Numerical Simulations of Plasma-Spacecraft Interactions Near Irregularly Shaped Small Asteroids

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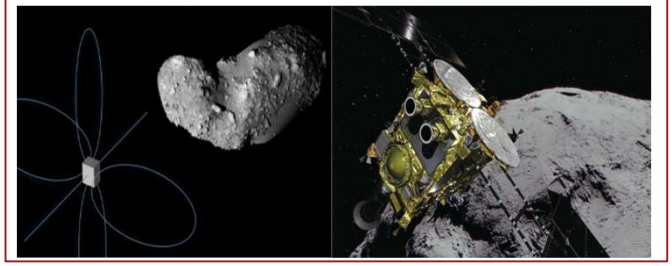
Introduction

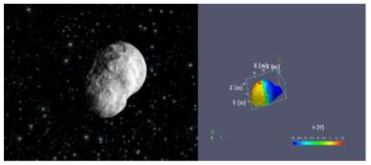
Small airless bodies in the solar system (small asteroids and comets) represent the next frontier in deep space exploration. Proximity operation around small asteroids presents several extremely challenging issues for spacecraft. In particular, irregularly shaped asteroids can produce a highly complex plasma flow field which affects spacecraft-plasma interaction. This paper presents a fully kinetic particle-in-cell simulation study of plasma interaction and charging for spacecraft near irregularly shaped asteroids. The simulations use a mesh resolution that resolves the local plasma sheath around *both* spacecraft and asteroid, and a simulation domain that contains the global plasma flow field around asteroid. Spacecraft charging is calculated directly from charge deposition on spacecraft.

1. **Assess different asteroid shape's effects on the plasma flow field**
2. **Study and predict the charging status of the spacecraft over asteroid**

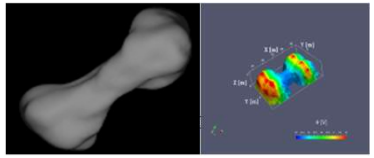


Asteroid Model

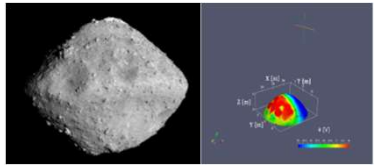
Three typical asteroid shapes are considered.



Asteroid 25143 Itokawa
"Potato Shape" Model



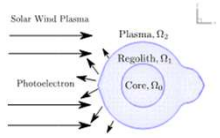
Asteroid 216 Kleopatra
"Bone" Model

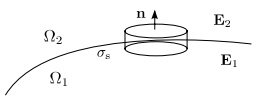


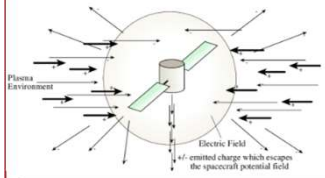
Asteroid 162173 Ryugu
"Top-Shaped" Model

Modeling Methodology

In this study, the Immersed-Finite-Element field solution method is incorporated with full Particle-in-Cell to study plasma interactions involving complex objects. We pursue this study to achieve these objects:







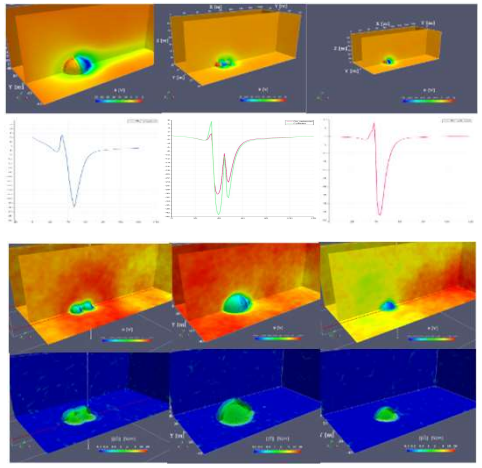
$$\nabla \cdot (\epsilon \boldsymbol{E}) = -\nabla \cdot \epsilon \nabla \Phi = \rho$$

$$\rho(X) = \begin{cases} \rho_i - \rho_e - \rho_{\text{photo}}, & X \in \Omega_2, \\ 0, & X \in \Omega_1, \\ 0, & X \in \Omega_0 \end{cases}$$

$$\sum_k J_k(\phi_s) = J_i(\phi_s) + J_e(\phi_s) + J_{\text{ph}}(\phi_s) + J_{\text{sec}}(\phi_s) + J_{\text{bk}}(\phi_s) = 0$$

Species	Number density n [cm^{-3}]	Drift velocity v_d [km/s]	Thermal velocity v_t [km/s]	Temp T [eV]	Debye length λ_D [m]
S.W. Electron	8.7	468	1450	12	8.73
S.W. Ions	8.7	468	31	10	7.97
Photoelectron	64	N/A	622	2.2	1.38

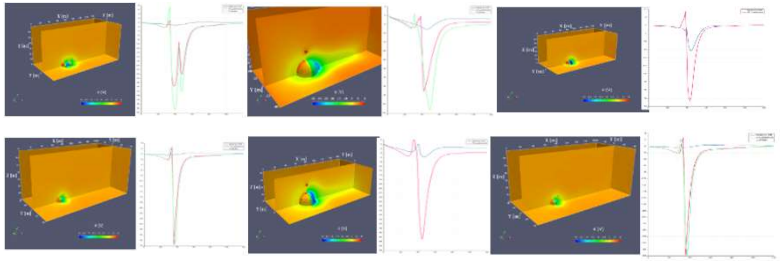
Species	Number Density(1/m^3)	Drift Velocity(km/s)	Thermal Velocity(km/s)	Temperature (eV)	Debye Length(m)
S.W. Electrons	8.7	468	9359.7	500	56.35
S.W. Ions	8.7	468	219.2	500	56.35



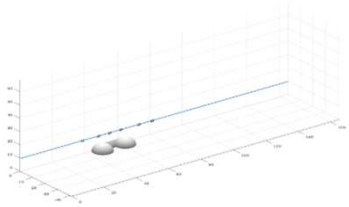
Plasma Environment around Asteroids: Average Solar Wind Condition.

Plasma Environment around Asteroids: "Severe" charging solar wind condition

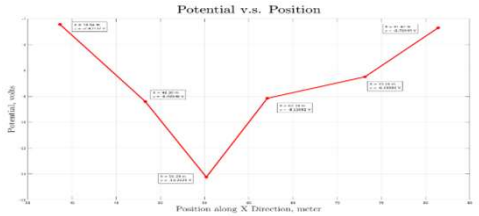
- The shape of plasma sheath and asteroid charging are sensitively influenced by ambient plasma condition



- Spacecraft charging around asteroids: Effects of Asteroid Shape



Spacecraft charging during asteroid fly-by



Average SW (condition. "Bone" shaped asteroid)

- Spacecraft charging is greatly influenced by relative position with respect to asteroid due to "multibody" plasma interaction effects. The worst spacecraft charging occurs in the deep wake region.

Conclusions

- Spacecraft charging is greatly influenced by the sheath around complex asteroid shape and the relative position with respect to asteroid due to multibody plasma interaction effects.
  - ➢ The "bone" shaped asteroid presents the most interesting situation
  - ➢ Worst charging occurs when spacecraft is in the deep wake region.
- Future work: more detailed studies of spacecraft charging for fly-by missions under different ambient plasma charging conditions