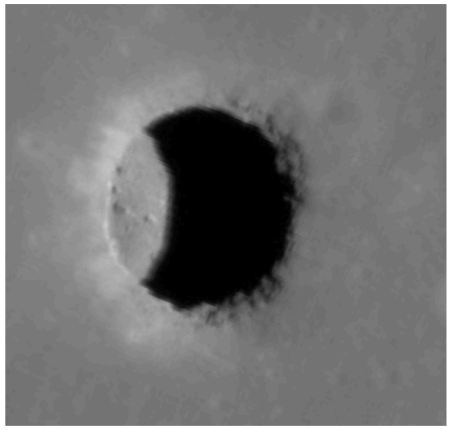
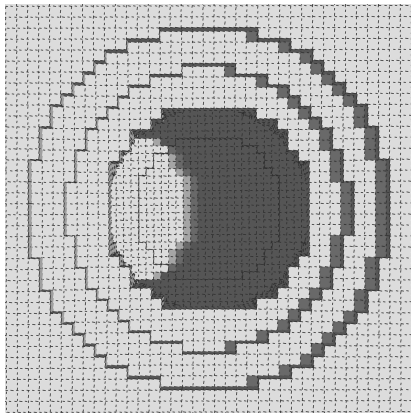
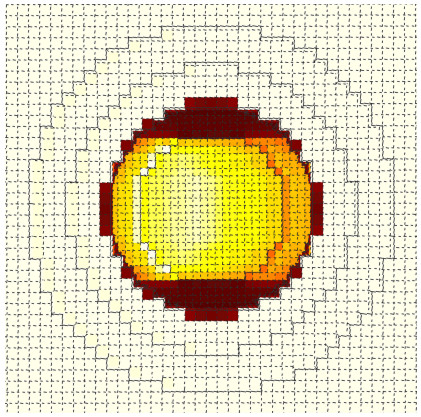


Wagner & Robinson, Icarus (2014)



Simulated illumination



Simulated Temperature

Simulations of the thermal and plasma environment within lunar pits and lava tubes: Could cryogenic regions trap ions from the solar wind?

Mike Zimmerman, JHU APL

D. B. J. Bussey, JHU APL

D. M. Hurley, JHU APL

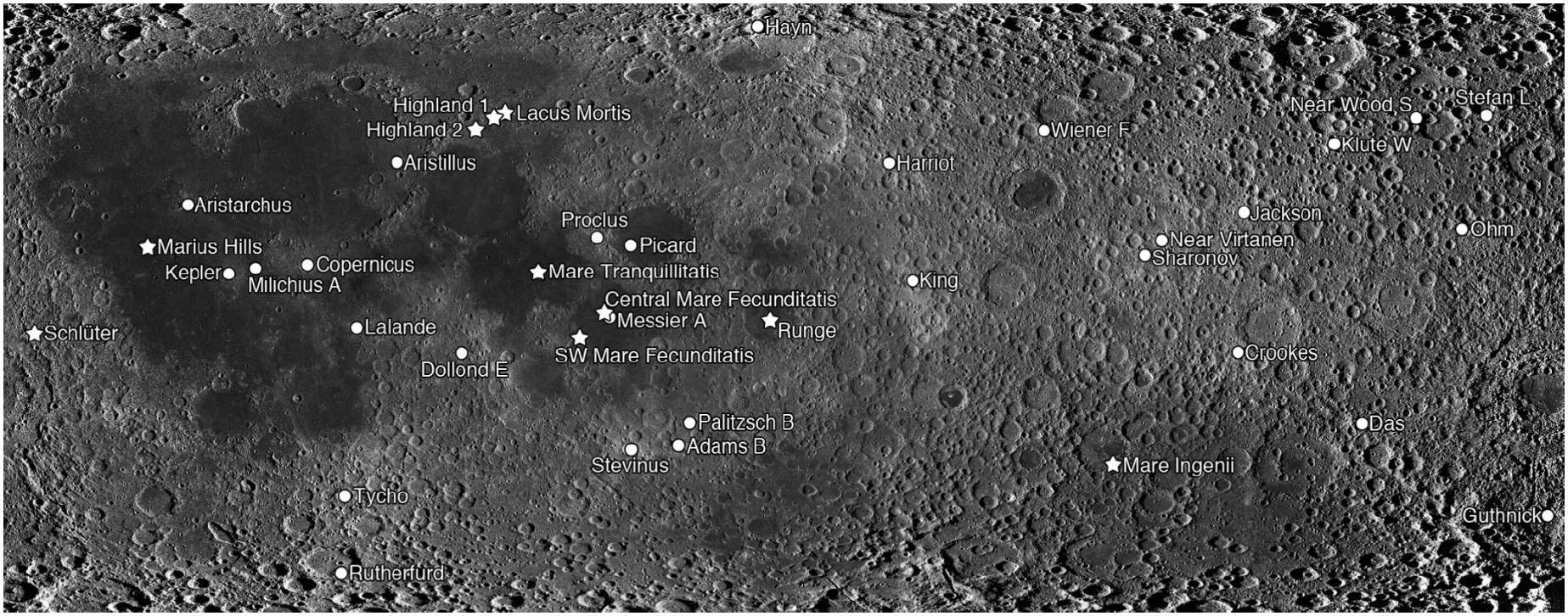
W. M. Farrell, NASA GSFC

Overview

- Lunar pits could provide partial shelter from the “elements” during in situ exploration
- We are developing a suite of APL/GSFC codes to characterize the thermal and plasma environment within lunar pits

- How does solar wind flow into lunar pits?
- Are shadowed regions cold enough to store volatiles delivered daily by the solar wind?

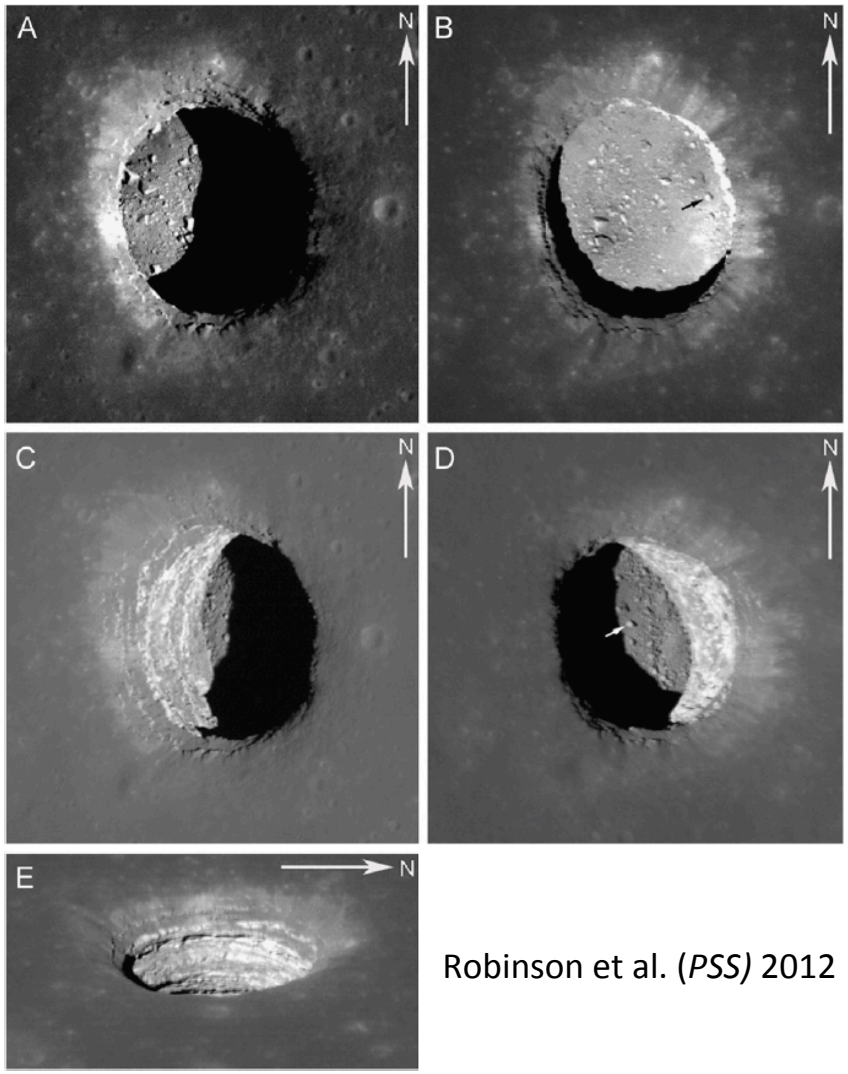
Lunar pits span the globe



Robinson et al. (*PSS)* 2012

- Wide range of latitudes (& env. conditions)
- Range of sizes, depths, and shapes
- How does plasma flow and solar heating change with latitude?

Subsurface pit structure is unknown

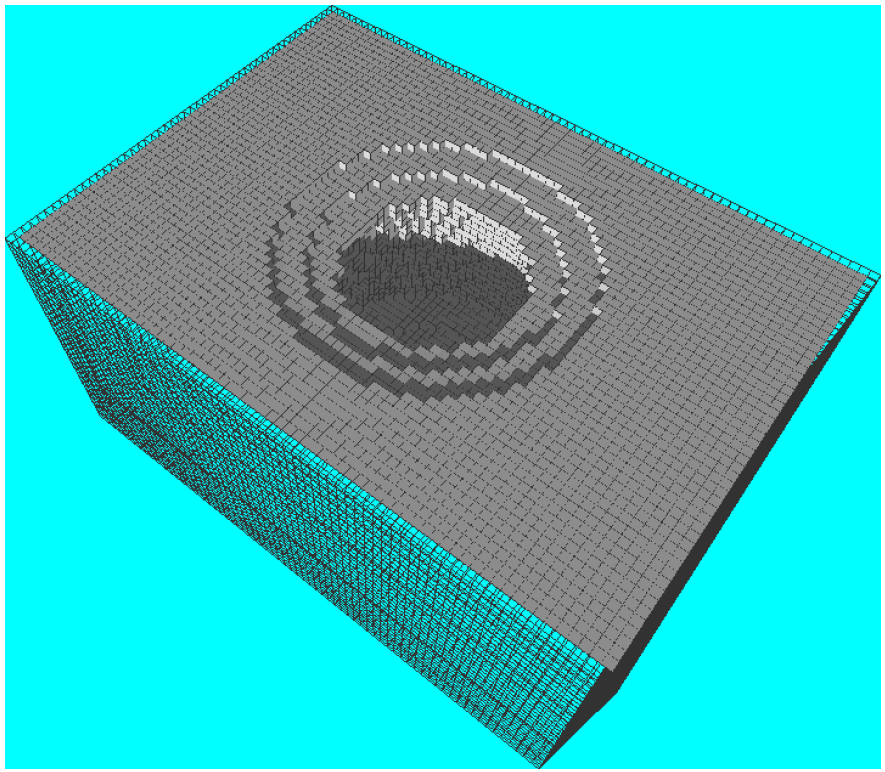


Robinson et al. (*PSS)* 2012

- Shadowing measurements provide some constraints on structure
- Lunar pits could provide shelter during exploration
  - Radiation
  - Heat
  - Plasma
  - Micrometeoroids
- What is the subsurface daily environment?

Simulating the Thermal Environment

- 3D voxel-based heat solver developed at APL
  - Homogeneous bulk solid
  - Time-dependent **solar illumination**
  - Arbitrary specification of **subsurface voids**



$$\dot{T} = \kappa \oint d\vec{S} \cdot \lambda \vec{\nabla} T = \kappa \sum_n s_n \left(\lambda \frac{\partial T}{\partial n} \right)$$

Volumetric Temperature Evolution

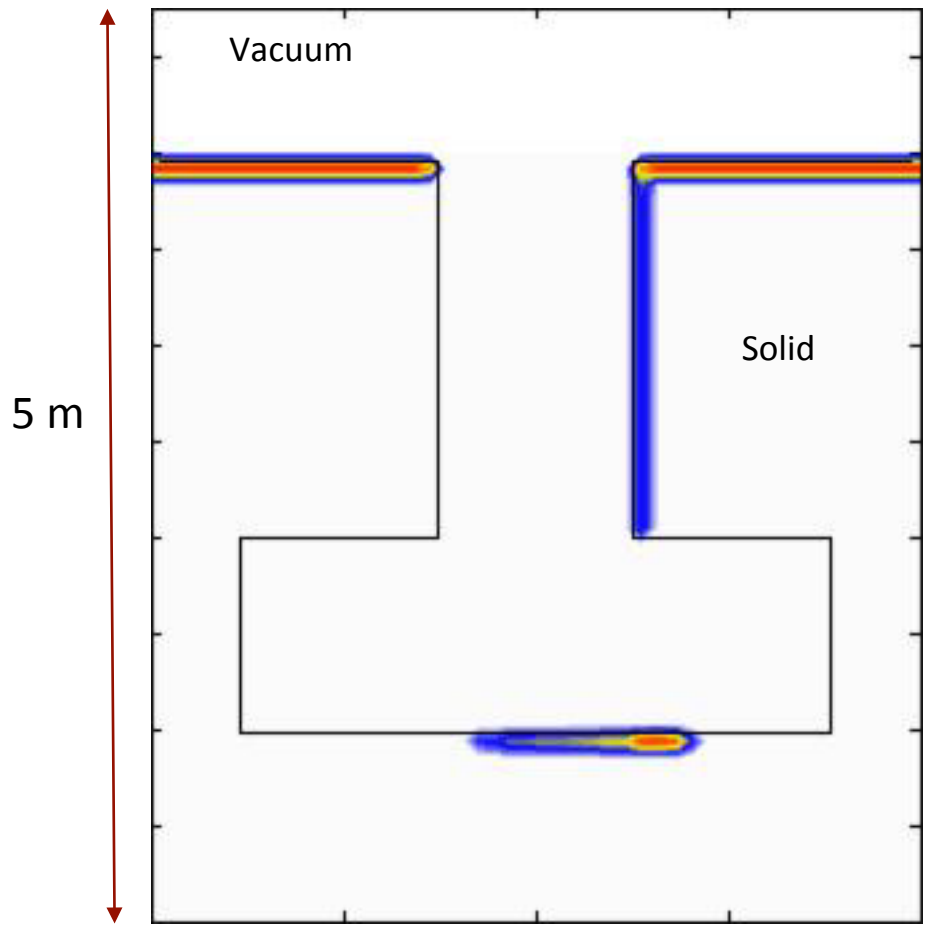
$$q_{i,NET} = (1-\alpha_i) h_i - \sigma \varepsilon_i T_i^4 - \kappa_i \frac{\partial T_i}{\partial n}$$

Surface Heat Flux

$$h_i = q_{i,0} + \sum_{j \neq i} \phi_{ji} \left(\sigma \varepsilon_j T_j^4 \right) + \sum_{j \neq i} \phi_{ji} \left(\alpha_j h_j \right)$$

Patch-Patch Radiative Transfer

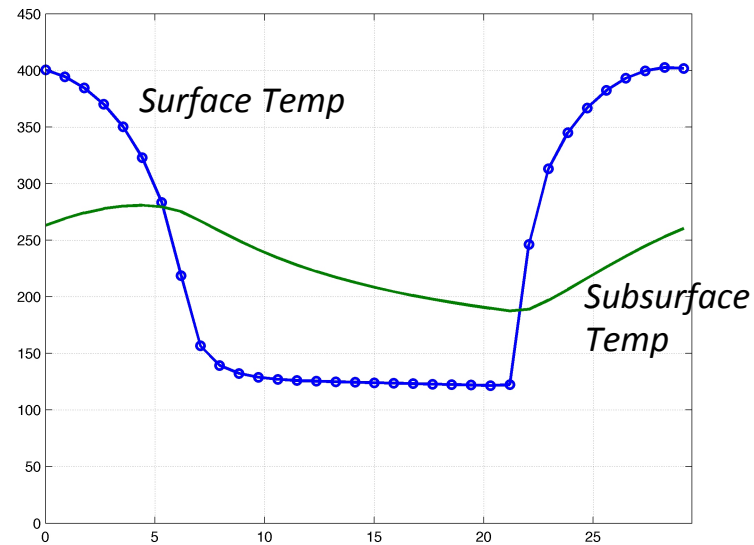
Daily Heat Cycle in a Lunar Pit



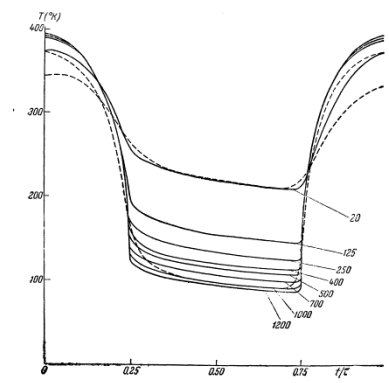
2D slice showing daily heat cycle

>400 K (unphysical) 0 K

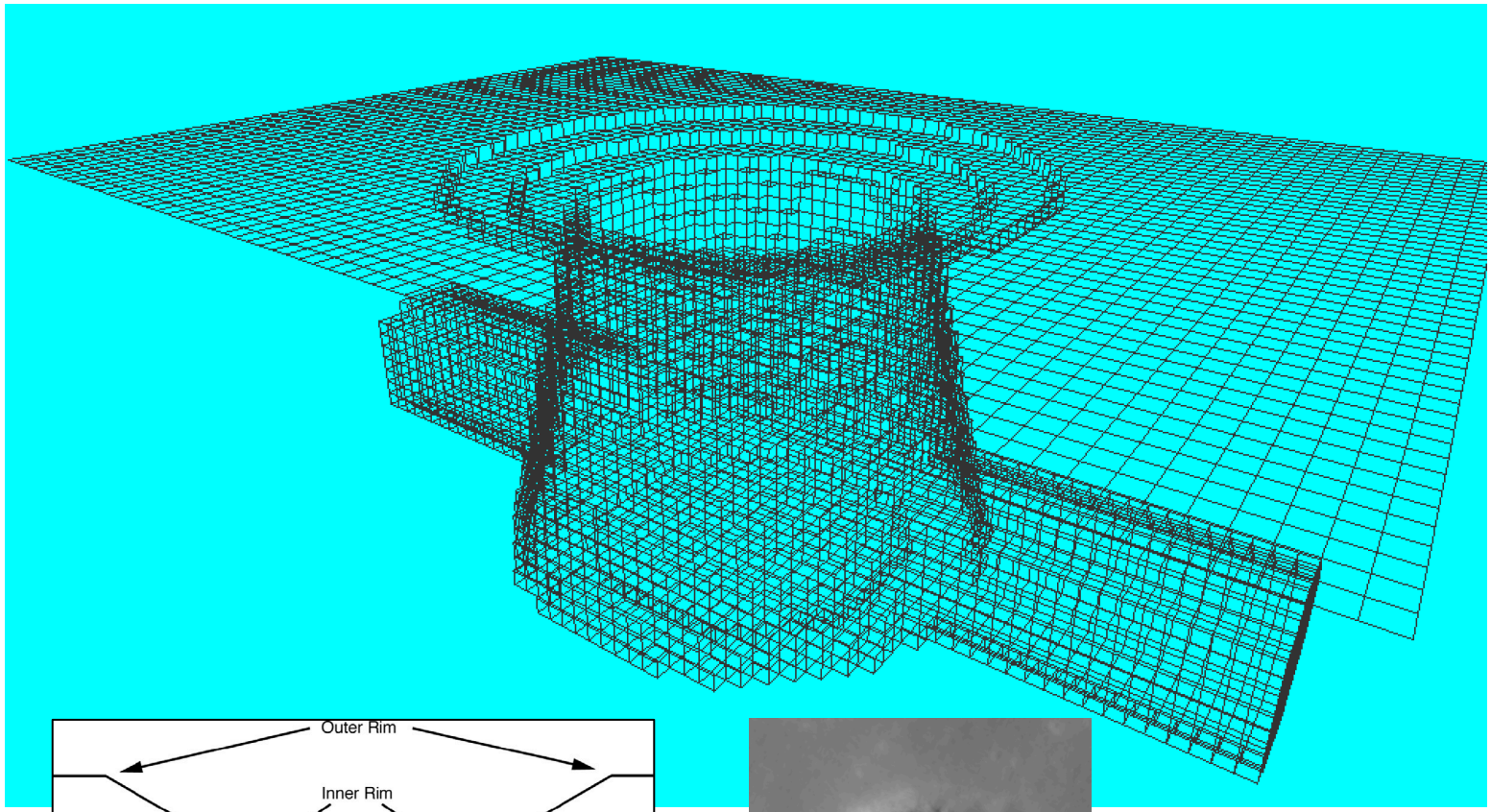
1D test case

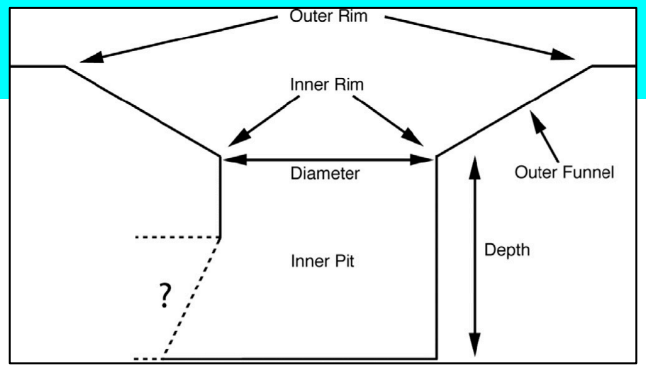


Krotikov and Schuko (Sov. Astr.) 1963

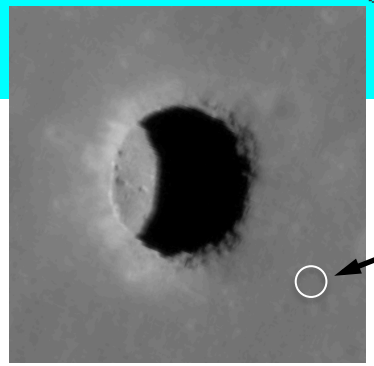


Daily Heat Cycle in a Lunar Pit





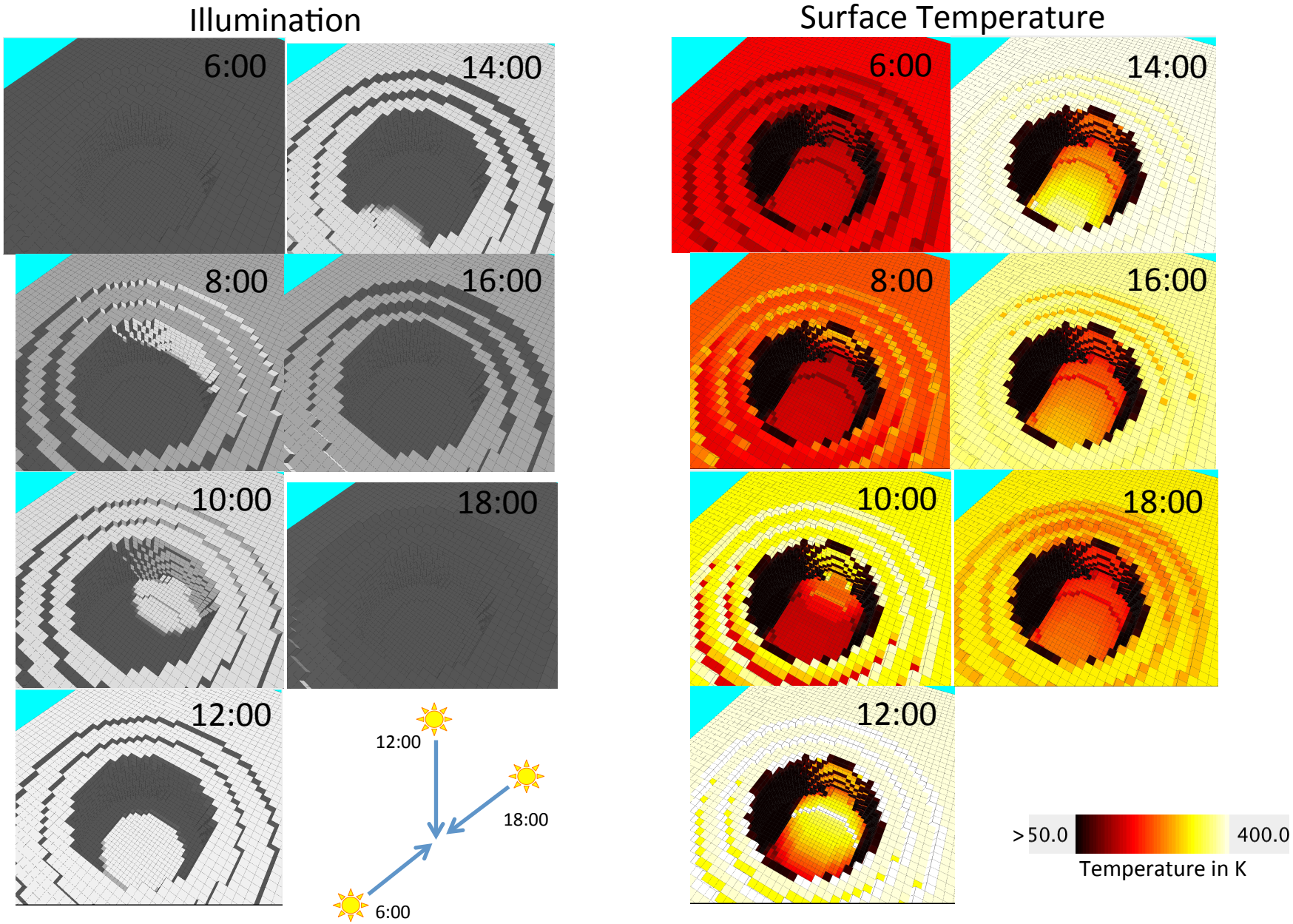
Wagner & Robinson et al. (*PSS)* 2014



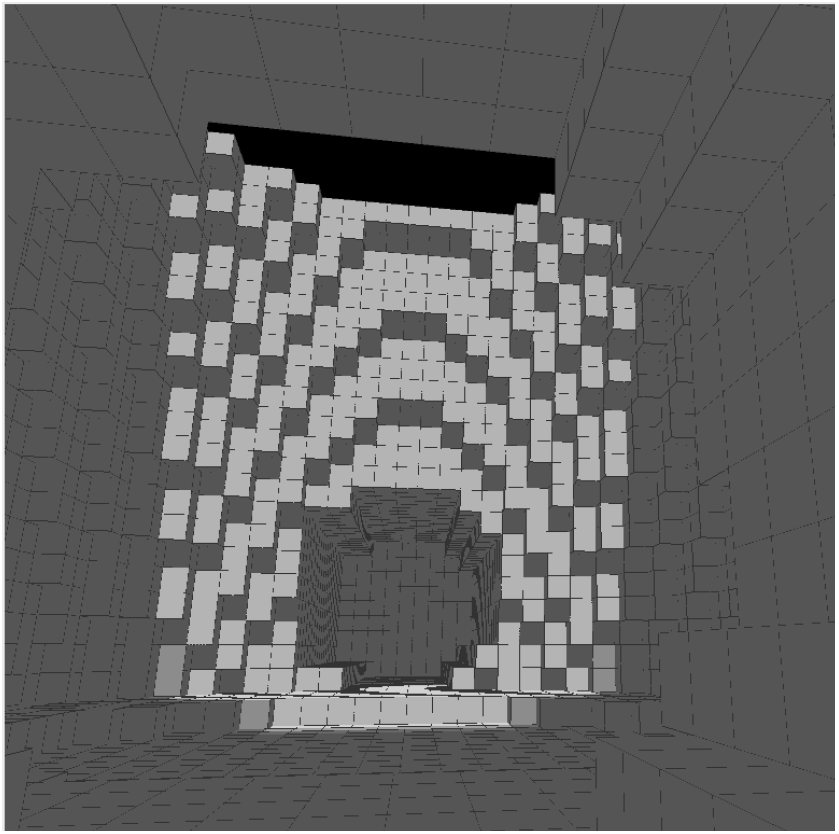
Simulated pit
20 m wide / 25 m deep

Mare Tranquillitatis Pit
100 m wide / 100 m deep

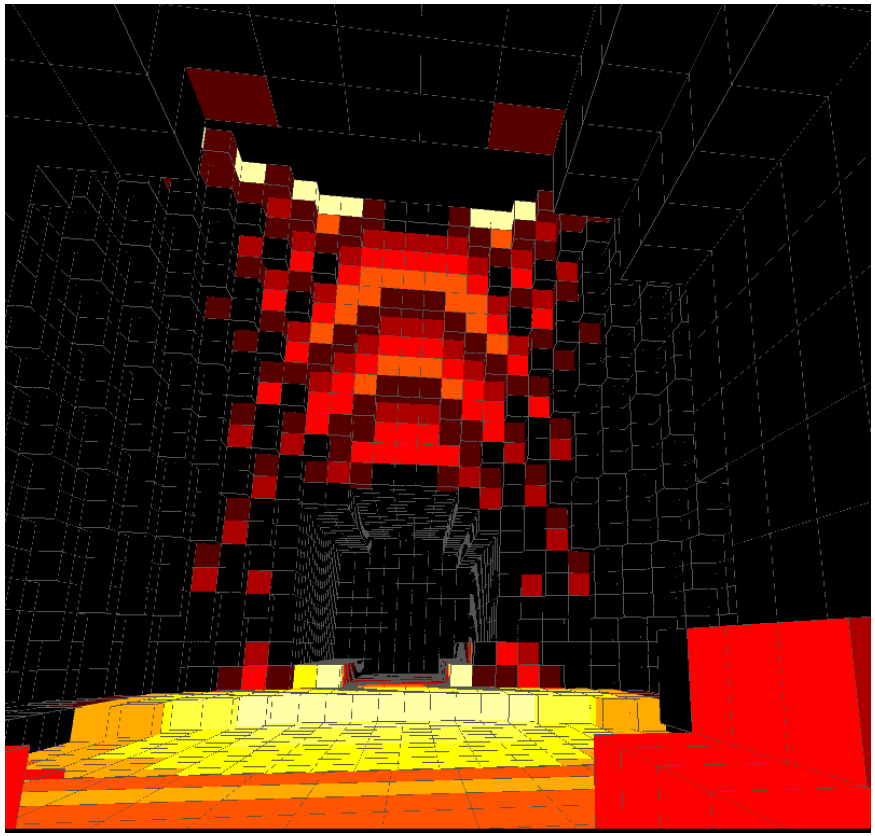
Daily Heat Cycle in a Lunar Pit



Secondary Radiative Transfer Could Heat Shadowed Regions



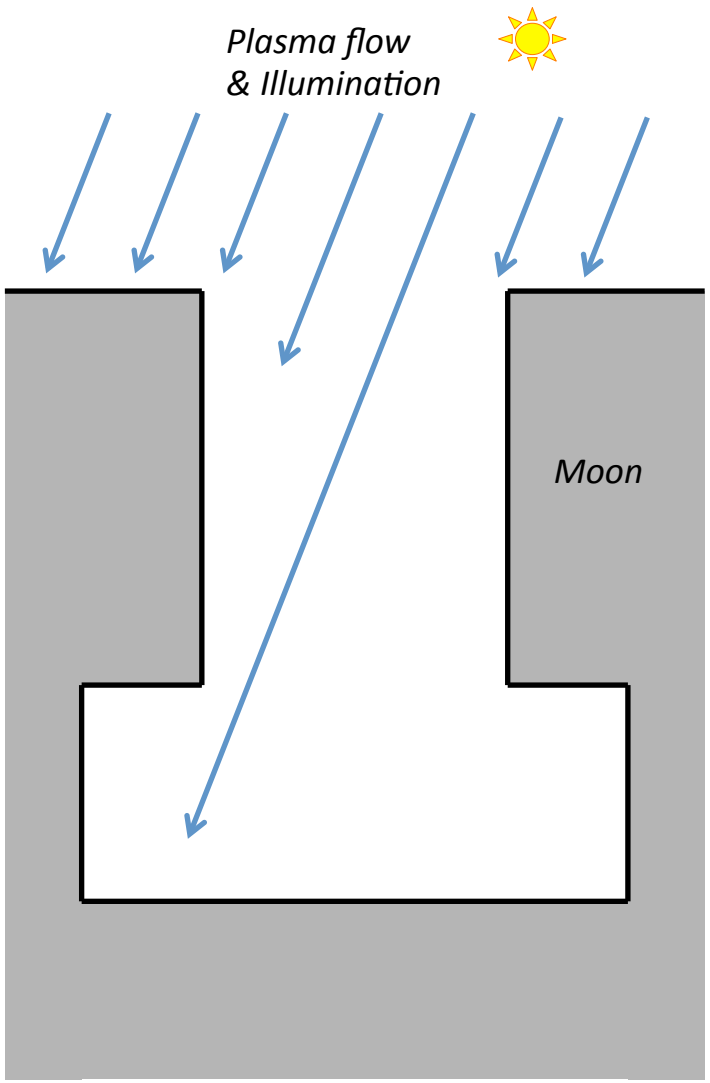
Direct Illumination at 2:30 PM



Solar + Conductive Heated Surfaces

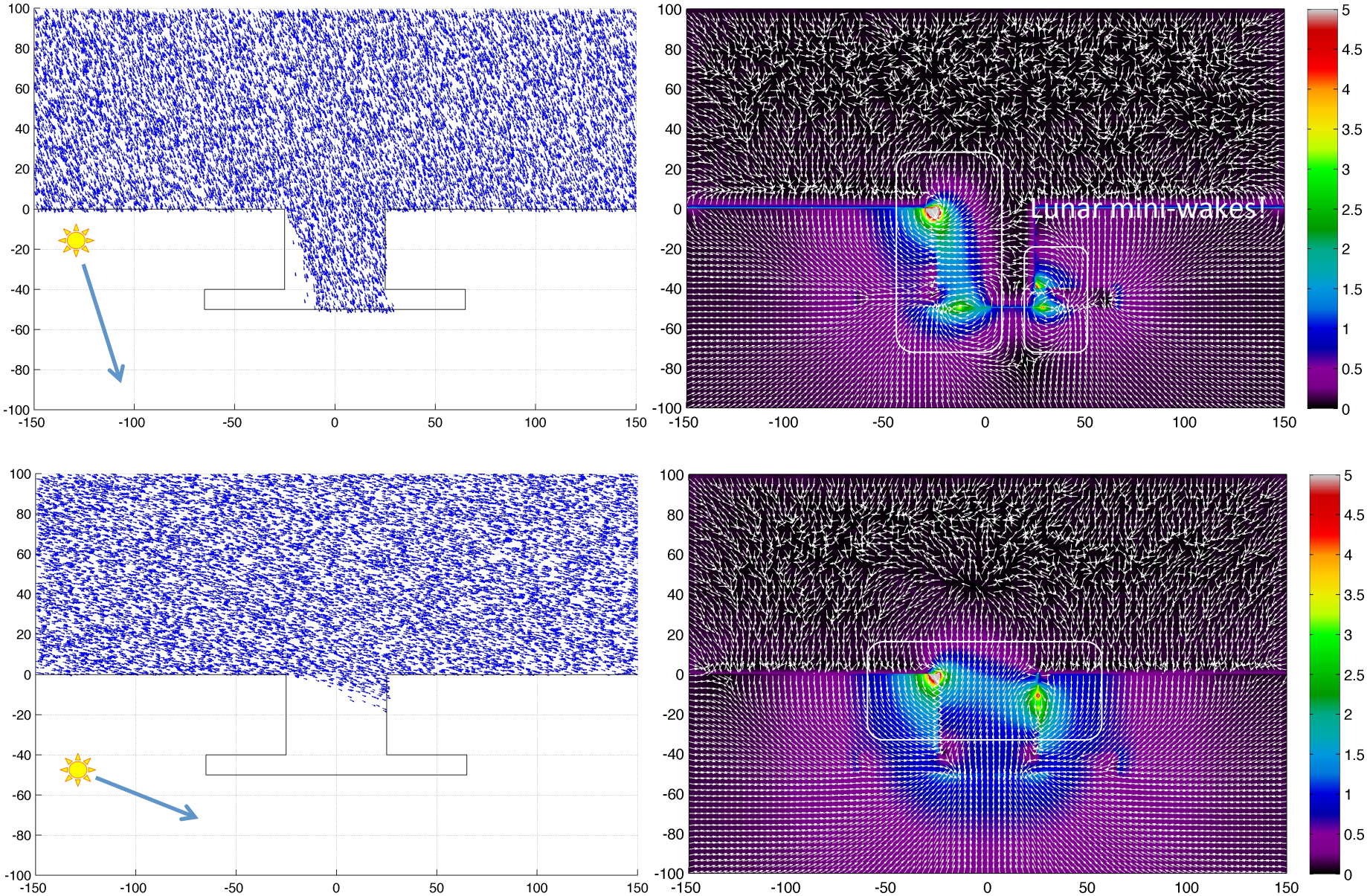
- Patch-patch radiative transfer not implemente, but affects:
  - Unlit lava tubes
  - Occluded regions of mid- and high-latitude pits

Plasma Environment Simulations

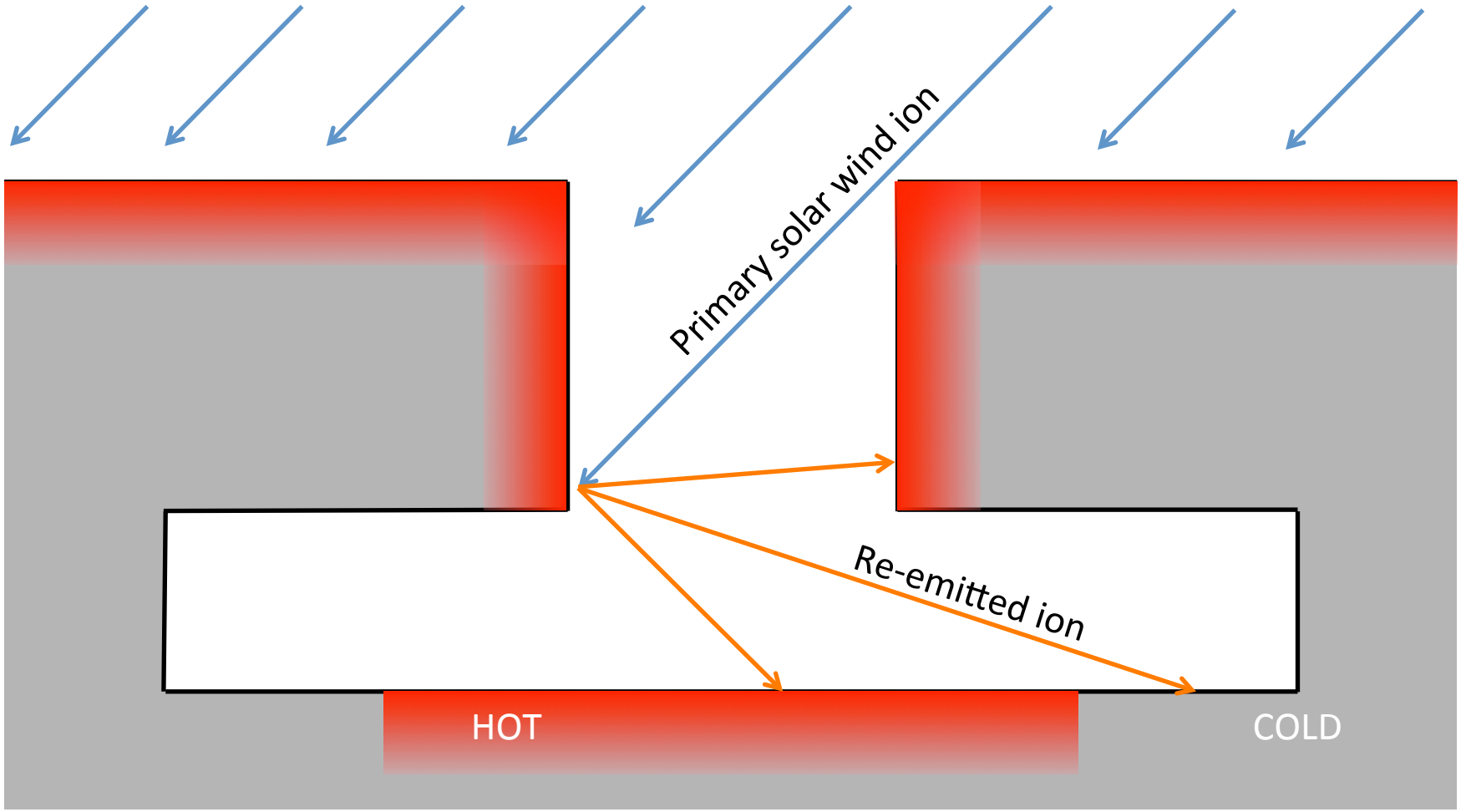


- 2D treecode developed at GSFC
  - Designed for small body & lunar simulations
    - Zimmerman et al. (Icarus) 2014
    - See **my poster** in "Dust and Regolith" section
  - Detailed shadowing and surface charging algorithms
  - Undergoing major improvements
    - Thanks, SSERVI!

Ions and Electric Fields in a Lunar Pit



Could Ions Thermally Hop into Cold Regions?



- On the Moon, maybe at higher latitudes, but near poles lunar pits are hard to find.
- Perhaps this is a possibility on small bodies farther from the sun.
- c.f. Farrell et al. talk tomorrow 1:45 – enhanced volatile retention due to surface defects.

Conclusions

- In a lunar pit there is something for everyone.
  - Plasma wakes, geologic stratigraphy, variable radiation, thermal processes, traces of volatiles?
- Physical fidelity of heating code will be significantly improved.
  - Parallelization for larger domains
  - Implementation of radiative transfer
  - Surface roughness, temp-dependent bulk parameters
- These codes can help identify future targets for exploration.
- Applicability to other bodies, incl. asteroids.