INTERBALL-2 THERMAL PLASMA MEASUREMENTS. 2. SPACECRAFT POTENTIAL IN MAGNETOSPHERIC AURORAL REGION AT ALTITUDES 2--3 R_E

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Abstract: A burst-type increase in interest to spacecraft potential, Usc, occurred when A. Pedersen have proposed to use the Usc measurements for determination of the thermal plasma density, the key parameter in most studies of magnetospheric plasma. As practically all satellites launched into high-altitude near-Earth plasma environment and most of deep-space probes were equipped with instruments using floating spherical probes for electric field measurements, the by-product of which, namely Usc data, were used for thermal plasma density determination. The Interball-2 carried several experiments capable to measure thermal plasma parameters. In view that the Usc became in recent years the main "source" of thermal plasma density determination in magnetosphere, Usc measurements by two experiments KM-7 and IESP are considered. It was shown that in the auroral region at altitudes 2--3 Re the spacecraft potential is predominantly negative in the range from 0 to –10 V. In the middle part of the auroral region it is between –4 V to –10 V, sometimes going lower than –10 V.

INTRODUCTION

The problem of determination of the spacecraft structure potential Usc with respect to the ambient plasma have arised since first satellites were flown into near-Earth space. This quantity was considered as being not of prime importance at that time and Usc was taken mostly as some technological parameter, although rather useful. Within the ionosphere this problem was solved with reasonable accuracy. Larger difficulties have appeared when a number of satellites were launched into regions outside the ionosphere-plasmasphere due to significantly lower values of the ambient plasma density.

A burst-type increase in interest to this parameter occurred when A. Pedersen [*Pedersen, 1995*] have proposed to use the Usc measurements for determination of the thermal plasma density, the key parameter in most studies of magnetospheric plasma. As practically all satellites launched into high-altitude near-Earth plasma environment --- S3-3, GEOS, ISEE-1, Viking, CRESS, Freja, FAST, POLAR, and CLUSTER [*Harvey et al., 1995*],--- and most of deep-space probes, were equipped with EFI-type instruments (Electric Field Instrument) using floating spherical probes for electric field measurements, the by-product of EFI-data, namely Usc data, was used, after the Pedersen's paper, for thermal plasma density determination. According to [*Johnson et al., 2000*], the method became "a routine method" for thermal plasma density measurements. The Interball-2 also carried experiment of this type, IESP.

Several experiments aboard the satellite were providing data for determination of Usc, namely, the electron temperature probe KM-7, wave experiment IESP, and retarding potential analyzer ALFA-3. In addition, a group of wave experiments and electrostatic analyzers could, in principle, provide some information on thermal (eV-range) plasma. First papers, published up to now, revealed striking disagreement in electron density and spacecraft potential values, although being made simultaneously on the same spacecraft.

The purpose of this paper is to compare Usc measurements by two instruments, namely electron temperature probe KM-7 and floating probe part of experiment IESP. In this paper we shall consider only the spacecraft potential Usc measurements on Interball-2, as it is, up to now, the main "source" of thermal plasma density determination in the magnetosphere.

BRIEF DESCRIPTION OF EXPERIMENTS

Experiment KM-7

Experiment KM-7 uses spherical probe with radius 60 mm made of stainless steel and with good protection against the photoelectrons. °°° The objective of the experiment was to measure electron temperature, *Te*, of thermal plasma in magnetospheric part of the Interball-2 orbit. Actually, it is swept floating Langmuir probe method, properly modified for low thermal plasma conditions [*Afonin and Smilauer, 1995; Afonin et al., 1998*]. Due to very low telemetry quota, assigned for the experiment, an automatic onboard data processing was implemented. Assuming, according to the common practice, Maxwellian distribution, the onboard program was searching the steepest portion of semi-log current-voltage curve (CVC) and the *Te* was calculated from the CVC slope and conveyed to the Earth in ready-to use form. Also were transmitted the values of probe potential relative to the spacecraft U_{PS} corresponding to these steepest portions of CVC, the negative value of which *Upk* =-*Ups* was expected to be within (1--3) *kTe*/*e* from the plasma potential and represent roughly the spacecraft potential *Usc* , i.e., "quasi *Usc* potential". It was assumed, in the design time, that the true *Usc* could be obtained by taking into account the probe floating potential *Ufp* , which could be calculated from the known *Te*. As for the accurate calculation of the probe floating potential rather detailed information on the ambient plasma are needed, in the paper, presenting the first results, [*Afonin et al., 1998*] a "rule of thumb" was formulated for express determination of the spacecraft potential relative to the ambient plasma *Usc* : within the plasmasphere *Usc* = *Upk* - 0.5 V and outside of it, in the magnetosphere, *Usc* = *Upk* – (2--3) V.

To account for possible deviations from Maxwellian distribution, the transmission of CVC via auxiliary TM-system STO was also provided. The KM-7 experiment produced CVCs transmitted each 5.12 s, what is a compromise between detalization of CVC and space--temporal resolution forced by TM-quota of KM-7. The time resolution 5.12 s corresponds, in auroral region at *H*=2--3 *Re*, to 0.01 L and 0.01° of *InvLat*. Detailed description of the measurement procedure is given in [*Afonin and Smilauer, 1995*]. Availability of CVCs is extremely useful and hardly can be overestimated for thermal plasma measurements, typical example of „signal under the noise" situation, as the „interfering signal", the spacecraft potential, *Usc*, or photoelectron current, *Iph*, may be significantly, up to tens or hundreds times, larger than the „measured signal", the electron temperature *Te* or number density *Ne*. Simple visual check of CVC immediately provides very important information:

- if the electron distribution is Maxwellian?
- if one or more Maxwellian components are present?
- if electrom beam(s) is present?
- if ion beam is present?

And finally, and may be the most important, the availability of CVCs allows to evaluate adequacy and accuracy of automatic onboard data processing.
The available data base consists of 555 polar magnetosphere passes, each file containing ~2000 CVC.

The Langmuir Probe Interball Model (LPIbM) was developed to determine the thermal plasma characteristics and the spacecraft potential by interactive visual fitting the analytic model of spherical Langmuir probe to experimental curves [*Afonin and Smilauer, 2000*]. The thermal and supra-thermal plasma environment assumed in the model may consist

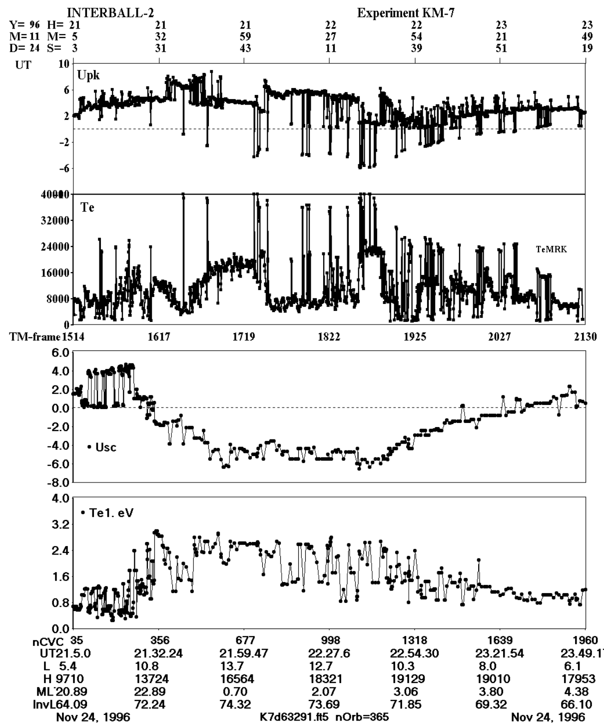

Fig. 1. Comparison of KM-7 automatic onboard data processing with results from CVC analysis for north auroral region pass on October 24, 1996. *Upk* (upper panel) is „quasi-spacecraft potential", determined from the steepest portion of the probe current-voltage curve. *Usc* (third pannel) is true spacecraft potential.

of two isotropic thermal populations (*Ne, Te,Ti=Te* for each), four electron beams, each characterized by its own streaming energy *Eb*, density *Nb* and temperature *Tb*, and one ion flux *Fi*. In most cases the fitting was possible with estimated accuracy not worse than 10% [*Afonin and Smilauer, 2000*]. The exceptions, leading to larger uncertainty, are related to some parameters in the most complicated cases, such as the electron temperature for the fourth (largest energy) beam, if present, or to situations when initial part of CVC, due to limited range of the probe bias, felt into logarithmically linear current range, the first electron beam energy *Eb1* (lowest) was less than about 3-4 eV, and its temperature was close to the isotropic thermal population temperature *Tb1*≅*Te1*. In such cases discrimination between the electron beam and isotropic thermal population is impossible.

These KM-7 CVC data provide unique possibility to get first reliable data on local thermal plasma parameters because the KM-7 probe was the first probe flown into the outer magnetosphere, which was rather reliably protected against influence of the main factor, preventing low-density plasma measurements --- photoelectrons, both own and those emitted by the spacecraft structure. We can not exclude completely that in some situations a minor contribution to the probe current from ambient photoelectrons is possible. But such situations are rather rare as several factors should coincide in time to make such contribution possible (s/c orientation, direction of local magnetic field, s/c structure potential etc.).

First results of automatic onboard data processing [*Afonin et al., 1998*] have shown striking fluctuations in T_e and Upk (see also Fig. 1, two upper panels). Therefore, CVCs were analysed with the LPIbM model and the first results of this analysis were presented in [*Afonin and Smilauer, 2000*]. The main result was that the thermal plasma in the auroral region at 2-3 Re altitudes is practically always not Maxwellian and some non-Maxwellian components are practically always present.

For the auroral region pass on October 24, 1996, Fig. 1 shows results of automated onboard data processing: the "quasi potential" U_{PK} and electron temperature T_e (two upper panels), next two panels show true spacecraft potential *Usc* and *Te* , derived from accurate ground analysis of CVCs.

Comparison between results of automated onboard (two upper panels) and detailed ground-based data (two lower panels) processing shows that results automated onboard processing in the region considered is far from being acceptable. The reasons of this discrepancy lies in the wrong (for considered magnetospheric region) assumption of Maxwellian distribution of thermal plasma [*Afonin and Smilauer, 2000*]. The operation of the KM-7 electronics and onboard data processing code was carefully checked, including inflight variations in possible operation modes by groung commands, and we could not find any mulfunctions. Thus we should conclude that
reliable data on thermal plasma parameters in high-altitude auroral region can not be obtained in experiments using automated onboard data processing or choice of operation mode.

Experimenr IESP

The IESP experiment was launched for the measurement of the waves in the ULF range and is part of a wider wave complex covering a frequency range from DC to 2 MHz. Basically, the IESP experiment has been designed for measuring the waveform of the six components of the electromagnetic field in the frequency ranges from 0.1 to 10 or 30 Hz, three components of the DC electric field and the electric potential of the satellite (1 sample/16s) which is the voltage measured between one of the spheres and the structure of the satellite [*Perraut et al., 1998*].

Spacecraft potential data from IESP experiment were obtained from Interaball-2 raw TM data server in SRI, Moscow. The needed TM-channels and initial conversion of raw TM-data to physical values at the output of the instrument IESP and further calculation of "input signal" were made by the code *cpy_iesp.exe* (available on the server), which takes into account the

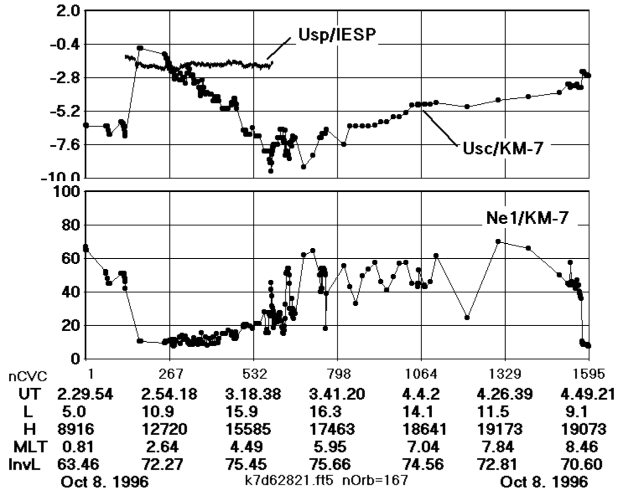

Fig. 2. Comparison of Usc from KM-7 and IESP for orbit 167.

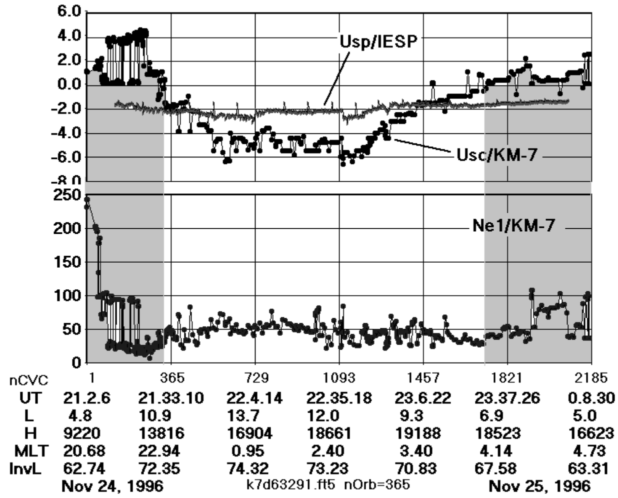

Fig. 3. Comparison of Usc from KM-7 and IESP for orbit 365.

instrument calibration curves. As the initial raw TM-data array was not sorted by periods where instruments were active, we have analysed the data and sorted out the real IESP operation periods. As a result, 775 passes over polar regions are available.

For the present comparison we have selected 4 cases of typical Usc-IESP behavior, two with "smooth" behavior, and two with some rather pronounced events in the Usc-IESP variation.

COMPARIZON OF KM-7 AND IESP SIMULTANEOUS DATA ON SPACECRAFT POTENTIAL

Comparison of *Usc*/*IESP* with *Usc*/*KM7* for orbit 167 and 365 is shown in Fig. 2--5. These figures share the same format. The upper panels shows values of Usc derived from both experiments. The *Usc/KM-7* parameter was determined by visual fitting of current-voltage curves as is described above. The Usc data from IESP are designated as *Usp/IESP* (spacecraft relative to the probe) to reflect the physical meaning of the IESP output signal, as we understand it (IESP measured the voltage difference between one of the spheres and the structure of the satellite [*Perraut et.al., 1998]*. Acordingly, the output signal of IESP, derived as described above, was inverted in sign to be compared with KM-7 data. Another reason of using different designation comes from the fact that in the Pedersen's floating probe method the probe is clamped to the plasma potential with accuracy, according to different papers, of 2-3 V. This should be kept in mind when comparing the curves.

The lower panels show the electron density of major isotropic Maxwellian component of the ambient plasma, determined by KM-7. Different and non-uniform distribution of KM-7 data points in all these 4 figures are due to the fact that only 15--30 % of total available CVCs in each pass were processed up to now.

All four presented cases are passes over north auroral zone at altitudes 1.5--3 Re, the flanks of plasmasphere evident in some passes.

Practically no correlation between *Usp/IESP* and *Usc/KM7* is seen in Fig. 2, orbit 167. In Fig. 3 , orbit 365, small correlation is seen, especially in the middle part. The shaded areas in this figure indicate positive values of *Usc/KM-7*, within which the *Usc/IEPS* stays negative. The step-wise fast alternating values just outside the plasmapasuse are caused by fast variations in intensity and energy of eV-range electron beams and were considered in [*Afonin, Smilauer, 2001*]. Inspite some correlation, the span of the Usc variation for IESP is significantly smaller than for KM-7. As is seen from the lower panel and the orbital data, this pass started inside the evening plasmasphere, rather close to the plasmapause, and ended somewhere close before entering the plasmasphere in the morning side. Accordingly, in this case the *Usc/KM7* shows slightly positive values near and just outside the plasmapause. As the satellite moved deeper into the auroral zone the wide region of negative spacecraft potential coinciding with the auroral zone was observed.

Comparison of *Usc/IESP* with *Usc/KM7* for orbits 216 and 257 is shown in Fig. 4, 5; in this case we see coindence for some small- and large-scale details of *Usp/IESP* and *Usc/KM7*, but the „amplitude“ of *Usp/IESP* variations are again much smaller than in KM-7. Fig. 4 shows negative Usc/KM7 inside the plasmasphere and small positive values just outside (the shaded area).

Frequency occurence of Usc values for simultaneous measurements by KM-7 and IESP for orbit 216 is

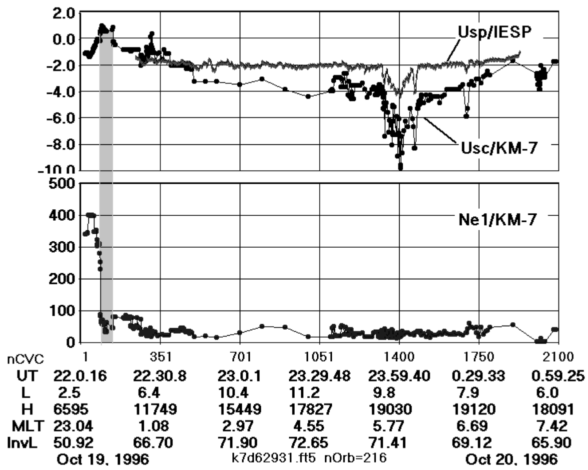

Fig. 4. Comparison of Usc from KM-7 and IESP for orbit 216.

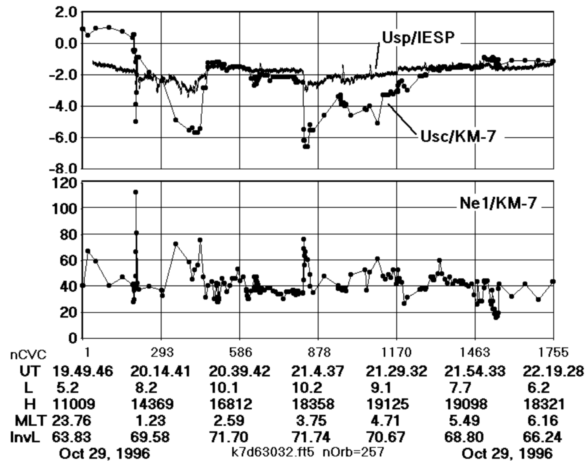

Fig. 5. Comparison of Usc from KM-7 and IESP for orbit 257.

shown in Fig. 6. The *Usp/IESP* values are concentrated within -2±1 V range, as can be seen also from other passes not shown here.

From these data we may conclude:

- When Usc is negative both experiments correctly define the sign of the s/c potential.
- IESP never shows positive values of Usc (this conclusion is based on the whole available passes).
- The values of *Usp/IESP* very rarely coincide with *Usc/KM7.*
- The sensitivity of *Usp/IESP* is significantly depressed with respect to the local plasma parameters variations. In case of "large amplitude" events IESP correctly reflects relative variations.

DISCUSSION

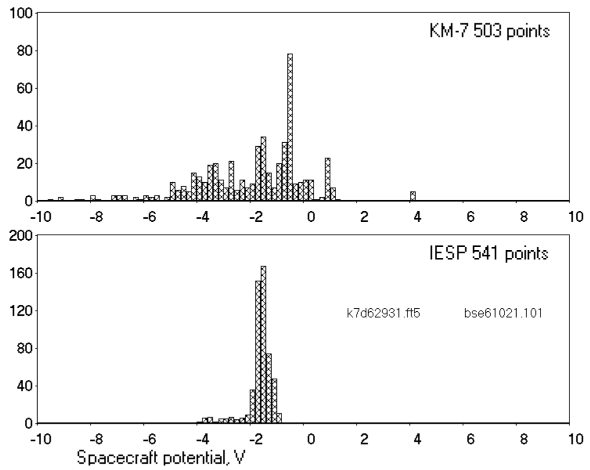

Fig. 6. Frequency occurence of Usc values for simultaneous measurements by KM-7 and IESP for orbit 216.

1. Presented above data display evident significant distinction between Usc measurements by two experiments. We believe that *Usc/KM7* are reliable both by sign and by values as:

- Each individual point on the plots was determined by fitting method from a number of point of current-voltage curve (CVC) – dependence of the current to the probe from ambient plasma on the probe potential relative to the plasma . Rough estimate of the result validity and any assumptions, if any, used in deriving the result can be easily gained by visual check of CVC. IESP produces one-point value for each measurement and uses numerous assumptions to produce this value, which can not be checked within the experiment itself.

- It shows expected and interpretable, from physical point of view, variations for passes plasmasphere-auroral zone-plasmasphere and its relative variations in each case, including small-scale features, can be interpreted by variations in thermal plasma parameters (*Ne*, *Te*, hot tails, eV-range electron beams etc., see [*Afonin, Smilauer 2001*].

2. The measured by IESP value, i.e., the voltage difference between the probe and the satellite structure, Ups, is always positive, and therefore the spacecraft potential is negative. This is opposite to similar measurements on a number of satellites using the same method. In view of this and of the above results of comparison with KM-7 a number of questions arises with respect to the data on Usc from IESP experiment.

- Why the *Usc/IESP* are always negative and never were observed to be positive?

- Why the sensitivity of the *Usc/IESP* was depressed?

- Why *Usp/IESP* values are strongly concentrated around –2 V?

Predominance of *Usp/IESP* values to be concentrated in rarher narrow range and „stable“ –2 V value in the most part of the overall period of measurements implies that the operation mode of IESP floating probe was not optimal. In our opinion, this should not significantly influence the wave measurements by IESP, but it is essential for deriving reliable information on the spacecraft potential and hence the thermal electron density.

In general, such a behavior of IESP is understood and detailed analysis shall follow, but this issue is out of scope of the present paper.

CONCLUSIONS

1. The comparison between two Interball-2 experiments (IESP and KM-7) has shown that in the auroral region at altitudes 2-3 Re the spacecraft potential is predominantly negative and ranges from 0 to –10 V. In the middle part of the auroral region it is between –4 V and –10 V, sometimes going lower than –10 V.

2. Comparison between results of automated onboard and detailed ground-based data processing shows that reliable data on thermal plasma parameters in high-altitude auroral region can not be obtained in experiments using automated onboard data processing or choice of operation mode.

3. The operation mode of Interball-2/IESP experiment in the part of the spacecraft potential measurements is was not optimal and these data require detailed analysis.

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