Modeling Spacecraft Charging around Irregularly Shaped Small Asteroids

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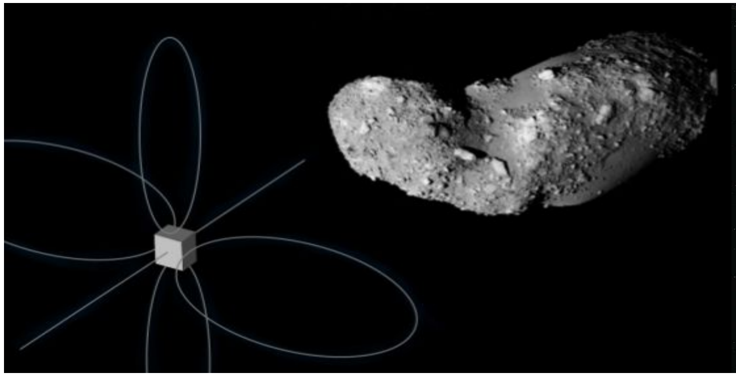
Outline

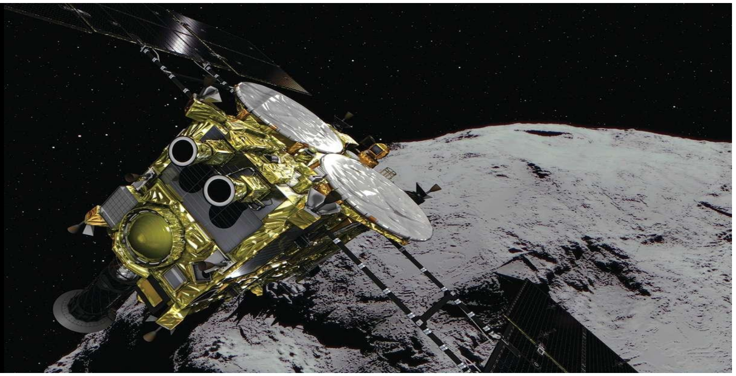
- Introduction
- Simulation Model
- Plasma Flow around Irregular Shaped Asteroids
- S/C Charging near Asteroids
- Summary

1. Introduction



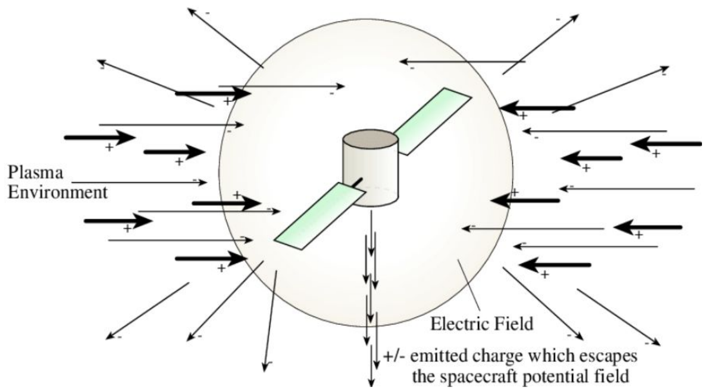
E-Glider near asteroid

Corpino, Sabrina, and Filippo Corradino. "Modeling of orbital and attitude dynamics of a satellite controlled via active electrostatic charging." (2018).



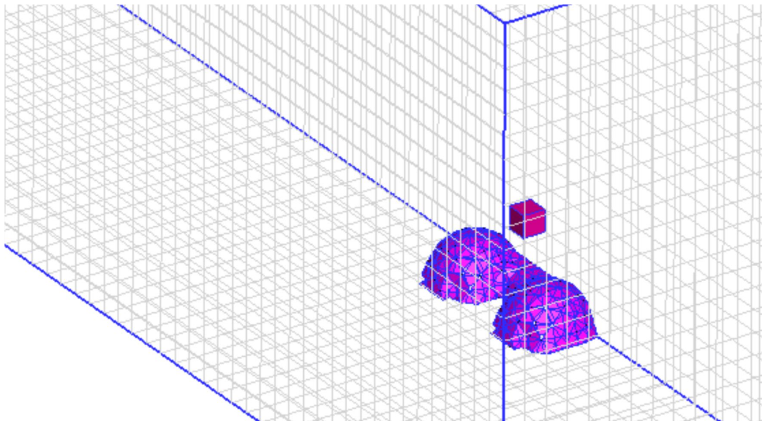
Spacecraft Hayabusa 2 Hovering over Asteroid

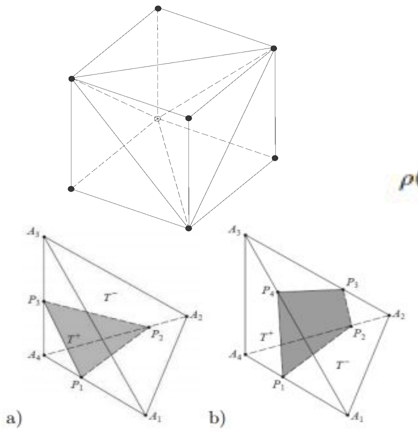
https://www.newscientist.com/article/2198839-japans-hayabusa-2-spacecraft-just-bombed-an-asteroid/



- **Spacecraft charging is determined by its plasma environment**
- **The plasma environment around small asteroids is complex**
- **Predictions of spacecraft charging around small asteroids requires fully kinetic simulations of plasma-asteroid-spacecraft interactions**

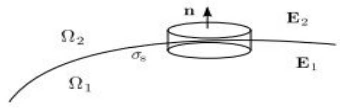
2A. Simulation Model: *USC-IFEPIC*





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

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



USC-IFEPIC

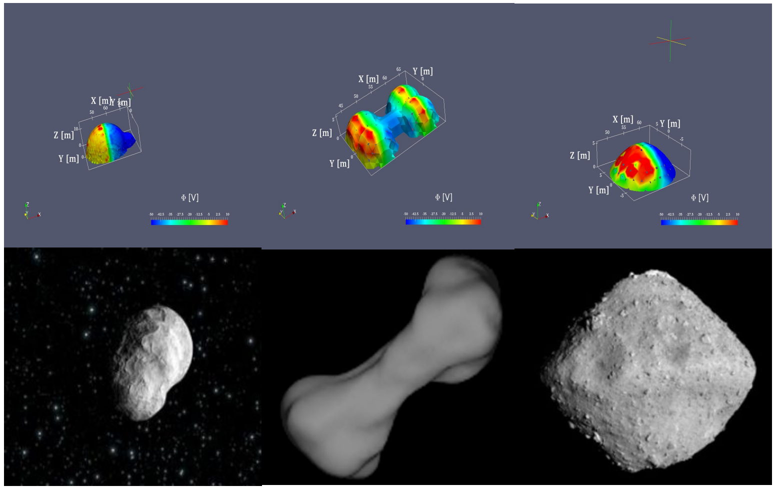
- **3D hybrid finite-element finite-difference particle-in-cell (PIC) using the immersed finite element (IFE) method to solve the electric field.**

(Han, Wang, He, Lin, Wang, *J. Comp. Phys*, 2016; Han, Wang, He, *JSR*, 2018; Han and Wang, *IEEE TPS*, 2019)

- **Cartesian+Tetrahedral mesh to resolve irregularly shaped objects (objects are allowed to cut through the cell) with 2nd order accuracy**
- **Asteroid/spacecraft are part of the simulation domain (not boundary); Electric field is calculated *both* inside and outside objects**
- **Asteroid/spacecraft charging are calculated directly from local charge deposition.**
- **The matrix arising in the IFE formulation is always symmetric, positive-definite, and sparse -> guarantees a convergent solution to Poisson's equation can always be obtained efficiently**

2B. Simulation Setup

Asteroids



- Potato Shape:

With 14.076m radius for the front sphere and 5.796m for back sphere, dielectric coefficient ~4

- Bone Shape:

With 5.52m radius for the front sphere and back sphere, 3.45m for cylinder and cylinder length 13.8m, dielectric coefficient ~4

- Top shape

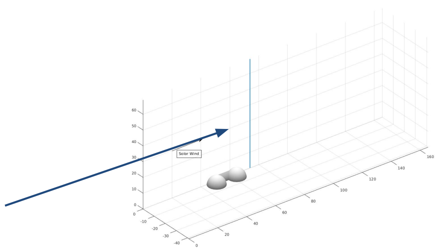
A parabolic with height 5.52m, and span 8.28m, dielectric coefficient ~4

Solar Wind Plasma

Average Solar Wind Condition

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

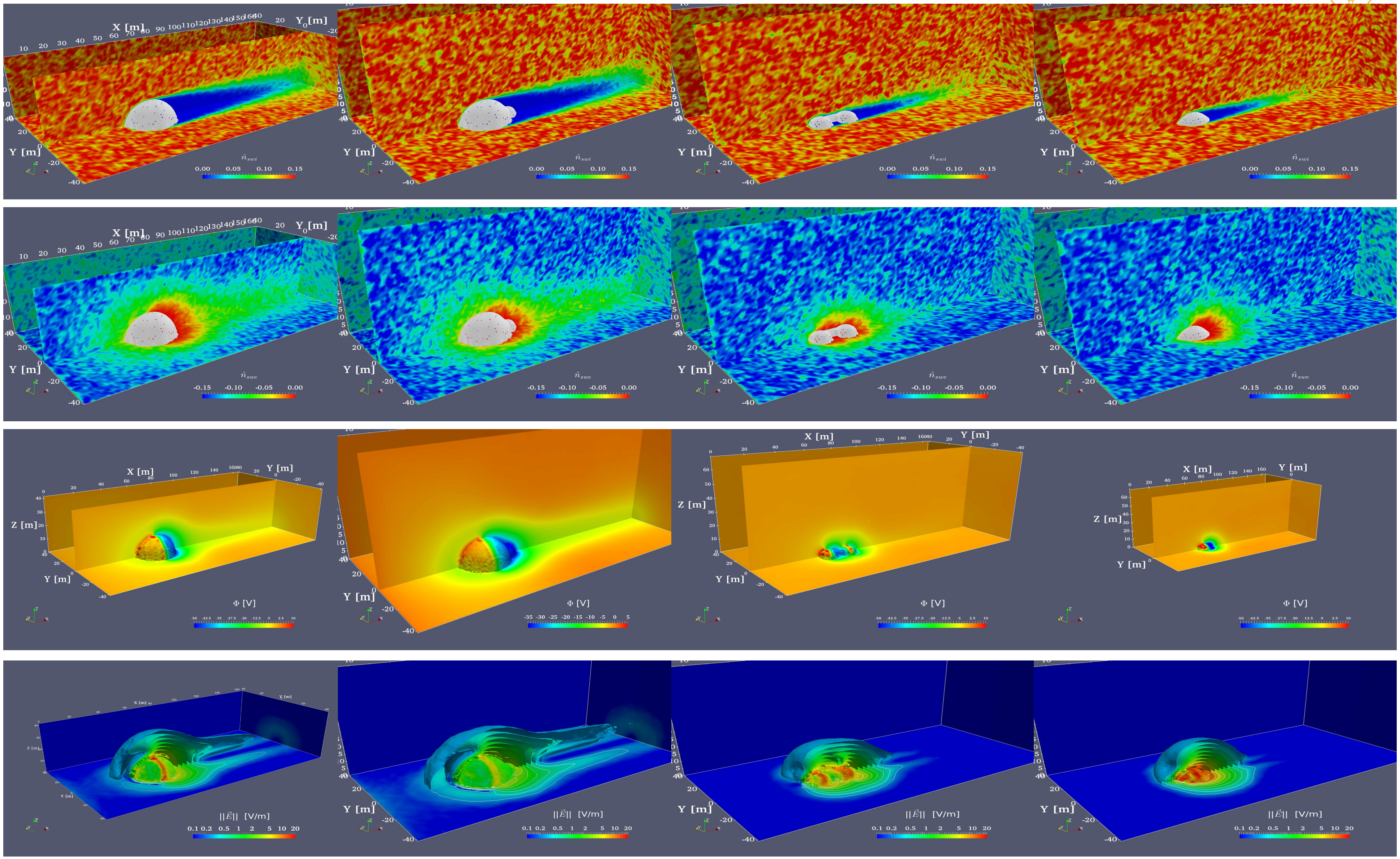
Spacecraft



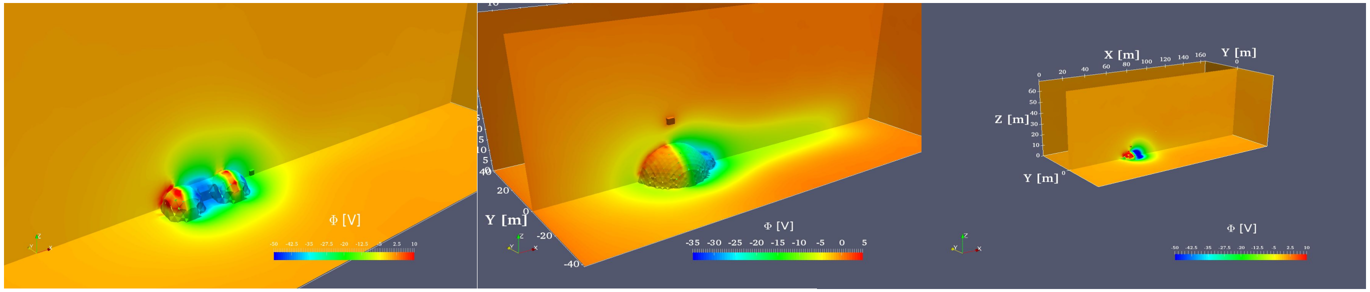
Spacecraft on flyby trajectory

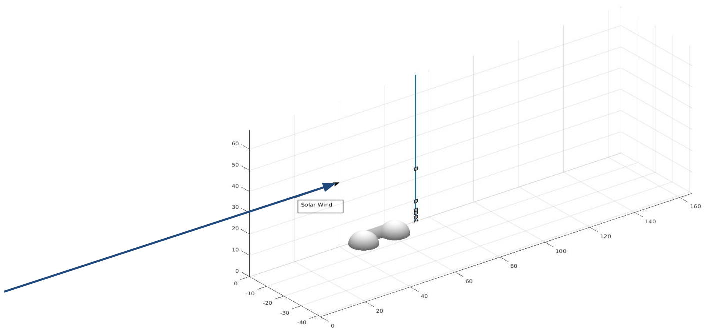
Spacecraft is 2.76m * 2.76m * 2.76m cube.
Closet approach: 6.38 m

3A. Plasma Environment and Asteroid Charging

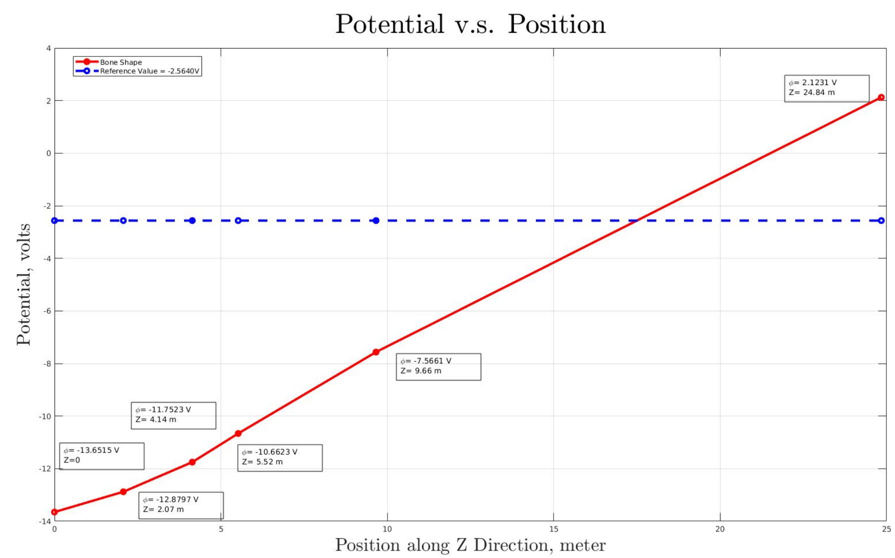


3B. S/C Charging around Irregular Shaped Asteroids





Spacecraft fly-by a Bone shape asteroid



The worst charging occurs at Z=0

The potential is ~ -13.6V

For comparison: charging estimation based on 1D calculation:

-2.6 V

$$\phi_w = \frac{kT_e}{e}\ln\left(v_0\sqrt{\frac{2\pi m_e}{kT_e}}\right)$$

4. Summary

- The recently developed *USC-IFEPIC* is applied to simulate spacecraft charging near irregularly shaped small asteroids
   - fully kinetic PIC plus immersed finite element field solver which simulates spacecraft charging, asteroid charging, and plasma environment self-consistently
- Irregularly shaped small asteroids generate a complex plasma flow field which can significant affect spacecraft charging.
   - for the average solar wind plasma condition considered: the spacecraft floating potential changes from slightly positive in ambient plasma to negative in the asteroid wake. The charging potential in asteroid wake is more than 5 times larger than simple 1-D estimation.
- Future studies will consider more several plasma charging environments and more realistic asteroid models

Thank You!

Feel free to ask any questions!