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Charge measurements for an asteroid sample return mission

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Abstract

Photoelectric charging of asteroid regolith material influences particle motion and escape. Differing spacecraft and asteroid charges may also affect sample return on missions such as Marco Polo-R. To study this, bespoke 2D particle-in-cell code simulating the behaviour of photoelectrons trapped near a photoemitting surface (photosheath) has been written and implemented. The spacecraft–photosheath system reaches equilibrium in 1 ms, which is rapid compared to the descent timescale. Equilibria reached in simulations are therefore assumed representative of the dynamic spacecraft environment. Predicted potentials at different heights and with different solar zenith angle are presented, so that an instrument to measure the potential difference across the spacecraft can be defined.

The distorting effect of the spacecraft significantly modifies the potential difference and displacement currents during the terminal descent, by introducing an equipotential body, creating a shadow, and photoemitting itself. By considering the distortion from different parts of the spacecraft, optimal locations for a set of electrodes to measure the potential difference are suggested. Potential differences of about 100 mV are expected to be generated across the electrodes, which should be representative of the electrical environment. The results demonstrate that a simple set of electrodes can measure the asteroid's surface electric field during sample collection.

1. Introduction

Electrostatic forces at asteroid surfaces may play a significant role in regolith redistribution. There is evidence that small particles on Eros accumulate in shadowed regions due to charging effects [1]. Measurement of the asteroid's surface electric field will give insight into the role of electrostatics in regolith movement and distribution. Electric field sensors will also provide a housekeeping role in ensuring that the potential difference between the spacecraft and asteroid does not perturb sampling.

2. Methodology

A 2-D particle in cell (PIC) electrostatic code is implemented, with an assumed lunar electron energy distribution. The PIC code was validated by comparison with the analytical 1D result using a Maxwellian distribution [2]. The maximum height at which the simulation is valid is conservatively set to 3m, as an upper limit below which the solar wind can be neglected. The spacecraft is modelled as a 1 x 1m equipotential square, with dimensions representative of the JAXA Hayabusa spacecraft. All potentials are normalised with respect to the surface, to compensate for photoelectrons leaving the top of the domain.

3. Results

3.1 Equilibriation of the spacecraft potential in the photosheath

The equilibriation time of the spacecraft with its centre at 2.5m above the surface has been considered for various solar angles, spacecraft potentials and with and without a shadow. Equilibriation always occurs on a timescale of milliseconds, as the spacecraft descends, whatever its potential. This timescale is consistent with simple estimates based on the expected asteroid (~16 pCm^{-2}) and spacecraft (~160pC) charge, and the assumed photocurrent from lunar scaling (~0.5 μAm^{-2}) [3, 4]. This rapid equilibration permits the assumption that the spacecraft passes through the equilibrium photosheath. The spacecraft shadow has a substantial effect on the predicted electrostatic environment, Figure 1.

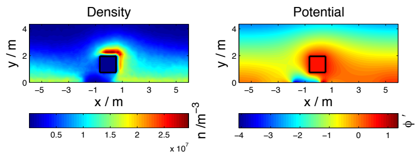

Figure 1: Equilibrium photoelectron concentration (left) and potential (right) after equilibriation for a solar zenith angle of 30° and at a spacecraft altitude of 1.5m. Shadow effects are clearly visible.

3.2 Electrode accommodation

Potential differences across various parts of the spacecraft have been estimated, to verify that the separated electrode instrument concept will produce resolvable voltage changes. Typical potential differences are expected to be 100-180 mV for isolated electrodes at the top and bottom of the spacecraft. These voltages are lower than those expected if the effect of the spacecraft is ignored, as the conductive spacecraft effectively shorts out the photosheath, but they remain readily detectable with simple electronics.

We propose a triangular set of electrodes (in 2D) with one electrode located at the top, and two on the bottom, either side of the spacecraft. This will permit measurement of the field on both the sunlit and shadowed sides of the spacecraft. The simulations show high asymmetry between the lit and unlit sides of the spacecraft when the sun is not directly overhead. This arrangement could be generalised to 3D by offsetting the lower sensors to the front and back of the spacecraft.

6. Conclusions

Isolated electrodes provide a simple way of measuring the asteroid photosheath and associated electric fields. There appear to be few electromagnetic compatibility or geometrical constraints on the electrode design, and no deployment is needed.

The spacecraft shadow is expected to have a significant local electrostatic effect, which may modify sampling.

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