Numerical modelling of the lunar exosphere and lunar lander interactions with SPIS-DUST

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Background

One of the complicating factors of the future robotic and human lunar landing missions is the influence of the dust. The absence of an atmosphere on the Moon's surface is leading to greater compaction and sintering. Properties of regolith and dust particles (density, temperature, composition, etc.) as well as near-surface lunar exosphere depend on solar activity, lunar local time and position of the Moon relative to the Earth's magnetotail. Upper layers of regolith are an insulator, which is charging as a result of solar UV radiation and the constant bombardment of charged particles, creates a charge distribution on the surface of the moon: positive on the illuminated side and negative on the night side. Charge distribution depends on the local lunar time, latitude and the electrical properties of the regolith (the presence of water in the regolith can influence the local distribution of charge).

Dust analyzer instrument PmL for future Russian lender missions intends for investigation the dynamics of dusty plasma near lunar surface. PmL consists of three parts: Impact Sensor and two Electric Field Sensors. Dust Experiment goals are:

1) Impact sensor to investigate the dynamics of dust particles near the lunar surface (speed, charge, mass, vectors of a fluxes)

   a) high speed micrometeorites

   b) secondary particles after micrometeorites soil bombardment

   c) levitating dust particles due to electrostatic fields. PmL instrument will measure dust particle impulses. In laboratory tests we used: min impulse so as $7 \cdot 10^{-11}$ N·s, by SiO2 dust particles, 20-40 m with velocity about 0,5 -2,5 m/s, dispersion 0.3; max impulse was 10^{-6} N·s with possibility increased it by particles Pb-Sn 0,7 mm with velocity 1 m/c, dispersion 0.3. Also Impact Sensor will measure the charge of dust SHORT TITLE HERE: A. B. Author and C. D. Author particle as far as 10-15 C (1000 electrons). In case the charge and impulse of a dust particle are measured we can obtain velocity and mass of them.

2) Electric field Sensor will measure the value and dynamics of the electric fields near the lunar surface. Two Electric Field Sensors both are measured the concentration and temperature of charged particles (electrons, ions, dust particles). Uncertainty of measurements is 10%. Electric Field Sensors contain of Langmuir probes. Using Langmuir probes near the surface through the lunar day and night, we can obtain the energy spectra photoelectrons in various periods of time.

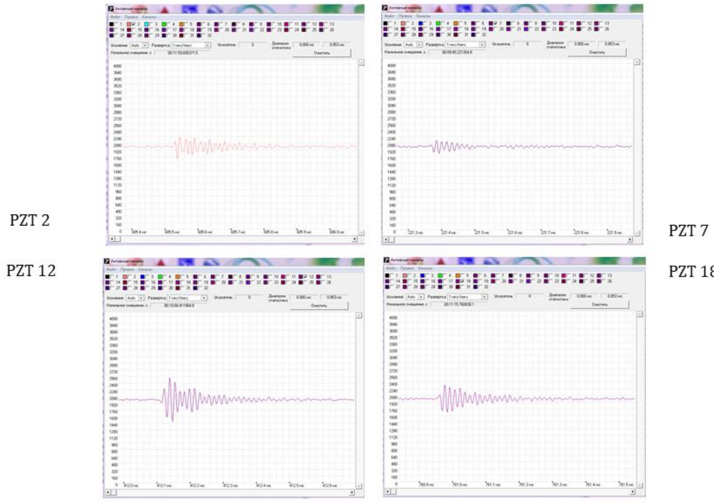
Purposes of the Dust Instrument

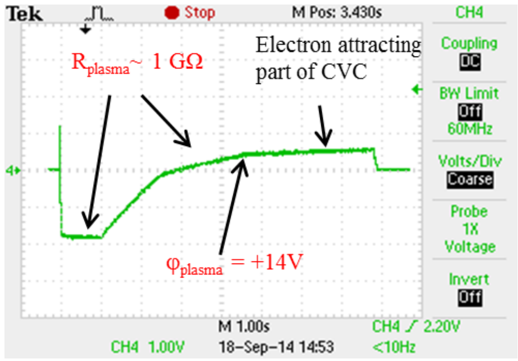
Instrument for measure dust particles physical behavior (impulse, velocity, charge, dimension etc.) is it represented of three type of sensor. The goals of it are to investigate the dust cycle in situ of dust flux at the surface.
The instrument LUNAR DUST MONITOR (PmL) intend to investigate the temporal variations of expected sources of dust in the lunar environment: lofted particles, eject production due to continual bombardment of interplanetary dusts, micrometeorite and dust produce landers itself.
This instrument is included into the payload of landers of both mission to moon: Luna-Globe and Luna-Resource.
To determine the near-surface electrostatic field is used method of measuring current-voltage characteristics of the surface plasma using Langmuir probes located at different distances from the surface of the Moon. Two proposed use of the Langmuir probe mounted on the housing of the lander on the distance of about 0.7 m from each other (vertical). This arrangement of sensors will provide data on electrostatic field near the surface of the Moon and the impact of the lander on the distribution of this field.

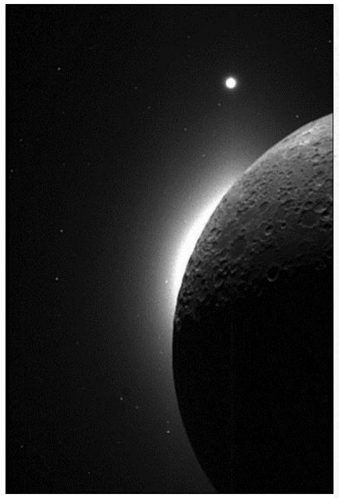
The instrument consists of 3 blocks for Luna-Globe (LG) mission and of 7 blocks for Luna-Resource mission:

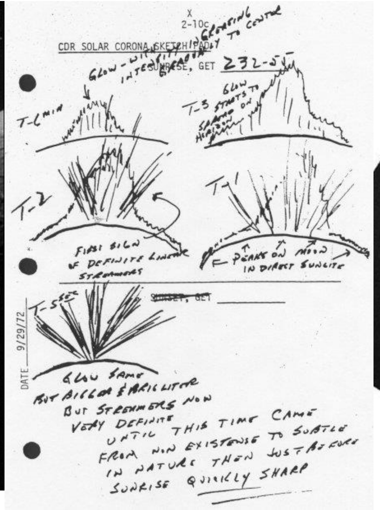
- Impact Sensor (IS) (or two IS for Luna-Resource (LR))
- Two Electrostatic Sensors (ES) for LG or four for LR
- Charge sensor (CS) combined with IS
- Small charged particle observer in the case of LR mission

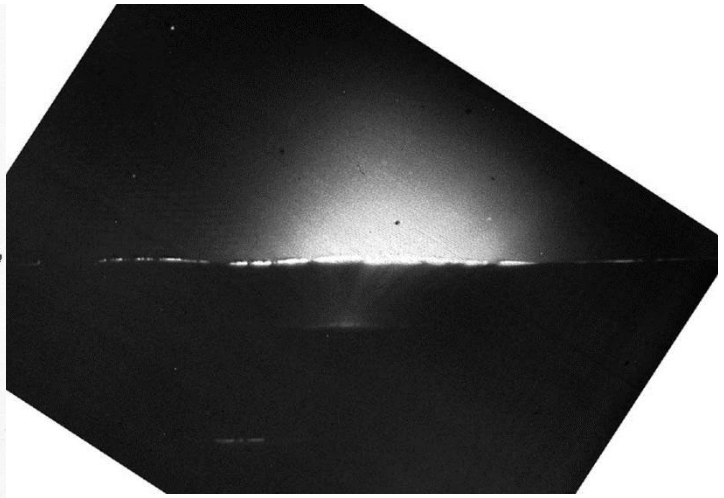
IS is a piezoceramic (PZT) sensor of square 0.15x0.15 m^2 and will allow to measure momentum of the dust grains from 10^{-12} kg·m/s.
ES will allow to measure potential of ambient dusty plasma at 20 cm and 90 cm from the Lunar surface.
CS is electric induction sensor to measure charge of the moving particles (with q > 1000 e)



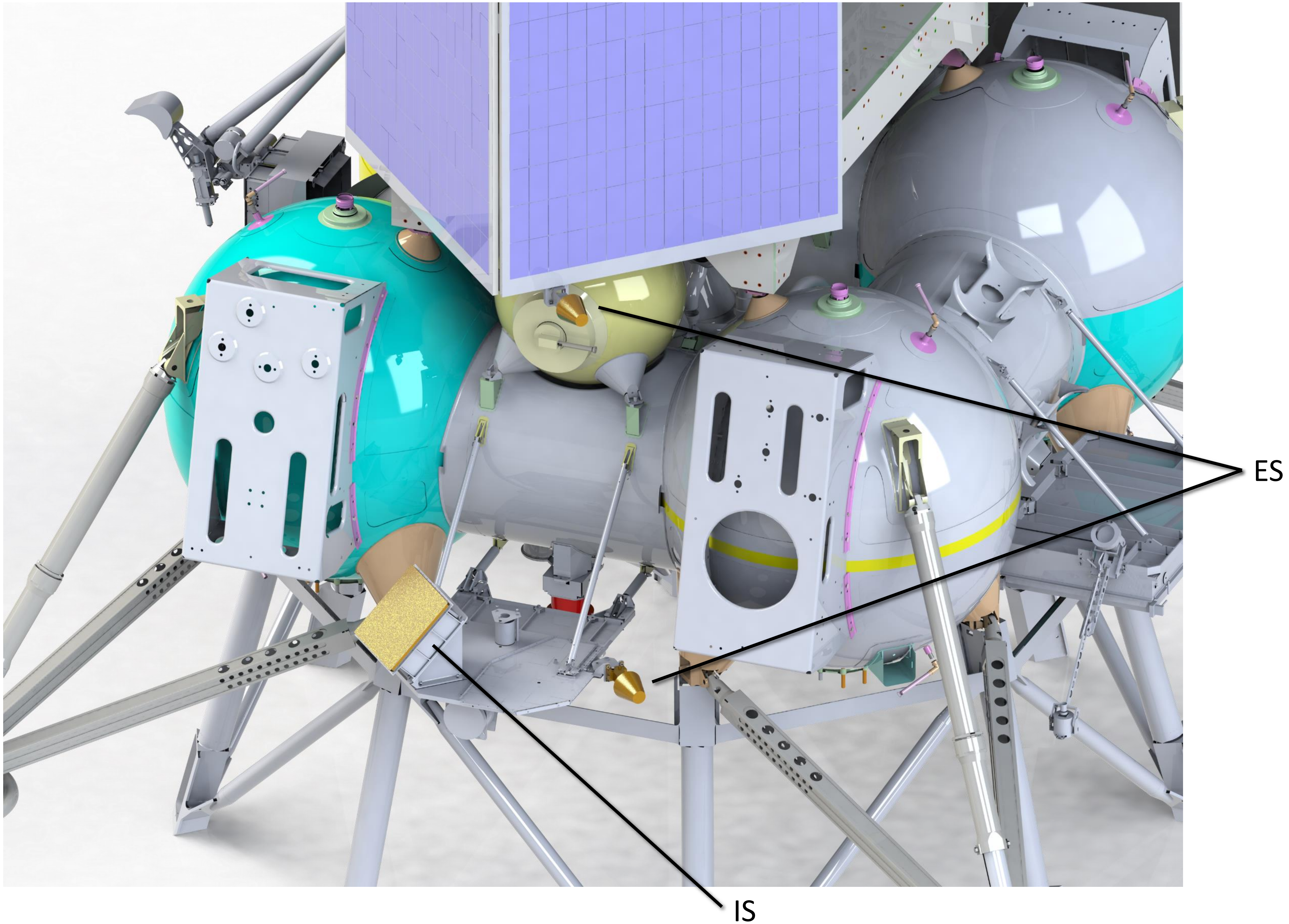








Accomodation of the PmL Dust Instrument on Luna-25 Lander



Conditions for numerical modelling

PLASMA CONDITIONS		
Parameter	UNIT	Value
Ion density, n_i	cm^{-3}	10
Electron density. n_e	cm^{-3}	10
Ion speed, V_i	$km \cdot s^{-1}$	430
Electron speed, V_e	$km \cdot s^{-1}$	430
Ion temperature, T_i	eV	10
Electron temperature, T_e	eV	10
Photoelectron temperature, T_{ph}	eV	2

[MRAD "Modelling requirements", 2013; Feuerbacher et al., 1972]

Situation	Surface Potential, V	North solar panel potential, V	Surface Temperature, K
Local Noon	0	0	288
Local Evening	0	27	240
Sunset	-10	5	130

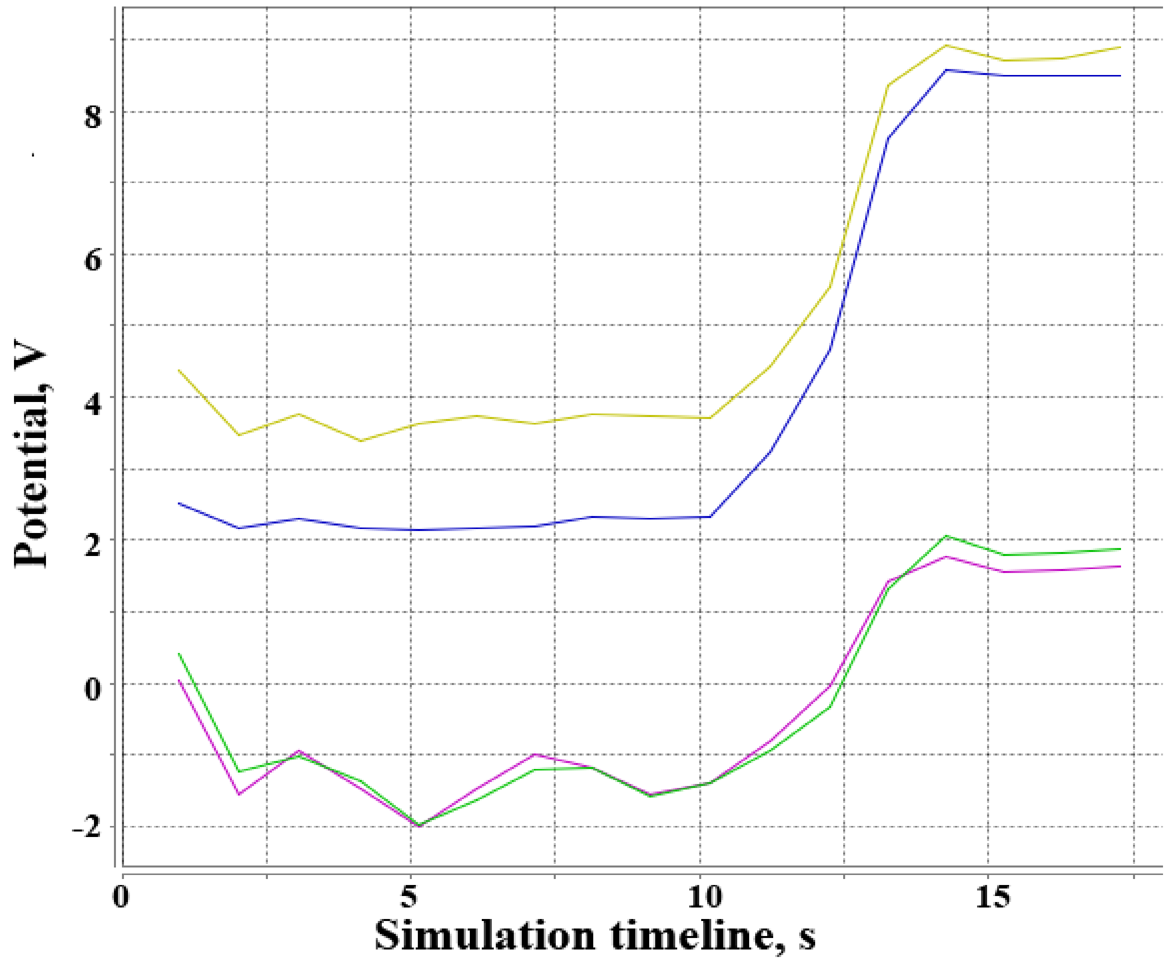
There are a number of RITEGs and RITs on-board, so after the thermal modelling we can estimate the temperatures of lander elements from 200 K (legs, fuel platform) to 233 K (solar panels and instrument surfaces).

Density of lunar dust layer of 1500 kg/m^3 [D.A. Kring, 2006]; the mass density of dust particles is taken as 3000 kg/m^3. The default dust size distribution is taken from 71501,1 Mare sample.

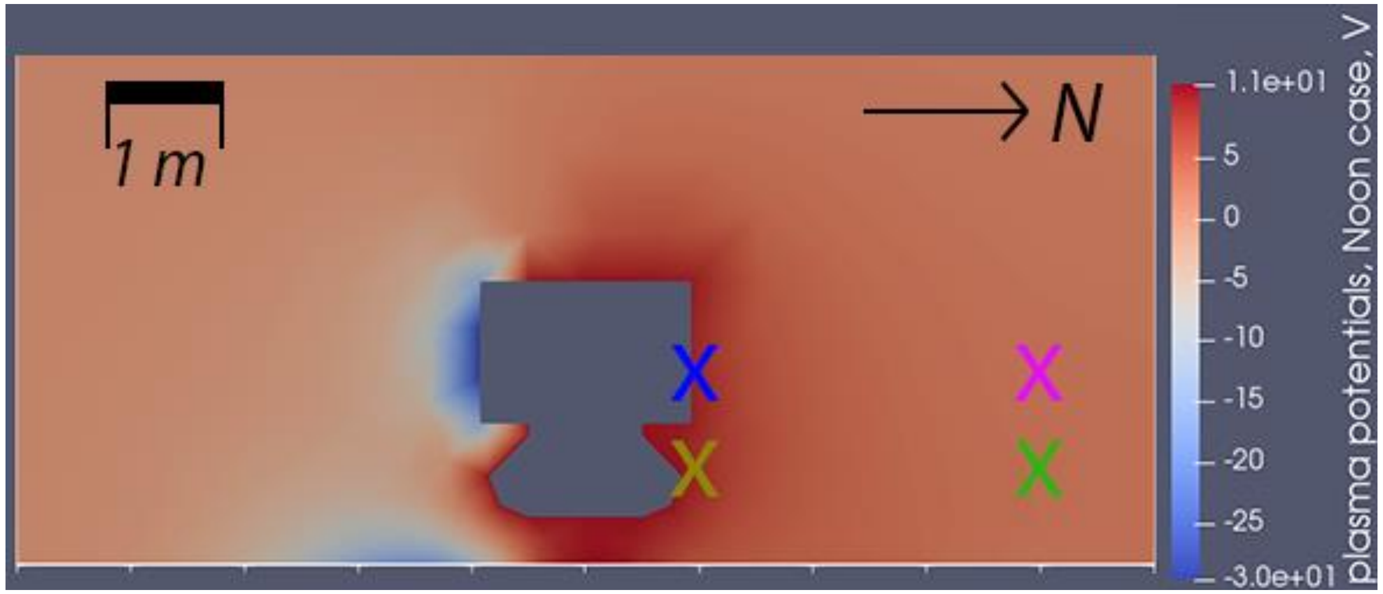
We assumed that the lander has one equipotential surface made of oxidized aluminum and gold layer of thermal shielding except the solar arrays, which are made of cerium doped silicon glass and have an initial potential of 0 V for the south panel and ~20 V for the north panel.

We simulated the sunrise period outside of the magnetospheric tail and in the case of absence of magnetic anomalies we can assume that all of the solar wind flux reaches the SC.

Results: Plasma potentials, Noon conditions

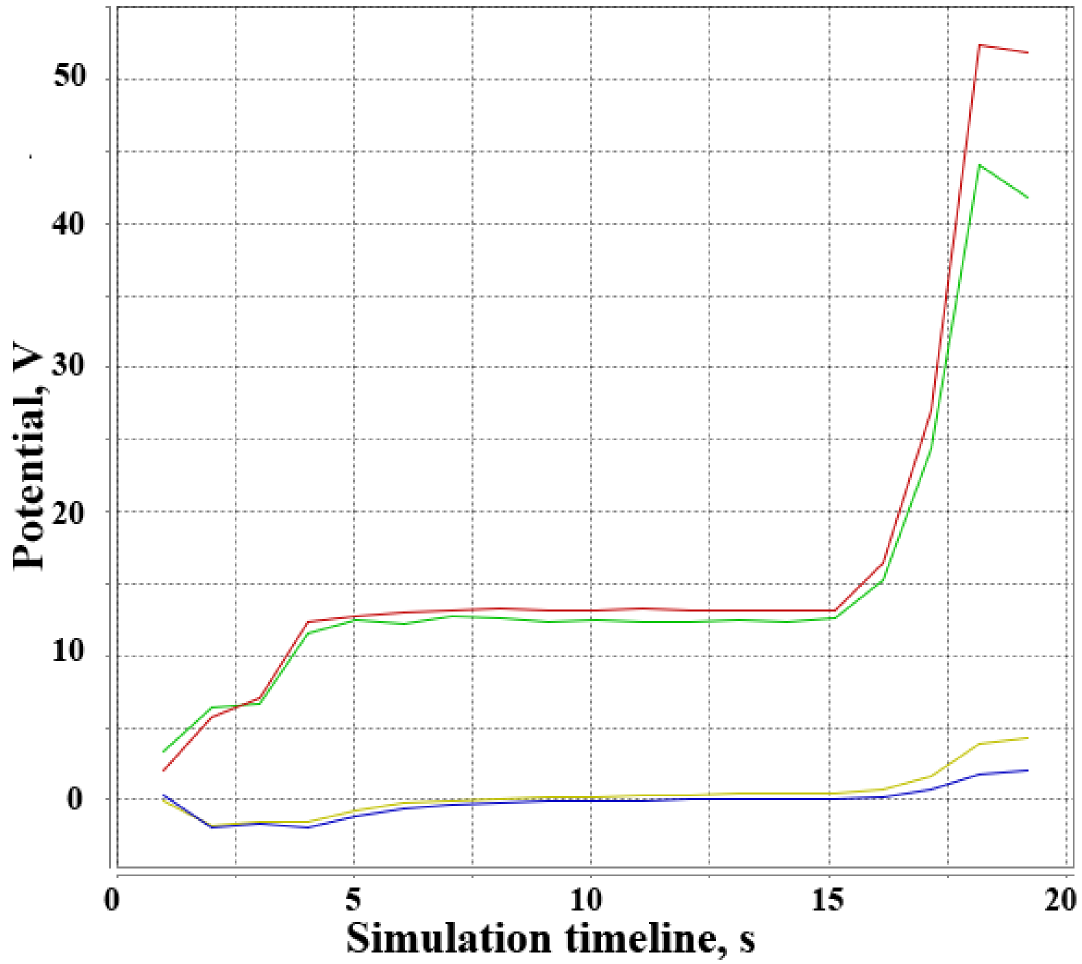


“Noon”. The Yellow and Blue lines are the potentials near the SC surface, lower (1 m above the surface) and higher (2 m) respectively; Green and Purple– the potentials on the 3 m distance from the SC on the same highs respectively.

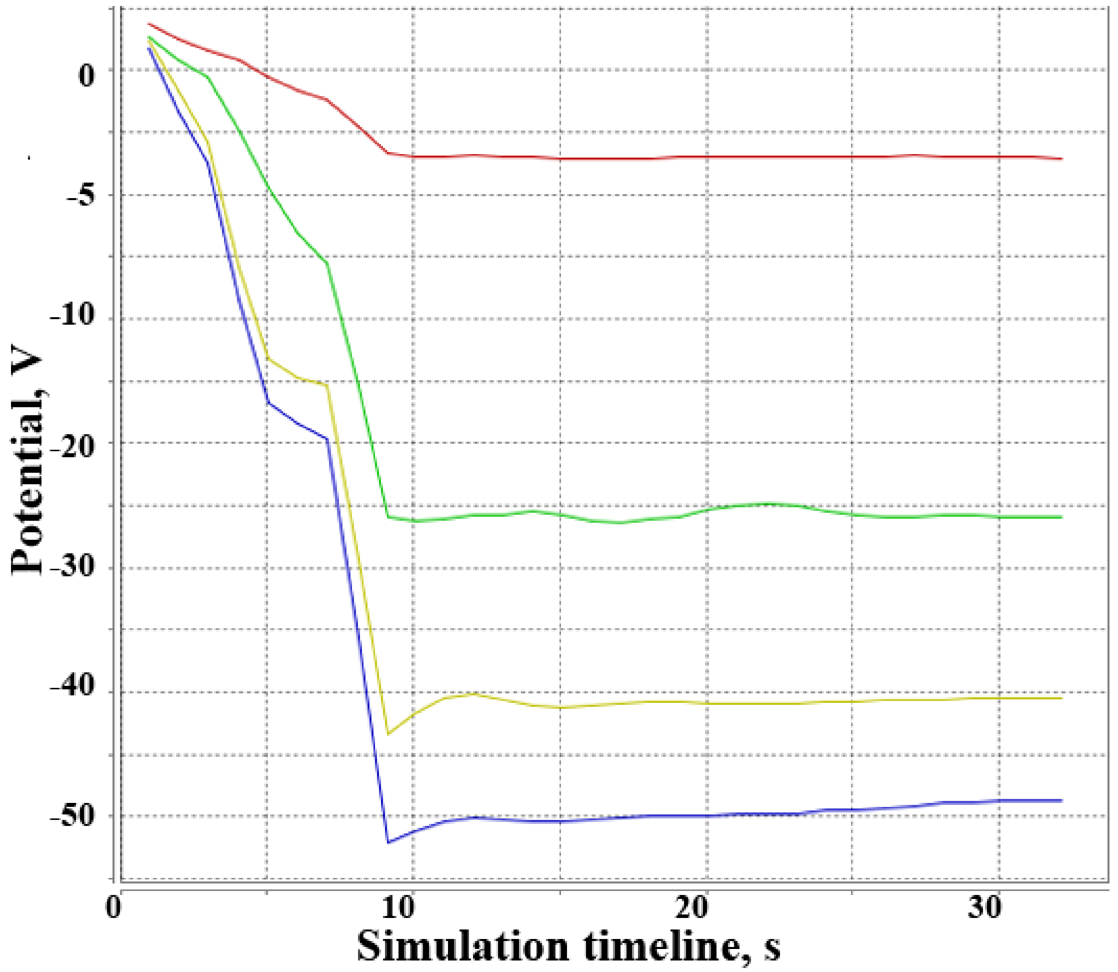


Plasma potentials at the steady-state in the “Noon” conditions. Sun is on the right. Virtual plasma potential sensors in SPIS simulation marked by “X” signs. Two of them matches with locations of the EP sensors on SC. We can see the strong positive bias in the SC vicinity in relation to undisturbed exosphere plasma. However, we have the strongly negative bias in the south (shadow) solar panel vicinity

Results: Plasma potentials, evening and sunset

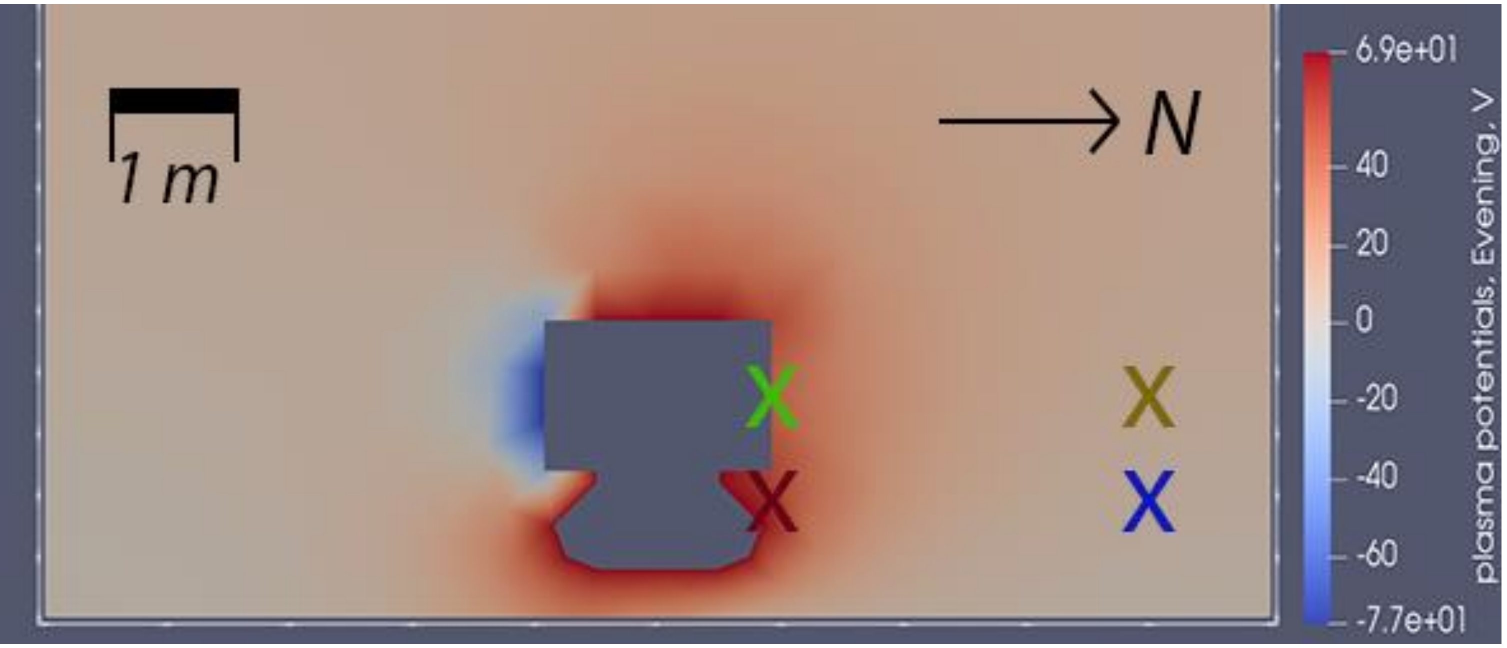


"Evening". The Green and Red lines are the potentials near the SC surface, the lower curve (1 m above the surface) and higher (2 m) respectively; Blue and Yellow – the potentials on the 4 m distance on the same highs respectively.

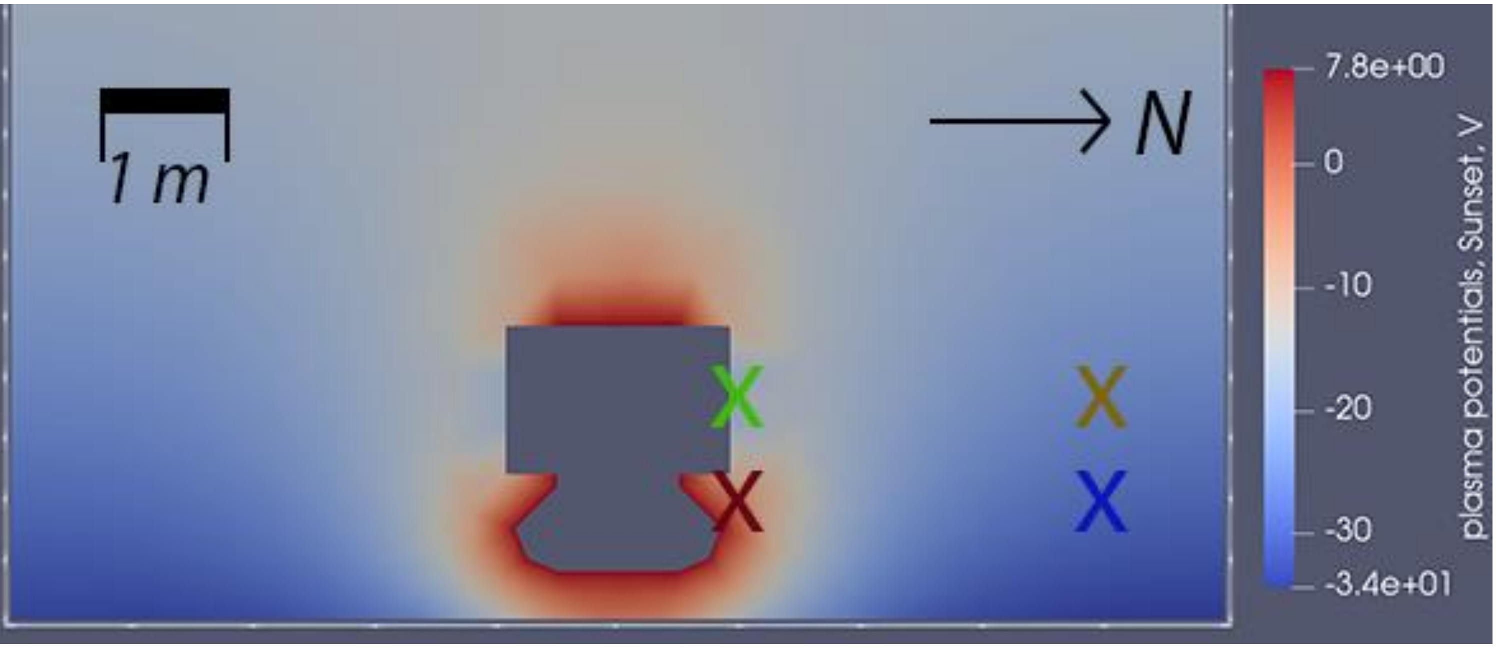


"Sunset". Green and Red lines are the potentials near the SC surface, lower (1 m above the surface) and higher (2 m) respectively; Blue and Yellow – the potentials on the 4 m distance on the same highs respectively.

Results: Plasma potentials, evening and sunset

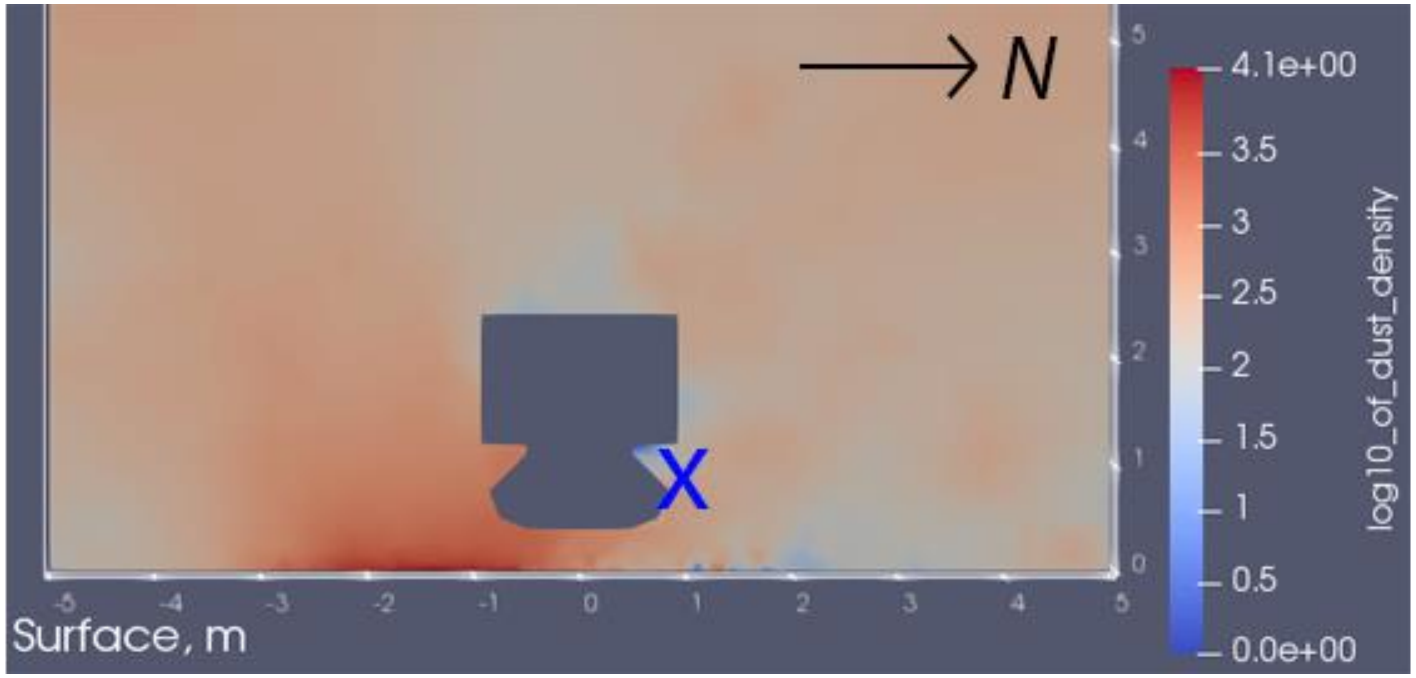


Plasma potentials at the steady state of simulation in “Evening” conditions. Sun is on the right. Virtual plasma potential sensors in SPIS simulation marked by “X” signs. Two of them matches with locations of the EP sensors on SC. We can see the stronger positive bias in SC vicinity in relation to undisturbed exosphere plasma.

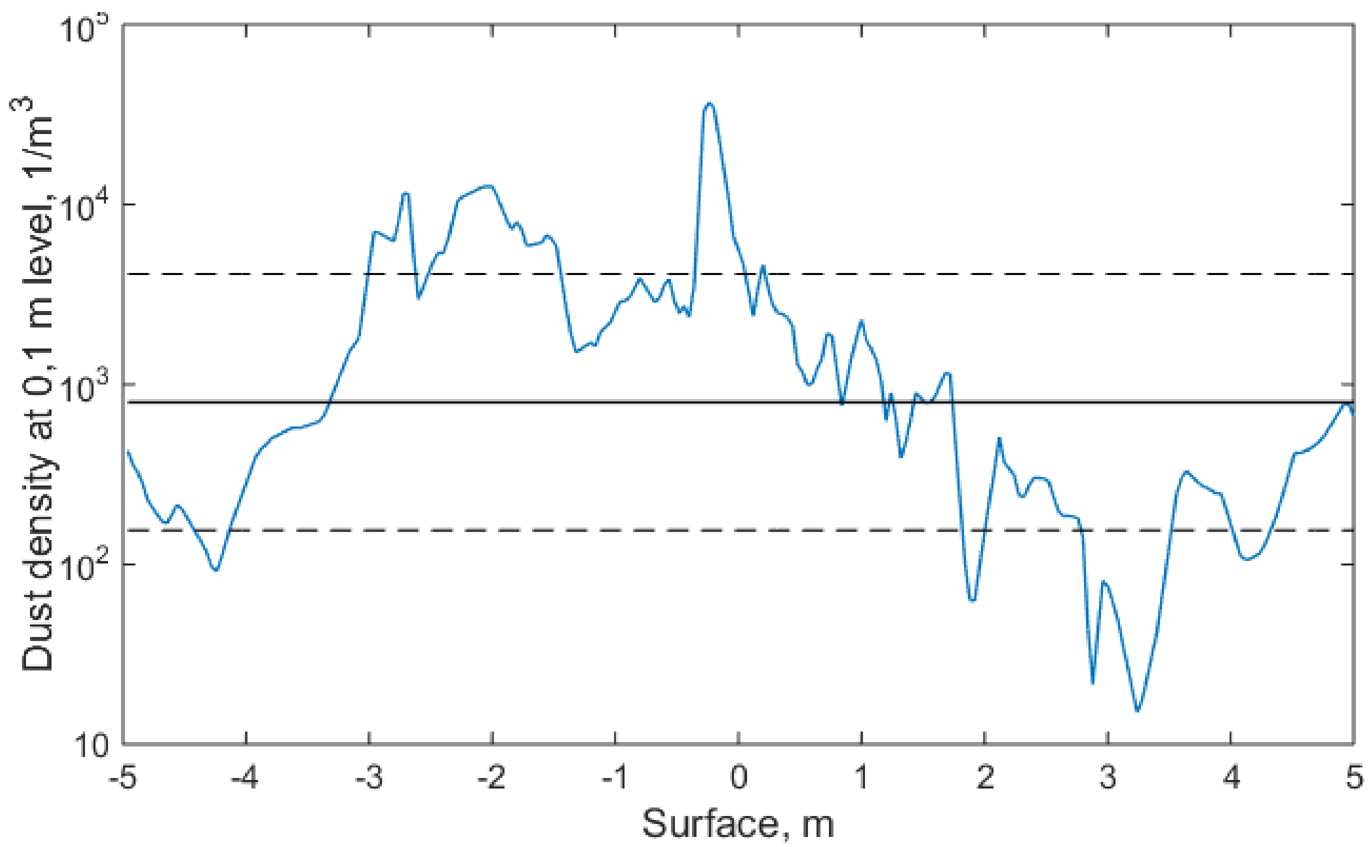


Plasma potentials at the steady state of simulation in “Sunset” conditions. Sun is behind the SC, 1° above the horizon. Virtual plasma potential sensors in SPIS simulation marked by “X” signs. Two of them (red, green) matches with locations of the EP sensors on SC.

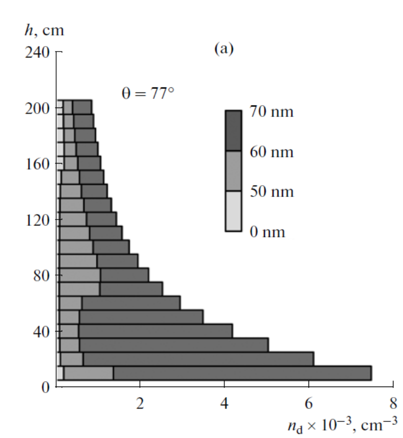
Dust densities



Common logarithm of the dust density in particles per cubic meter at the local lunar noon. The sun is on the right, 22° above the horizon. IS from the PmL instrument location marked by "X" sign.



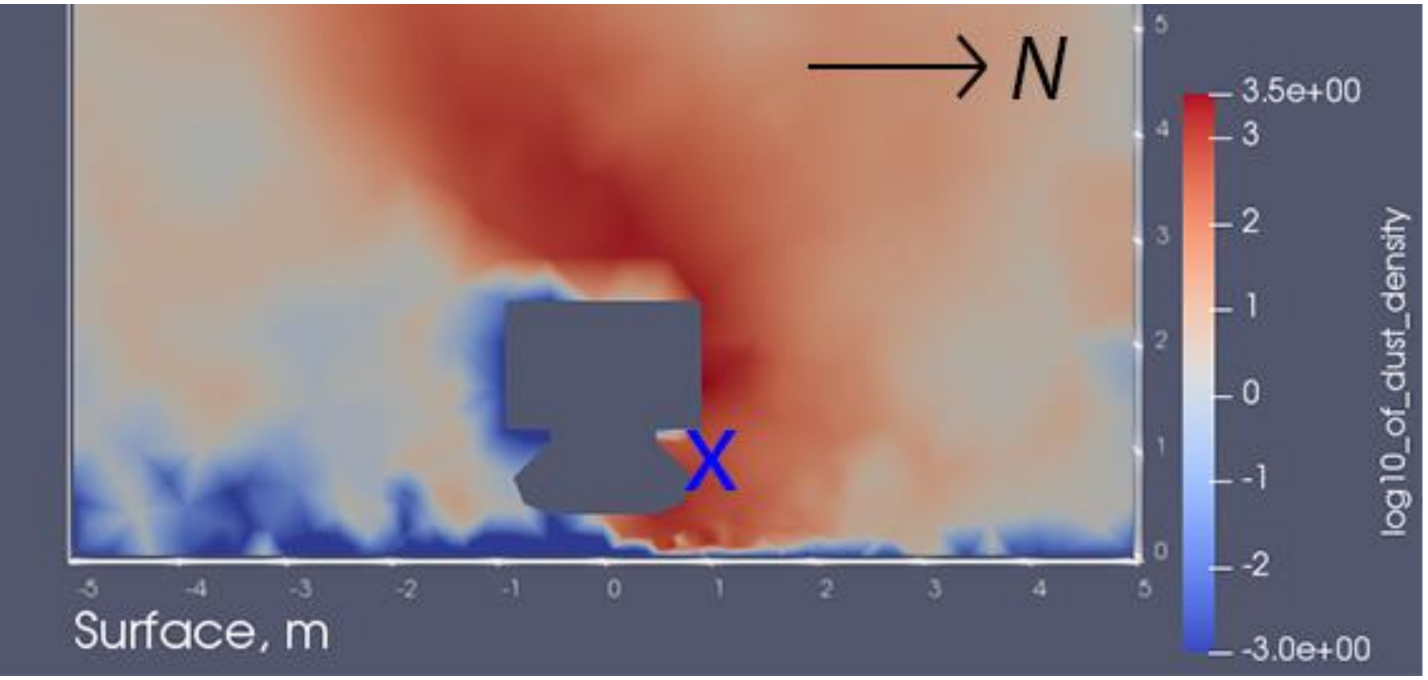
These results correspond to the theoretical model (Popel et al., 2013), where values of dust density vary from $4.5 \cdot 10^3$ m^{-3} to $7.5 \cdot 10^{10}$ m^{-3} near the lunar surface (from 0 to 10 cm) depending on latitude (from 77° to 87°).

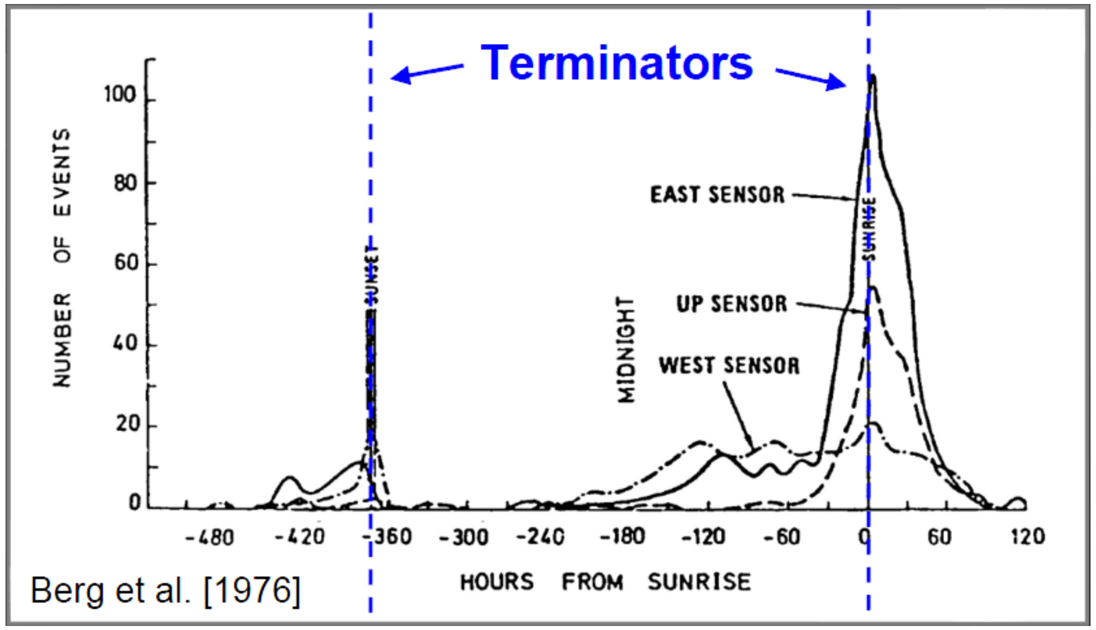


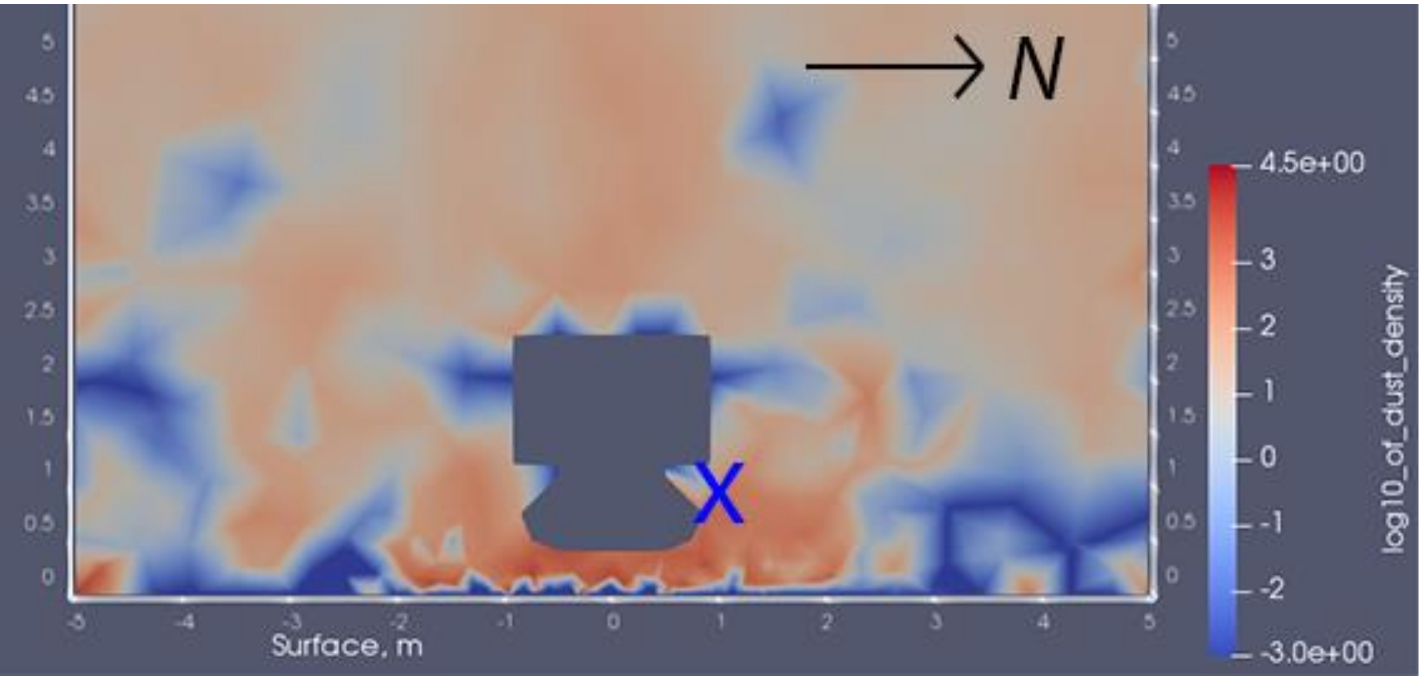
[Popel et al., 2013]

Dust densities

Apollo 17 Lunar Ejecta and Meteorites (LEAM) experiment

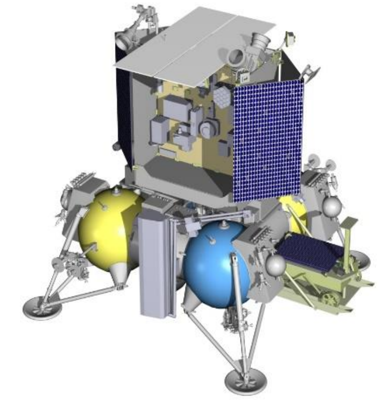






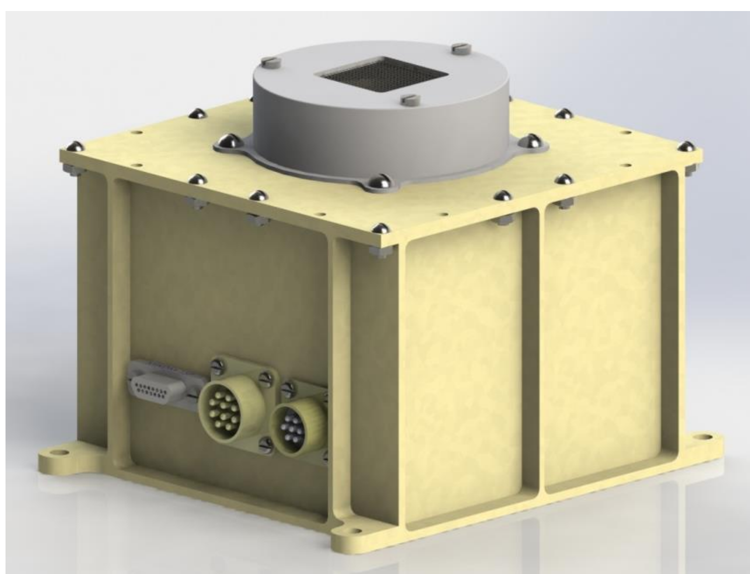
Common logarithm of the dust density in particle per cubic meter at the local lunar evening (top) and sunset (bottom). The sun is on the right, 11° (top) and 1° (bottom) above the horizon . IS from the PmL instrument location marked by “X” sign.

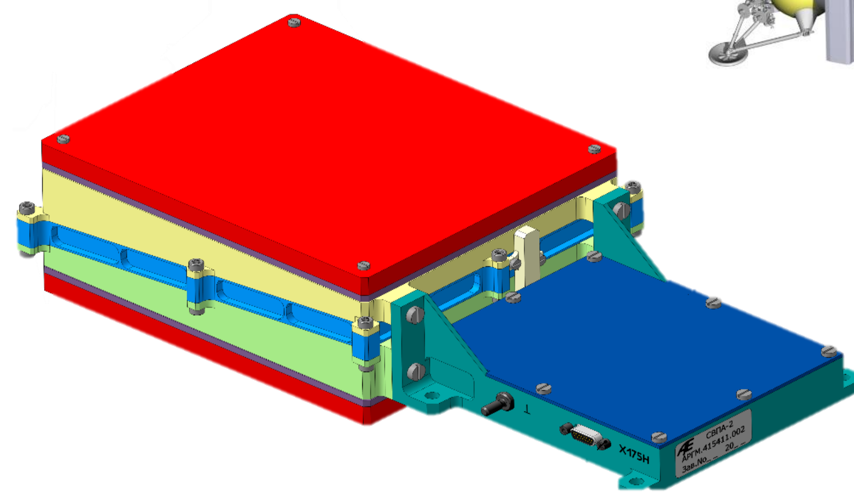
Luna-27 Improvements



2 x IS

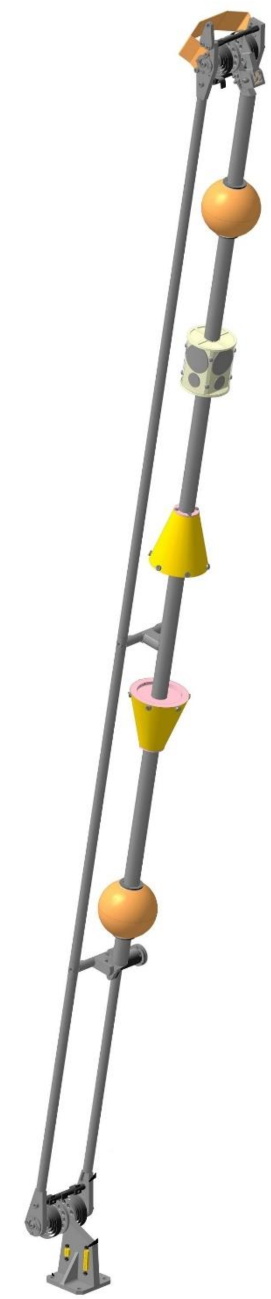
+ various angles





Dust Flight Analyzer

Measuring the levitating dust particles that passes through the sensitive grids



Solar Wind Detector

Measuring the solar wind ions and ions reflected from surface

(2 + 3) x Langmuir Probes

2 LP on the same places as on Luna-25
and
3 LP on the Boom with 1.2 m from Lander

Discussion

PmL instrument is developing, working out and manufacturing in IKI. Simultaneously with the PmL dust instrument to study lunar dust it would be very important to use an onboard TV system adjusted for imaging physical properties of dust on the lunar surface (adhesion, albedo, porosity, etc), and to collect dust particles samples from the lunar surface to return these samples to the Earth for measure a number of physic-chemical properties of the lunar dust, e.g. a quantum yield of photoemission, which is very important for modeling physical processes of the lunar exosphere.

Unsolved questions

Lunar landers (Luna-Glob, Luna-Resourse)

- What is the influence from the SC on the lunar dusty plasma exosphere? On the Langmuir probes? Can we count it?
- What is the influence of the SC on electric field?
- The influence from Solar Panels on the field and plasma?

Acknowledgements

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