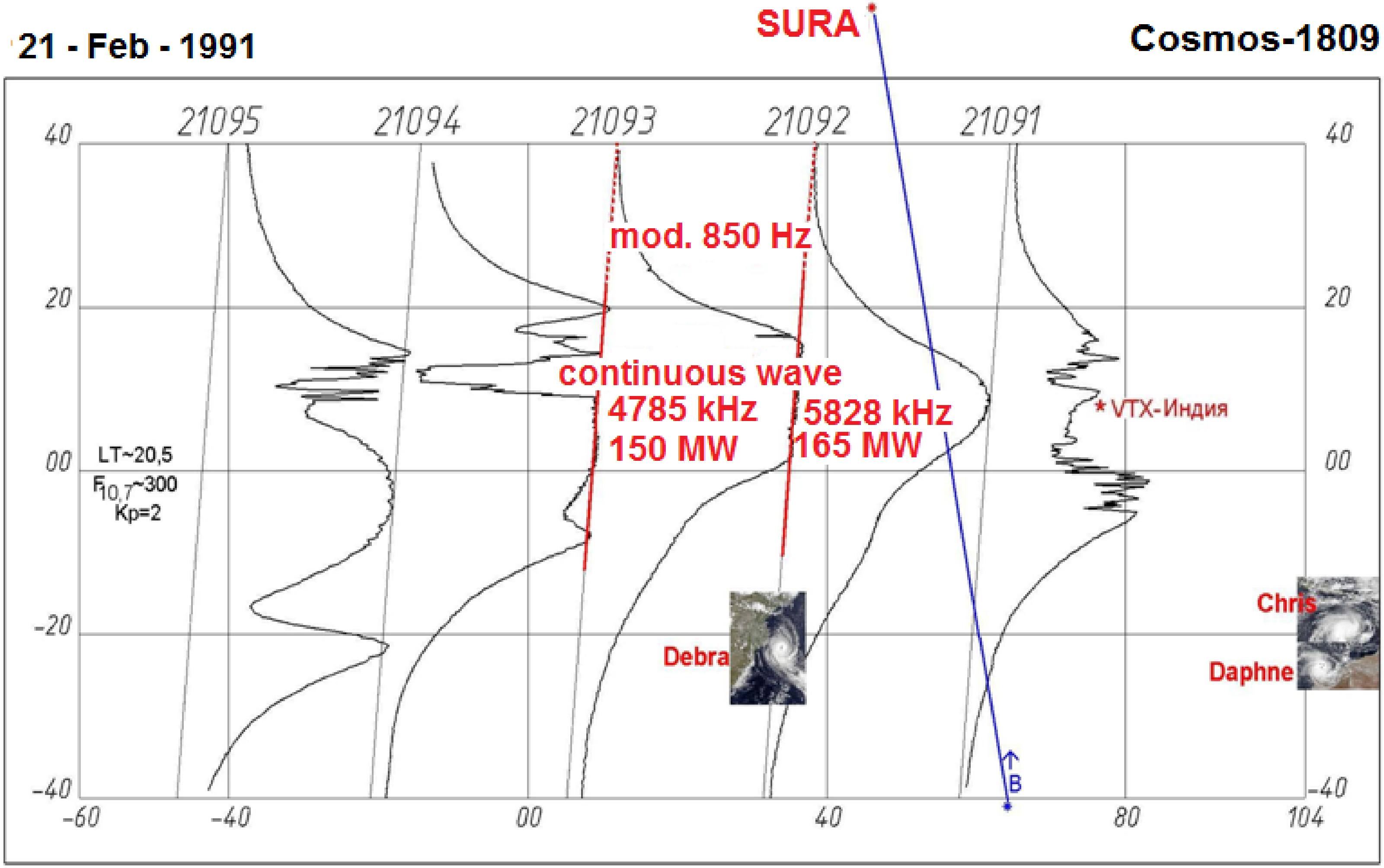
# Nighttime ionosphere parameters on stand SURA at high solar activity when HF radiation is modulated by 850 Hz



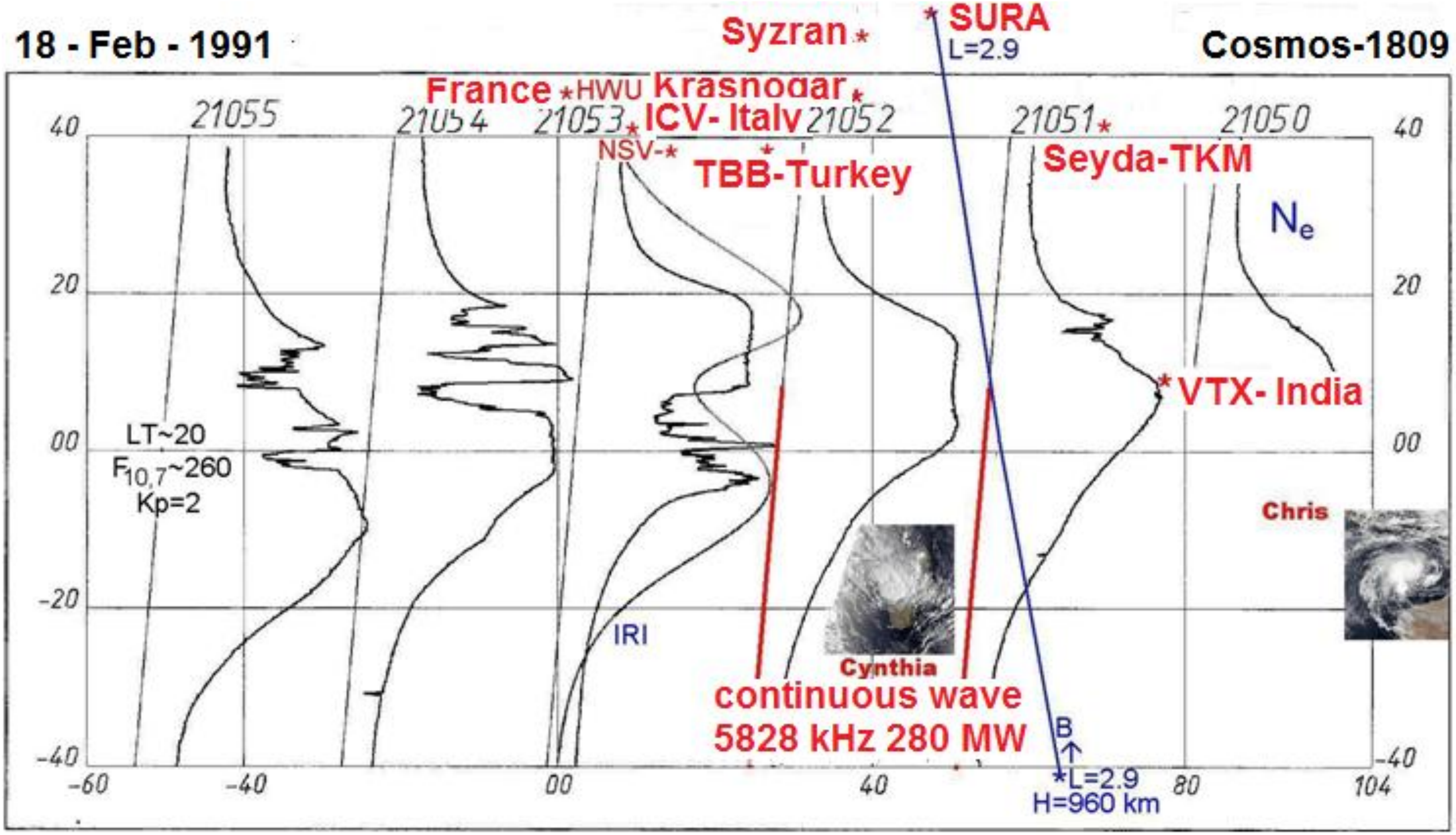
# Nighttime ionosphere parameters west stand SURA at high solar activity when HF radiation is modulated by 850 Hz



# Repression of formation of bubbles in ionosphere when running stand SURA



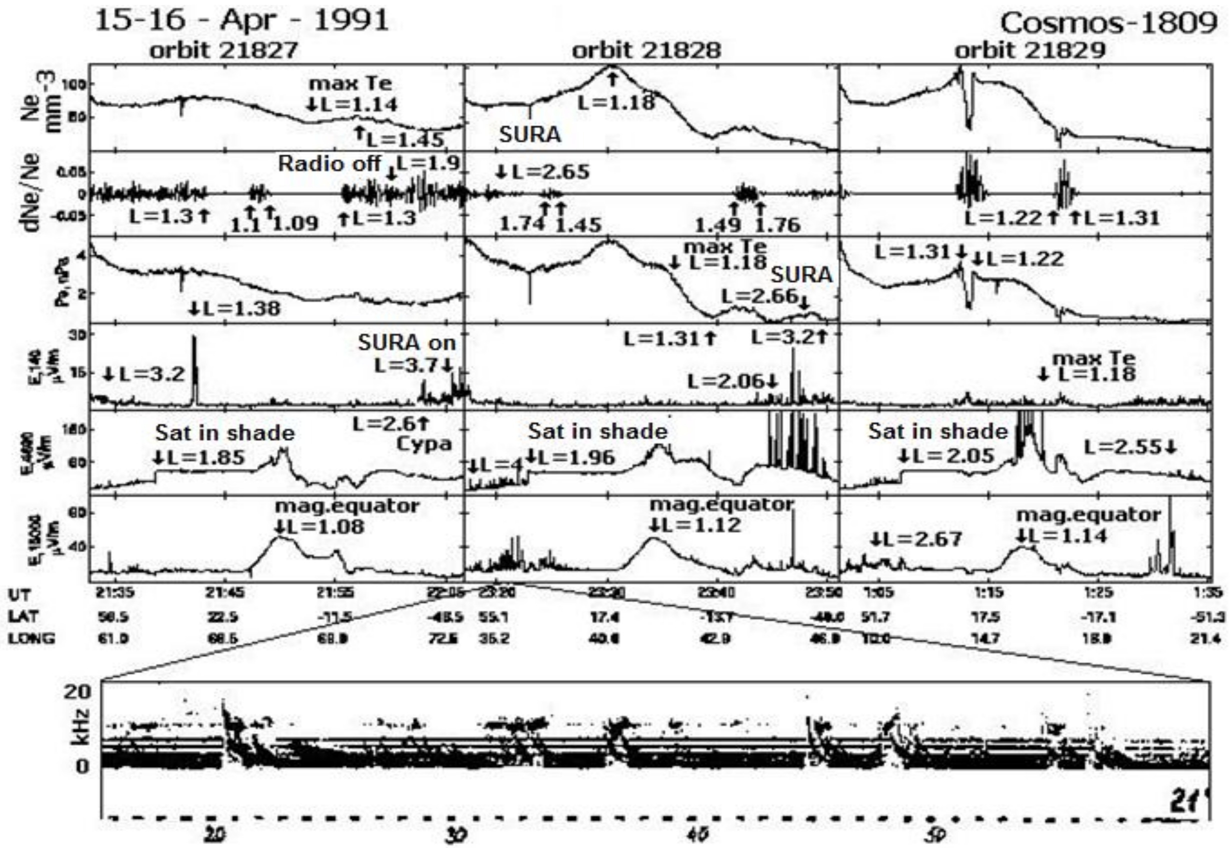
# Repression of formation of bubbles in ionosphere when running stand SURA



## The stand SURA in the evening, will greatly change the effects of remote influence on the ionosphere:

1. ELF electrostatic turbulence on the modulation frequency of the HF radiation doesn't stand out in a dark ionosphere.
2. Oscillations at the cyclotron frequency of hydrogen is more pronounced in the magnetically region near the terminator (orbit 21077-78 and 21091-93).
3. Abnormal passage of signals from RSDN transmitters observed in the conjugate hemisphere (20 and 21 Feb 1991).
4. The effect of turning off stand SURA is transmitted in the magnetically region with a characteristic speed of propagation whistler.
5. The satellite was recorded in a period of high solar activity, the formation of babbles for the terminator. HF radiation suppressed the development of babbles West of the magnetic Meridian of the stand SURA. This effect is interpreted as the impact of hydrogen atoms injected into the area of heating on instability of Rayleigh-Taylor.

# Plasma parameters of the ionosphere after heating HF radiation SURA and Research Institute of Radio




**Heatable stand of the Institute of radio started working since 1961. The history of its creation and arising in the ionosphere nonlinear effects set out in the review [19].**

**In April 1991, the stand of NII Radio and the stand SURA worked together given the movement of the satellite Cosmos-1809 under the program of the "Active experiments and anthropogenic effects in the ionosphere“ [17] . He radiated at the frequency of 1350 kHz with an effective capacity of 80 MW. Its radiation modified the E-layer of the ionosphere.**

**The joint work of two stands led to the appearance of long-lived magnetospheric channels filled with whistles. Satellite Cosmos 1809 was also observed long-lived ionospheric channels filled with whistles after a powerful ground explosions [20].**

**The mechanism of formation of longitudinal cracks filled with whistles, requires further study.**

# Conclusion

**The model of ballistic injection of meta stable atoms of hydrogen, helium and oxygen with height above 230 km (from the field of a powerful heat input ) helped to explain a number of observed disturbances in the ionosphere.**

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