

“Obstanovka” experiment on determining spacecraft surface charging aboard the International Space Station

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Abstract

First data from the measurements of the surface charging and potential of the International Space Station (ISS) is presented. The data is a result of the 'Obstanovka' scientific experiment and hardware currently operating aboard ISS since 19 April 2013. The initial results show the ISS surface potential varies in the range $\sim (10-25)$ V.

Introduction

In the last decades the Langmuir probe is one of the classical instruments for plasma diagnostics [1] and among the first space-borne instruments. Langmuir probes have been successfully used aboard a number of rockets and satellites for in situ measurements of thermal plasma parameters in the terrestrial ionosphere [2], at other planets [3] and comets [4-5]– e.g. in satellite mission such as Tiros, Explorer, Alouette, ISIS, DMSP, Atmosphere Explorer, Interkosmos, Dynamics Explorer, Kosmos, Interball, Demeter, Astrid, Freja, Kyushu, CHAMP, CRRES, SCATHA, KOREASAT and many other, including several stratosphere rocket launches of the Vertical series, and planetary exploration missions such as Viking (Mars), Cassini (Saturn), Pioneer Venus (Venus), VEGA (Venus and the Comet Halley), etc.

The objective of this work is to describe the plasma wave complex (PWC) “Obstanovka” (“Situation”) experiment carried out aboard the International Space Station (ISS) and, in particular, the operation and the results from the Langmuir Probe (LP) device designed to characterize the surface charging and potential of ISS. The hardware was brought in operation aboard ISS on April 19, 2013, after 6 hours of extra vehicular activity (EVA) of a team of the ISS crew.

The ISS surface charging characterization

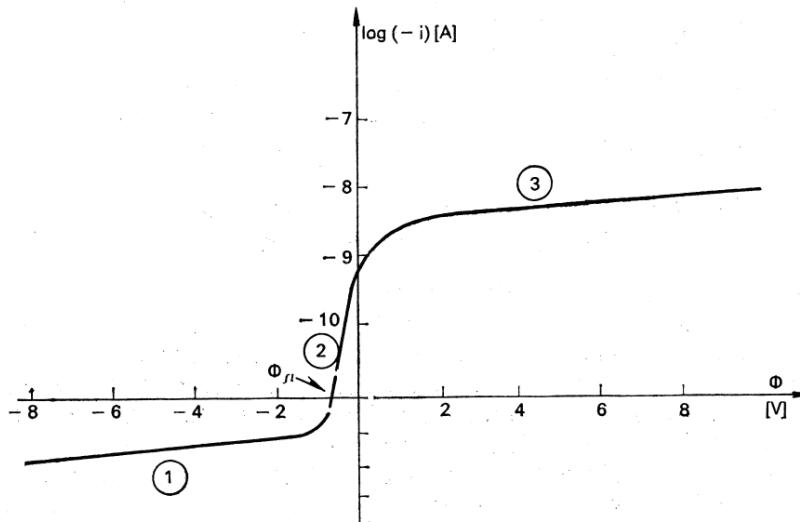
The specific research goals of 'Obstanovka' were defined as follows:

- Study the plasma wave processes established in the outer environment of ISS in result of its interaction with the ionosphere;
- Determination of the sources for disturbance of the plasma flux and the electromagnetic field around ISS;
- Geophysics study of the plasma wave processes related to the solar- Earth magnetosphere-ionosphere-atmosphere and lithosphere interactions;
- Ecology control of the low frequency anthropogenic electromagnetic radiation [2];
- Study of the disturbances in the surrounding ISS plasma and electromagnetic field in result of the activity of the electron and ion gun aboard ISS, and the mechanism of propagation of artificial electromagnetic waves;
- Study of the space weather environment in the equatorial and mid-Earth altitudes and in the sub-auroral ionosphere.

Theory

In general, any conductive body placed in plasma environment can be used as an LP. One needs to apply potential across the LP and measure the probe current. The achieved specific IV is used to determine the plasma parameters.

In it, section (1) represents the ion saturation regime, in which the probe current is entirely due to plasma charging due to ions (all electrons are repelled by the probe negative potential). In regime (2), the less negative probe potential allows the most energetic electrons to overcome the probe potential barrier and to generate exponentially increasing electron current, in addition to the background ion current. In region (3), the probe positive potential (relative to the plasma) accelerates the electrons and repels the ions, thus the probe current is entirely made of electrons.



a) Fig.1. Typical IV of a Langmuir probe at $T_e = 20000\text{ K}$, $N_i = N_e = 108\text{ m}^{-3}$, $M_i = 16\text{ a.m.u.}$

The LP current in region (1) is described by Equation 1, where I_i is the net ion current from the different ion species (1-j), φ is the potential applied to the probe with respect to the plasma, a and b are physical coefficients:

$$I_i = \sum_{j=1}^n (\alpha_j \varphi + b_j)^{\frac{1}{2}} \quad (1)$$

Typically, the space environment plasma prevails of two types of ions, and the concentration of the other ion types can be neglected since it is at least an order of magnitude lower. In this case, $n=2$ and a good approximation of (1) is expressed as:

$$I_i = (\alpha \varphi + b)^{\frac{1}{2}} \quad (2)$$

Using Eq.2, and the experimental IV data, one could extract the coefficients a and b . Knowing the two, one could identify the plasma total ion concentration N_i and the effective ion mass M_i :

$$N_i = \frac{\pi}{A_{ew}} \sqrt{\frac{2be - akT}{2e}} \quad (3)$$

$$M_i = \frac{2be - akT}{2e} \quad (4)$$

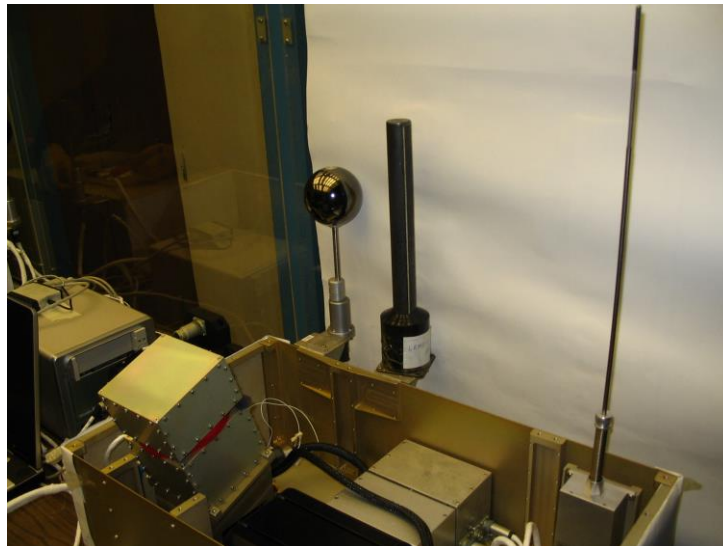
From region (2) of the IV, one could determine the electron temperature $T_e = \frac{e}{k} \left(\frac{d \ln I_e}{d U} \right)^{-1}$ [6]. In the above equations, I_i is ion current, A is the probe area, N_j , q_j , T_j , m_j are the concentration, the charge, the temperature and the mass of the j -th type of ions in the plasma; w is the plasma velocity, ϕ is the probe potential, e - the electron charge, and k - the Boltzmann's constant.

Nevertheless, despite the challenges posed by various factors and uncertainties, it is important to note that most processes exhibit a high degree of nonlinearity [7-10], making their behavior difficult to predict and analyze using traditional linear models.

“Obstanovka” Hardware

The PWC hardware of 'Obstanovka' consists of several modules, combined in three blocks. Two of them are placed in open space location outside of ISS and the third block (BSTM) is located inside the station. The following physical parameters are being measured by the system: - electron and ion temperatures T_e and T_i ; electron and ion concentrations N_e , N_i ; DC and AC electrostatic and magnetic fields and currents; plasma and ISS potentials; electron spectra in the range 0.01-10keV; spectra of the VLF electromagnetic waves. To study the plasma discharge effects in space, PWC includes as well a separate discharge generator.

There are two cylindrical LP probe setups (LP-1,2), see Figure 2.



b) Figure 2: View of one of the the cylindrical LP modules

LP1 and LP2 are used to characterize

- the thermal plasma parameters in two locations outside ISS;
- plasma electron temperature T_e in the range 1000-6000 Kelvin;
- electron and ion concentration N_e , N_i in the range $1.109 - 1.1013 \text{ m}^{-3}$;
- the ISS potential U_p , (referenced to the surrounding plasma, in the range $\pm 100 \text{ V}$;
- fast fluctuations in the plasma concentration.

Figure 3 Further Illustrates the position of the PWC on the body of ISS and the location of LP1 and LP2 in a cross-section.

The complete hardware setup of PWC “Obstanovka” is shown in Table 1. Several research teams from the UK, Poland, Russia, Ukraine, Hungary, Sweden and Bulgaria partnered in the full PWC implementation.

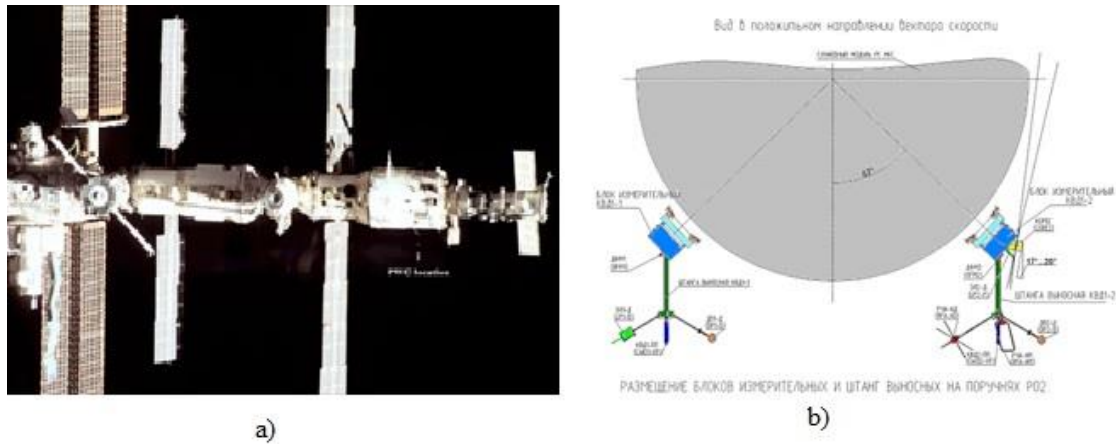


Fig. 3 (a) location of the PWC modules placed on the outer surface of ISS; (b) cross section of the position of LP1 and LP2 on the body of ISS, in the direction of the positive ISS speed vector.

Table 1: Full hardware module list of the PWC setup

Device	Research Organization
C	LC ISR
Magnetometer – DFM-1	IKI
Magnetometer – DFM-2	LC ISR
,	SRTI-BAS
D	SRTI-BAS
Plasma discharge simulator – SPP	SKB
eV – 10KeV) CORES	Sussex University
Radio frequency Analyzer – RFA (Scorpion)	SISP; SRC
Signal Analyser – SAS3	SRG, BLE
D A	KFKI RMKI; Sheffield University
Telemetry information storage module – BSTM (inside ISS)	KFKI RMKI; Sheffield University
Ground segment equipment – GSE	KFKI RMKI; SRC

Results and discussion

The system generates a lot of real-time data, which is being stored on a hard drive aboard ISS, and which is to be send back to Earth when the ISS crew completes its mission. Only limited amount of data is sent through the regular ISS telemetry channels.

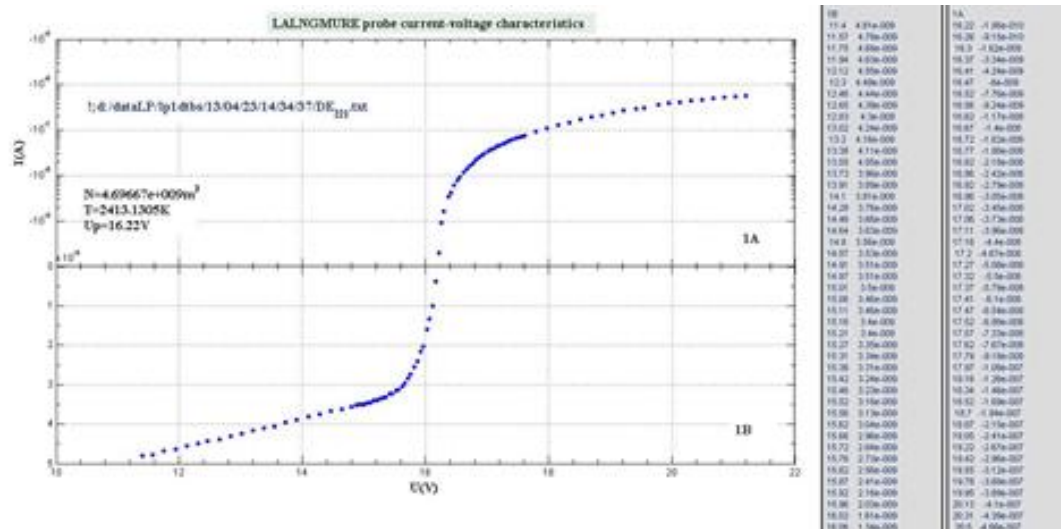


Fig. 4 Experimental IV of the Langmuir probe providing data to characterize the plasma surrounding ISS

Figure 4 shows typical Volt-Ampere curves from one of the Langmuir probes placed in the plasma surrounding the ISS. From the plot, the following preliminary plasma parameters are identified: plasma electron concentration $N=4.69667 \cdot 10^{-9} \text{ [m}^{-3}\text{]}$, the electron temperature $T=2413.1305 \text{ K}$, ISS surface potential $U_p=16.22\text{V}$. Figure 5 Further shows the evolution of the extracted plasma parameters in a typical 20 minutes' measurement session. An interesting observation is that the ISS surface potential U_p never drops below 10V. This is not quite yet understood and needs further investigation. It is further needed to study and understand the mechanism of charging large spacecraft such as the ISS.

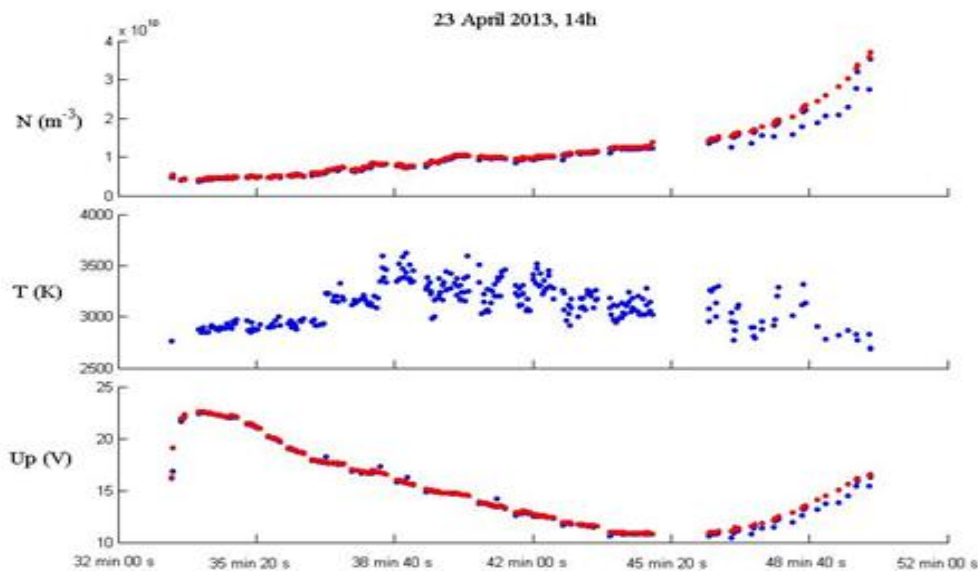


Fig. 5 Evolution of the extracted plasma parameters in time

Conclusions

First results from the ongoing “Obstanovka” (“Situation”) experiment aboard the ISS are presented. The Plasma Wave Complex is shown to be fully operational and providing scientific data about the parameters of the plasma surrounding the ISS in flight. The specially developed Langmuir probes allow to extract the charging and the potential of the ISS surface (relative to

the surrounding plasma). Further understanding of the charging mechanism of large spacecraft such as ISS is needed.

Acknowledgment

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