Mitigating Lunar Dust with Cryogenic Liquids

An effective and synergistic tool with high potential for lunar implementation

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The Challenge

"I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust."

- Gene Cernan, Apollo 17 Technical Debrief

BIG Idea Challenge

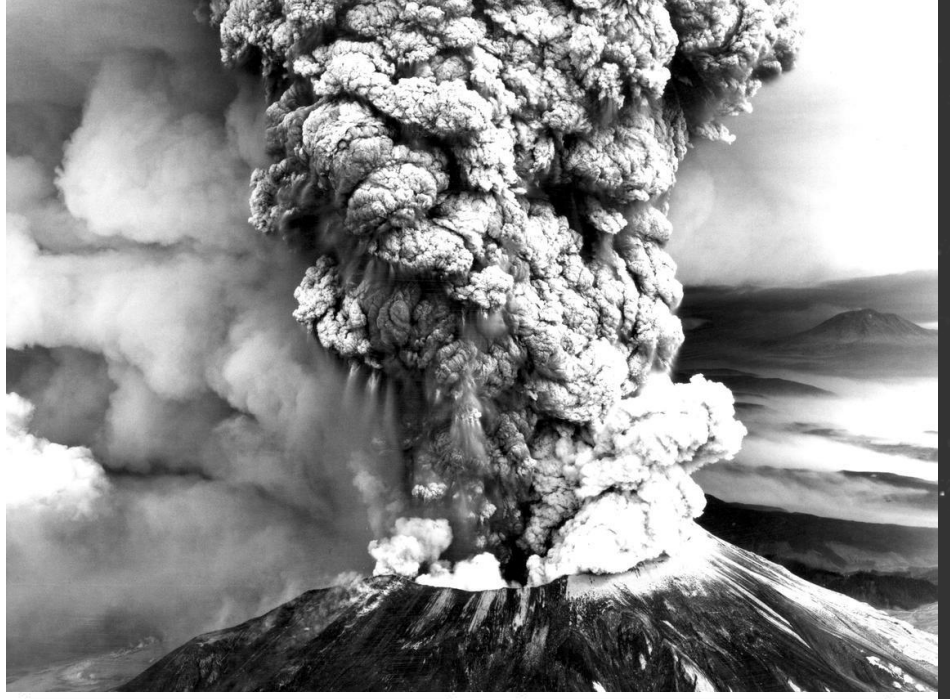
- NASA's Breakthrough, Innovative and Game-changing Idea Challenge:
  - Lunar Dust Mitigation Solutions
- WSU Awarded funds with 6 other schools out of ~70 university applicants
- **The Artemis Award**
  - Awarded for "potential to contribute to and be integrated into NASA's Artemis mission, which aims to land the first woman and person of color on the moon in 2024."
- **Best Technical Paper**

Background

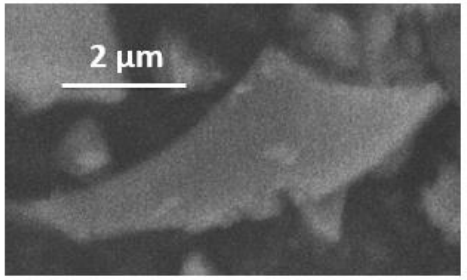
- **Dusting the Floor**
- **Background**
  - No literature on cryogenic cleaning
  - Leidenfrost Effect and Liquid Cryogen Sprays
- **Verification**: TRL 2-5
  - What's the next, simple, effective step?
  - How do we verify the solution for lunar use?

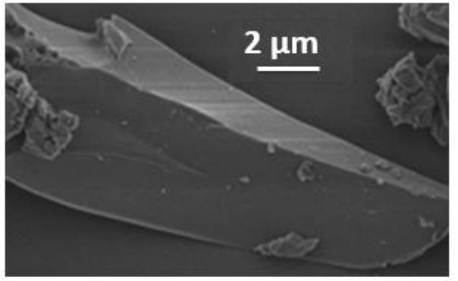
Mt. St. Helens Ash

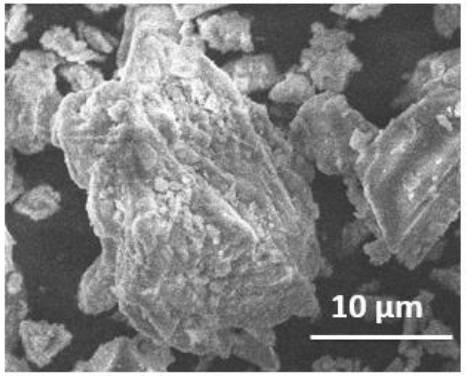
- Need to find some way to replicate moon dust
- Very small, abrasive, jagged, and hazardous.
- Moon Dust from meteor impact
  - Extreme heat and pressure
  - Mt. St. Helens ash was hypothesized to be similar
- WSU stored this ash
  - Collected day of explosion – no weathering

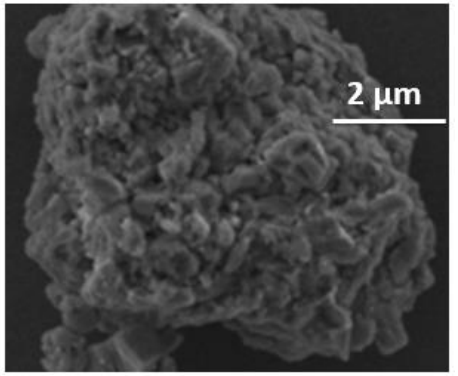


Mt. St. Helens Ash **Lunar Regolith**









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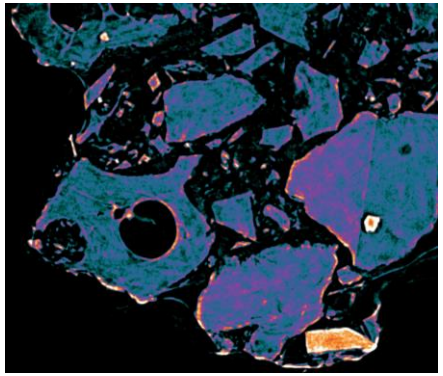
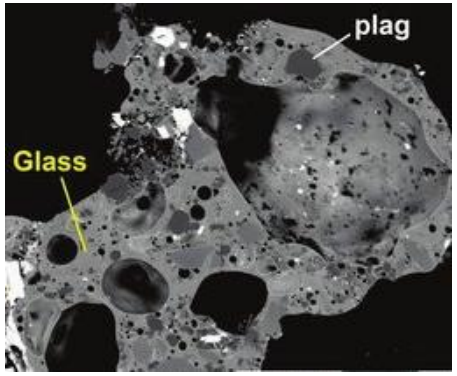




WSU Study: Very similar shape, size, and make-up

Simulating Relevant Environment

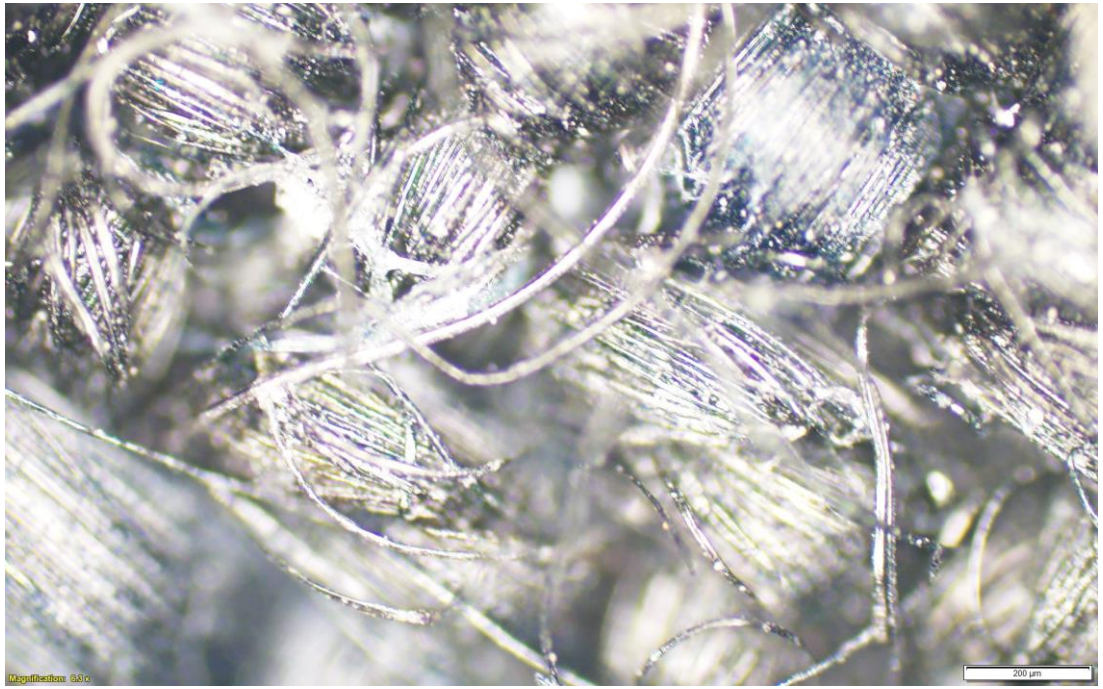
Dust
- Mt. St. Helens ash
- Off Planet Research
  - Lacey, WA
  - One of 2 NASA approved simulants

Suit material
- Ortho-fabric Kevlar
  - High durability

Gravity
- Modelling indicated minimal effect for dusting

Airlock
- Experiment showed similar performance from wide range of pressures - such as in airlock

Cryogen
- Nitrogen used for experiments
- Expect to use liquid air mixture

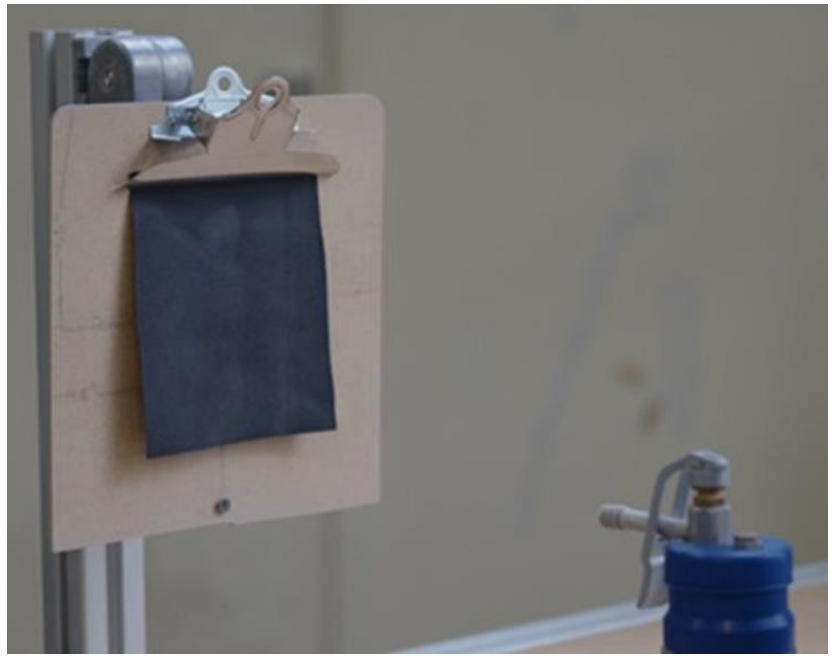


Testing

Video
Early Testing
Testing in a Relevant Environment
Outcomes

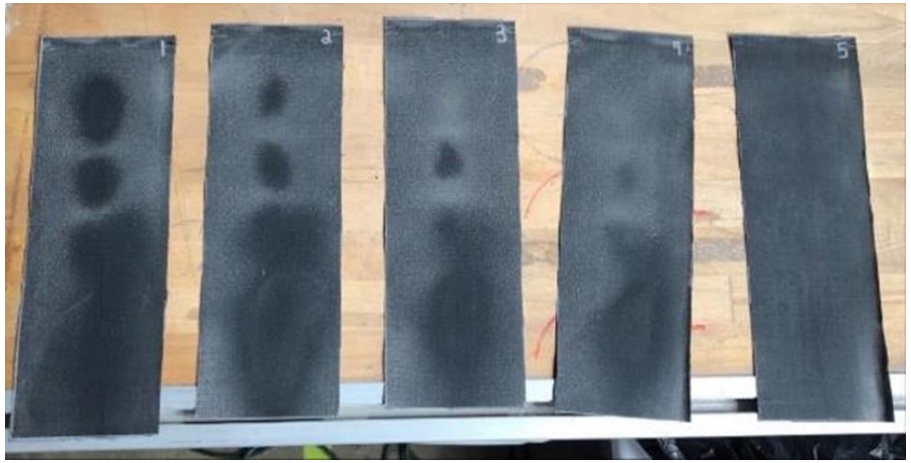
Early Testing

- Preliminary Tests
  - Compressed Air & Liquid Nitrogen Pour
    - Each cleaned roughly 70% of applied lunar simulant
- Liquid Cryogen Sprayer Tests
  - Used a sprayer that is also commonly used in dermatology
  - Being a handheld system, it allowed for large variation in cleaning parameters
  - Cleaned 97% of applied lunar simulant



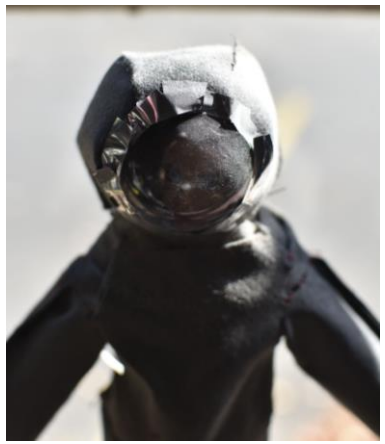
Low-Pressure Testing

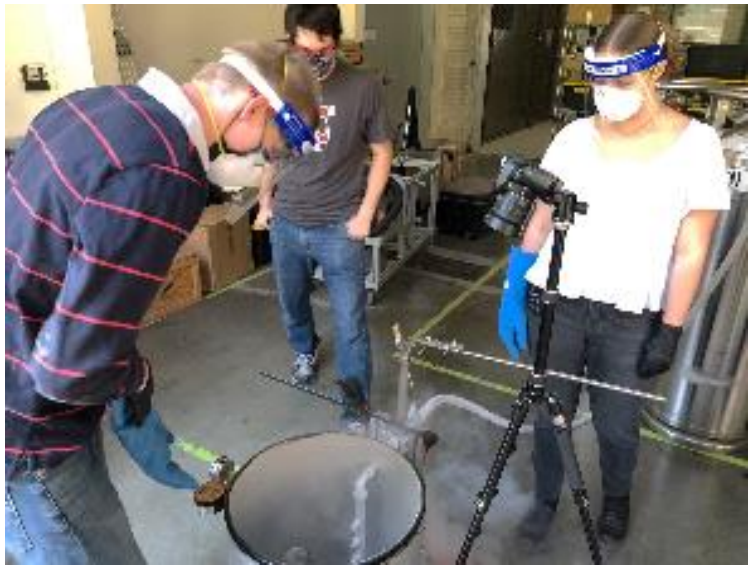
- Single Nozzle Testing
  - Cleaned 98% of applied lunar simulant
  - Spray system cleans in a low-pressure environment
- Spray Bar Testing
  - Cleaned 88% of applied lunar simulant
  - Boiloff within the spray bar resulted in a spray gradient

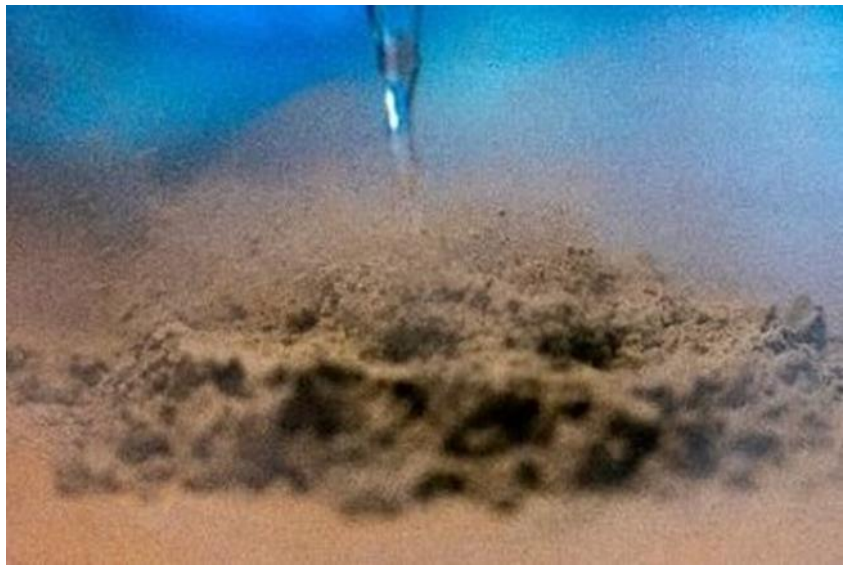


Testing Outcomes

- Constructed a 1/6 Scale Astronaut, Rosie the Coug-monaut
  - Allowed for qualitative tests
- The 592 trials conducted up to this point in the project proved that our proposed system of cleaning is viable for cleaning suits within the lunar habitat, with removals of up to 98% of lunar simulant







Looking Ahead

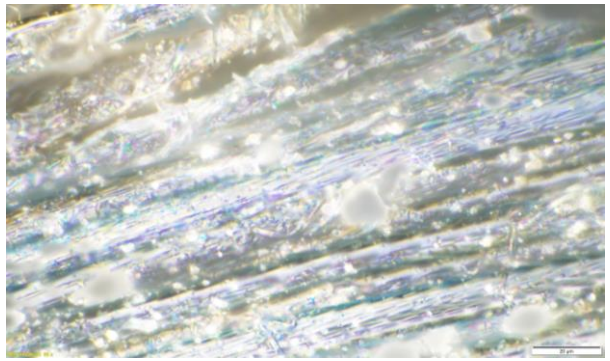
Path to Flight
Future Work

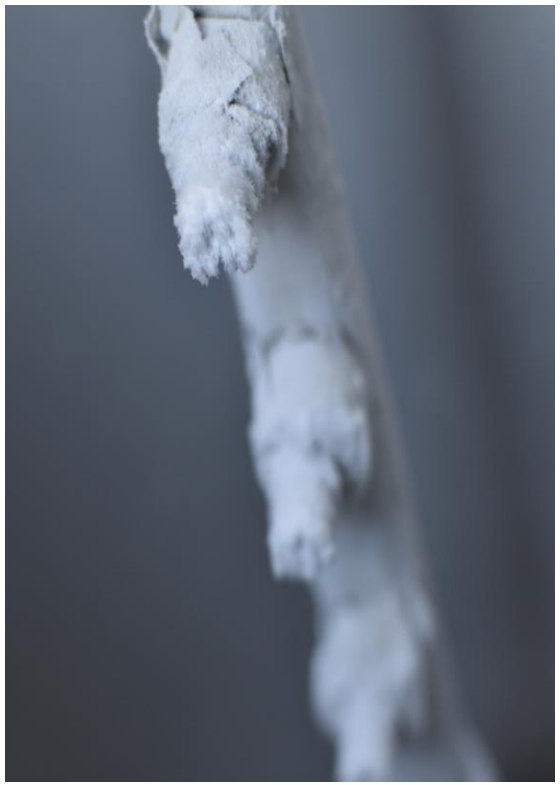
Path to Flight

- Further testing and investigations
  - Impact of multiple washings
  - CFD or low gravity
  - Spray bar shape
- Technology has other potential applications.
- A nitrogen liquefaction method is recommended.
- All components need qualification in a full-scale system.

Path to Flight and Implications

- Further investigation of cleaning mechanisms
- Test removal of electrically charged dust particles
- Exploration of nozzle size, shape, and distance
- Development of a full-sized array
- HVAC system for moisture control when testing
- Low-gravity testing
- Technology can be ready for use on the Moon in the NASA Artemis Missions by 2026.
- Potential application to future Martian missions.





What We Learned

Conclusions

Acknowledgements

Conclusions

- Testing indicates technology will remove dust at high levels
  - Cryogen spray exceeds conventional treatments
  - Qualitative efficacy on 1/6 scale astronaut (Rosie)
  - Recommended parameters established

- Benefits:
  - Synergy with airlock pressurization
  - Low material and power requirements
  - Simple path-to-flight
  - Very high dust removal

- Viable use by 2026 for the NASA Artemis missions back to the moon

Related Opportunities at WSU

- Space Related Research
  - 3D printing with lunar regolith
  - Materials for hypersonic rockets
- Space Related Clubs
  - Cougs in Space: Cube satellite
  - Aerospace club: Rocket competition

WASHINGTON STATE UNIVERSITY

Acknowledgements

University Partners:

Our Team:

WA Industry Partners:

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Thank you!
Questions?