P12-SPS2020

Recent Activities of Solid Body-Plasma Interaction Simulations

Y. Miyake[1]*, M. N. Nishino[2], Y. Harada[3], W. J. Miloch[4], and H. Usui[1]
1. Kobe University, 2. ISAS/JAXA, 3. Kyoto University, and 4, University of Oslo.
Contact: *y-miyake@eagle.kobe-u.ac.jp

Interactions between space plasma and solar system solid bodies (airless bodies with no global magnetosphere) have been one of outstanding problems in the space science community, in the context of its application for understanding the plasma environment near the terrestrial moon, asteroids, spacecraft, and small dust grains. A solid object immersed in space plasma absorbs most of impacting plasma electrons and ions, and in some occasions it also releases charged particles such as photoelectrons, secondary electrons, and some other minor charged particles. As a result, the object in space will be electrically charged. The solid surfaces and electric potential of the object also alter the dynamics of charged particles in its vicinity, giving rise to a sheath or wake around it, where the plasma quasi-neutrality is locally violated.

It is generally believed that the spatial extent of such non-neutral regions is characterized by the Debye length, the shortest characteristic length in the plasma. Our recent studies, however, show that in some particular conditions, the presence of a solid body can exert longer-range effects on surrounding plasmas than previously considered. One of such conditions is that the dimensions (D) of the solid body are greater than the average electron gyroradius (ρ_{eg}) of the environment. Attributed to the strong magnetization of electrons, plasma disturbances generated at the solid surface will survive in a long distance along magnetic field lines and extend much farther than the local Debye length of the plasma. Such sufficient spatial extent of the disturbance will also support wave-associated phenomena generated away from the bodies. The condition ($D > \rho_{\mathrm{eg}}$) in consideration will be satisfied for some sort of solar-system bodies such as the terrestrial moon in the solar wind, as well as manmade spacecraft in the ionospheric plasmas.

We have started to model and investigate the plasma and wave environment near airless solid bodies based on the particle-in-cell numerical simulations. In the work, we face a number of numerical challenges to employ appropriate boundary conditions at solid surfaces and to have sufficient computational domains to support generated waves. We present numerical results showing the recently identified “electron wings” [1] and electromagnetic waves above the dayside Moon surface.

References

[1]Miyake, Y., Miloch, W. J., Kjus, S. H., & Pecseli, H. L. (2020). Electron wing-like structures formed at a negatively charged spacecraft moving in a magnetized plasma. J. Geophys. Res., 125, e2019JA027379. https://doi.org/10.1029/2019JA027379

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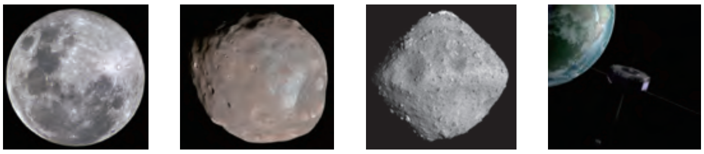
Yohei Miyake[1]*, Masaki N. Nishino[2], Yuki Harada[3], Wojciech J. Miloch[4], and Hideyuki Usui[1]

1. Kobe University (*y-miyake@eagle.kobe-u.ac.jp), 2. ISAS/JAXA, 3. Kyoto University, Japan, and 4, University of Oslo, Norway

Solid surface-plasma interactions in space

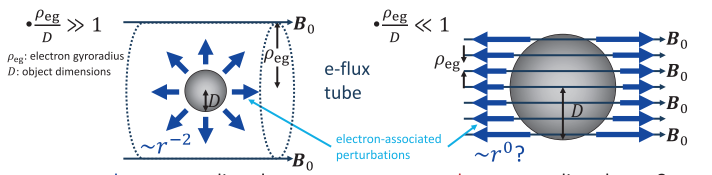
Interactions between space plasma and solar system solid bodies (airless bodies with no global magnetosphere): one of outstanding problems in the space science, in the context of its application for in-space natural and artificial small objects such as…



Our interest is on all the following aspects…

Space plasma		Solid surface
sheath (this study) wake density depletion/enhancement VDF deformation waves / wings shock?	⟷	electric charging SW reflection/scattering electron emission implantation/sputtering regolith mobilization weathering

In some situations, solid objects may incur long-range effects on surrounding space…

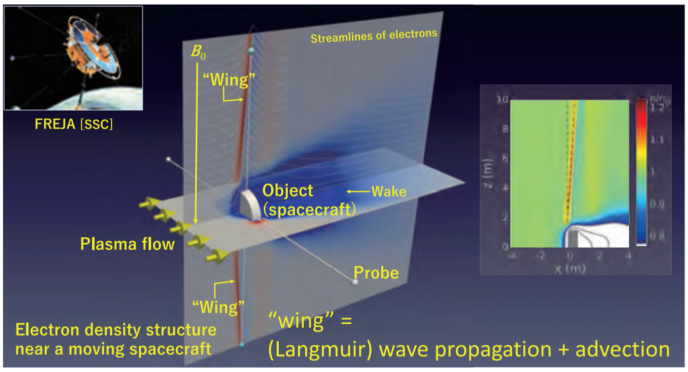


	solar wind / magnetosphere		ionosphere
object	natural small body (10^0〜10^3 km)	spacecraft (10 cm〜m)	spacecraft / rocket
ρ_{eg}/D	10^{-3} – 10^0	10^3	10^{-2}
	long-range	short-range	long-range

Solid objects ($\rho_{eg}/D < 1$) emanate "electron wings"

Studying spacecraft-plasma interaction in ionosphere provides (unexpectedly!) us numerous implications on natural small-body interaction with SW and planetary-magnetosphere plasmas.

- Recently identified long-range disturbance originated at the solid body surface [Miyake et al., JGR, in press]

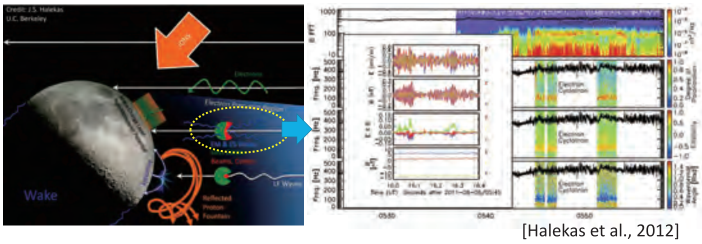


- Spacecraft moving fast in the De-Hoffmann Teller frame
- Both enhancement and depletion of electron density
- Field-aligned (both outgoing & returning) electron flows within "wings"
- Long-range ($> 100\lambda_D$) effect
- Associated potential perturbations detected by probe measurements

- Prospective
  - Wave activities? → Likely! (We identified ES oscillations ($\perp \boldsymbol{B}_0$) of depletion wings. May be LH instabilities?) Any other ideas?
  - Similar wings around natural solid bodies (e.g., Moon) in SW? → Not known. (Does anyone know?) We will search in satellite observation data.

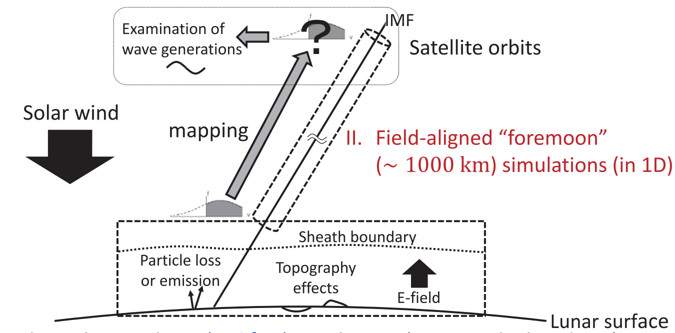
Numerical study of upstream waves at the Moon: motivation and our solutions

Main focus on the near-Moon wave environments has been on a lunar wake@nightside and magnetic anomalies (MA)@dayside. How about non-MA regions@dayside? The ALTEMIS observations identified upstream waves, when the satellite is magnetically connected to, but more than 1000 km (cf. λ_D = 10 m) away from non-MA lunar surfaces.



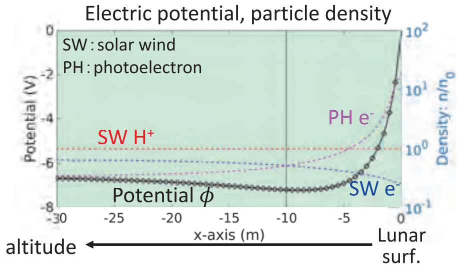
[Halekas et al., 2012]

Our solution: $10^5\lambda_D$ full-PIC to simulate lunar precursor regions



I. Photoelectron-layer (~ 1 km) simulations (in one or higher dims.)

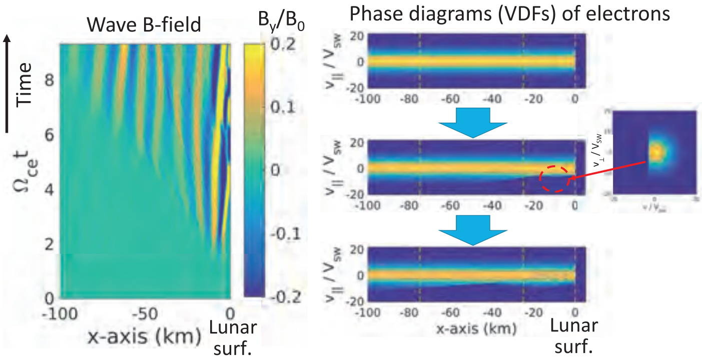
I. Simulations of photoelectron-sheath layer



Non-monotonic ϕ = Potential barrier for both SW e- and PH e-

⇒ Particle penetration / reflection rates at the sheath boundary utilized for subsequent simulations

II. Simulations of wave activity regions (~ 100 km, $10^4\lambda_D$)



1. Returning electrons lost partially at the solid lunar surface. 2. Electron temp. anisotropy. 3. Generation of narrowband whistler waves.

→ Next steps: exams on polarization, ellipticity, Poynting flux, etc.