Space Research Institute of Russian Academy of Sciences

5. Research and Supervision Results Obtained by Russian Scientists and Specialists during (in the course of) Implementation of Flight Scientific Programmes in cooperation and with assistance of Foreign Scientists and Specialists

Institute for Space Research of the Russian Academy of Sciences in cooperation with:

- Russian Space Corporation "Energia", Korolev, Russia.
- Lebedev Physical Institute, Russian Academy of Sciences, Moscow, Russia.
- Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia.
- Lviv Center Institute of Space Research, National Academy of Sciences of Ukraine, Lviv, Ukraine.
- Eotvos Lorand University, Budapest, Hungary.
- DOSAAF Research Laboratory of Aerospace Technique, Kaluga, Russia.
- SKANEX Research and Development Center, Moscow, Russia.
- NPO Mashinostroyenia, Reutov, Moscow region, Russia,

have implemented a set of works which provided creation of the experimental space platform for launching microsatellites into orbit using the infrastructure of the Russian segment of the International Space Station (ISS). Payload of the microsatellite called «Chibis-M» was the complex of scientific instruments for the study of new physical mechanisms of lightning discharges (KNA «Groza»).

In the framework of the project "Microsatellite" (scientific co-leaders of the academician L. M. Zelenyi, and academician A. V. Gurevich), included in the "Program of scientific and applied research on the ISS Russian segment", the first time the universal transport-launching device (TLD) was developed (Fig. 1). The microsatellite is placed in the TLD that allows: to deliver the microsatellite to the ISS safely; to realize with the microsatellite necessary preparatory actions by the crew (Fig. 2); to ensure of separation of the microsatellite from the transport cargo ship (TCS) «Progress»; to launch of the microsatellite into orbit with a given speed of separation (Fig.3).

Figure 1. Transport-launching device (TLD)

Figure 2. The work of cosmonauts O. Kononenko and A. Shkaplerov with TLD and «Chibis-M» inside TLD

Another innovative solution used for the first time in the framework of the project was to increase the altitude of TSC «Progress» orbit after fulfilling the main task that is the delivery of cargo to the ISS. Calculations and modeling showed that the use of fuel reserves makes it possible to raise the orbit altitude of the microsatellite up to 500 km. This solution provides significant economic benefits and allows in the future within certain limits to vary the orbit altitude of the microsatellite that increases its lifetime before entering to the dense layers of the atmosphere.

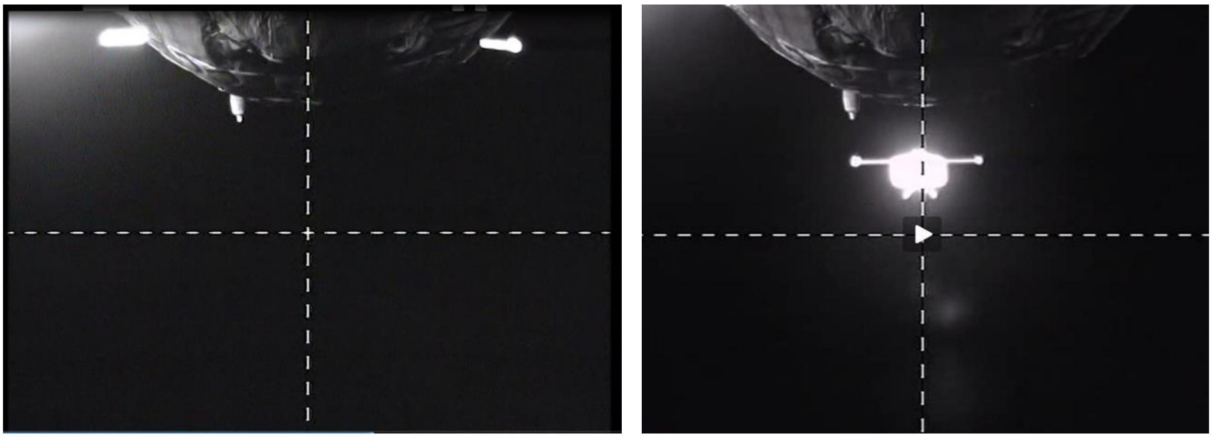

Figure 3. Separation of «Chibis-M» from TCS «Progress»

The next most important part of the problem solution was to develop the fully functional microsatellite complex (Fig. 4). Such complex should provide service functions in the interests of work of the target payload. It includes a three-axis orientation system, power supply system, navigation tools, radio system for reception of commands and transmission of service information, the elements ensuring the thermal regime and the control computer. In the process of the microsatellite complex creating it have been worked out the test cycles and diagrams of the flight control of the spacecraft, which can be used for future projects.

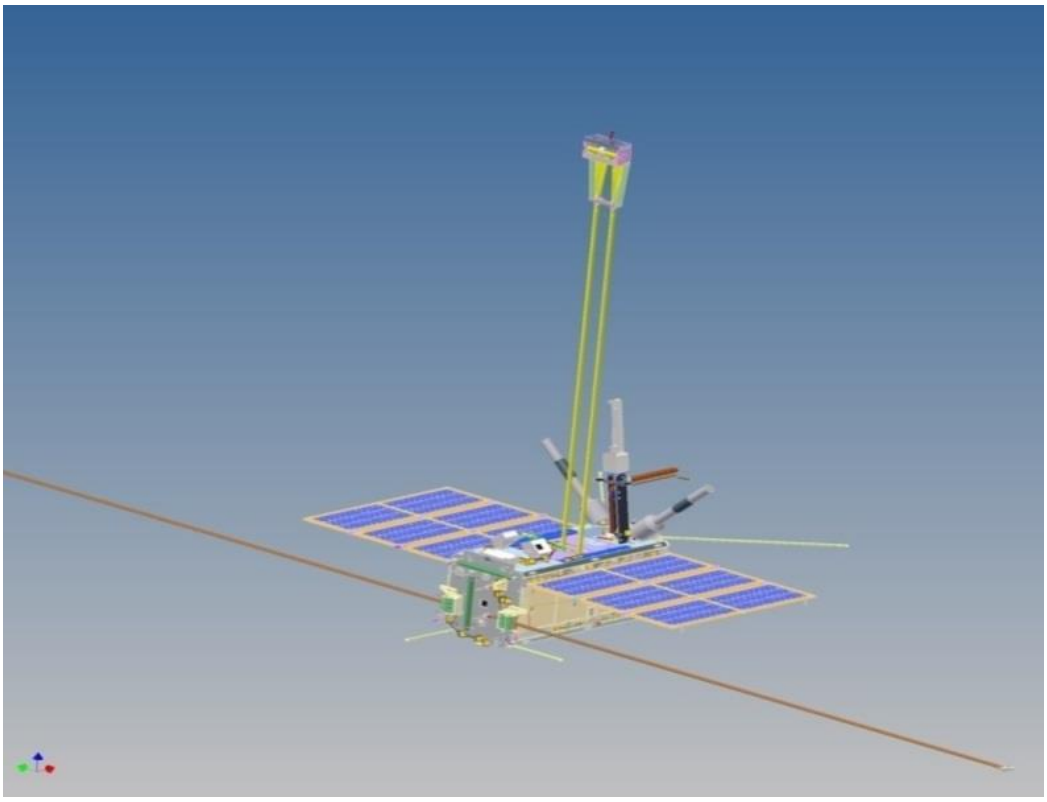

Figure 4. General view of «Chibis-M» with open antennas and solar panels

The microsatellites created on this basis can carry various payloads of national economic or scientific purposes. Implemented solutions provide the ability to deliver of microsatellites to orbit by economically and technically efficient methods.

An obligatory element of any satellite complex is a ground segment. In this project the data from the satellite were received not only in Russia, but also foreign partners in Hungary and the Czech Republic. For registration and processing of information and providing further access to data the cost-effective ground infrastructure was created. This ground infrastructure uses the usual online channels and allows serving similar projects in the future.

The main characteristics of the microsatellite «Chibis-M»

- Total mass .... ~ 40 kg
- Mass of scientific payloads (KNA «Groza»)...... 10,8 kg
- Mass of service systems .... 12,6 kg

- Orientation to the Sun and the Nadir with the use of flywheels, magnetometer, electromagnets, gravity boom (alternate version)
- Navigation and time system .... GPS – GLONASS
- Power supply... solar batteries, 50 W, accumulators
- Altitude of the orbit .... ~500 km
- Active lifetime .... 2 years 8 months

The composition of KNA «Groza»: x-ray and gamma detector, ultraviolet-infrared detector, RF analyzer, optical camera, magnetic-wave complex, block accumulation of scientific data, transmitter of quick channel.

Scientific equipment of the satellite on orbit during the measurements decides the following scientific tasks:

a) search of powerful gamma-ray bursts and its association with stepped leader of high-altitude lightning;
b) determination of the height distribution of discharges cloud-to-ground and cloud-cloud;
c) study of narrow bipolar radio pulses (NBP);
d) check the background of radio emission in the range of 20...50 MHz;
e) check the bursts of UV radiation;
f) estimation of electromagnetic parameters of space weather in the frequency range $1\cdot10^{-2}…2\cdot10^{4}$ Hz.

«Chibis-M» has successfully operated for the entire term of ballistic existence and gave valuable information about the fine structure of lightning discharge (Fig. 5), about percolation processes occurring during the preparation and during the actual discharge, allowed to estimate the altitude of occurrence of the discharges and to consider the discrete mechanisms that occur in a thundercloud.

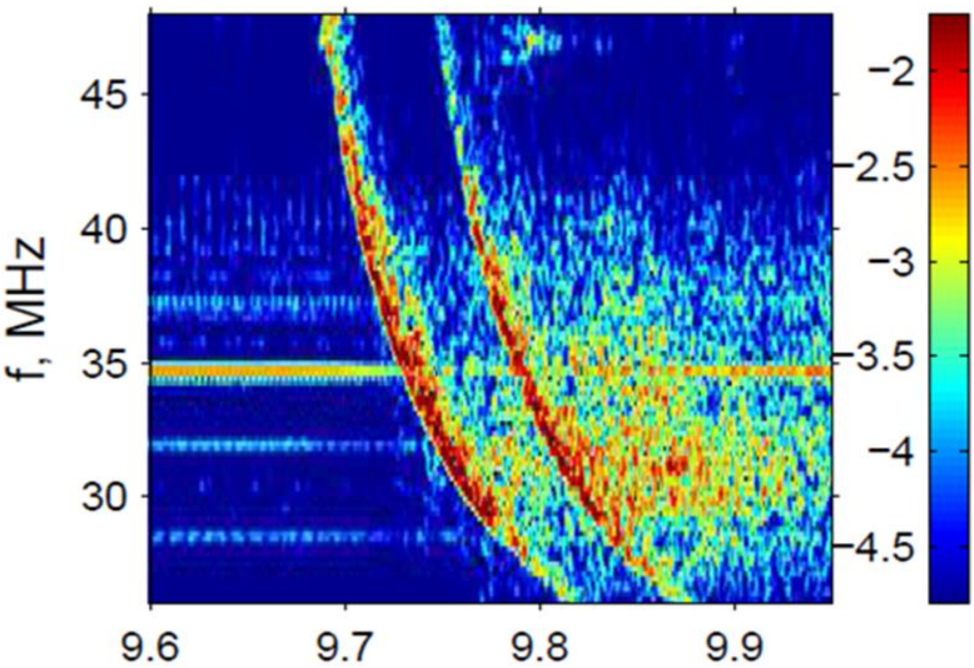

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Figure 5. Example of the short intercloud lightning discharge - the result of runaway breakdown and its reflection from the surface of the Earth, which allows to determine the altitude of origin discharge

Two types of VHF patterns related to TIPPs and obtained onboard "Chibis-M" microsatellite were analyzed on the basis of the "ground reflection" theory explaining the origin of the second pulse in the pair as a result from the ground reflection. First group of TIPPs presented in Fig. 6, which we are calling "normal", were well known from previous spaceborn measurements made. As it was established before typical temporal properties of pulses are around several microseconds for each pulse and some tens of microseconds for the time delay in a pair. TIPPs in Fig. 6 completely confirms the measurements of ALEXIS and FORTEr radioreceivers. The length of the ring memory aboard "Chibis-M" is enough to record up 50 ms (25 ms pre/post trigger time) of the VHF environment around trigger event thus it allows us to follow development in time (and as a consequence) and space (along vertical axis) of the TIPP source. Development of the TIPP source in time (descending in our case) can help in identifying of the physical origin of the TIPPs. VHF emission presented in Fig. 6 more likely corresponds to the descending stepped leader.

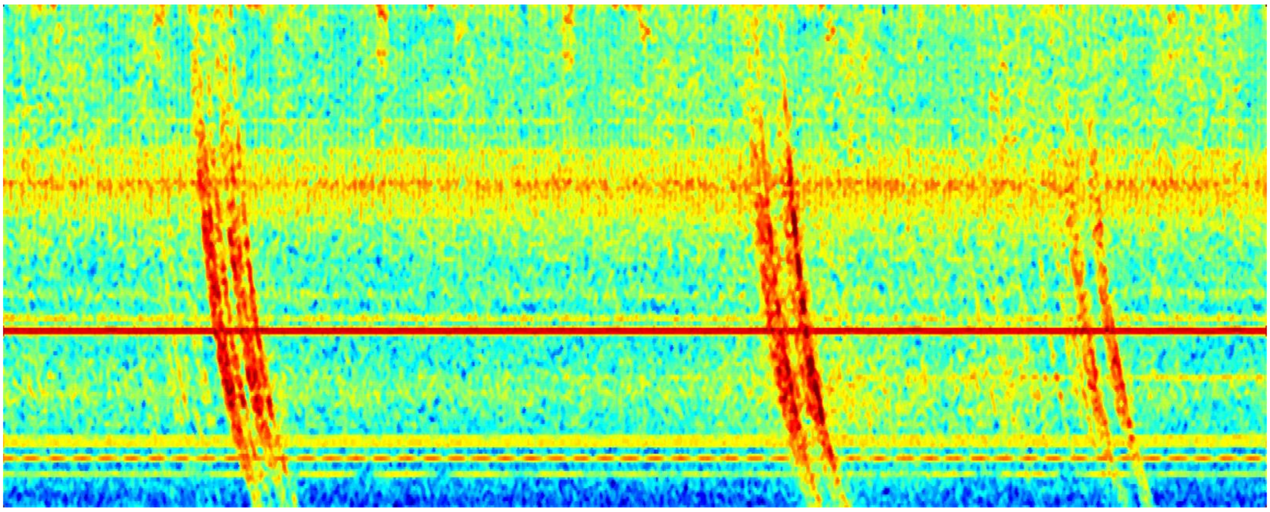
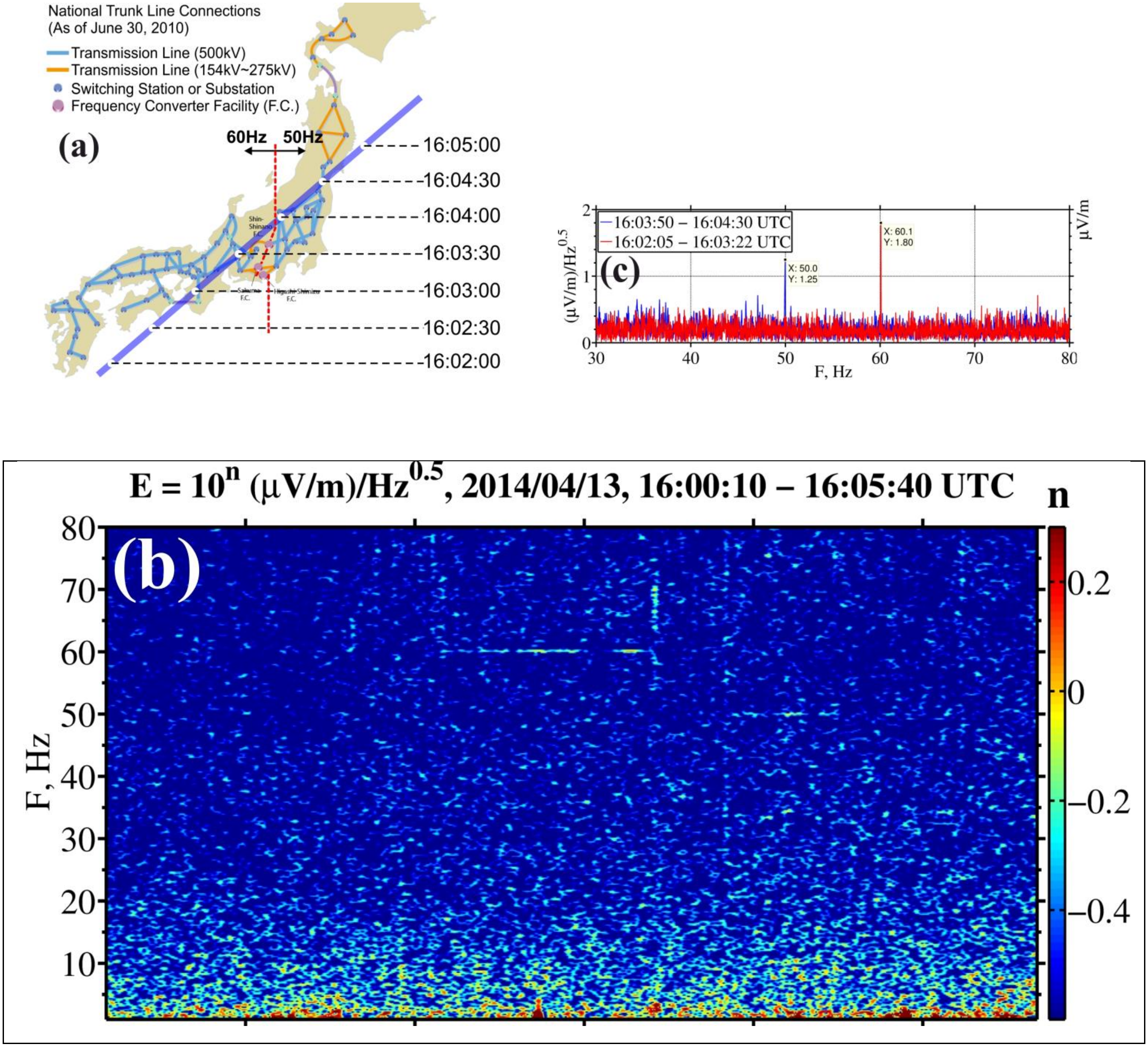


Figure 6. Typical "Chibis-M" periodogram TIPP occurred on June 7, 2013 at 11:53:14.848 UT over Africa.

"Solitary" VHF structures represent copious class of events. Occurrence frequency of "solitary" radio bursts is of the order of 1%. Its distinctive feature is that radio bursts are not accompanied by the pronounced "counterpart" within 150mcs (equivalent to height of the source discharge less 22 km) but instead occurs almost undetectable splitting (6 mcs) between pulses. On the basis of the "ground reflection" theory source of the "solitary" TIPPs is at 2.6 km.

The merit of the ground reflection theory is to provide an explanatory framework for vast set of experimental data, and from the assumptions of the explanation is following a number of possible hypotheses that can be tested in order to provide support for, or challenge, the theory. As it was mentioned, most of the hypotheses resulting from ground reflection theory (e.g. ratio between VHF impulse energies in particular TIPP) already have been tested, except one. Since the discovery of TIPPs solitary waveforms were left outside the evidentiary basis.

The «Chibis-M» data analysis (Fig. 7) and numerical simulation for the first time proved the existence in the upper ionosphere during night hours of low-frequency (100 Hz) electromagnetic radiation with the bandpass spectral structure excited by atmospheric lightning activity and power lines emission (PLE). Still the possibility of its infiltration in the upper ionosphere remained a hypothetical one. The mechanisms of penetration, in particular, are the ionospheric Alfven resonator (IAR) and Schumann resonance (SR).



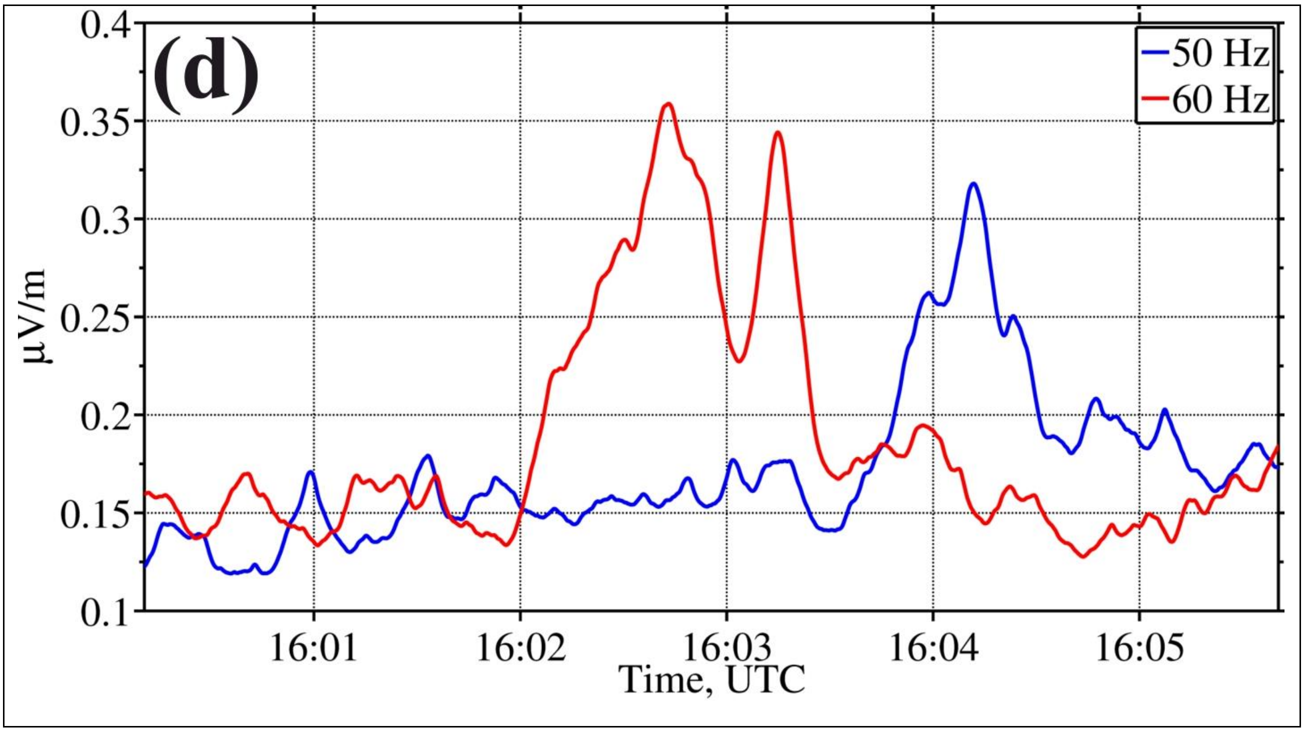


Fig. 7. Power transmission line emission 50/60 Hz observed over Japan. See text for details.

The typical case of PLE harmonics observation is shown in Figure 7 (orbit 12406, 2014/04/13, 16:00:10-16:05:40 UTC, local nighttime, altitude about 413 km). Hereinafter the shadow parts of MS orbit are marked by blue. The "Chibis-M" was over Japan, where crossed, at first, 60 Hz and then 50 Hz power line networks, see Figure 7a (the power grid map was taken from http://www.fepc.or.jp/english/library/electricity_eview_japan/). The 1st signal maximum 60 Hz with averaged amplitude value 0.36 μV/m was registered near branched power lines of Shikoku and western part of Honshu Islands (see dynamic Fourier spectrum in Figure 7b and the averaged absolute value of 50/60 Hz signals in Figure 7d. At digital averaging procedure the PLE signals were extracted by a Butterworth bandpass filter of first order with bandwidth 1 Hz and resonant frequency 50/60 Hz, then the signal absolute value data were treated with low pass filter of first order and cut-off frequency 0.03 Hz). The 2nd maximum of 60 Hz signal appeared after crossing over the power line cluster near Nagoya. The 50 Hz signal maximum 0.32 μV/m was detected after the Chibis-M passage of the boundary between 60 and 50 Hz electrical networks. It corresponds to the dense 50 Hz power lines grid placed about 100 km to the north direction from Tokyo. The FFT spectra of signal for the separate time intervals, which correspond to time intervals of 50 and 60 Hz harmonic detection, are shown in Figure 7c.

Registration of radiation in the ionosphere with frequencies 50/60 Hz (Fig. 7b) from the above-ground power lines (transmission lines, Fig. 7c) gives the answer to the question of how great the impact of atmospheric processes and industrial activities in the near-Earth space.

On 2013/08/08 (05:52:43–05:54:43 MSK) the “Chibis-M” detected multi-band “fingerprint” emission with frequencies from 0.5 Hz up to 6Hz (Fig. 8a). There are 9 bands observed, with frequency gaps of Δf 0.5 Hz (Fig. 8b). The frequency of this multi-band emission gradually decreased till 05:54 MSK, and then started to increase. The spectral amplitude of the eigen frequencywas Ef 4.8 (μV/m)/Hz1/2 at f 0.5 Hz. During this event the “Chibis-M” orbit was on the nightside and passed over Brazil, approaching the geomagnetic equator (Fig. 8c). We suppose that this spectral structure could be caused by the IAR occurrence. The non-monotonic variations of IAR frequencies may be caused by the combined effect of the field line mass loading by heavy ionospheric ions, and variations of total magnetic field in the vicinity of the South-Atlantic anomaly.

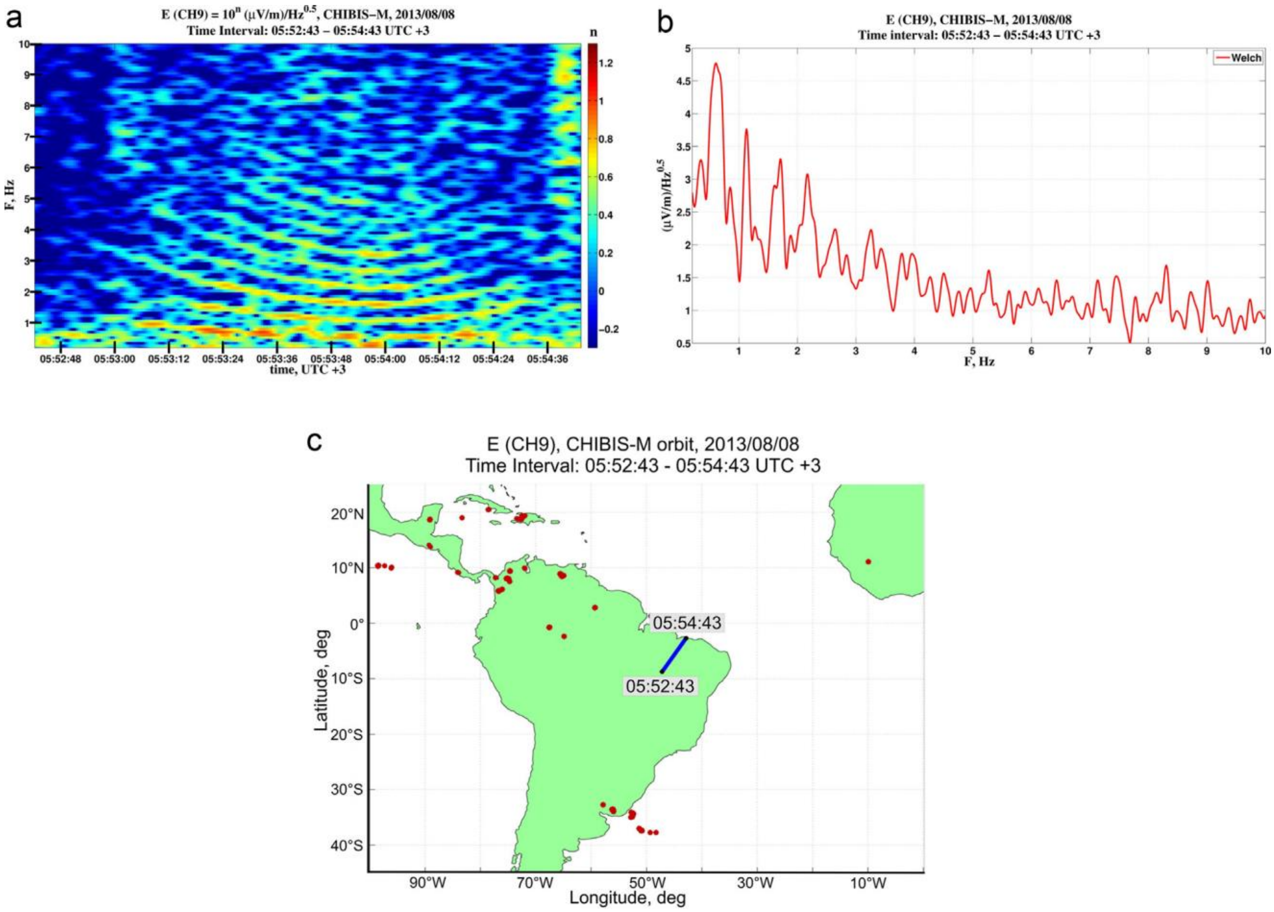


Figure 8. (a) Dynamic spectrum of electric component of "fingerprint" emission detected on 2013/08/08 starting 05:52:43MST. (b) The Welch spectrum of electric field variations recorded on 2013/08/08 (shownin(a)). (c) The vertical projection of the Chibis-M orbit during ULF emission observation, superposed with lightning activity, as identified by WWLLNarray.

The "Chibis-M" electric field observations confirmed the possibility of the SR leakage in to the upper ionosphere, earlier discovered by C/NOFS. The "Chibis-M" observations also revealed spectral harmonics of triggered emission in the IAR band. At the same time, these observations have not revealed any long-term the IAR signatures, similar to ground observations. In contrast to dominating view, the IAR has been found to be effectively excited on the dayside, too. The absence of the daytime the IAR features on the ground is probably caused by the elevated absorption of ULF waves in the lower ionosphere during daytime hours. Comparison of theoretical estimates with amplitudes of ULF emissions detected by the "Chibis- M" indicate, that the IAR signatures in the upper ionosphere are probably excited by relatively rare, but more intense, positive atmospheric discharges.

The received data are available on the server of IKI RAS http://chibis.cosmos.ru/index.php?id=1674 for all Russian and foreign researchers involved in this project. The main results were published.

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