SCIENTIFIC AND METHODOLOGICAL ASPECTS OF SPATIAL-TEMPORAL RESOLUTION BY THE PLASMA AND WAVE PARAMETERS OF THE IONOSPHERE BY MEANS OF MICROSATELLITES.

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Spatial-temporal parameters

The solar-terrestrial system is the largest complex system that mankind can study by **in-situ observation**.
It involves dimensions ranging from ***1 AU (10*8 m)*** to the radius of charged particle motions as they spiral around magnetic fields, which can be only a ***few centimetres (10*-2 m).***

Accurate and reliable **predictions of geospace weather** require the understanding of all aspects of the complex interplay of external and internal regulating factors operating at ***time-scales from minutes to days***.

Spatial-temporal parameters

Numerous theoretical studies and model experiments indicate the presence of **a wide class of spatial plasma irregularities**, which in the ionosphere make errors in GPS.

Spatial-temporal parameters

Electron density irregularities in the low-latitude ionosphere (so-called Equatorial spread-F, ESF) were observed on the ground using either conventional ionosphere sounding or by recording of incoherent radar scattering signals or by scintillation technique.

Spatial spectrum (or wave number spectrum) of the irregularities vary from

large scale with length L=20 km to

short scale with L=0.1–10m [**Kelley, 1989**].

Kelley, M. C.: The Earth’s Ionosphere: Plasma Physics and Electrodynamics, *Int. Geophys. Ser.*, 43, Academic Press, San Diego, Calif., 1989.

Spatial-temporal parameters

In-situ measurements on board satellites and rockets have given a great contribution to the present understanding of the ionosphere dynamics.

There were probe measurements of electrostatic potential fluctuations at wavelengths from a ***few meters to a few kilometers*** in the low-latitude ionosphere. In particular, vector electric fields in the frequency range from 10 to 500 Hz have been measured on the 400 km altitude polar orbiting OV1–17 satellite [**Kelley and Mozer, 1972**].

Kelley, M. C., and Mozer, F. S.: A satellite survey of vector electric fields in the ionosphere at frequencies of 10 to 500Hz, 3, Lowfrequency equatorial emissions and their relationship to ionospheric turbulence, *J. Geophys. Res.*, 77, 4183–4189, 1972.

Spatial-temporal parameters

Rather useful information on ***multi-scale*** near-equatorial spread-F turbulence was obtained from frequency spectra of electron density and electric field fluctuations observed on rockets [**Kelley, 1989**].

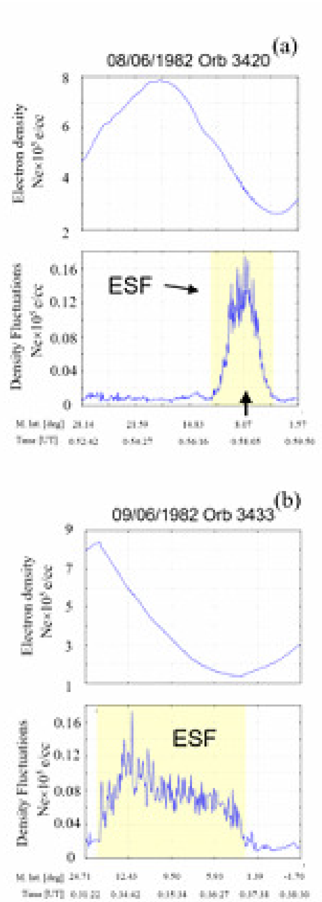
Kelley, M. C. The Earth's Ionosphere: Plasma Physics and Electrodynamics, *Int. Geophys. Ser.*, 43, Academic Press, San Diego, Calif., 1989.

Spatial-temporal parameters

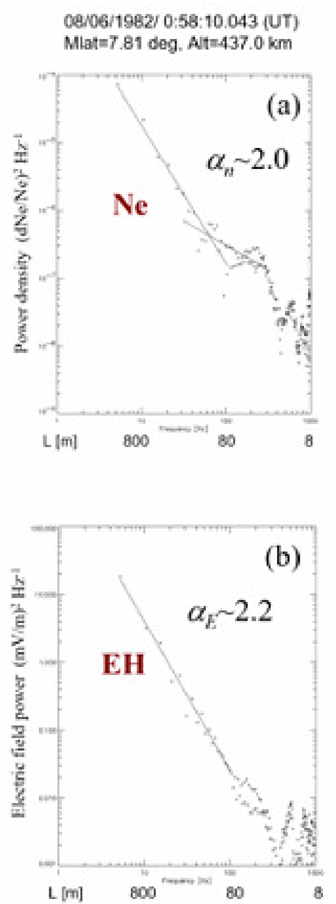
Cerisier et al. (1985) analyzed electron density and electric field variations on board the **Aureol-3** satellite in the frequency range 30–1000 Hz (scales ***L ~ 10–300 m***). However, they only analyzed one case at h=600 km and at rather high magnetic latitude ~63.

Cerisier, J.C., J.J. Berthelier, C. Beghin. Unstble density gradients in the high-latitude ionosphere. *Radio Science,* Volume 20, Number 4, Pages 755-761, July-August 1985

Spatial-temporal parameters



Latitudinal variations (geo-magnetic latitude) of the Ne along the equatorial pass for 8 and 9 June and relevant RMS amplitude the density fluctuations (bottom panels). The arrow in (a) indicates the time when the power spectral density in Fig. 2 is taken.



Power spectra of Ne (a) and horizontal electric field fluctuations, (b) inside the ionospheric turbulence (IT) to be associated with the Equatorial spread-F (ESF) observed during the 8 June pass

Aureol-3 satellite (1982)

The density and electric field spectra obey a power law fairly well in the frequency range 6□100Hz (lower portion of the frequencies in the figure). This frequency range corresponds to ***the spatial scale from 80m to 1.3km*** by assuming that the group velocity of irregularity is significantly smaller than the satellite velocity □8km/s. For this long wavelength, E and δNe/Ne have a same frequency or k-dependence.

Y. Hobara, F. Lefeuvre, M. Parrot, and O. A. Molchanov. Low-latitude ionospheric turbulence observed by Aureol-3 satellite. *Annales Geophysicae*, 23, 1259–1270, 2005

Spatial-temporal parameters

Molchanov et al. (2002) showed the connection between burst position of electric field variations at frequencies 10 kHz and 15 kHz (***L~0.5–0.8 m***) and the Equatorial Anomaly (EA) depletion from observations performed with the **satellite IK-24**. They revealed two regions of short-scale electric field ionospheric turbulence near the equator and near the pole-ward gradient of the EA (invariant latitudes 20–35).

In their recent paper, **Molchanov et al. (2004)** analyzed, in addition, large-scale (***L=15–300 km***) low-latitude density turbulence using **Cosmos-900** data.

Molchanov, O.A., M. Hayakawa, et al. Possible influence of seismicity by gravity waves on ionospheric equatrial anomaly from data of IK-24 satellite. 2. Equatorial anomaly and small-scale ionospheric turbulence. In: Hayakawa, M., Molchanov, O.A. (Eds.) Seismo Electromagnetics: Lithosphere-Atmosphere-Ionosphere Coupling. Terrapub, Tokyo, 2002, p.p. 287-296

Molchanov, O. A., et al.: Plasma density-electric field turbulence in the low-latitude ionosphere from the observation on satellites; possible connection with seismicity, Phys. Chem. Earth, 29, 569– 577, 2004.

Spatial-temporal parameters

Hobara et al. (2005) are going to produce similar research with Aureol-3 data but with middle spatial scale, low-altitude, and low-to-middle latitudes, which are not covered by the previous works from Cosmos-900 and IK-24.

Using PSD (Power Spectral Density) data on electron density and electric field variations observed on board **Aureol-3** satellite at low-to-mid-latitude ionosphere was analyze a scale distribution of the ionospheric turbulence in a form k–, where k is the wave number and is the spectral index. At first, high-resolution data in the near-equator region for several orbits have been processed. In this case the frequency range is from 6 Hz to 100 Hz (corresponding ***spatial scales from 80 m to 1.3 km***).

Hobara, Y., Lefeuvre, F., Parrot, M., and Molchanov, O. A.: Lowlatitude ionospheric turbulence observed by Aureol-3 satellite, Ann. Geophys., 23, 1259–1270, 2005,

Spatial-temporal parameters

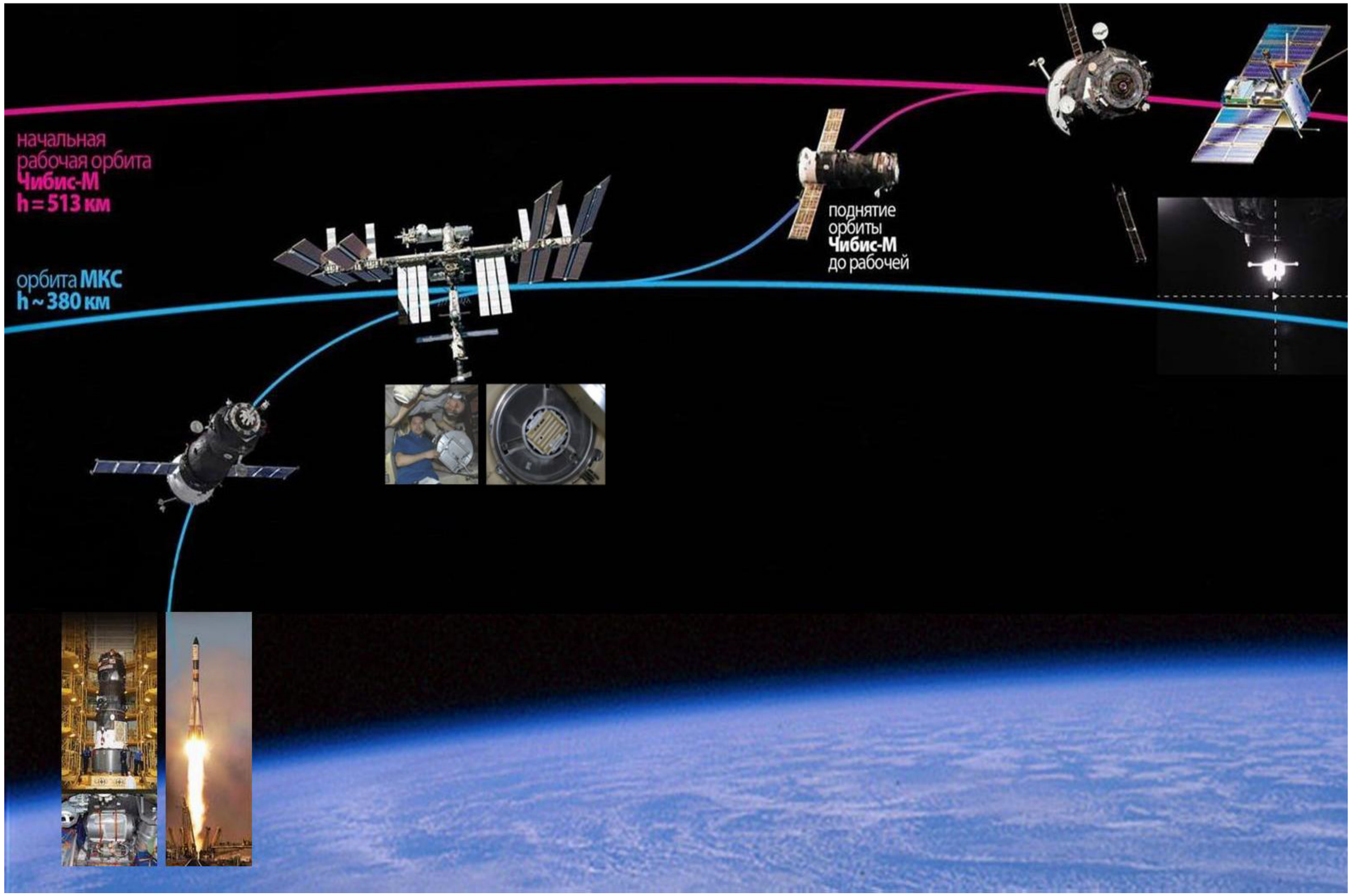
As we can see, the number of experiments in the ionosphere on the study of spatial-temporal resolution is extremely limited.

The separation of spatial and temporal inhomogeneities is possible in synchronous measurements on, at least, two spacecrafts.

Implementation of two-point measurements in the ionosphere

Two-point measurements

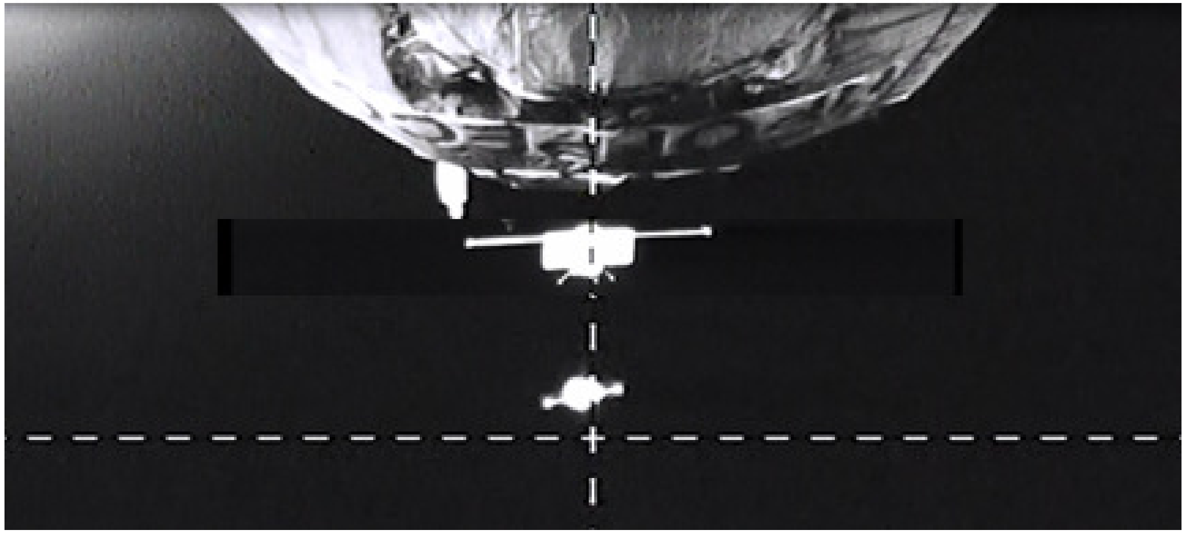
On the experience of space experiments with microsatellites (MS) "Kolibri-2000" (2002) and "Chibis-M" (2012-2014) the technology of "Double start" with the flight of the Progress spacecraft to a higher orbit (from 400 to 500 km) was developed and implemented for the first time in the world, which increases the lifetime of the MS in orbit by almost 2 times.



Two-point measurements

Output circuit 2 microsatellites "Trabant" for autonomous orbit

Planning video recording from the transport ship "Progress" the output on autonomous orbit two micro-satellites “Trabant”



Two-point measurements

The composition of scientific equipment microsatellites "Trabant".

№	Name	Designation	Developer, Manufacturer
1	Magnetic wave complex consisting of: - signal spectral analysis processor; - memory block includes interfaces to devices MS "Trabant"; - flux-gate magnetometer consisting of: (a) sensor; (b) electronics unit; - induction magnetometer system; - electric probe.	MWC-T SAS-T BMS-T FGM-T FGS-T EU FGM-T SIM-T EP-T	ELTE, Hungary BL-Electronics, ELTE, MTA WIGNER , Hungary ELTE
2	Plasma parameters sensor	DPP-T	API RAS, Russia
3	Radio frequency analyzer	RFA-T	SRI RAS, Russia
4	Phase meter of electron concentration	FIEC-T	SRI RAS, Russia
5	Electron spectrometer with narrow field of view	BAES-T	SRI RAS, Russia
6	Ion energy-mass spectrometer with wide field of view	ARIES-T	SRI RAS, Russia
7	Transmitter of scientific information (2.2 / 8.0 GHz) with cold reserve	FALCON-S/X	BHE, Hungary
8	Control and test equipment	EGSE-T	MTA WIGNER, Hungary

Two-point measurements

MWC-T must fulfill the following scientific objectives:

~ registration of ***magnetic and electric field*** from the SIM-T and EP-T for the four inputs in the range from ***0.1 Hz to 100 kHz*** with the sampling frequency (programmable) 5 to 200 thousand points per second (default 100 thousand points per second);

~ registration of ***magnetic field*** from the FGM-T for the three inputs in the range ***DC – 125 Hz***;

~ onboard frequency-time signal processing and dynamic spectrum formation in the range from 0.1 Hz to 100 kHz for electric and magnetic field.

DPP-T controlled the following parameters:

~ plasma density Ne in the range from 10*3 to 10*6 cm*-3;

~ plasma density fluctuations in the range from ***1 to 40000 Hz*** with an amplitude of not less 10*3 cm*-3.

The sensitivity of the radio track **RFA-T** in the frequency band from ***15 to 48 MHz*** should be not worse than 30 mV at a signal / noise ratio of 6 dB and at frequencies below 15 MHz not worse than 200 mV.

FIEC-T to measure the integrated electron density between the two MS, equipped with identical instruments FIEC-T, at distances from 100 m to 10 km. Range of measured values of the integral of the plasma ***electron density of the 10*2...10*6 cm*-3***. The measurement accuracy is not worse than 10 cm-3. Time of measurement of the electron concentration ~1 m s.

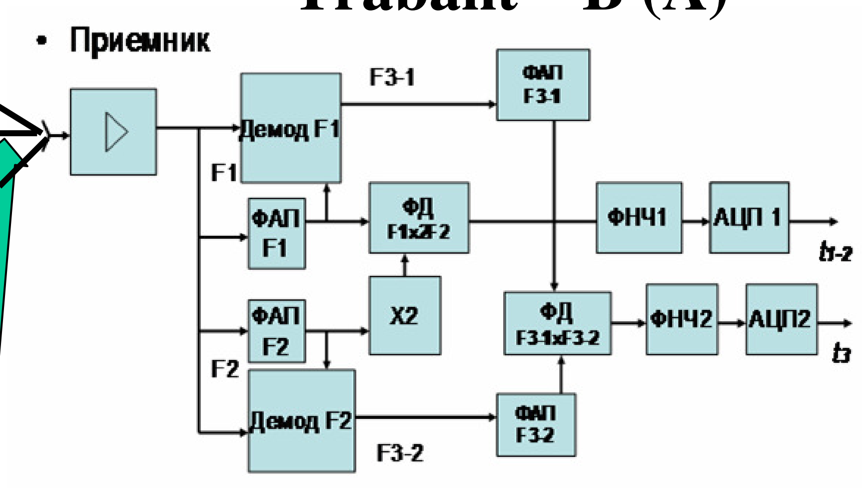
BAES-T is intended for registration of ***electrons in the energy range from 1 to 10 keV***. Sensitivity shall allow measurements at a frequency of 10 Hz at a particle flow value of at least 10*7 cm*-2.·s*-1. Energy resolution shall be not less than 10 %.

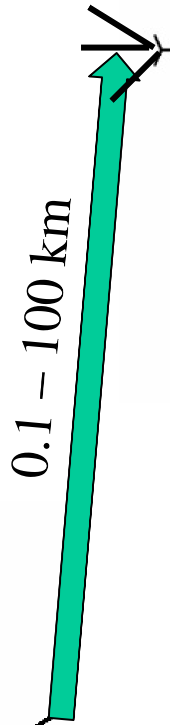
ARIES-T to register positively charged particles in the ***energy range from 10 to 5000 eV*** with the ability to measure the elemental composition of the particle fluxes, studies: characteristics and dynamics of the magnetospheric plasma; distribution functions of magnetospheric ions, especially ***H+, He+ and O+;*** interaction of ions with plasma waves and diagnosis of wave processes; energy resolution 15%; mass range: from ***1 to 100 e.m***; the mass resolution of at least 20 to 1кэВ.

Two-point measurements

F1 = 20 MHz, F2 = 40 MHz, F3 = 10 kHz (F3 amplitude modulates F1 and F2). 10 kHz provides a measurement of the TEC up to 3x10*(17) that at the distance of 30 km corresponds to Ne of 10*7 e/cm*3.

Trabant – B (A)

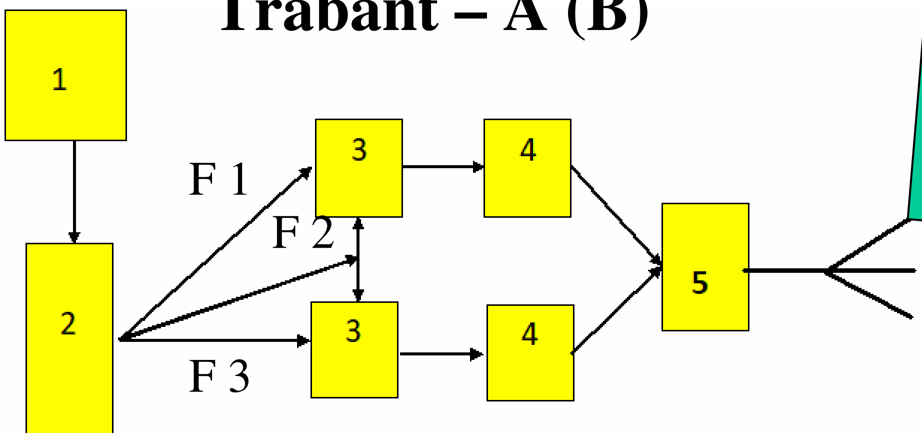




Block diagram of the receiver

Демод-demodulator, ФД- phase detector, ФНЧ- low-pass filter, АЦП- analog-to-digital converter, ФАП- phase-amplitude converter

Trabant – A (B)



Block diagram of the transmitter

1- master oscillator, 2- synthesiter, 3- modulator, 4- amplifier, 5- mixer

The determined distance between MS within 0.1-100 km is supported by small gas-jet engines)

Conclusion

The ability to measure the parameters of the ionosphere in two different, almost synchronously moving in orbit points, will solve a number of issues of ionosphere dynamics and behavior of other near-earth processes.

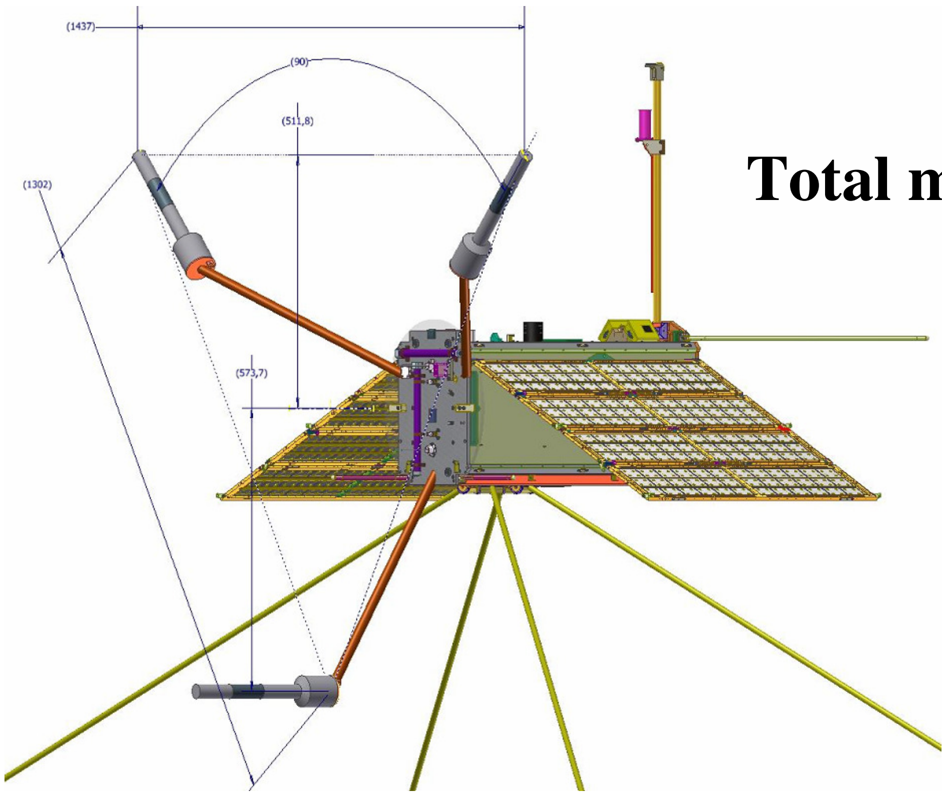
The main scientific objectives of the two satellite measurements will be:

- study of mechanisms of occurrence and dynamics of ionospheric inhomogeneities of various scales depending on daily, seasonal, latitudinal factors, active processes in the Sun and on the Earth;
- study of the regularities of changes in plasma-wave (0.01 Hz – 80 kHz) and electromagnetic parameters in the ionosphere of natural and man-made character in a wide dynamic and frequency ranges;
- continuation of the study of lightning activity in the study of compact inter-cloud discharges, which are a special kind of atmospheric processes;

Micro-satellite "Trabant" – 2019-2023.

Basic objective mission of the "Trabant" is the development of the electromagnetic clean micro-satellite.

Wave Complex (MWC) in the frequency range of 0.1 Hz – 80 kHz and instrument for study the high-frequency fluctuation of the ionospheric plasma concentration - a key scientific tools "Trabant".



Total mass ~ 50 kg

Size and weight comparison

Thanks for the attention