Long Range Organic Footprint Transport on the Lunar Surface

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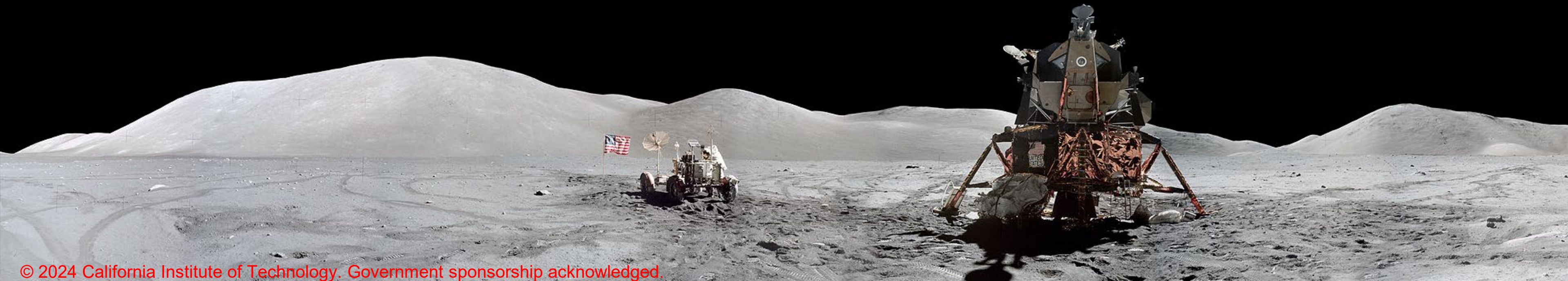
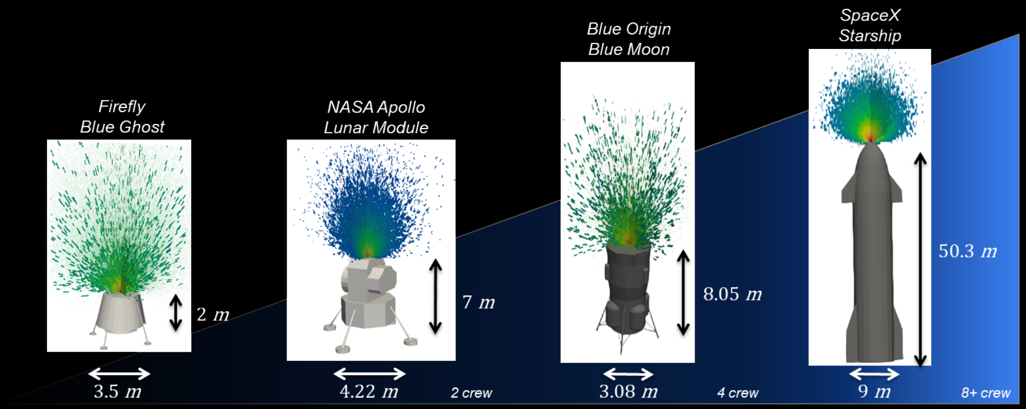
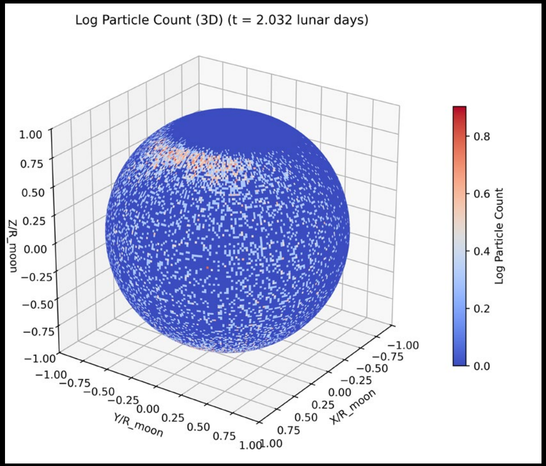
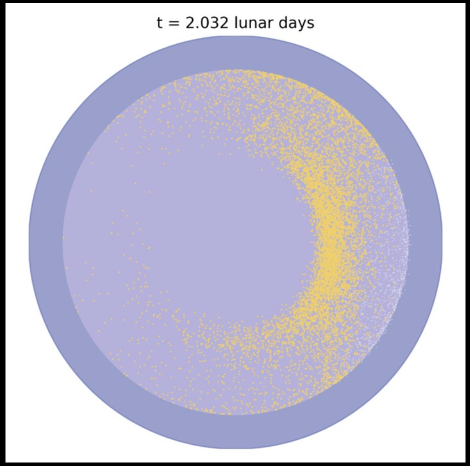


Introduction

- Landed spacecraft introduce organic footprint signatures into the lunar environment through outgassing, venting, and plume byproducts.
- In the lunar vacuum, released molecular species can undergo long-range transport, adsorption, and trapping in regions of scientific interest.
- Understanding this contaminant footprint is important for protecting science measurements, interpreting returned data, and informing Planetary Protection policy.
- This work develops a physics-based framework to estimate contamination source terms, transport pathways, and loss mechanisms relevant to lunar missions.





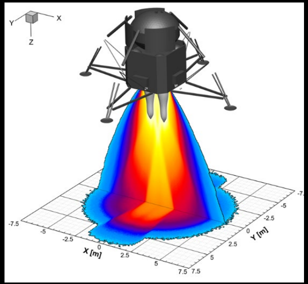


Long Range Dynamic Transport

- JPL developed model to study long range transport of spacecraft organic signatures in lunar environment
  - Trajectories of molecules
  - Molecular dependent thermal adsorption/desorption
  - Cold trapping in poles and PSR
- Residence time characterizes contaminant adsorption $\tau = \tau_0 e^{-\frac{E_a}{RT}}$
  - T: Residence time
  - E_a: Activation energy (contaminant + surface dependent)
  - τ_0: 'Attempt period' prefactor
  - T: Lunar surface temperature
- Currently using physisorption Alkane adsorption energy
  - Some lunar minerals contain TiO2
  - Not the most abundant regolith material
  - Extensible to other regolith materials
- Study consisted of molecules seeded at the sun spot to simulate spacecraft organic signature event (thrusters, outgassing, venting, EVA)
  - Ability to process higher fidelity simulations of organic footprint event (DSMC: Thrusters, venting, Free molecular: Outgassing)

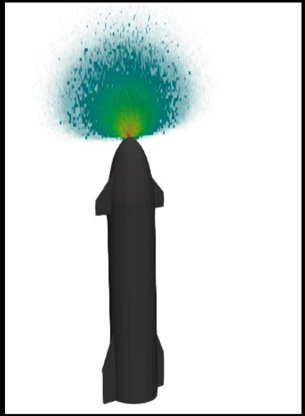
Event → Kinetics ↔ Transport

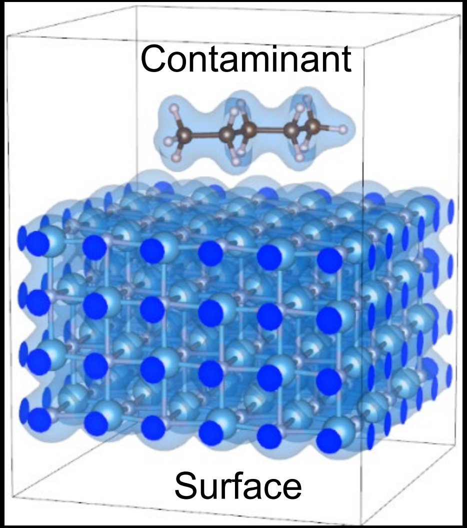
Thrusters

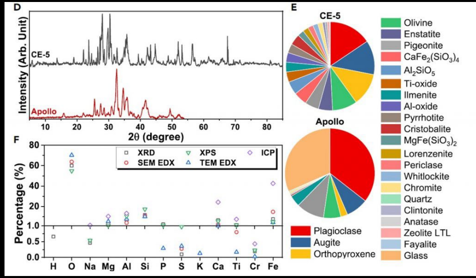


Outgassing

Venting







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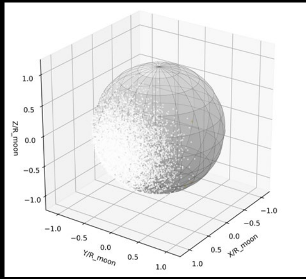
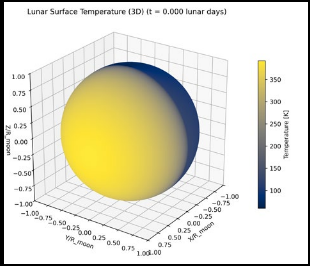
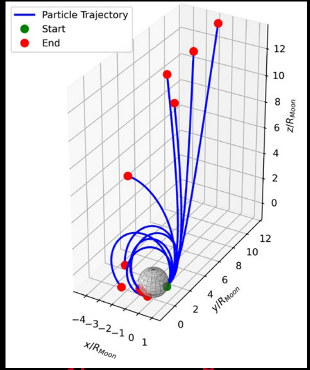
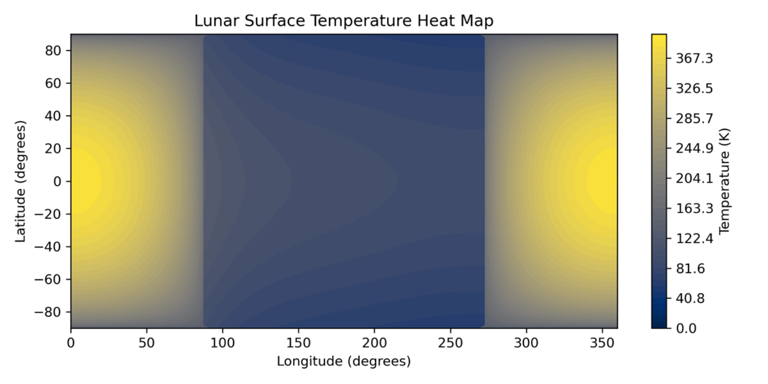


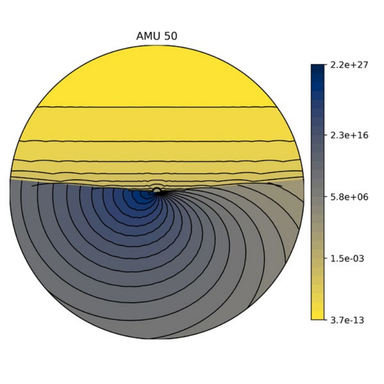


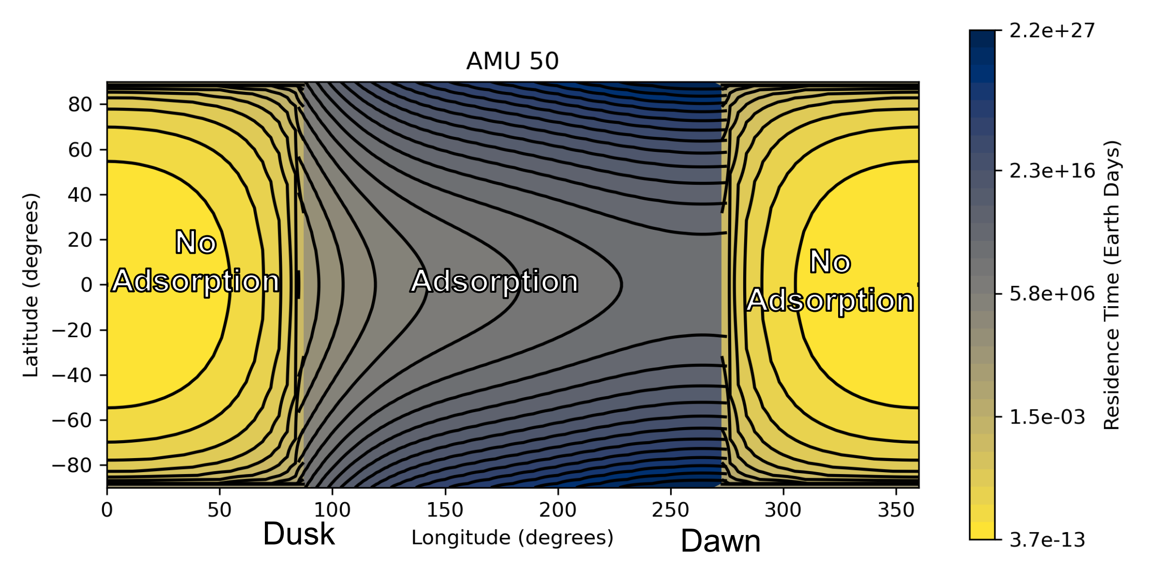


Low AMU Adsorption

- Low AMU contaminants
  - Plume constituents
  - Outgassing
  - Venting
- Will not stick on day side except possibly poles
- Will stick on night side
- In lunar day cycle will be volatized



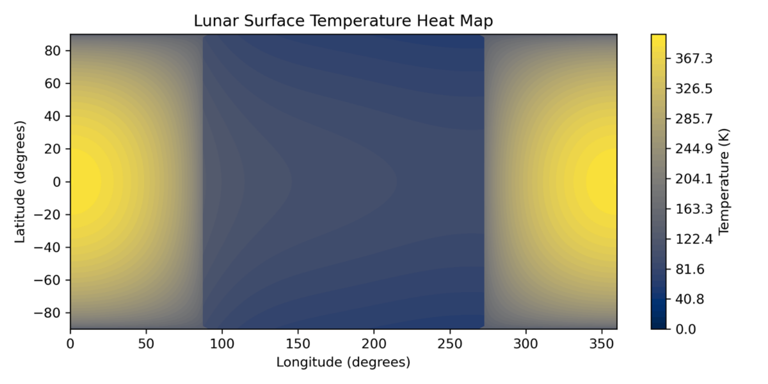


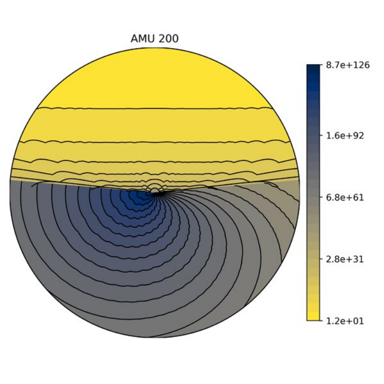


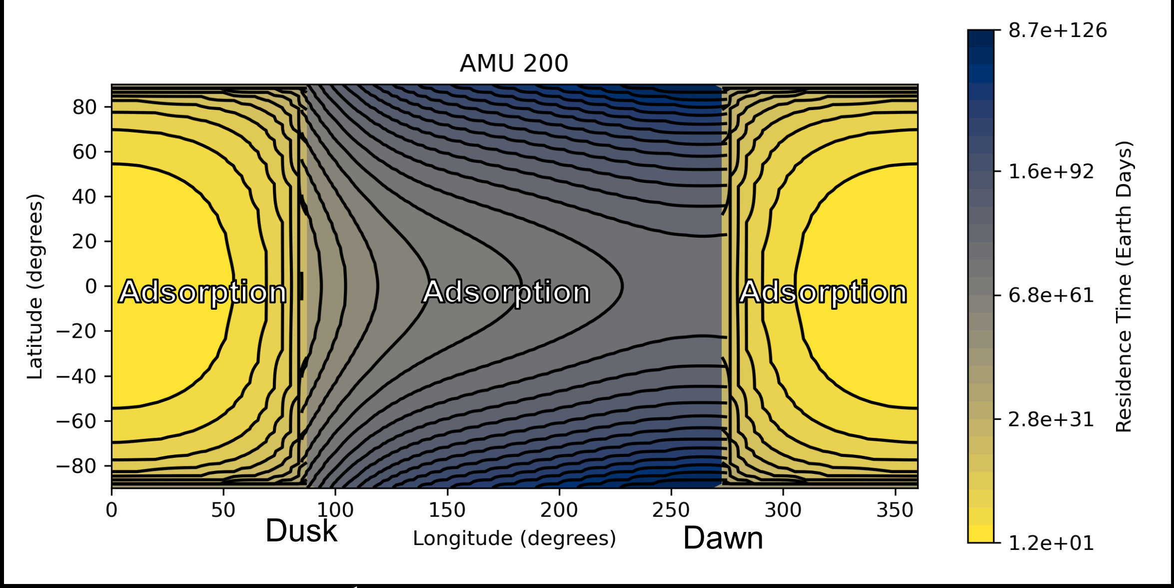
Lunar Rotation
360° / 30 Earth days

High Range AMU

- Low AMU contaminants
  - Outgassing
  - Venting
  - EVA
- Will stick 'permanently' at all latitudes on night and day side
- In lunar day cycle will not be volatized

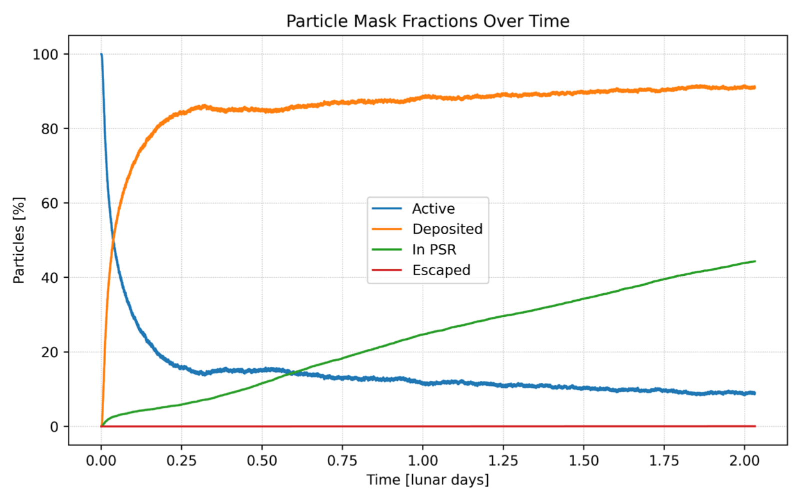


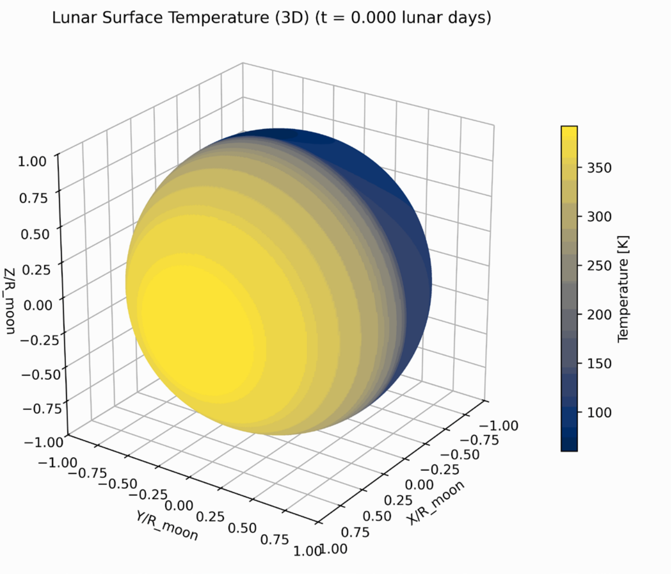


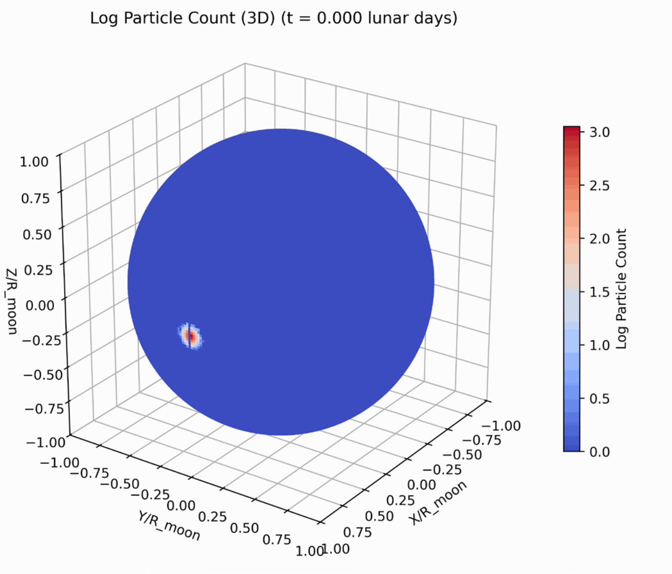


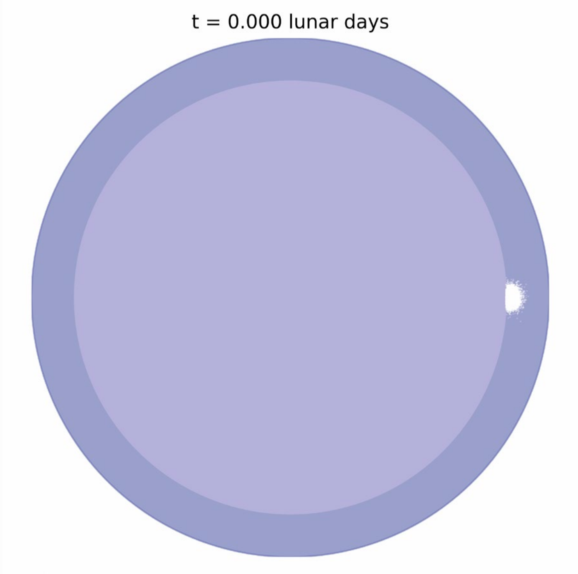
Results AMU16

- Very mobile and large thermal velocities
- Able to adsorb near poles on dark side
- Large amount quickly migrate to PSR where no thermal desorption can occur
- Even molecules at poles are desorbed on sun side



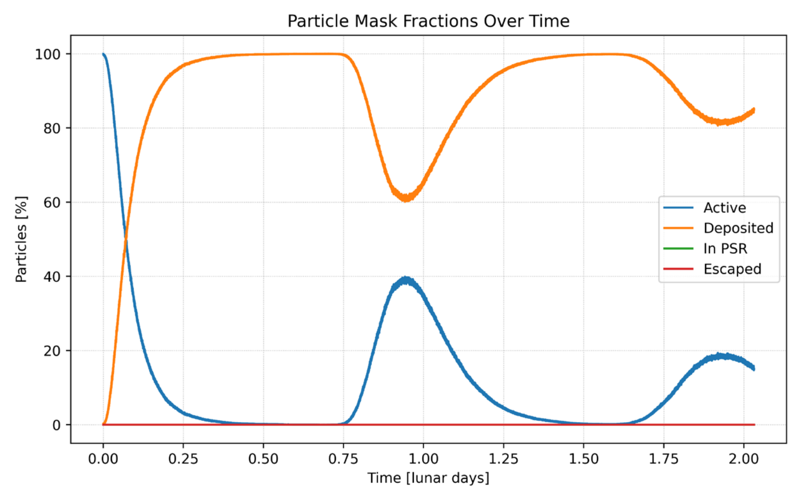


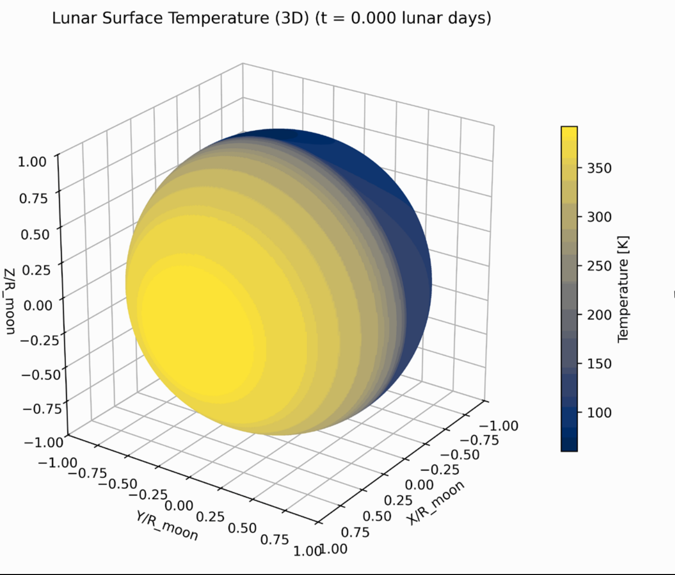


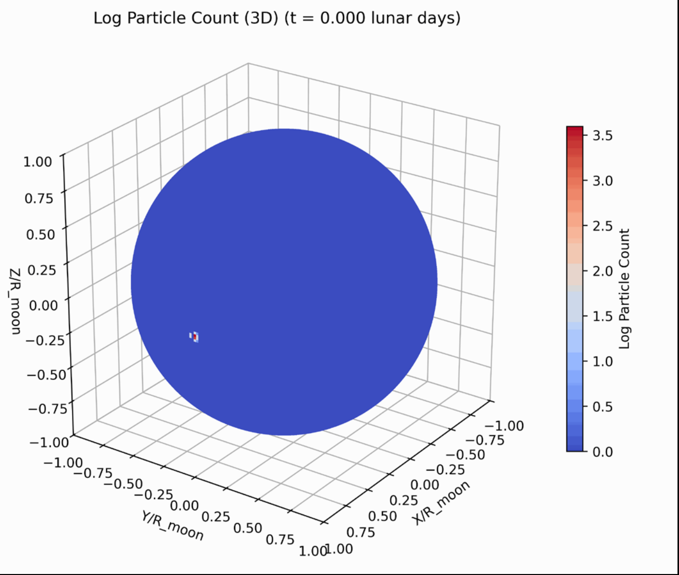


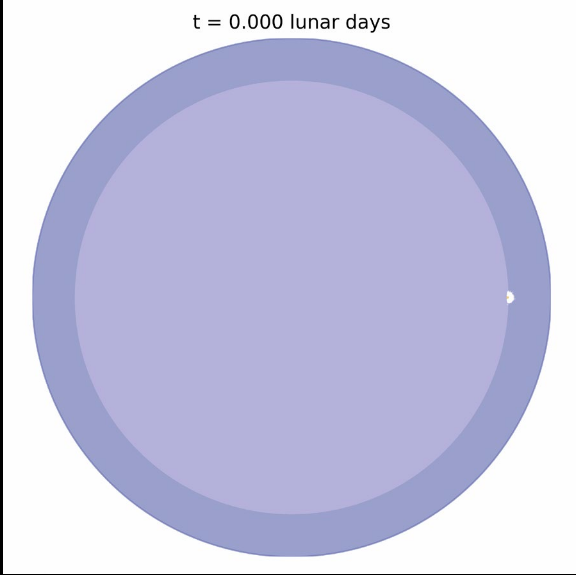
Results AMU150

- Less mobile
- Deposit on dark side and sun side ~30 degrees from poles
- Unable to migrate to poles
- Rings of molecules form far away from poles



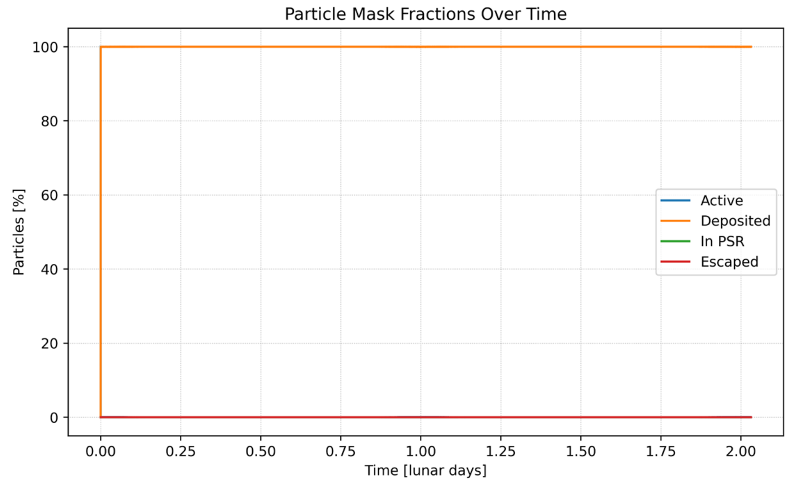


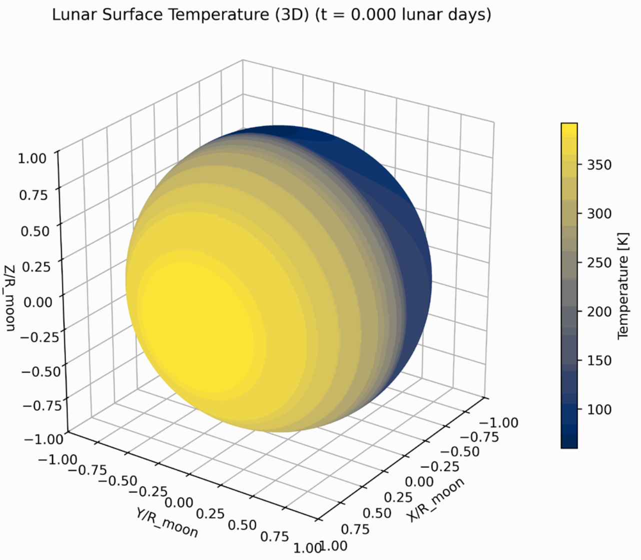


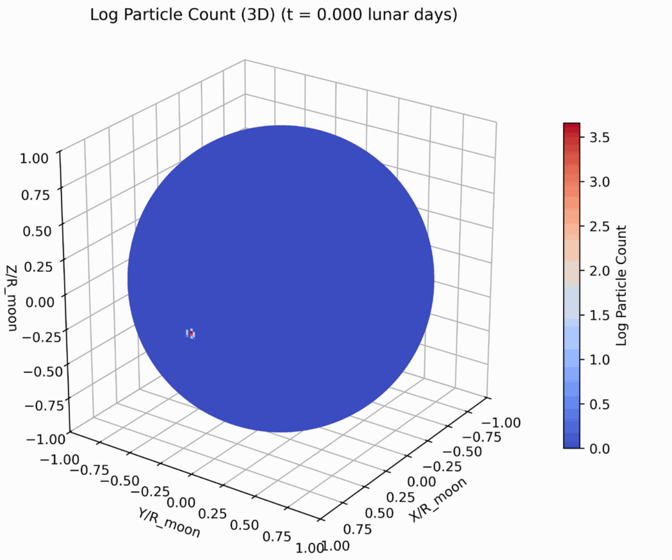


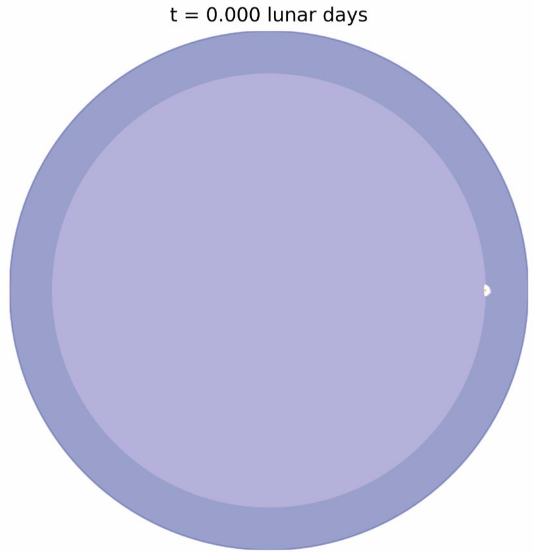
Results AMU200

- Not Mobile
- Molecules adsorb at site and never desorb



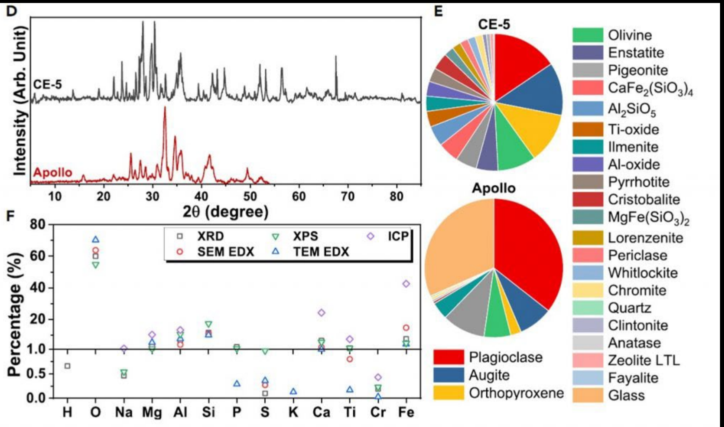


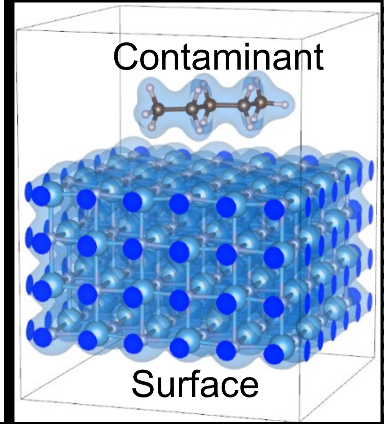


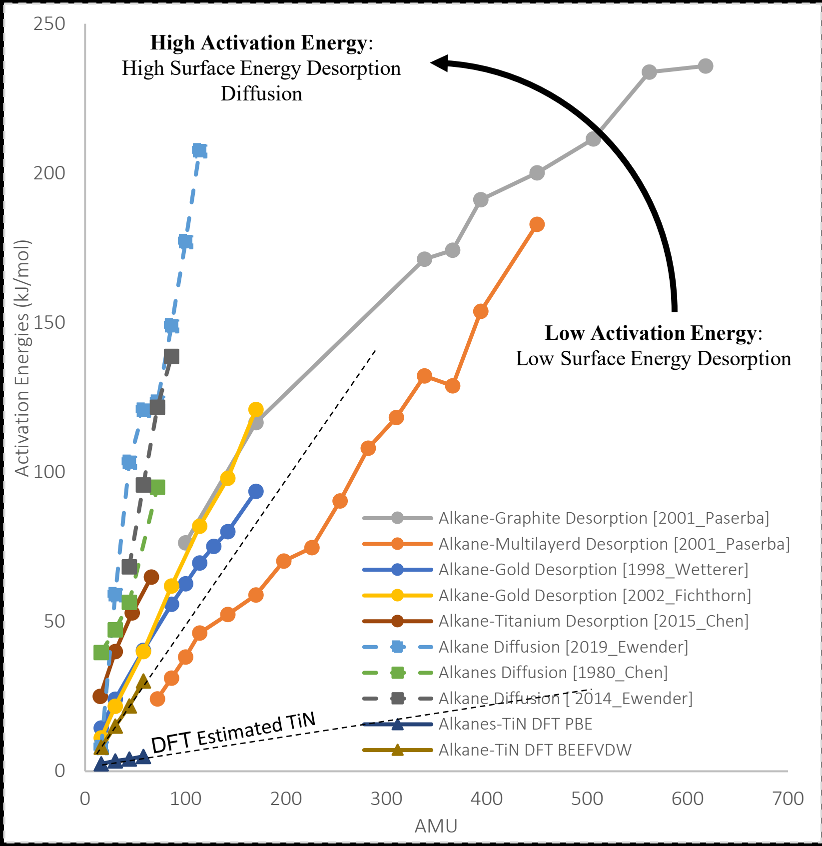


Multiple Surface Interactions

- Model has been extended to sample multiple surface interaction energies to model different regolith constituents
- Surface binding has been identified as probably biggest unknown in transport
  - Low surface energy regolith will promote transport to higher latitudes (colder)
  - Higher surface energy regolith will ‘trap’ molecules at lower latitudes
- Important extension to connect model to experimental collaboration or computational material science simulations
- Needed for accurate accounting of organic contamination on regolith type







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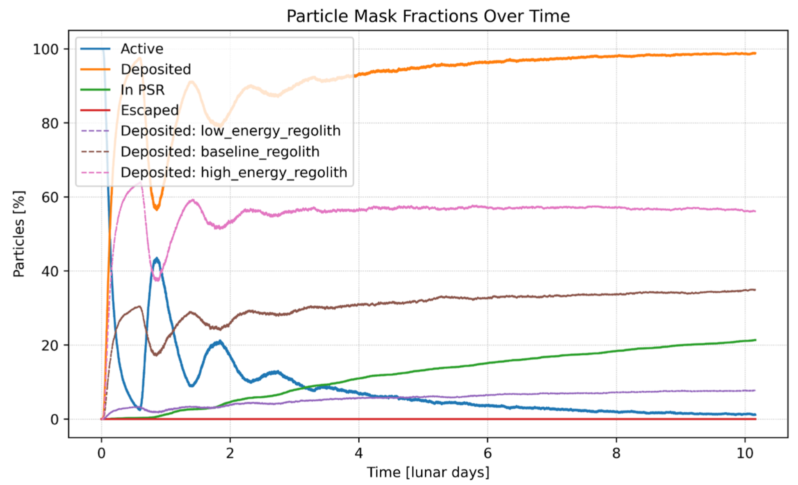
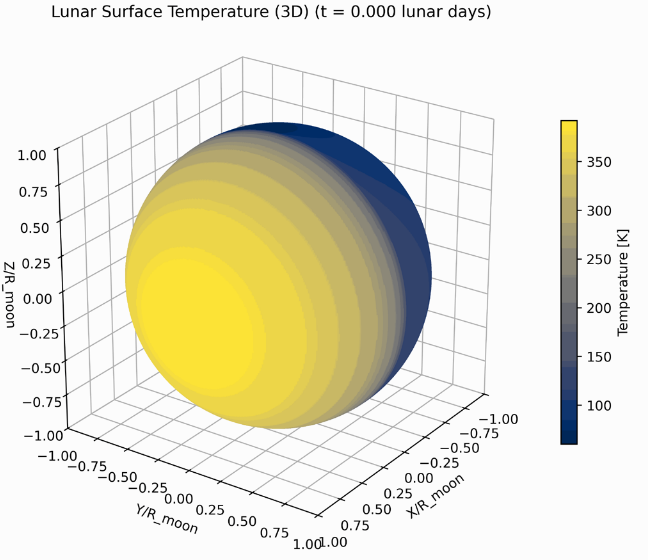
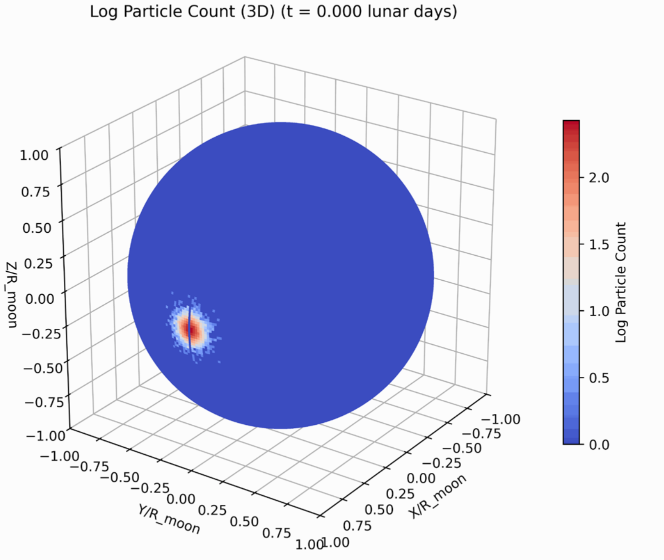
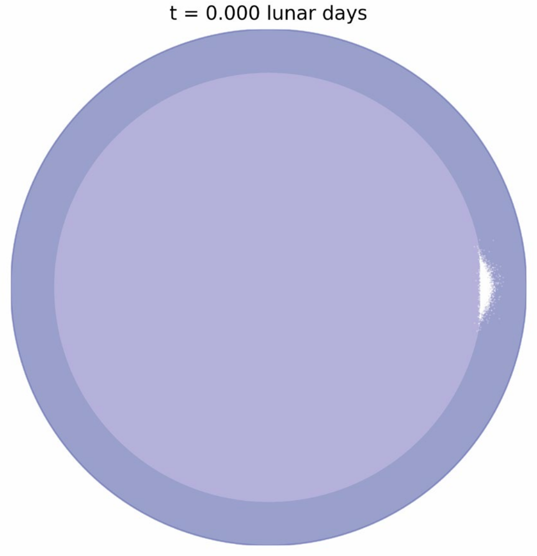
AMU100 Multiple surfaces

- 10 lunar day simulation
- 50% baseline regolith, 25% low energy regolith, 25% high energy regolith
- Molecular adsorption trends towards higher energy regolith
- Molecules adsorbed on lower energy regolith remain mobile over larger distances



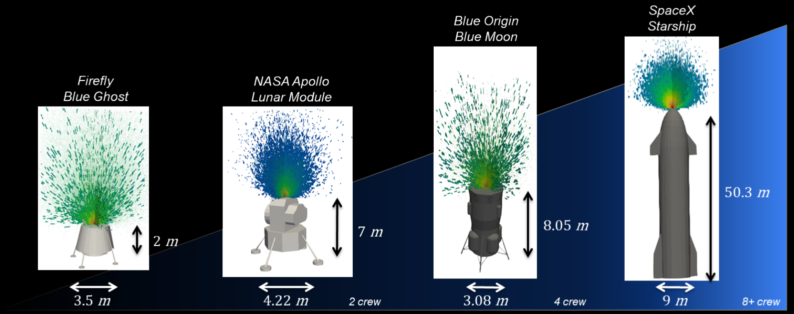


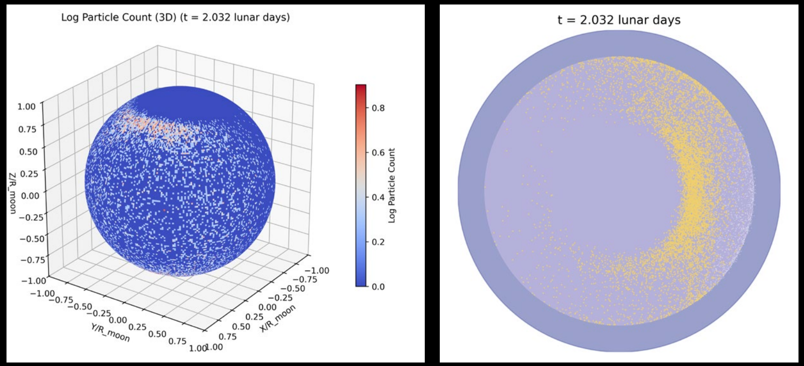




Future Work

- Preliminary molecule dependent behavior quantified
  - AMU16-50: Desorb and transport very quickly. Large percentage permanently deposit in PSRs. ~50% in 2 lunar rotations.
  - AMU100: Able to desorb and transport but many get trapped before transporting to PSR. <10% in 2 lunar rotations.
  - AMU150: Still able to desorb on sun side but get trapped before transporting to PSR. 0% in PSR.
  - AMU200: Not mobile. Remain in local site even in subsolar point.
- Current model could be deployed to bound and track organic footprint and impact on areas of interest for a given landing site
  - Track PSR / non-PSR deposition for given landing site
  - Each lander could necessitate a specific study with amount of organic inventory released and site
  - Assign binding energies and probabilities based on regolith composition
    - Not all surface properties may be known (contaminant – regolith binding energy)
  - Currently performing study of impact of Apollo Landers
- Still more detailed physics which could be necessary to include
  - Surface energies: Biggest believed model uncertainty
    - Supplement with computational material science methods which would allow better predictive capability
    - Physisorption
      - Currently assuming model system of hydrocarbons
    - Chemisorption
      - Experiments would provide better estimation of driving kinetics
    - Experimental and computational prospects for improving it
  - Easier things we already know how to do. Incrementally add as derived from well-founded existing literature
    - Photodissociation and Photoionization
    - Lorentz forces, reference frame effects
  - Current understanding of how model limitations could impact possible predictions





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