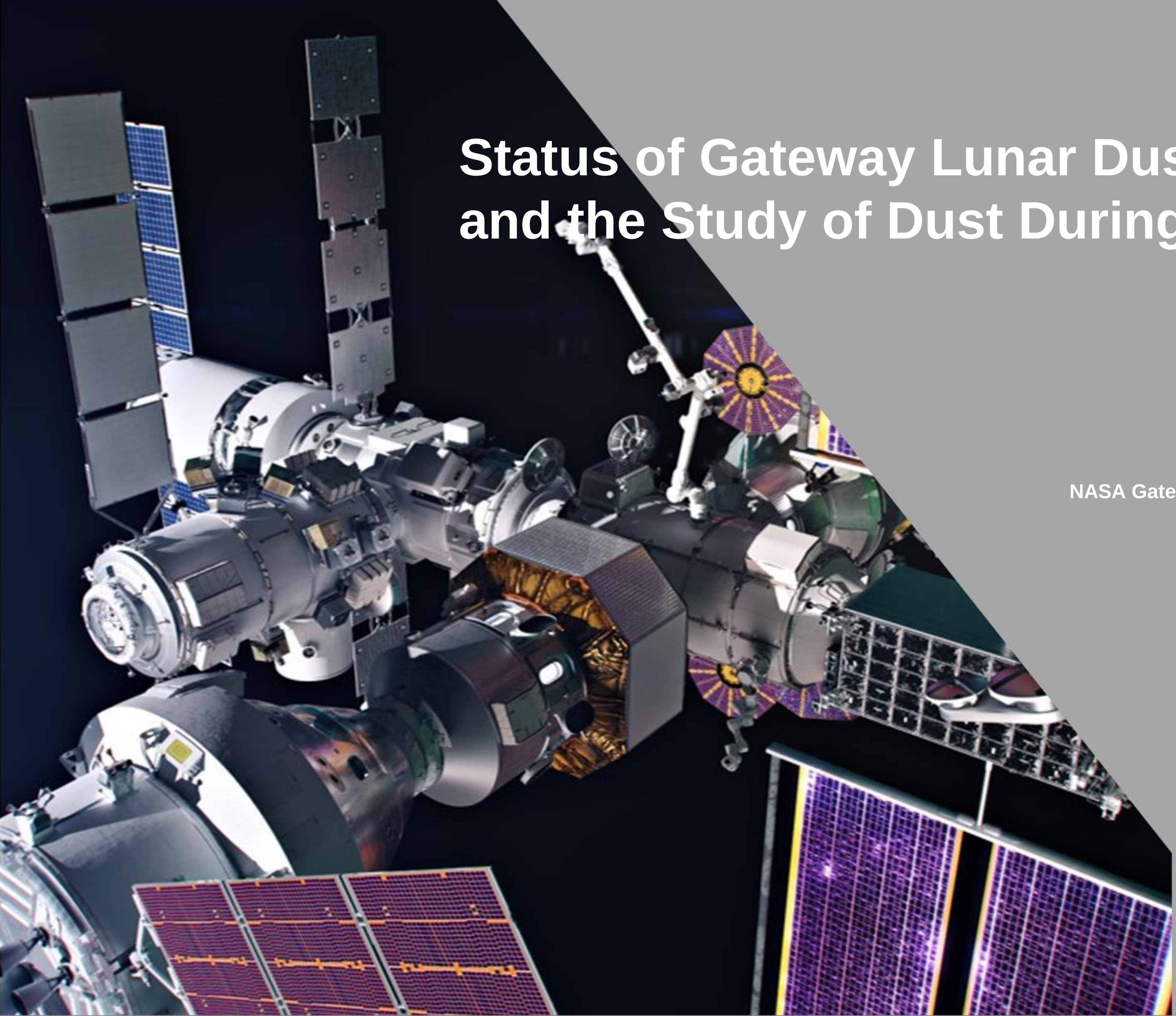
# Status of Gateway Lunar Dust Modeling and the Study of Dust During Docking



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# Overview

## NASA Gateway

- Built with International Partners
- Central to Artemis missions and charting a path to human Mars missions
- Small lunar space station in near-rectilinear halo orbit (NRHO)
- Will support science in orbit and human exploration

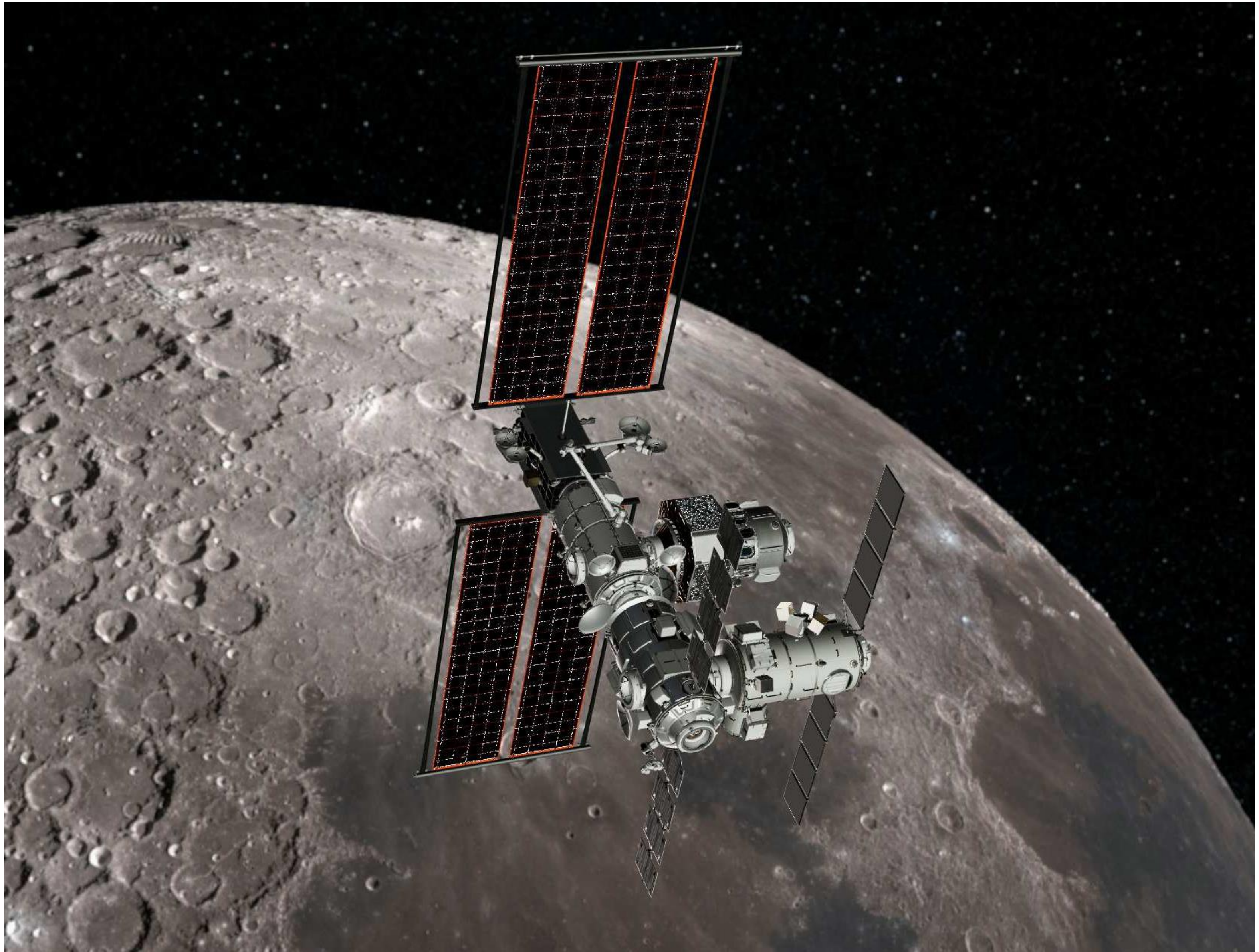

Fig. 1. NASA Gateway CAD. Source: NASA JSC Graphics and Animation Lab. https://nasa3d.arc.nasa.gov/detail/gateway

# Overview

## Lunar Dust

- May be moved due to natural and induced phenomena
- Known to cause hardware performance issues (Apollo)
- Surface assets, e.g., Human Landing System (HLS) vehicles will likely be contaminated

## …and the Problem for Gateway

- HLS vehicles return to Gateway after lunar surface mission
- Gateway dust risk **unique** – several contamination opportunities

## Gateway has two-pronged approach to dust

| Quantify the Problem | Mitigate the Problem |
|---|---|
| • Modeling (GOLDMAP)<br>• Experiments & Testing<br>• In-Situ Data | • Dust Mitigation Strategy<br>• Requirement Development<br>• Mitigation Solutions |

**Table 1. Gateway Program's approach to exterior dust**

# Modeling

# GOLDMAP Study

- Gateway On-orbit Lunar Dust Modeling and Analysis Program (GOLDMAP) developed and used to study potential dust transfer between HLS and Gateway
- Present study to
  - Investigate effect of electric field between HLS and Gateway on dust transfer during docking
  - Inform dust payloads

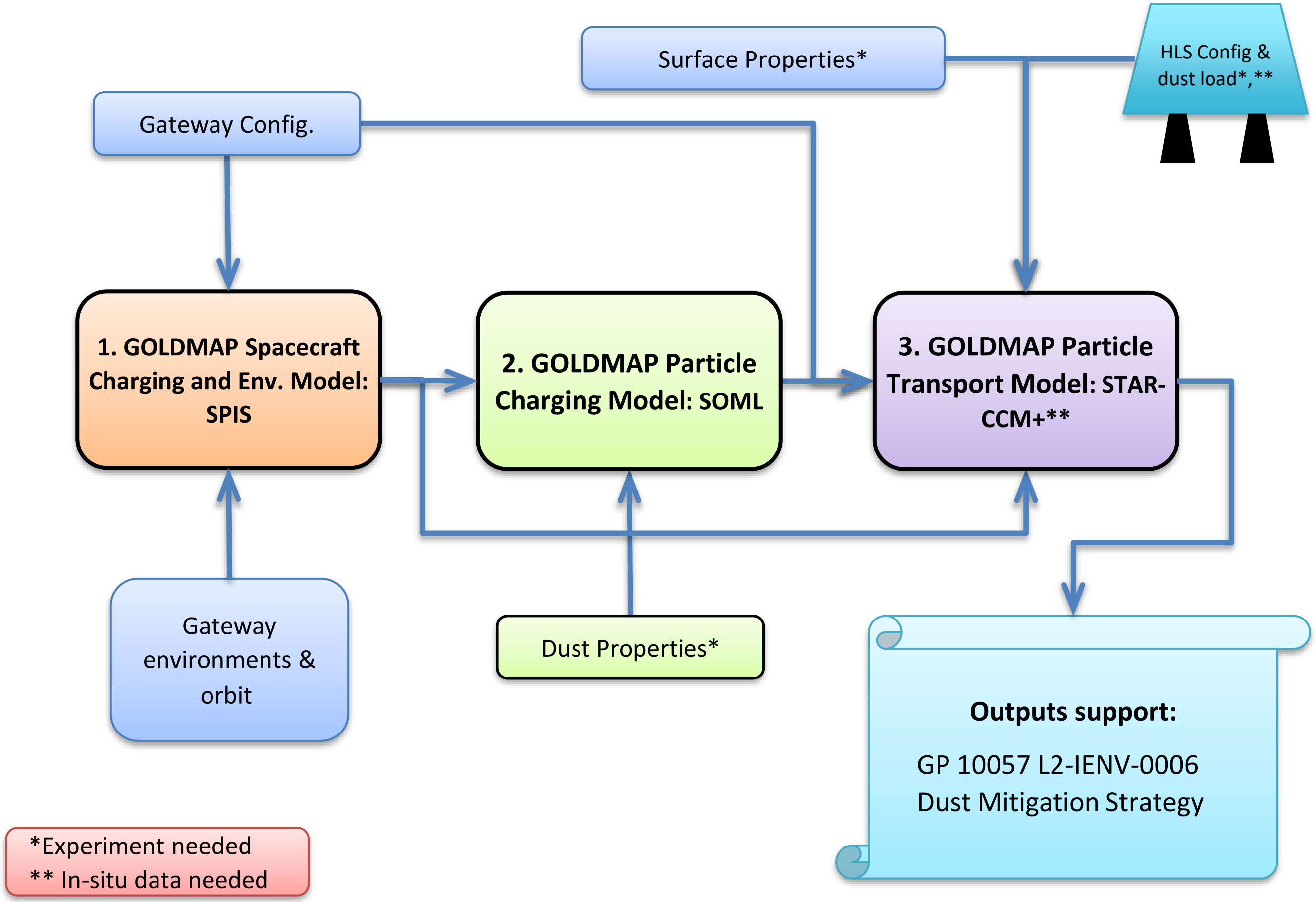


Fig. 2. GOLDMAP Framework

# Case Setup – Dust Transfer at Docking

- Spacecraft charging models run using mean dayside solar wind plasma properties for
  - HLS solo
    - Docking port to sun
  - Gateway
    - PPE, HALO, and IHAB stacked with Orion at HALO –Y, sun in +Y direction
  - Gateway + GRM HLS
    - PPE, HALO, and IHAB stacked with Orion at HALO –Y and GRM HLS at HALO +Y, sun in +Y direction
    - 4, 3, 2, 1, 0.8, and 0.5 [m] separation

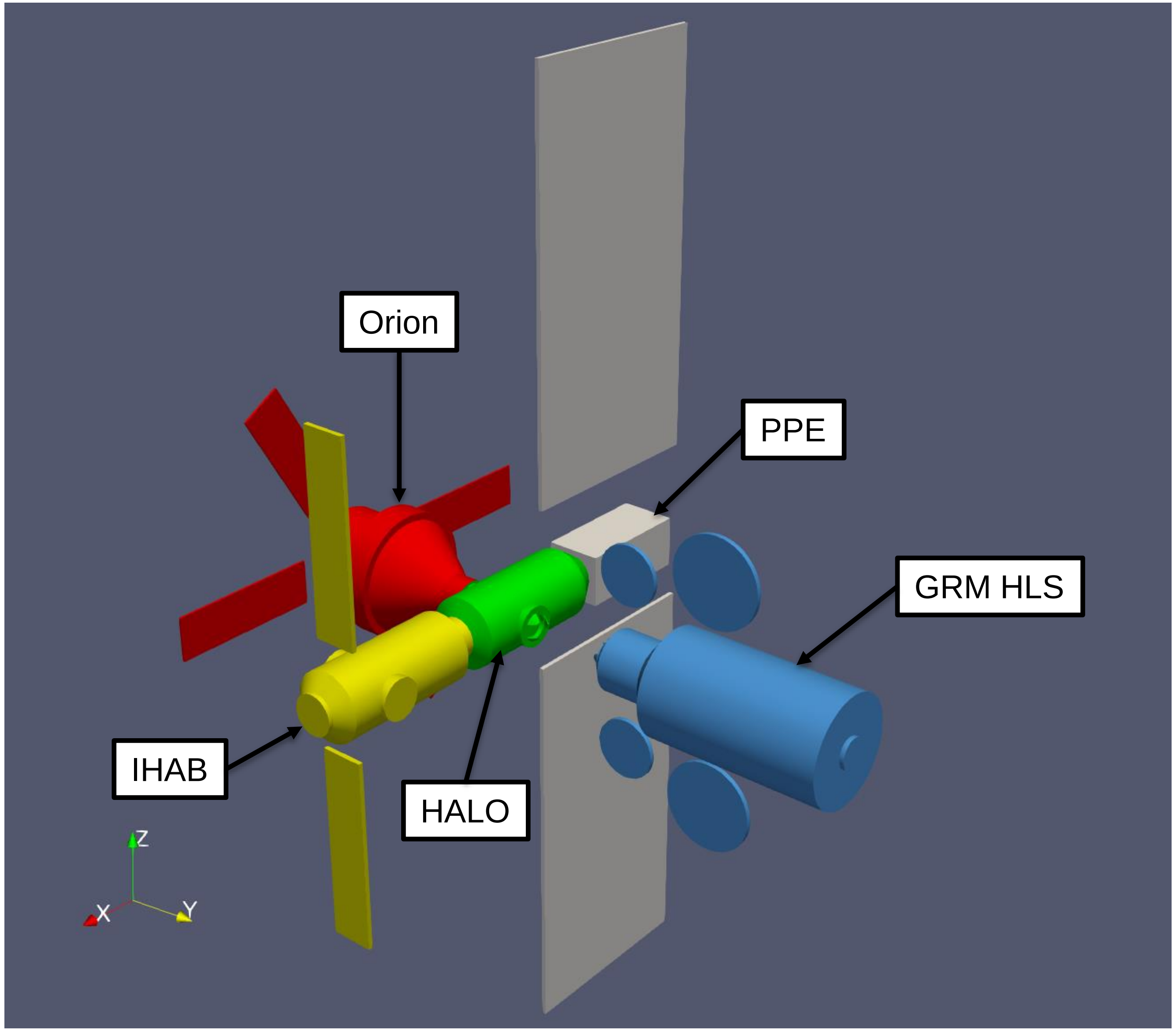


Fig. 3. Gateway with GRM HLS, 4-meter separation

# Case Setup – Dust Transfer at Docking

- Gateway-HLS spacecraft charging cases completed for 4, 3, 2, 1, 0.8, and 0.5 [m] separation
- Solo HLS surface potentials imposed upon HLS discretized docking system surfaces of interest
  - Surface potentials between +0.1V and +10.5V
  - HLS + Gateway cases run with frozen surface circuit solver
  - Csat: ~1E-09 [Farad]
  - SC ground circuit: C (GW GND) (HLS GND) ~1E-10 [Farad]
- Lorentz force calculated for 5e-2, 1.0, and 50 [μm] diameter particles

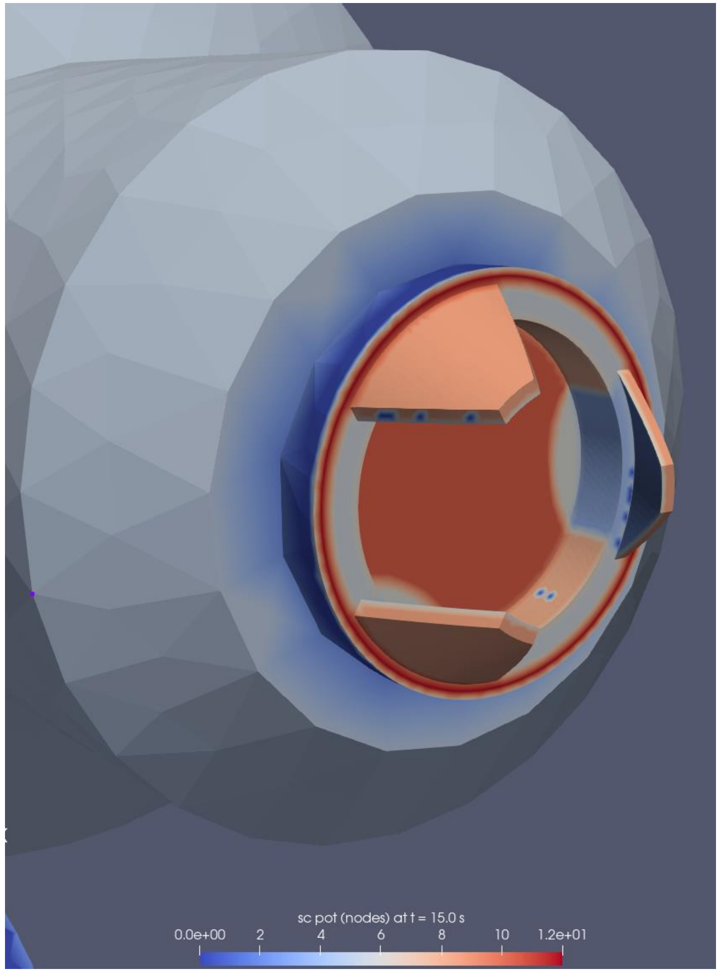

Fig. 4. HLS docking system equilibrium surface potential

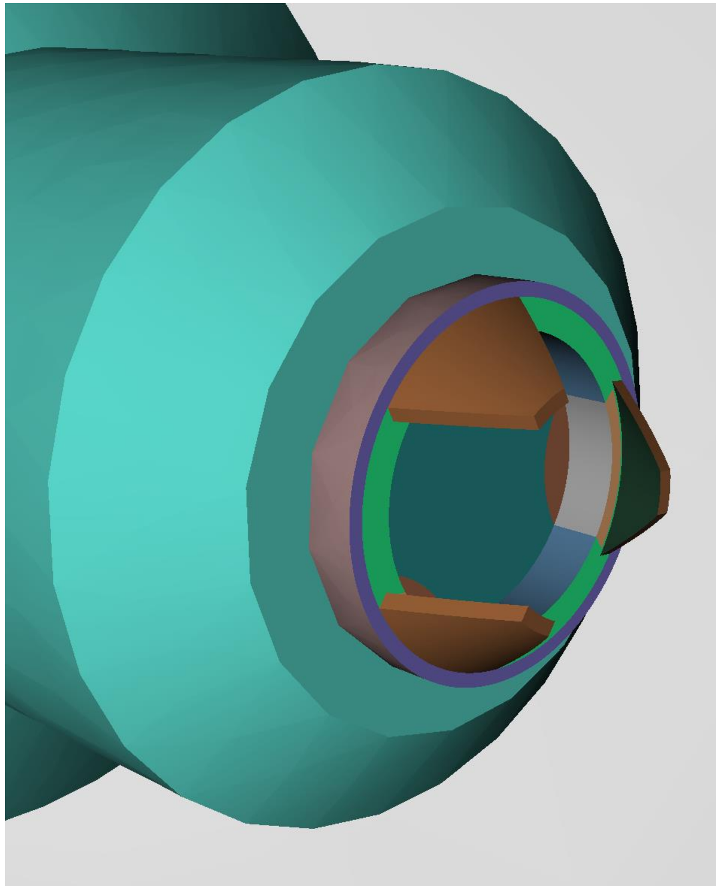
Fig. 5. HLS surface discretization

# Validation Cases

- Assumption: dielectric surface potentials change slowly enough to justify freezing spacecraft surface circuit solver
- Initial validation cases
  - Circuit solver turned on
  - Reduced geometry: HALO with Orion docked at HALO –Y, part of GRM HLS separated from HALO +Y docking port by 2 m along docking axis
  - HLS charged negatively due to ion wake
- Final validation case
  - HLS docking system surfaces charge more positively at 2-meter distance than Dust Transfer case

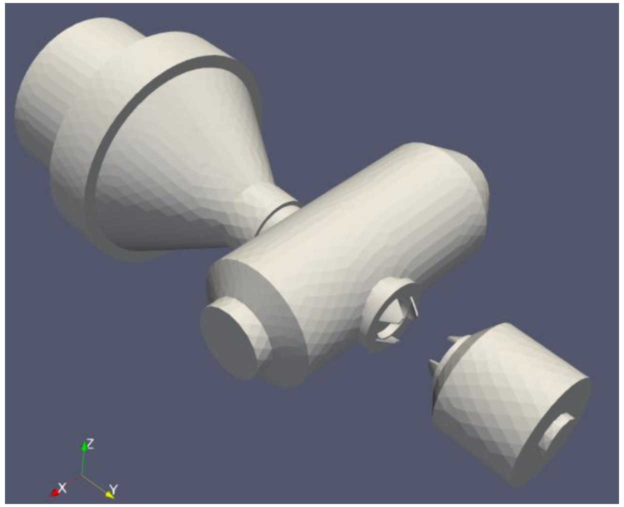

Fig. 6. Initial validation case geometry

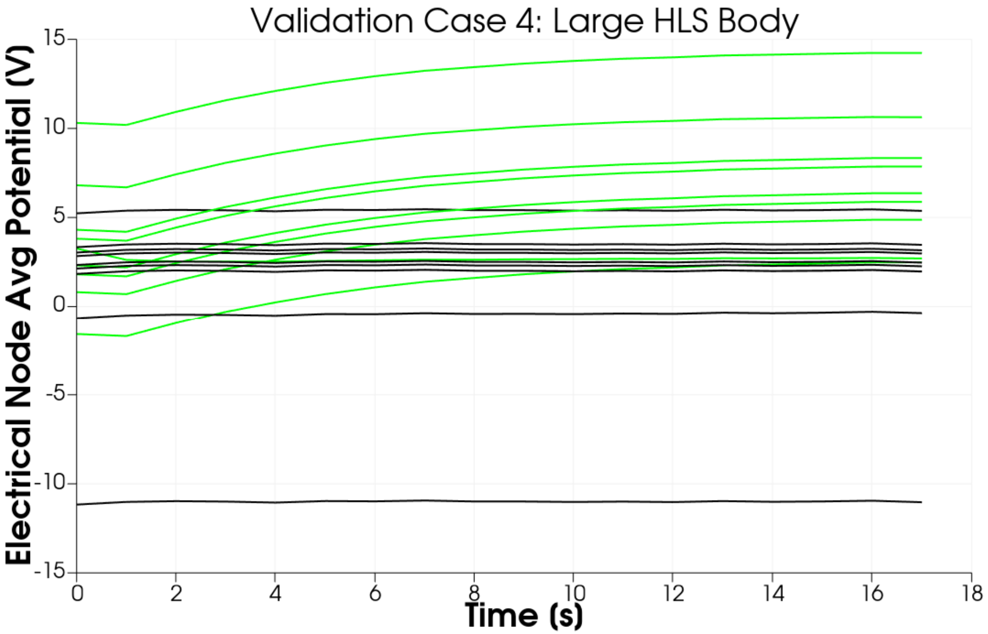

Fig. 7. Validation case 4 electrical node potentials. Black: Gateway, green: HLS

# Results – Dust Transfer at Docking

- Force direction is dynamic
- Dust may impinge or stay stuck to HLS at large separation distances
- Dust may move towards Gateway within 3 meters
- Lorentz force on Case 4 surfaces higher than Dust Transfer case

**Table 2. Grain potential and Lorentz force comparisons**

| | | Mean Grain Potential [V] | | Mean Lorentz Force [nN] | |
|---|---|---|---|---|---|
| Separation Distance [m] | Dust Grain Dia [μm] | Docking Case | Validation Case 4 | Docking Case | Validation Case 4 |
| 2 | 5e-2 | 4.47 | 6.27 | 6.44E+00 | 7.61E+00 |
| | 1 | 3.00 | 4.01 | | |
| | 50 | 3.01 | 3.96 | | |

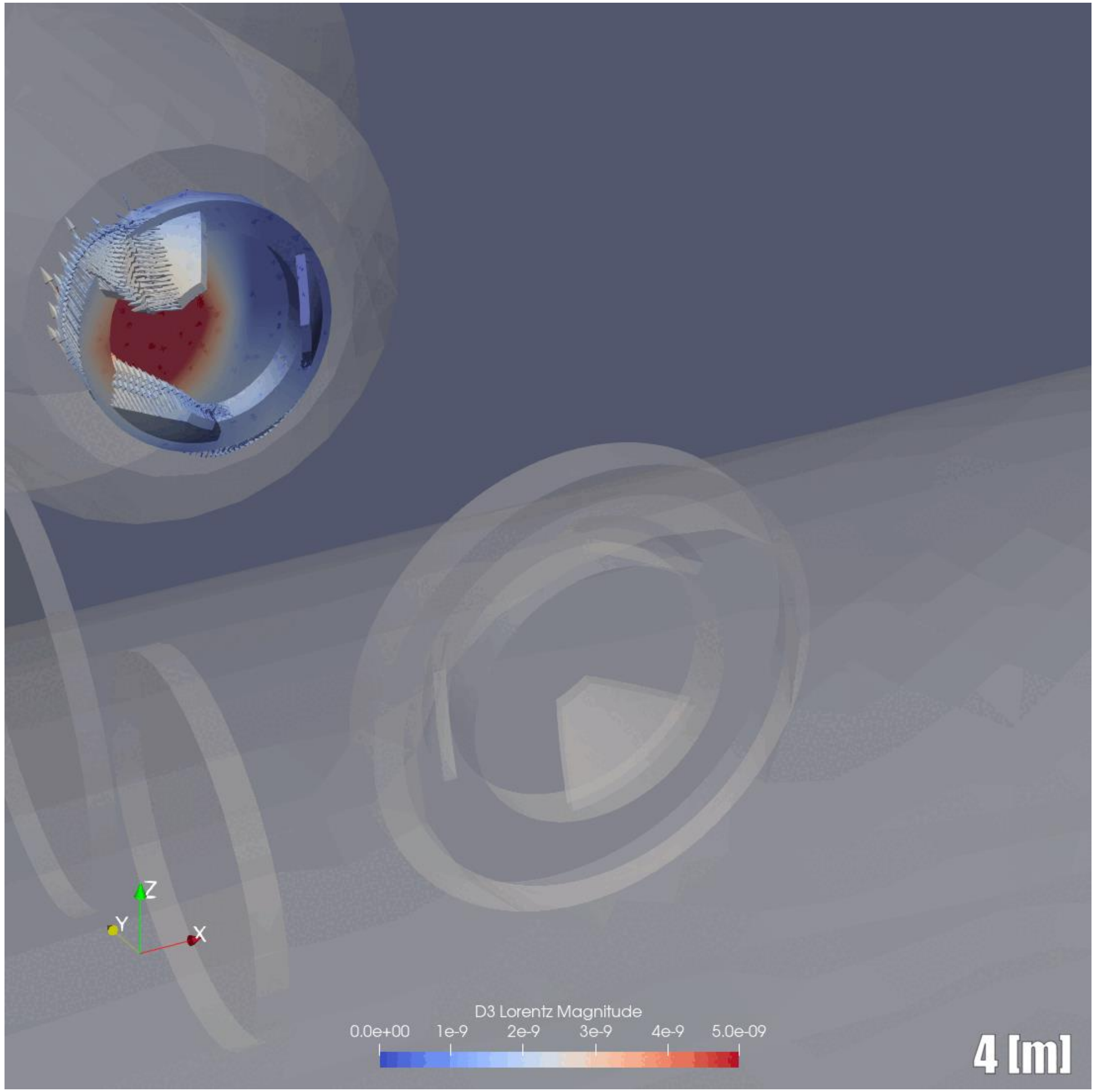


Fig. 8. Lorentz force vector change over 4- to 0.5-meter HLS separation

# Results – Dust Transfer at Docking

- Lorentz force at HLS docking system surfaces increases as vehicle separation distance decreases
- Forces in Table 3 exceed adhesive forces* in Table 4
- Indicates dust may contaminate Gateway docking system

**Table 3. Docking case Lorentz force**

| Separation Distance [m] | Max Lorentz Force, HLS DP Surface [nN] | Mean Lorentz Force, HLS DP Surface [nN] | Min Lorentz Force, HLS DP Surface [nN] |
|---|---|---|---|
| 4 | 4.73E+00 | 2.49E+00 | 2.49E-01 |
| 3 | 1.65E+01 | 8.71E+00 | 8.71E-01 |
| 2 | 1.22E+01 | 6.44E+00 | 6.44E-01 |
| 1 | 1.42E+01 | 7.48E+00 | 7.48E-01 |
| 0.8 | 1.89E+01 | 9.93E+00 | 9.93E-01 |
| 0.5 | 4.22E+01 | 2.22E+01 | 2.22E+00 |

**Table 4. Adhesive force experiment results***

| Percentile | Sample | Condition | Grain size diameter (μm, Barker et. al.) | Adhesion Force (nN, Barker et. al) | Grain size diameter (μm, current work) | Adhesion Force (nN, current work) |
|---|---|---|---|---|---|---|
| 0.98 | Anodized Al | Vacuum + UV | 0.63 | 1.49E-03 | 2.88 | 2.06E-01 |
| 0.5 | | | 0.35 | 3.03E-04 | 0.63 | 2.18E-03 |
| 0.001 | | | 0.13 | 1.31E-05 | 0.17 | 4.47E-05 |

*Results from March 2024, "Gateway Lunar Dust Adhesion", Gateway Lunar Dust Adhesion Team. Testing funded by Gateway Program and performed by NASA JSC/EX2.

# Experiments and Testing

# Secondary Electron Yield of Individual Regolith Grains

- Experiment to measure secondary electron emission of individual regolith grain on-going at MSFC Dusty Plasma Lab
  - Electron and proton beam sources, 5 eV to 2k eV
  - Monochromator emitting at Lyman alpha wavelength
  - Measure secondary electron emission due to incident electrons, protons, and photoemission
  - Gateway Program funded
- Status
  - Apollo 16 Highland Mare sample request approved January 2024 and delivered
  - Several automations implemented
  - Calibrating on JSC-1A
  - ECD end of calendar year 2024
- Investigators: Dennis Gallagher/MSFC DPL Director, PI; Todd Bradley/UCF; Eric Cantrell/MSFC

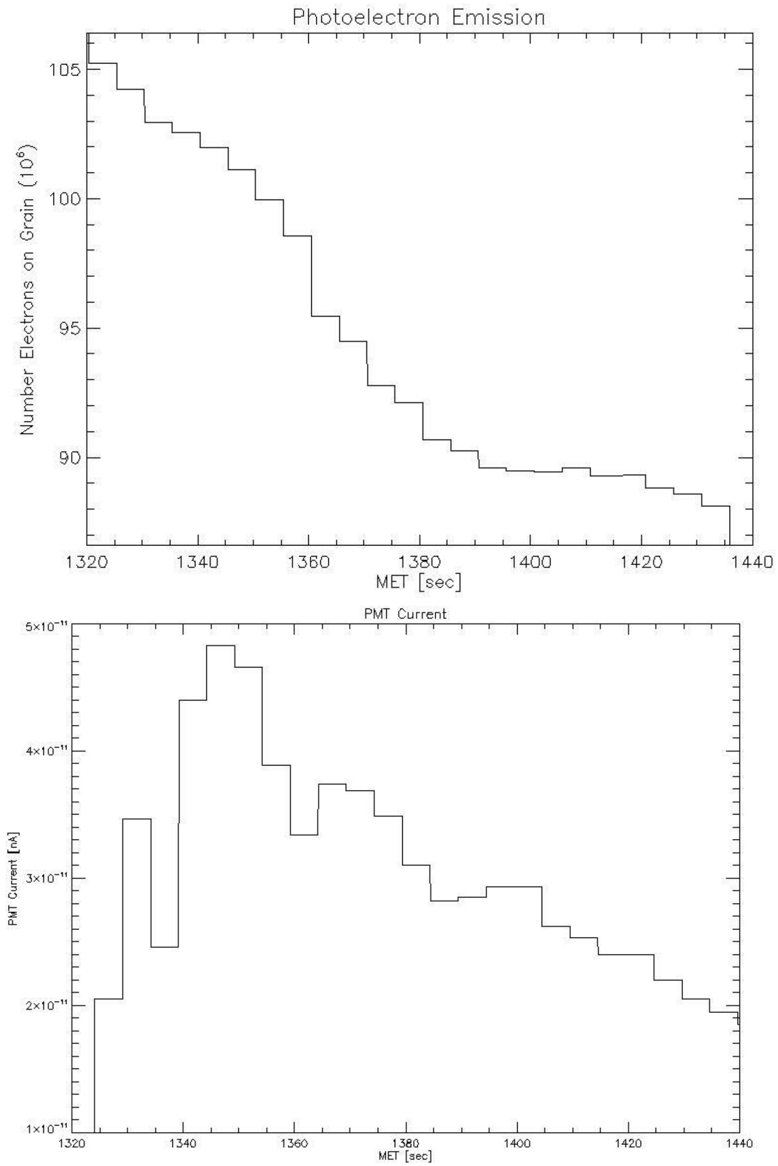


Fig. 9. Recent data, photoelectron emission (top), photomultiplier current (bottom). Source: D. Gallagher, 22 Aug 24

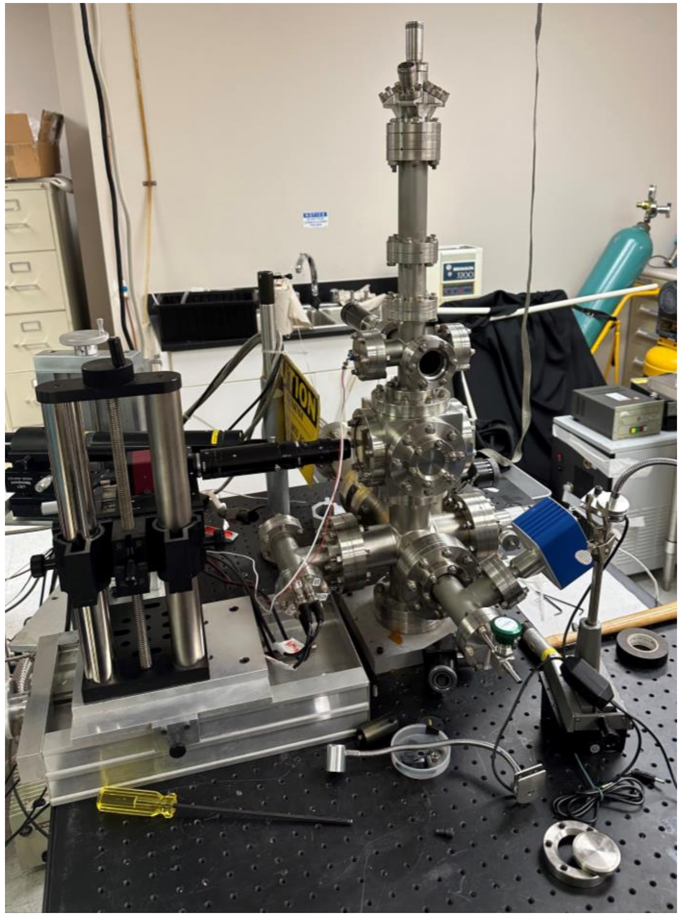

Fig. 10. Experimental apparatus circa October 2023. PC R. Lee

# Adhesion of Regolith to Spacecraft Materials

- Experiment to calculate adhesive force of lunar regolith simulant to spacecraft surfaces as a function of particle size is on-going at NASA JSC/EX2
  - Several improvements implemented to mitigate cohesion, and repeatable, in-vacuum dusting achieved
  - Gateway Program funded
- Upcoming testing
  - Measure 16 samples simultaneously
  - Test 20+ spacecraft materials
  - Perform microscopy after each acceleration bin to provide more complete adhesion data
  - ECD 2024

Gateway Lunar Dust Adhesion Team:
Josh Litofsky, PhD – Principal Investigator
Michael Urrutia – Test Development Engineer
Alejandro Rincon – Hardware Specialist
Jeremy Wilson – Software Engineer
Sonali Nagpal – Microscopy and Image Processing Lead
Amy Fritz and Maria Choi – Gateway Lead

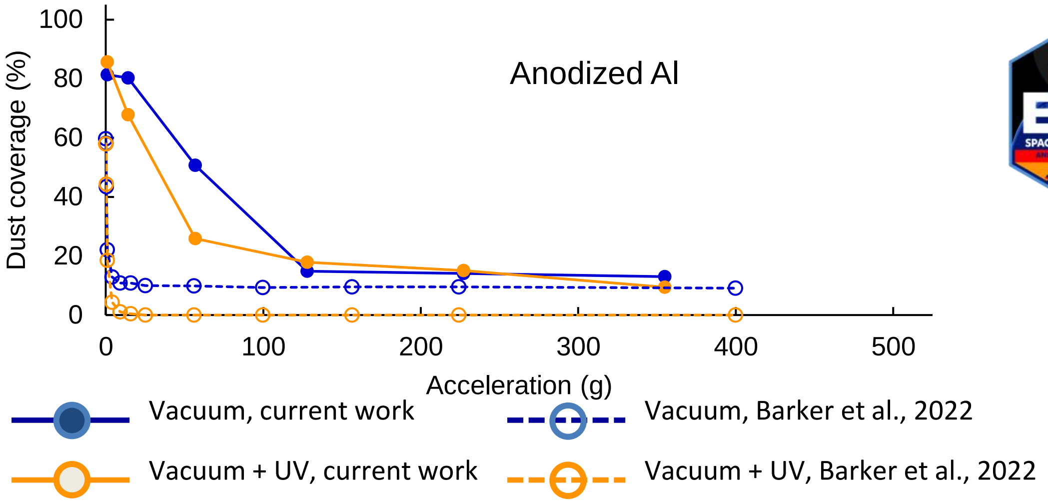


Fig. 11. March 2024 results. Source: Gateway Lunar Dust Adhesion, Gateway Lunar Dust Adhesion Team

Fig. 12. Latest experimental apparatus. Source: J. Litofsky, Aug. 2024, Gateway Lunar Dust Adhesion Team PI

# In-Situ Data

# On-Orbit Lunar Dust Measurement

- **Low Velocity Dust Monitor (LVDM)**
  - Approved on-orbit active dust sensor payload
  - JAXA technology partnership
  - High TRL from Mercury Dust Monitor (MDM) payload on BepiColumbo mission [11]
  - Located on European Radiation Sensors Array (ERSA) on Gateway Power and Propulsion Element (PPE)

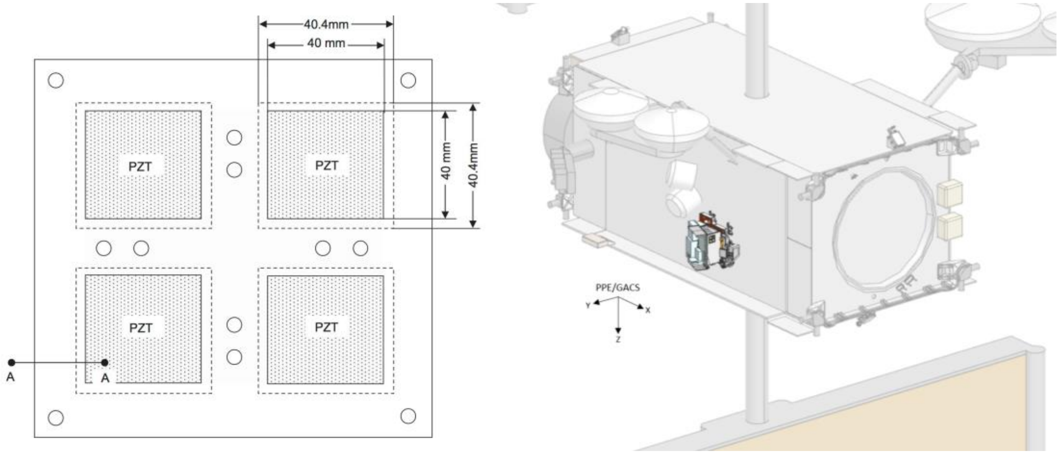


Fig. 13. Left: LVDM sensors [11] . Right: ERSA on PPE

- **Dust collector**
  - Carbon nano tube witness plates
  - High TRL, installed on Tanpopo 1 and 2 and Hayabusa 2 sample container
  - In-work for approval
  - JAXA technology partnership

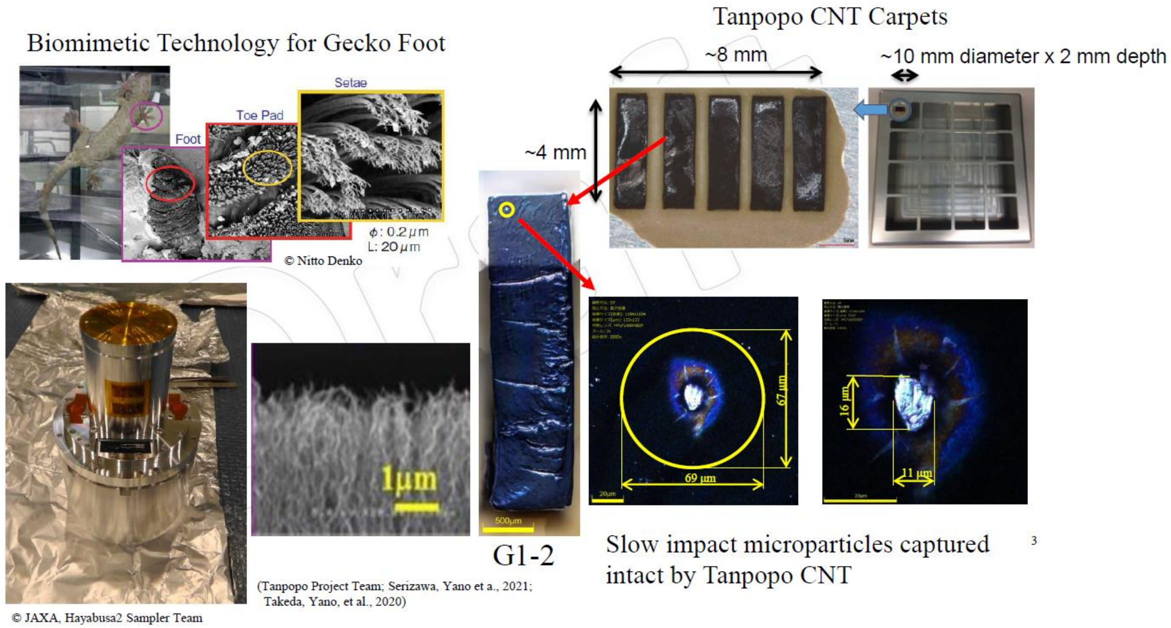


Fig. 14. Dust collector technology overview. Courtesy JAXA

# Conclusions

# Conclusions

- Dust transfer at docking case
  - Electrostatic forces may exceed adhesive forces to docking system surfaces when HLS is approaching Gateway
    - Validation case 4 indicates forces may be higher
  - Dust may impinge Gateway docking system surfaces
  - Supports proposed dust collector proposed on Gateway docking hatches
- Further investigation is needed
  - More realistic validation case geometry
  - Use steady-state snapshots to interpolate a time-dependent model
- Experimental results to be incorporated into GOLDMAP analysis in 2025

# Thank you

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