Full-Particle Simulations on Electrostatic Plasma Environment near Lunar Vertical Holes

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ABSTRACT: The Kaguya satellite and the Lunar Reconnaissance Orbiter have observed a number of vertical holes on the terrestrial Moon [Haruyama et al., GRL, 2009; Robinson et al., PSS, 2012], which have spatial scales of tens of meters and are possible lava tube skylights. These holes are not only interesting in selenology, but are also significant from the viewpoint of electrostatic environments. We use the three-dimensional, massively-parallelized, particle-in-cell simulation code EMSES [Miyake and Usui, POP, 2009] to simulate the near-hole plasma environment on the Moon [Miyake and Nishino, Icarus, 2015]. The self-consistent modeling not only reproduces intense differential charging between sunlit and shadowed surfaces, but also reveals the potential difference between sunlit surfaces inside and outside the hole. The results demonstrate the uniqueness of the near-hole plasma environment as well as provide useful knowledge for future landing missions.

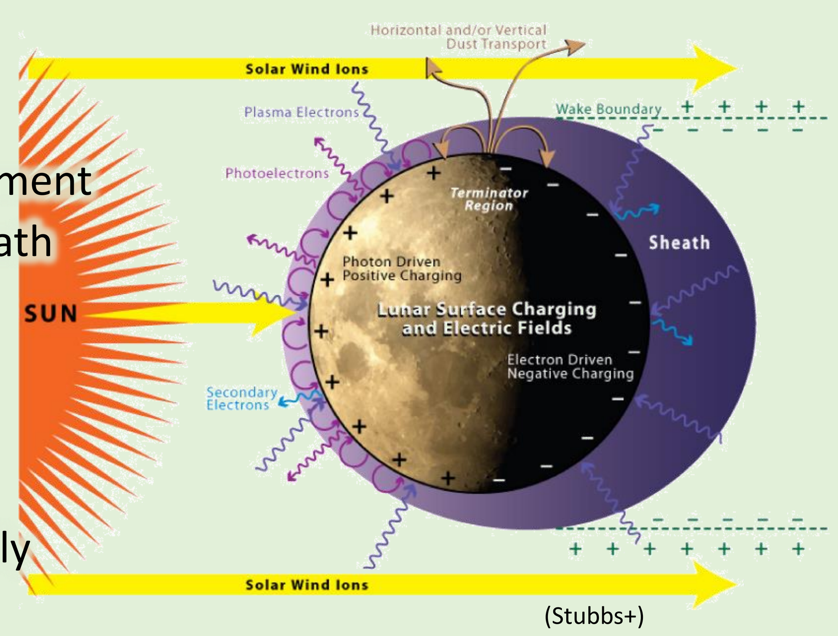
Electrostatic environment near the Moon

Solar wind plasma directly interacts with the surface
- No air
- No global magnetic field

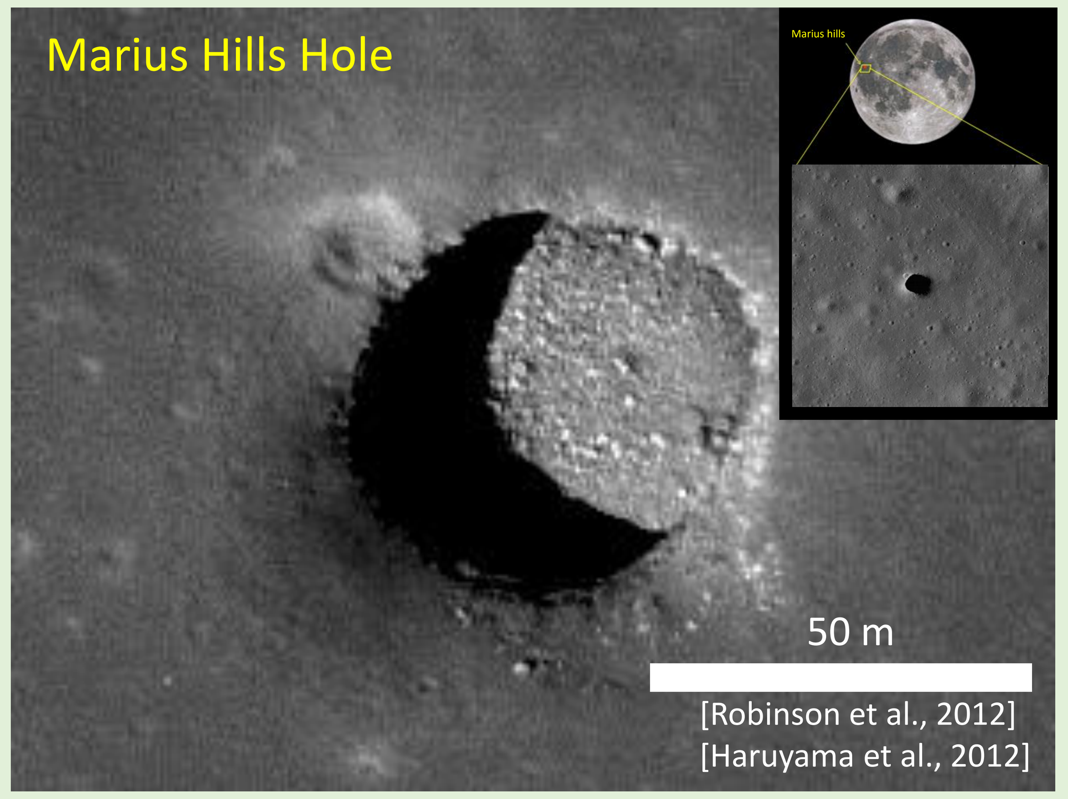
Near-surface plasma environment
- Dayside: photoelectron sheath
- Nightside: wake formation

Surface charging
- Dayside: charged positively
- Nightside: charged negatively

E-field near sunlit-sunless interface
- Acceleration of plasma & charged dust grains



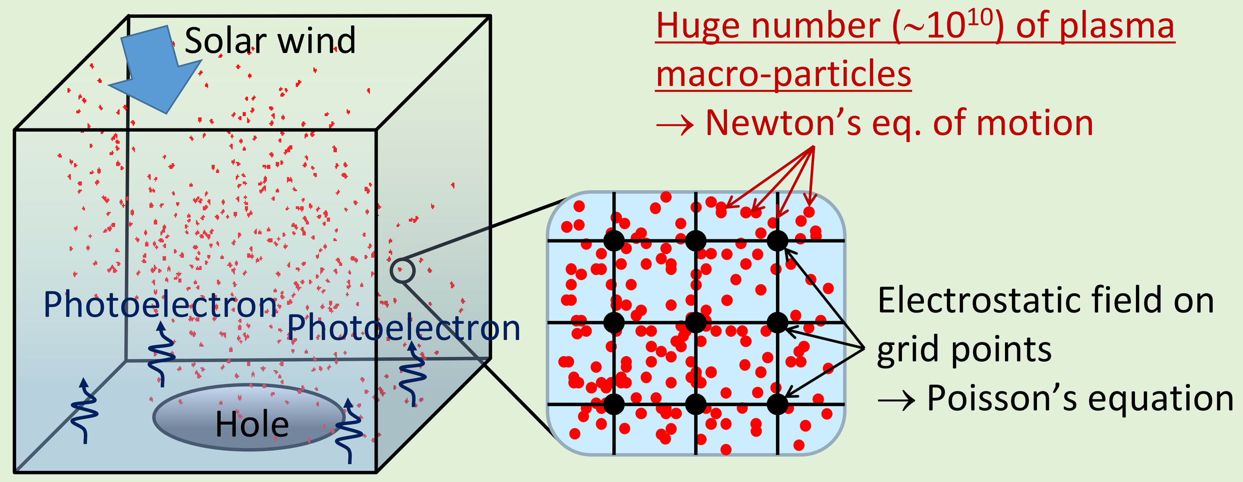
Lunar vertical holes



- Strongly suggesting the existence of lunar lave tubes
- Potential locations for constructing lunar bases

Full-particle plasma simulations

We applied our original particle-in-cell simulation code "EMSES" to plasma environment around a lunar hole.



Simulation parameters
- SW: 5 /cc, 8.6 eV, 450 km/s, 5nT
- PE: 4.5 mA/m^2, 2.2 eV [Willis et al., 1973]

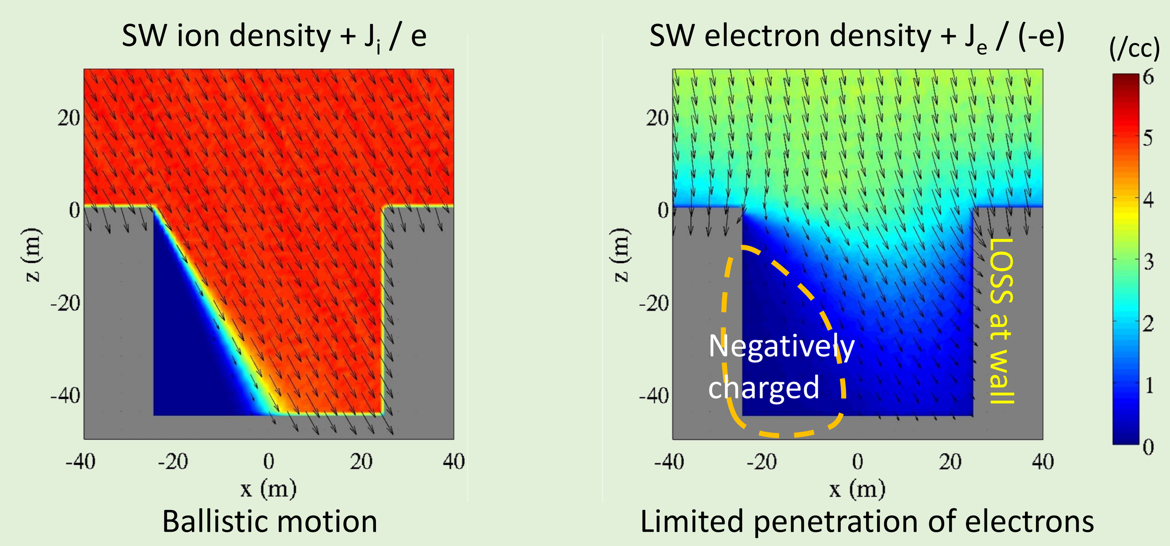
Spatial resolution: 50 cm
System size: 200 × 200 × 1000 m^3
# of particles: ~10^{10}

⇒ Use of supercomputer (10^3 parallelism)

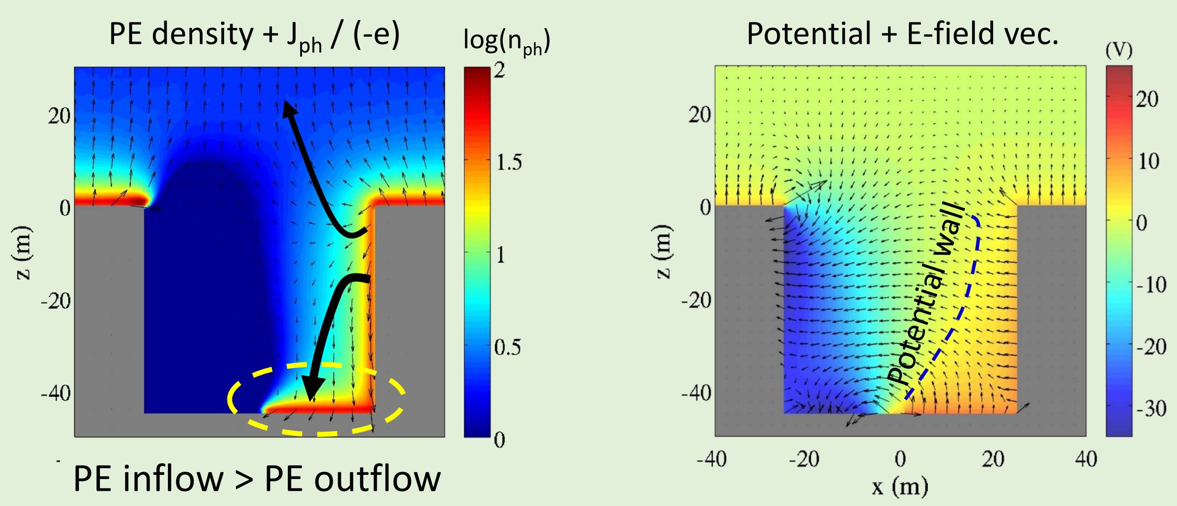
1. Solar wind (SW) plasma downflow
2. Photoelectron (PE) emission
3. Plasma captured at lunar surface

} ...are taken into account

Plasma environment near hole



$J_i > J_e$ ➡ Higher potential at hole bottom

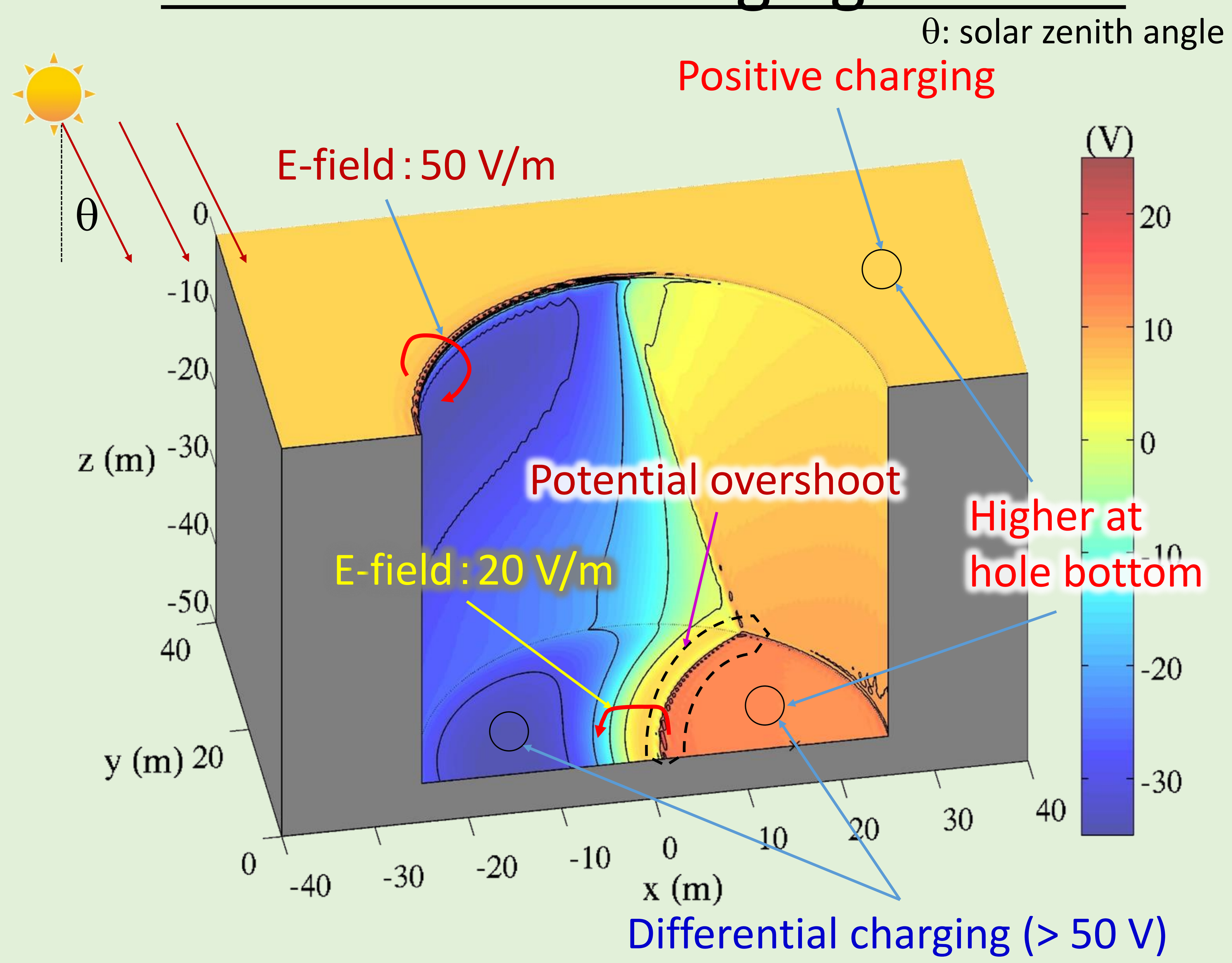


(SW protons) ballistic motion, due to supersonic flow & large mass
(SW electrons) limited access into the hole due to...
1. negatively potential at shadow region
2. electron loss at the sunlit wall, with positive (attracting) potential

(PE) emitted from vertical wall and going down to the hole bottom

Lunar surface charging: θ = 30°

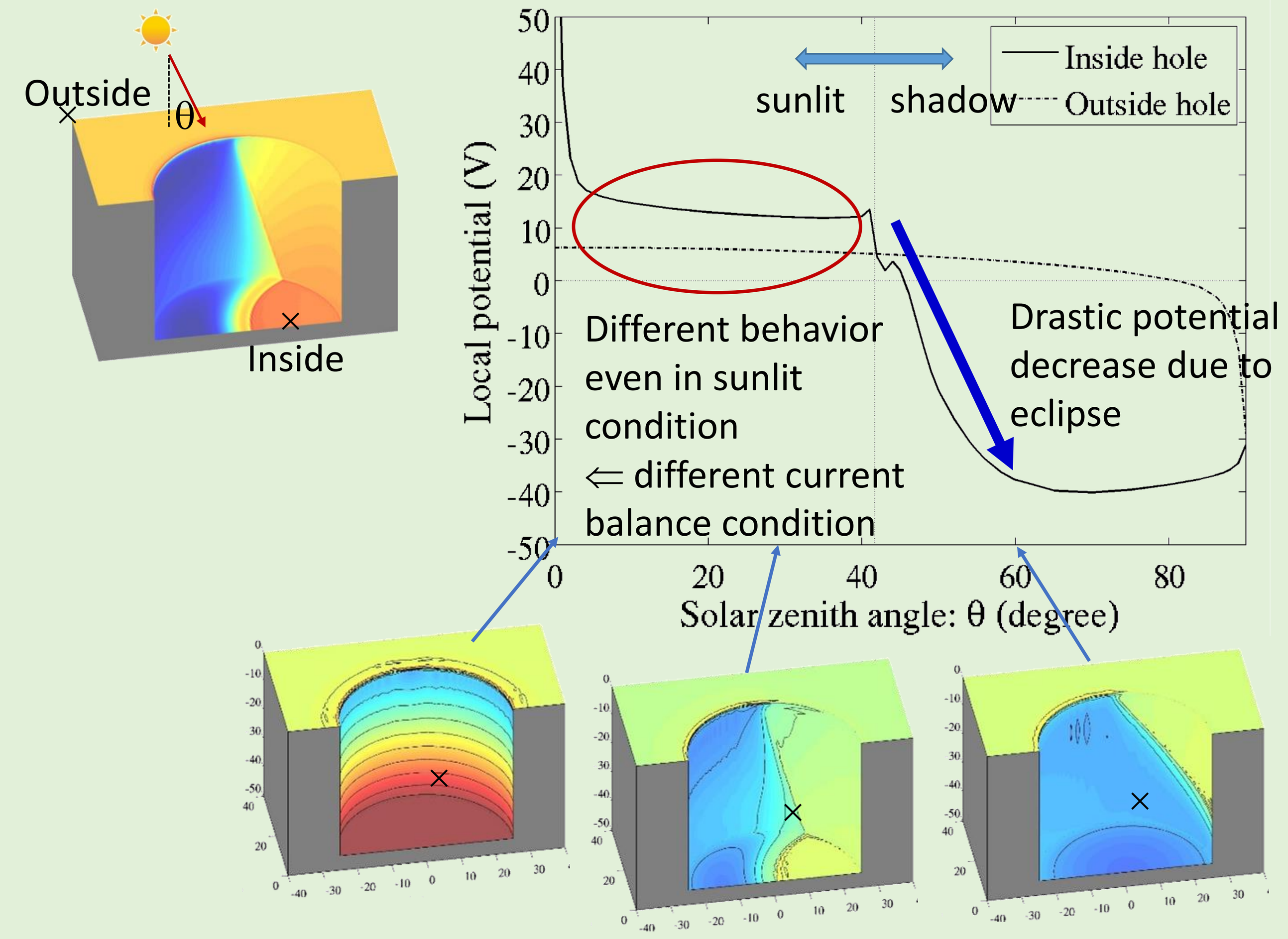
θ: solar zenith angle



The simulations reproduce the differential charging between the sunlit and shadowed faces, and the potential overshoot at the sunlit-shaded interface, predicting a local electric field of tens of V at maximum. The self-consistent modeling also predicts a higher potential at the hole bottom than outside the hole as long as the surface is in a sunlit condition. This reflects the modified plasma dynamics inside the hole.

Dependence on solar zenith angle

Surface potentials measured at fixed points inside & outside the hole



Summary

Particle-in-cell simulations on plasma environment around lunar holes

... reveal unique electrostatic structures:
1. Differential charging between sunlit & shadow regions
2. Higher potential at hole bottom resulting from modified current balance
3. Potential overshoot near sunlit-shadow boundary

Future works:
Modeling of charged-dust environment around the holes