Asteroid electrostatic instrumentation and modelling

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Abstract. Asteroid surface material is expected to become photoelectrically charged, and is likely to be transported through electrostatic levitation. Understanding any movement of the surface material is relevant to proposed space missions to return samples to Earth for detailed isotopic analysis. Motivated by preparations for the Marco Polo sample return mission, we present electrostatic modelling for a real asteroid, Itokawa, for which detailed shape information is available, and verify that charging effects are likely to be significant at the terminator and at the edges of shadow regions for the Marco Polo baseline asteroid, 1999JU3. We also describe the Asteroid Charge Experiment electric field instrumentation intended for Marco Polo. Finally, we find that the differing asteroid and spacecraft potentials on landing could perturb sample collection for the short landing time of 20min that is currently planned.

1. Introduction

The work presented here was motivated by the study of an Asteroid Charge Experiment (ACE) for the Marco Polo mission. Marco Polo is a sample return mission currently under consideration by the European Space Agency, and, as the sampling process and surface material are both likely to be influenced by electrostatics, the ACE instrument was proposed to measure electric fields at the asteroid visited by Marco Polo.

By analogy with the Moon, there is likely to be considerable photoelectric charging of asteroid surfaces. Electrostatic dust levitation has been proposed as a method to redistribute particles [1,2], and also as a loss mechanism for smaller particles, not bound by the gravitational field of the asteroid [1]. Asteroid electric charge has never been measured, but simple estimates predict that an electric potential (~1 kV) can be attained on the dark side compared to the sunlit side, which becomes slightly positively charged by photoelectron emission. These differences are enhanced further at the terminator (the day/night boundary), when fields could reach ~100-300 kV/m [1].

Section 2 describes electric field modelling for a real example, the Itokawa asteroid, visited by the Japanese Hayabusa mission in 2005, and for which a full shape model was obtained. The ACE instrument specification is described in section 3.
2. Modelling the electrical environment of an asteroid

The most electrically significant regions of an asteroid are expected to be solar irradiation boundaries, i.e. the terminator, and shading caused by local topography. Electrostatic modeling was used to confirm the ACE electric field instrumentation requirements. The Marco Polo baseline asteroid (1999JU3) is not characterised in detail, however a full shape model for another asteroid, Itokawa, is available [4]. 1999JU3 and Itokawa are similar (Table 1), but asteroids like Itokawa are expected to contain iron, unrepresentative of the electrical conditions on 1999JU3, a carbonaceous asteroid. The Itokawa shape model and orbital parameters have therefore been assumed, with the electrical properties of a typical carbonaceous asteroid.

Three finite element analysis electrostatic modelling packages were used, FEMM and Ansoft Maxwell SV for 2D calculations, and ALGOR FemPro for 3D. The results were insensitive to the range of electrical conductivities and dielectric permittivities expected for a carbonaceous asteroid (\(0.113<\varepsilon_r<112.9\) and \(10^{-9}<\sigma<10^{-3}\) S/m), therefore values in the middle of these range were selected.

The dayside potential was set at +5V and the nightside at -1000V [1] (these values are related to the orbital distance, and insensitive to the composition of the asteroid). Firstly, horizontal electric fields across the asteroid surface at the terminator for a cross-section through a spherical asteroid were determined using two different packages, for verification. For a spherical asteroid, the maximum terminator field \(~50\text{kV/m}~\) and electric fields at the sub-solar point \(~50\text{V/m}~\), consistent with analytical results [1]. Following this, a 3D model was established based on the Itokawa shape model. This proved useful for visualization of the potential (Figure 1), but the mesh resolution limited electric field calculations.

![3D model results for Itokawa](image)

**Figure 1** 3D model results for Itokawa, showing local surface potential and including the terminator region (Red (on left): +5V (dayside), blue (on right): -1000 V( nightside)

**Table 1.** Comparison of 1999JU3, asteroid proposed for the Marco Polo mission, and Itokawa, whose shape model is used here. 1 Astronomical Unit (AU) is the distance from the Sun to the Earth.

| Name [Reference] | 1999 JU3 [3] | Itokawa [4] |
|------------------|--------------|-------------|
| Period (hours)   | 7.6          | 12.1        |
| Type             | Carbonaceous chondrite, representative of primitive solar nebula | Stony, made of iron and magnesium silicates |
| Diameter         | 900m         | 500 x 300 x 200 m |
| Orbit (AU)       | 0.96-1.41    | 0.95-1.70   |

The 3D model was used to investigate the effect of shadowing for a segment of Itokawa. It suggested that localised regions of high field (~1kV/m) occur at dayside shadow boundaries (Figure 2). Following [1] it is possible to estimate the typical sizes of particles that can be electrostatically
levitated: \textasciitilde 300\mu m at the terminator and \textasciitilde 100\mu m in the shadow region, representing a substantial fraction of a Moon-like surface particle distribution [5]. Photographs of the Eros asteroid show that the “ponds”, craters filled with smooth deposits, are thought to have been formed by the build up of dust, whereas regions exposed to solar radiation are stripped of smaller particles [4,6]. Electrostatically transported material could therefore form a significant proportion of the sample. A detailed understanding of the size fraction most likely to have been electrostatically moved or even removed at the sampling site can only be achieved by electrical measurements, for which instrumentation is described in the next section.

Figure 2 3D model results showing electric fields generated by local shadowing. The sun is illuminating the asteroid from the left, causing shadowed regions (lighter colours. It is assumed that these regions acquire the nightside potential of -1kV.

3. Asteroid electric field measurements
The Asteroid Charge Experiment (ACE) comprises electric field detectors for both remote and in situ sensing of the asteroid potential (it also includes an electron spectrometer and a radiation detector, which are not discussed here). Its scientific aims are to characterise the electrical environment of the asteroid and the dosage the sample receives on its return to Earth.

3.1. Instrument description and expected signal levels
The electric field instruments are essentially two sets of isolated electrodes, one set for in situ sensing and one set for remote sensing. The in situ sensing electrodes are three physically-separated conducting electrodes for horizontal and vertical electric field sensing. The electrodes acquire the local potential, and differencing the potentials across them gives the electric field. It is intended that they will be mounted on the spacecraft legs to give an indication of both horizontal and vertical electric fields, Figure 3.

The remote sensing electrodes rely on the principle that displacement and induced currents in the sensing electrodes are proportional to electric field changes from the asteroid during orbit and approach. This can be used to detect the whole body potential on the asteroid at a distance. Two adjacent electrodes of differing geometry are used to separate out the currents caused by the asteroid electric field and currents caused by local charged particles impacting the electrodes, similar to [7]. Estimates suggest that the change in induced potential on the plate is expected to be in the range 1mV-1V (0.1m edge plate, with 10pF capacitance) which is readily detectable with a straightforward amplifier circuit, whereas the displacement current is expected to be small, \textasciitilde 1fA for this size of plate.
Figure 3 Electric field sensing electrodes (left) Spacecraft showing suggested locations for in situ electrodes, marked in black (not to scale). (right) Remote electric field sensor concept, showing isolated metallic plates of differing geometry.

3.2. Electrostatic effects on sampling
The spacecraft will be positively charged on arrival at the asteroid [8], which is expected to become positively charged on the dayside from photoemission, and negatively charged on the nightside from the solar wind. If the spacecraft capacitance is 200pF, then current flow is ~10pA if the spacecraft lands on the dayside as planned, suggesting that the spacecraft-asteroid potential difference may change by only ~1V during the proposed 20min landing time. One way to avoid electrostatic effects on sampling would be to use the remote measurement of asteroid potential, made before landing, and drive the (isolated) sampling apparatus at this voltage. Further work is needed to study this in detail.

4. Discussion
Theoretical and modelling work presented here and elsewhere [1] suggests that substantial electric fields can develop at asteroid terminators and between shadowed and sunny regions. The asteroid-spacecraft potential difference implies that a current will flow when the spacecraft lands, and that this may not equilibrate during the 20min scheduled for sampling collection. Under these circumstances the spacecraft itself may modify the sample collection, most likely by electrostatic repulsion. Remote sensing of the asteroid potential and driving the sample mechanism at this potential could provide a solution to this problem. It is also essential to measure the electrostatic environment at asteroid surfaces to understand the context of the sample taken, before the charge state of the sample is modified. The ACE instrument contains separated electrodes for in situ measurement of electric fields and also electrodes for remote sensing of the asteroid charge through induction.

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