The Influence of Smoke Particle Properties and Cabin Characteristics on Smoke Detection in Lunar Gravity

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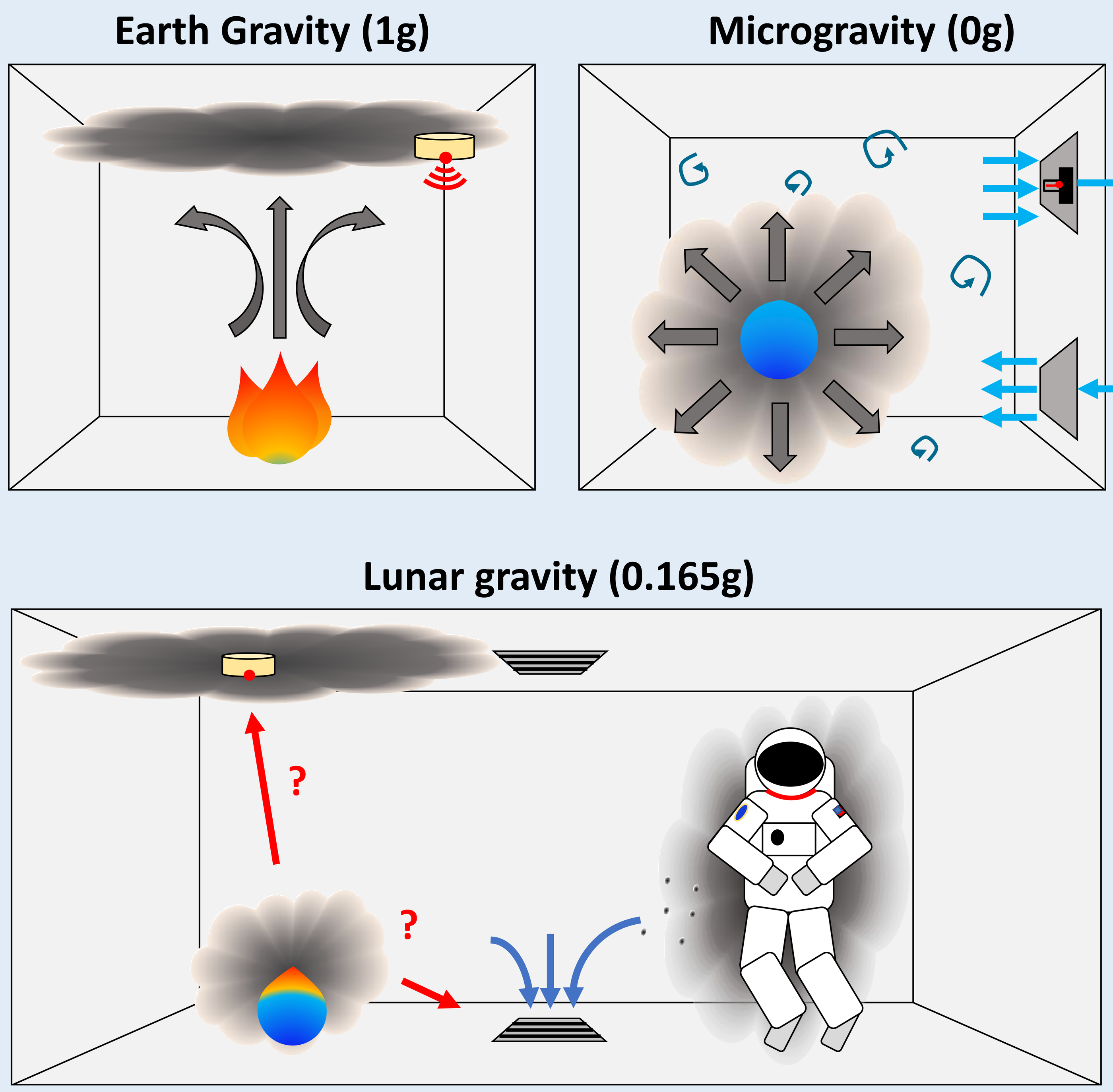
Background and Motivation



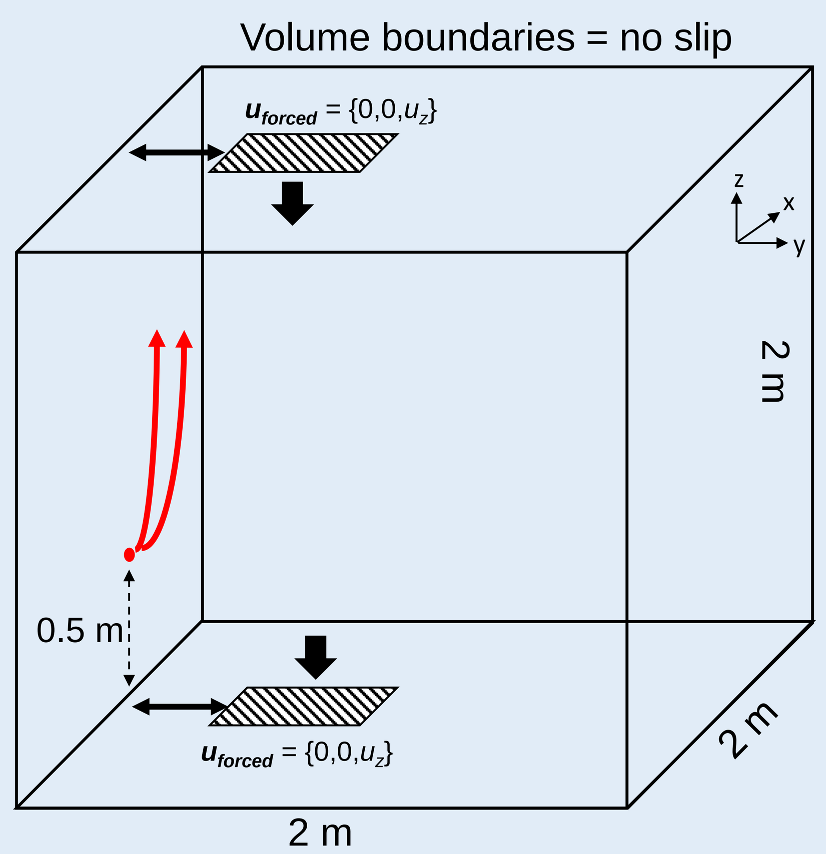
- Earth gravity: smoke stratifies and preconcentrates at ceiling
- Microgravity: no buoyancy, mixing driven by low-speed turbulent flow and high filtration rates
- Some buoyant plume flow expected in lunar gravity
- Plume transport will be governed by combination of buoyant flow and forced flow, which may be similar orders of magnitude
- How will lunar dust mitigation strategy affect smoke transport?
- Where should smoke detectors be placed in a lunar habitat?
- What should smoke detectors be set to? Times to alarm?

Modeling Strategy

Computations performed using COMSOL Multiphysics:

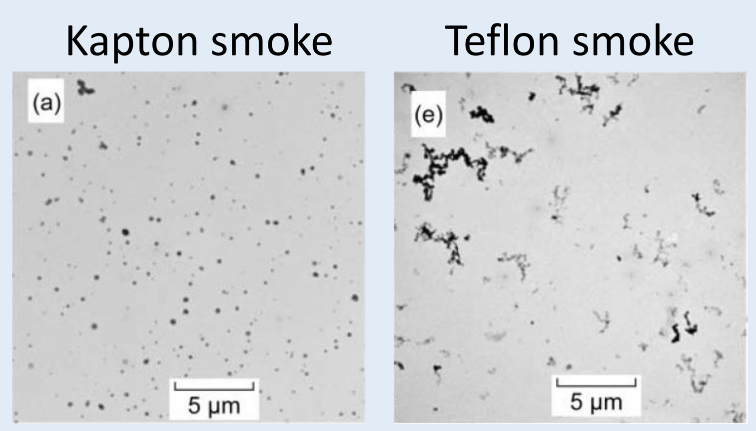
Study 1: Calculate flow field

- Fluid flow model: large eddy simulation (LES)
  - $P_{ambient}$ = 8.2 psia, $T_{ambient}$ = 293.15 K
  - Gravity $\mathbf{g} = \{0,0,g_z\}$ where $g_z = g_{Lunar}$ or g_{Earth}
- Heat transfer in fluids
  - Walls = open boundaries, $T = T_{ambient}$
  - Overheating 2 cm circular patch on wall
  - T_{fuel} ranging from 600-1000K ± 1 K fluctuation
- Mass and heat transfer coupled through nonisothermal fluid flow multiphysics node
- Forced flow introduced from supply on/near ceiling and return on floor



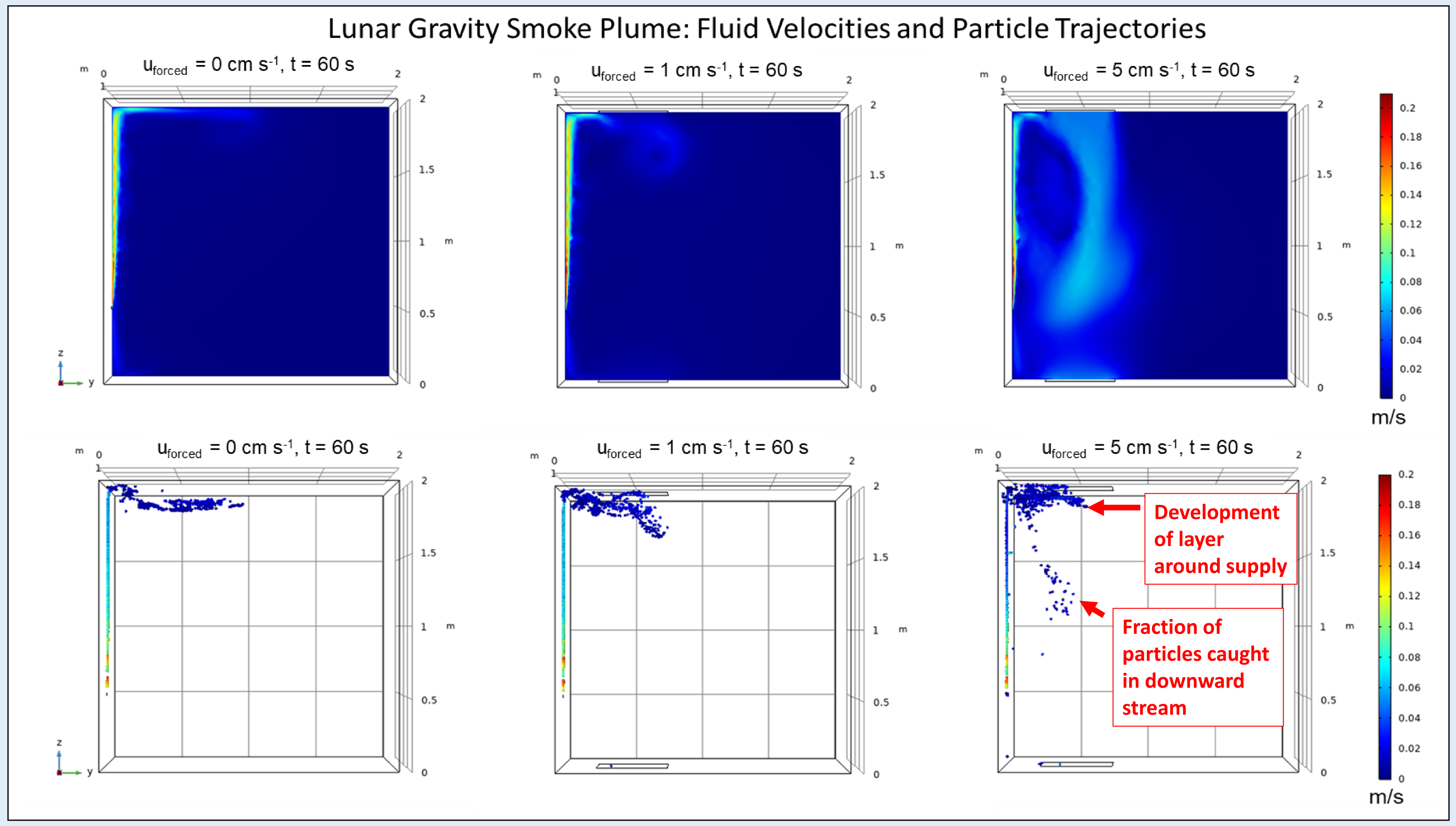
Study 2: Calculate particle trajectories

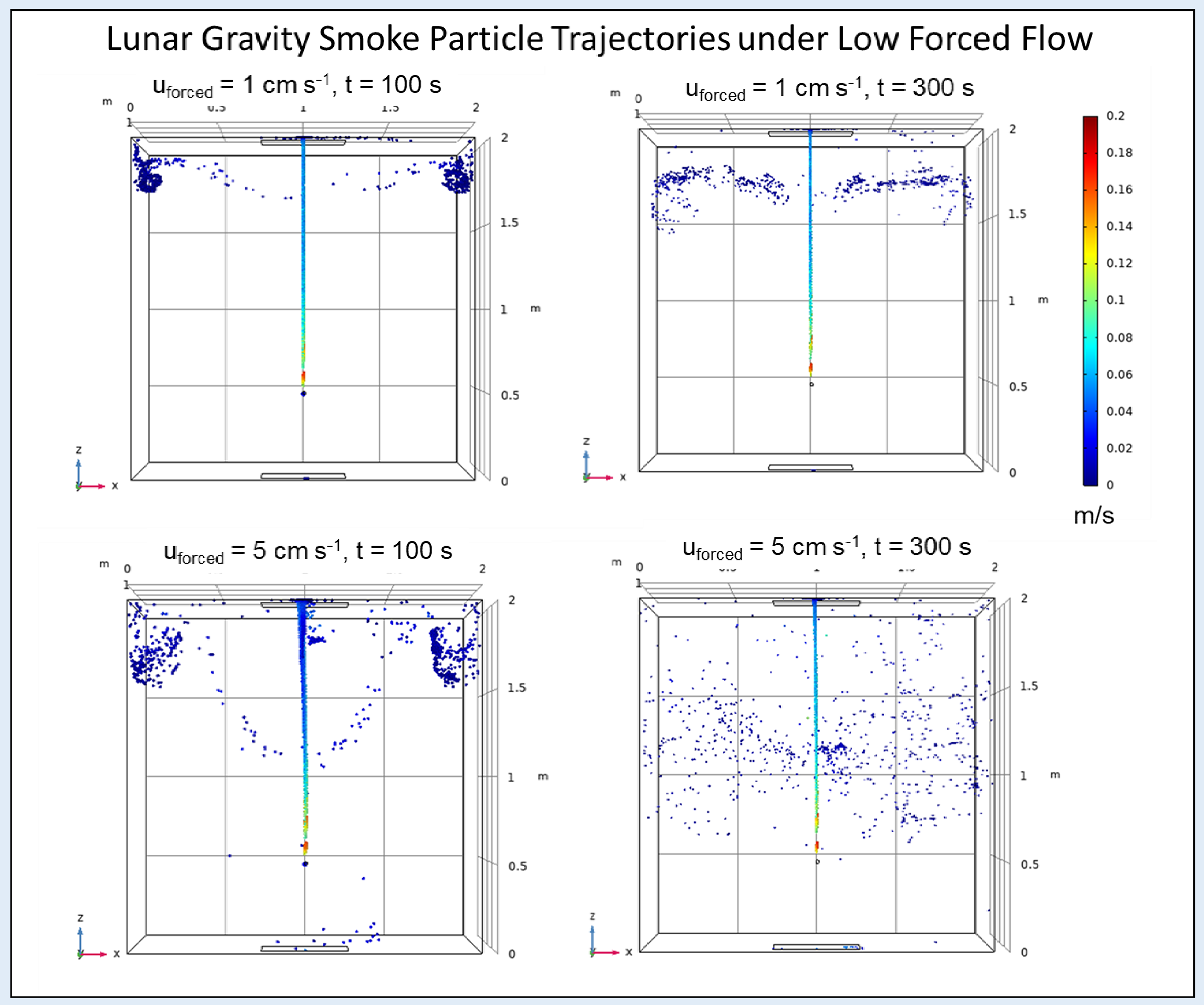
- Newtonian formulation: $F_{Total} = F_{Drag} + F_{Brownian} + F_{Gravity}$
- Massless formulation: particle velocities are the same as velocity of surrounding fluid; **dramatically reduces computation time**
- Particle assumptions: d < 1 um, spherical, density ~1-2 g/cm^3
- With these assumptions, **Re_p < 0.5 with external velocities of 100 cm/s**



Meyer et al., Aerosol Sci. Tech., 49, 5, 299-309, 2015.

Results and Discussion





- In lunar gravity, stratified plume layer is somewhat retained at u_{forced} = 1 cm/s condition, before forced flow path develops
- At u_{forced} = 5 cm/s, particles are mixed into volume at 5 minutes
- **US ECLSS velocity requirements for intramodule circulation: 5.1-20 cm/s (3.6-102 cm/s as lower/upper limits)**
- In a scenario where an early fire occurs near vent flow path, even low forced flow velocities (5 cm/s) can impede development of smoke layer at ceiling

Conclusions and Future Work

What does this mean for future Lunar habitats?

- In Lunar gravity, even very low forced flow velocities can disrupt smoke layer formation
- Smoke detectors ***could*** be placed on ceilings to facilitate earlier smoke detection, but detector placement relative to supplies and returns must be carefully considered

What are the next steps?

- Evaluate different supply/return placements and range of tested flow velocities
  - How does smoke layer development change?
  - Is there an alternative to ceiling/floor placement?
  - **Simplifying assumptions about particle transport must be considered with each scenario**
- Explore different, more realistic early fire scenarios