

2nd June 2026

Organic Inventory – Planetary Protection on the Moon

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Organic Inventory – Planetary Protection on the Moon

1. The Contamination Footprint of Lunar Surface Operations

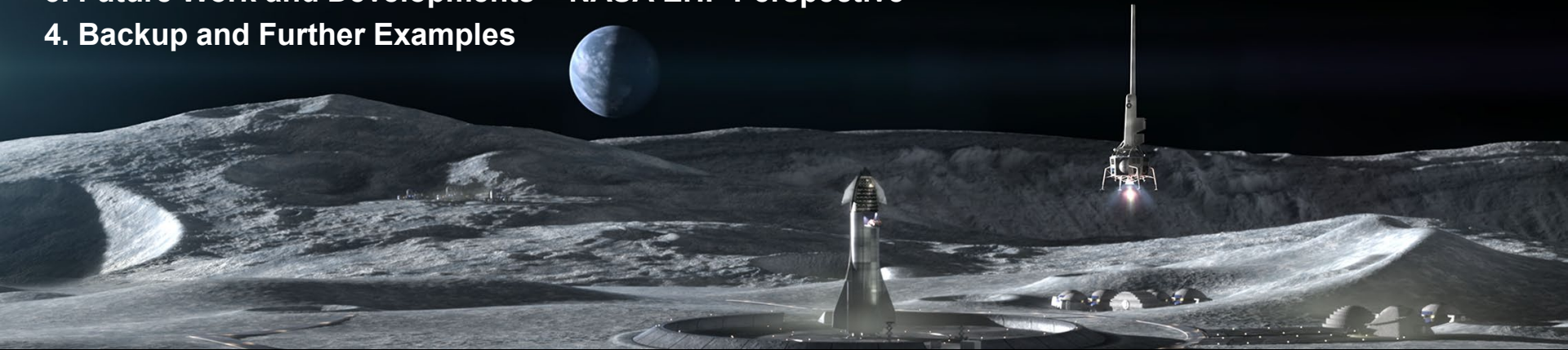
- Example of NASA's Extravehicular Activity and Human Surface Mobility Program (EHP)
- Lunar Surface Molecular Contamination Environment
- A "T-shirt Chart" for Categorizing Lunar Assets
- EHP Insights and Status

2. Defining and Quantifying the Organic Footprint

- The Contaminant Footprint of Landed Spacecraft
- Source Terms: Outgassing, Venting, Plumbing
- Comparing and Contrasting Source Terms
- Modeling Long-Distance Free Molecular Transport

3. Future Work and Developments – NASA EHP Perspective

4. Backup and Further Examples



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Organic Inventory

The Contamination Footprint of Lunar Surface Operations

Carlos Soares & William Hoey

Amentum Space Missions Division, JETS II
NASA JSC ES4 – Space Environments

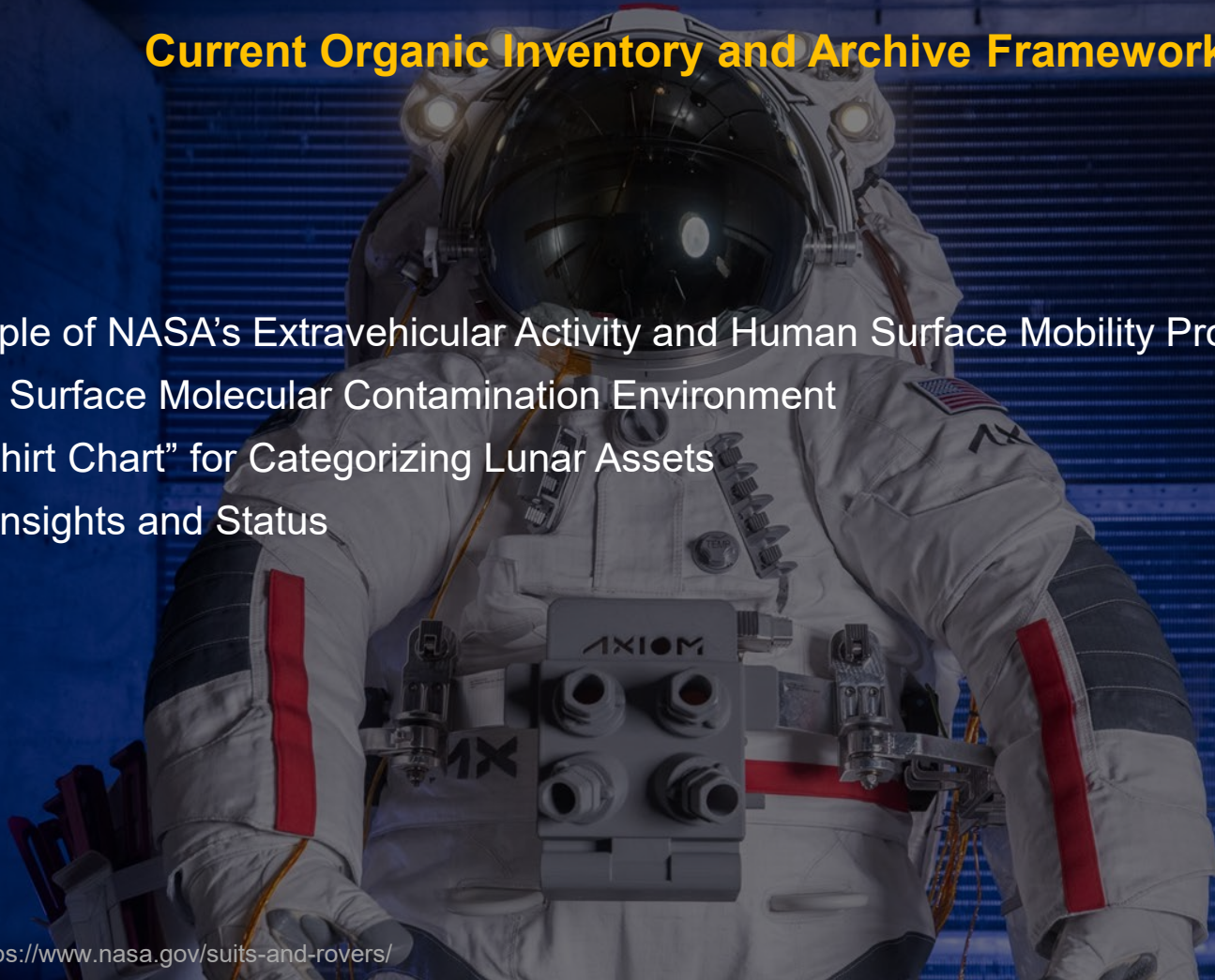
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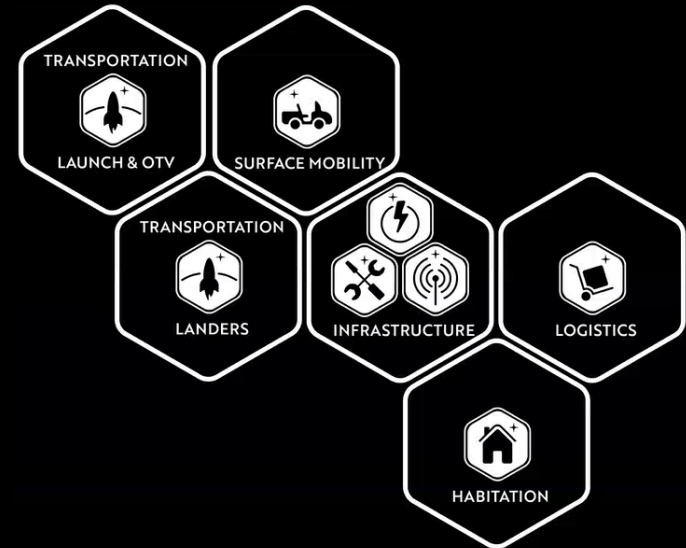
Current Organic Inventory and Archive Framework

- Example of NASA's Extravehicular Activity and Human Surface Mobility Program (EHP)
- Lunar Surface Molecular Contamination Environment
- A “T-shirt Chart” for Categorizing Lunar Assets
- EHP Insights and Status



Extravehicular Activity and Human Surface Mobility Program

- The **Extravehicular Activity and Human Surface Mobility Program (EHP)** serves as NASA's program to develop next-generation spacesuits, human-rated rovers, robotic rovers, EVA tools, and the spacewalk support systems that will enable astronauts to conduct lunar surface operations. See: <https://www.nasa.gov/suits-and-rovers/>.

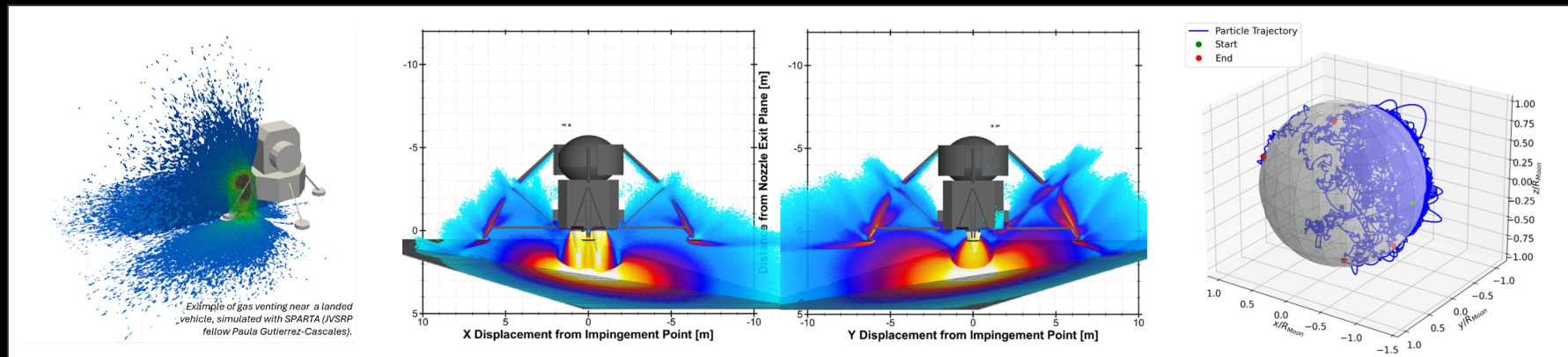


Lunar Surface Molecular Contamination Environment

Lunar landing vehicles and surface assets generate molecular contamination that alter the lunar environment and will affect EHP.

- Landed spacecraft contribute **pluming** sources in descent and ascent.
- Landed spacecraft and surface assets also contribute **materials outgassing** and **venting** (propellant, ECLSS, crew waste, etc.)

These sources of contamination are also relevant to Planetary Protection and planetary science, particularly for organic molecules!

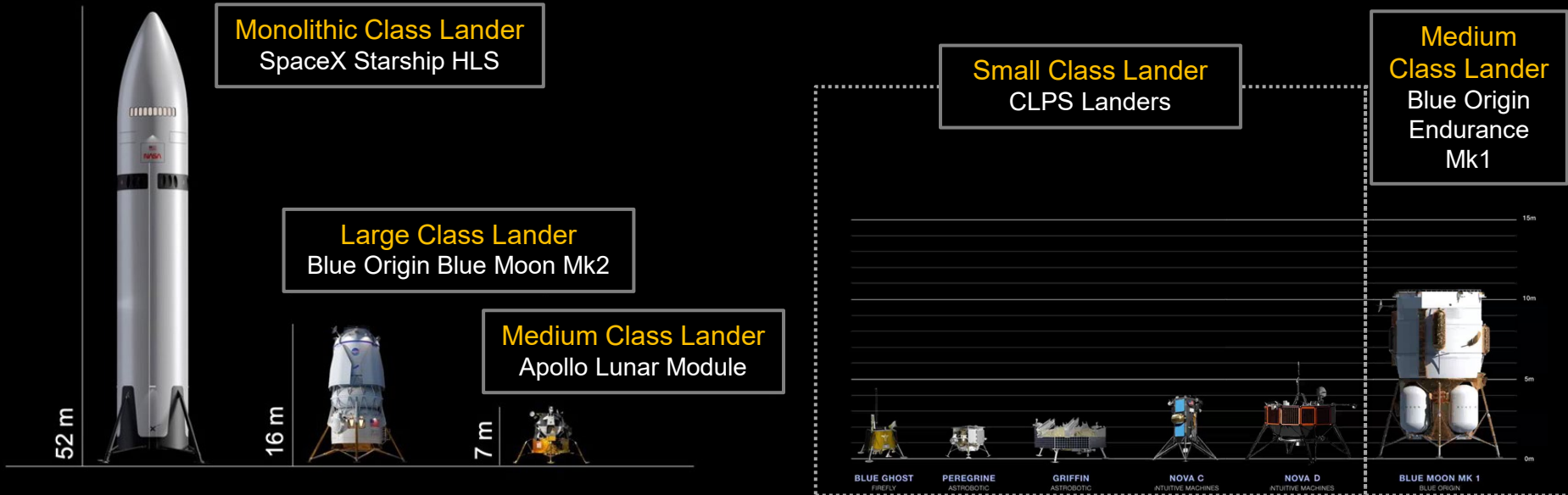


Landed vehicle local- and lunar-scale models of molecular contamination from venting and plume effects.

Left: Hoey et al. (2025), LPSC. | Center: Hoey et al. (2023), ICES. | Right: Alves Hailer et al. (2024).

Lander Classes - Magnitude

- Characterizing the lunar surface molecular contamination environment is important for EHP assets and operations.
- Lander class/size will be a major driver in landing site alteration and the 'organic footprint' of lunar surface operations.

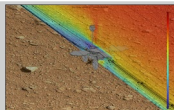
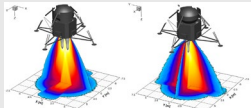
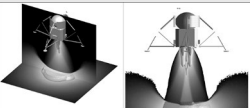
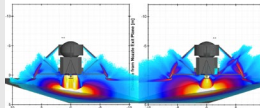
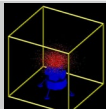
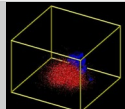
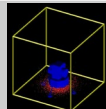


Lander Classes – the “T-Shirt” Chart



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An initial study proposed at the 2024 NASA HQ Planetary Protection Organic Inventory Workshop* targeted an order-of-magnitude characterization of organic contamination and landing site alteration for selected thresholds (i.e., a broad composition and radius of organic contamination) given typical spacecraft contamination vectors.

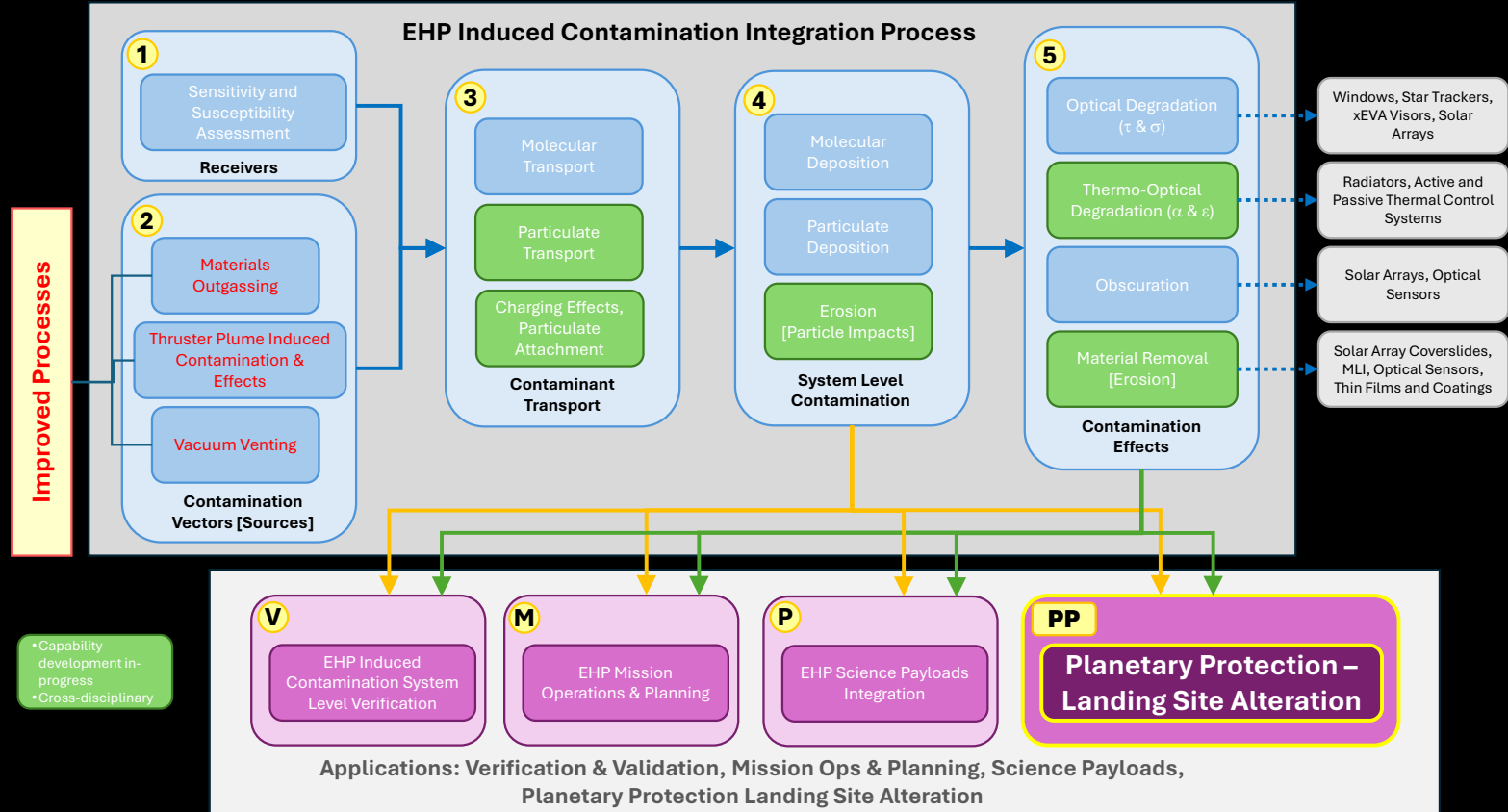
Lander Type				
Organic Contamination Vector	Small Lander (CLPS Class lander)	Medium Lander (Apollo Class Lander)	Large Lander (Blue Origin Concept)	Monolithic Lander (SpaceX Starship)
Materials Outgassing	<i>Radius and broad composition of organic contamination for selected thresholds</i>			
Thruster Plume Induced Contamination				
Vacuum venting (vehicle and science payloads)				
Leakage				

*Reference: <https://sma.nasa.gov/sma-disciplines/planetary-protection/planetary-protection-workshop/agenda>

EHP Proposed Induced Environments Integration Process

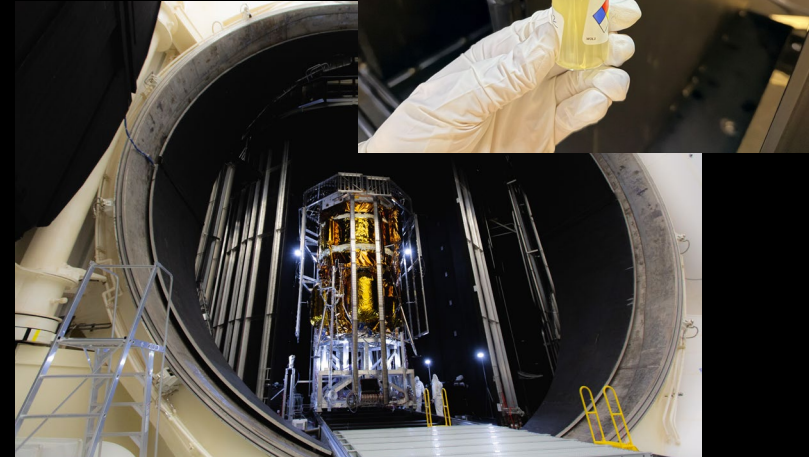
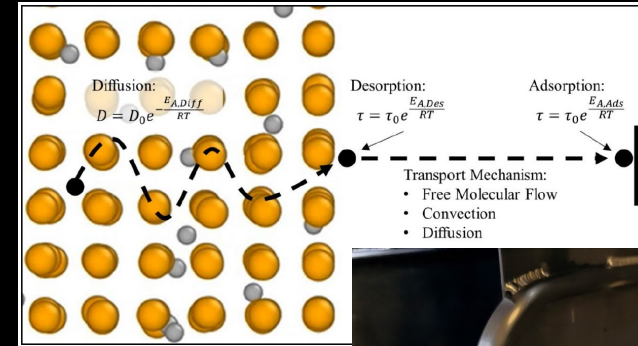
- The proposed process for evaluation of **landing site contamination** from EHP integrated lunar surface operations described here is awaiting evaluation and approval by Program Review Boards.
- Proposed process characterizes:
 - Induced contamination vectors:
 - Materials outgassing, thruster plume effects, and vacuum venting
 - Molecular and particulate transport
 - Contaminant deposition and attachment to surfaces
 - Contaminant effects, impacts to systems/science performance and threats to survivability
- Proposed process is based on heritage from ISS, Gateway, Mars 2020 and Europa Clipper, and includes improvements from capability development from recent program applications (Gateway, Mars 2020, Europa Clipper, Europa Lander)
- Deliverables support EHP integration & requirements verification, and have direct application to lunar surface operations, integrated mission planning, science operations **and the Planetary Protection and planetary science disciplines.**

EHP Proposed Induced Environments Integration Process



Insights from EHP: Improved Characterization of Materials Outgassing

Characterization of Materials Outgassing	Responsibility
Materials lists (non-metallics) • Identification • Vacuum exposed surface areas • Operating temperatures	Input from each surface element
Materials outgassing rate data	Input from each surface element * This can also be performed by EHP Induced Environments
Thermal-vacuum data • Condensate collection • Witness surfaces • QCM, RGA and QTGA data	EHP Induced Environments product
Materials outgassing source terms	EHP Induced Environments product



2nd June 2026

Organic Inventory

Defining and Quantifying the Organic Footprint

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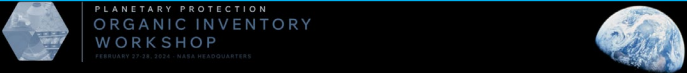


Understanding Source Terms



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In the 2024 NASA HQ Planetary Protection Organic Inventory Workshop,* the authors presented detailed characterizations of **outgassing**, **venting**, and **pluming** as contamination source terms based on engineering experience with NASA programs and projects including Mars 2020, Europa Clipper, ISS, and Lunar Gateway.



Engineering Models
Organic Contamination From Venting and Leakage (Environmental Control, Life Support Systems, IVA Science and Spacecraft Systems) - The ISS Experience

Carlos Soares
Principal Engineer | Group Supervisor - Contamination Control Engineering
Jet Propulsion Laboratory, California Institute of Technology
February 27-28, 2024



Refer to the presentations linked in these images for more information!



Engineering Models:
Thruster Plume-Surface Interactions, Landing Site Alteration, Organic Footprint and Acceleration / Dispersion of Dust and Regolith

William A. Hoey, PhD
Technologist, Propulsion, Thermal and Materials Engineering Section
Jet Propulsion Laboratory (JPL), California Institute of Technology
February 27 & 28, 2024



Outgassing Contaminant Species Extraction, Characterization and Modeling

John M. Alred, Maxwell G. Martin, William A. Hoey,
Carlos E. Soares

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This document has been reviewed and determined not to contain export controlled technical data.

*Reference: <https://sma.nasa.gov/sma-disciplines/planetary-protection/planetary-protection-workshop/agenda>

The Contaminant Footprint of Landed Spacecraft

The “footprint” of a lunar surface asset encompasses:

- The total amount of *contamination* introduced by a spacecraft into its environment (potentially across the solar system body onto which it has landed) by all processes across the spacecraft’s life during and after its landing.
 - A subset of this is ‘*organic*,’ including a range of carbon compounds as simple as methane (CH_4) commonly borne by spacecraft, not necessarily biological.
- A spacecraft’s footprint may include both lofted / volatile and surface-deposited contaminants of *molecular, droplet or particulate nature*, and it *will evolve transiently* as contaminants are generated and transport.
 - Over long timescales, e.g., years, we could evaluate a spacecraft’s organic contamination footprint as a steady-state contribution to its environment including deposition into distant regions of science or ISRU interest.
 - Each spacecraft or lunar surface asset will contribute its own footprint.

The Contaminant Footprint of Landed Spacecraft

The “footprint” of a lunar surface asset – its contributions of organic molecular contaminant to the lunar environment inclusive of release, transport, loss, and deposition processes – encompasses:

1. **Source terms**: high-level inventory of organic contaminants released by lunar surface assets.
 - *Common materials used on such vehicles and their available outgassing characterizations, &*
 - *Common propulsion systems used on such vehicles and their primary plume byproducts, &*
 - *Common modes and quantities of vented material, e.g., through passivation, ECLSS, etc.*
2. **Loss terms**: high-level models for loss processes relevant to species of organic contaminant.
 - *Photodissociation and ionization; related surface chemistry;*
 - *Gravitational or thermal escape (loss of molecules to space); &*
 - *Adsorption / desorption onto the lunar surface and permanent deposition into ‘cold traps’ like PSRs.*
3. **Transport terms**: **a probabilistic free molecular transport model** for organic molecules from release and their first contact with the lunar surface until their loss, that can compare and report on each generation and loss process (i.e., which are driving, and for which class of vehicle?)
 - Examples of RGD/FM frameworks for, e.g., water transport in lunar landings have been published by [Prem et al. 2020](#) and [Farrell et al. 2024](#), and recently also for methane by [Paiva and Sinibaldi \(2025\)](#).

See also: Hoey, W., Soares, C., 2024. “Engineering Models: Thruster Plume-Surface Interactions, Landing Site Alteration, Organic Footprint and Acceleration / Dispersion of Dust and Regolith,” Invited presentation, NASA Office of Planetary Protection Organic Inventory Workshop. [Link](#)

Repurposed from “**The Footprint of Landed Spacecraft in Near-Vacuum: Contamination Sources and Transport Terms**,” by Hoey et al., presented at the 33rd International Symposium on Rarefied Gas Dynamics, July 2024. JPL CL#24-3655. <https://doi.org/10.48577/jpl.QCQ97L>

Source Terms: Outgassing

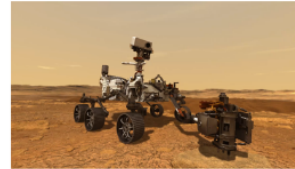
Material outgassing is a predominant source of molecular contamination in vacuum.

Example **receiver** surface onto which adsorption occurs

$$\text{Adsorption/ Desorption: } \frac{dm}{dt} = \frac{m}{\tau_{ads}} e^{\frac{E_{A,ads}}{RT}}$$
$$\tau_{ads} = \tau_0 e^{\frac{E_{A,ads}}{RT}}$$

Figures by co-author J. Alred, derived from: Alred, J., et al. 2024. "Outgassing Contaminant Species Extraction, Characterization and Modeling," Invited presentation to the NASA Office of Planetary Protection - Planetary Protection Organic Inventory Workshop. See also: [DOI](#)

Mars 2020



Alred, J., Martin, M., Hoey, W., et al., 2020. Proc. v. 11489, SPIE Systems Contamination; 1148904. [DOI](#)

Mission: Sampling Mars with objectives to detect organic signatures

Instrument: Returned samples, multiple instruments

Threat: Outgassing contaminants condensing within sample tubes could jeopardize detection

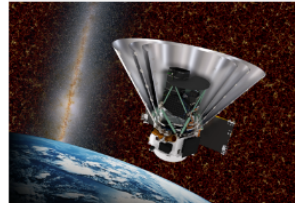
Mars Sample Return



Alred, J., Martin, M., Hoey, W., Soares, C., 2024. NASA Office of Planetary Protection - Planetary Protection Organic Inventory Workshop. [NASA VPJ Link](#)

Life detections instruments require understanding of contamination chemical constituents to guarantee unambiguous detection

SPHEREx



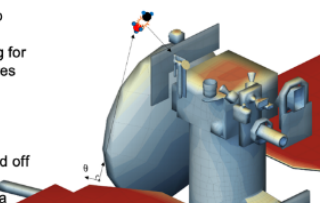
Alred, J. et al., 2021. Proc. IEEE Aerospace Conference. [DOI](#)

Mission: Scientific objectives to image biogenic molecules in the universe

Instrument: Optical characterization

Threat: Water and other biogenic molecules outgassing condensing in telescope causes severe attenuation of throughput

Europa Clipper



Soares, C., Hoey, W., Anderson, J., Ferraro, N., 2019. Proc. 70th Int'l Astronautical Cong. IAC-19-D5.3.12.x50567. [DOI](#)

Mission: Objectives to sample Europa's atmosphere, including for organics / biosignatures

Instrument: Mass spectrometer

Threat: Outgassing contaminants reflected off atmosphere induce spurious mass spectra

Source Terms: Outgassing

Materials Identification & Usage Lists

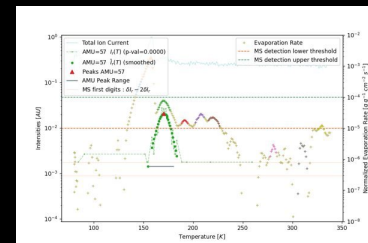
- Use of enhanced template (include entry fields for mass, volume, vacuum exposed surface area and location of application) – i.e., Europa Clipper template
- Enforce population of required entries

Multi-Species Materials Outgassing Testing and Modeling

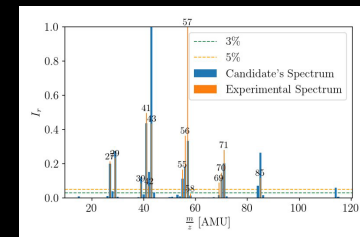
- ASTM E595 is only a screening criteria – it is inadequate to characterize organic contamination
- New multispecies testing and modeling framework in development at ONERA/CNES, ESA and NASA reduces testing requirements (schedule and cost), compared to ASTM E1559 testing, and provides information on organic contaminant composition
- Multispecies outgassing testing and modeling has already been used on Mars 2020 and currently in evaluation for Artemis

Analysis and archival of condensate from spacecraft thermal-vacuum, along with mass spectrometry provides critical information in support of the organic inventory and definition of landing site alteration

QCM Mass Spectrometry Correlation



Single matched spectra for single species



Ranking of all matched molecules

Rank	Name	DAE % Relative Intensity	Name	MS/MS (m/z)	SpecDec > 0.01	MS/MS (m/z) > 0.01	Comparison > 0.01
1	Chloroacetic acid (m/z 105)	14.1	200.0	105.0	100.0	100.0	100.0
2	Formic acid (m/z 45)	10.0	100.0	45.0	100.0	100.0	100.0
3	Acetic acid (m/z 60)	10.0	100.0	60.0	100.0	100.0	100.0
4	Propanoic acid (m/z 74)	10.0	100.0	74.0	100.0	100.0	100.0
5	Butanoic acid (m/z 88)	10.0	100.0	88.0	100.0	100.0	100.0
6	Pentanoic acid (m/z 102)	10.0	100.0	102.0	100.0	100.0	100.0
7	Hexanoic acid (m/z 116)	10.0	100.0	116.0	100.0	100.0	100.0
8	Heptanoic acid (m/z 130)	10.0	100.0	130.0	100.0	100.0	100.0
9	Octanoic acid (m/z 144)	10.0	100.0	144.0	100.0	100.0	100.0
10	Nonanoic acid (m/z 158)	10.0	100.0	158.0	100.0	100.0	100.0
11	Decanoic acid (m/z 172)	10.0	100.0	172.0	100.0	100.0	100.0
12	Undecanoic acid (m/z 186)	10.0	100.0	186.0	100.0	100.0	100.0
13	Dodecanoic acid (m/z 200)	10.0	100.0	200.0	100.0	100.0	100.0
14	Tridecanoic acid (m/z 214)	10.0	100.0	214.0	100.0	100.0	100.0
15	Tetradecanoic acid (m/z 228)	10.0	100.0	228.0	100.0	100.0	100.0
16	Pentadecanoic acid (m/z 242)	10.0	100.0	242.0	100.0	100.0	100.0
17	Hexadecanoic acid (m/z 256)	10.0	100.0	256.0	100.0	100.0	100.0
18	Heptadecanoic acid (m/z 270)	10.0	100.0	270.0	100.0	100.0	100.0
19	Octadecanoic acid (m/z 284)	10.0	100.0	284.0	100.0	100.0	100.0
20	Nonadecanoic acid (m/z 298)	10.0	100.0	298.0	100.0	100.0	100.0

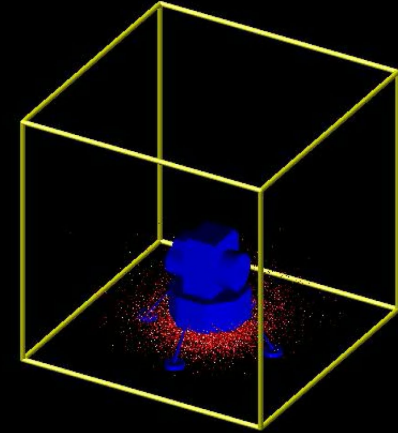
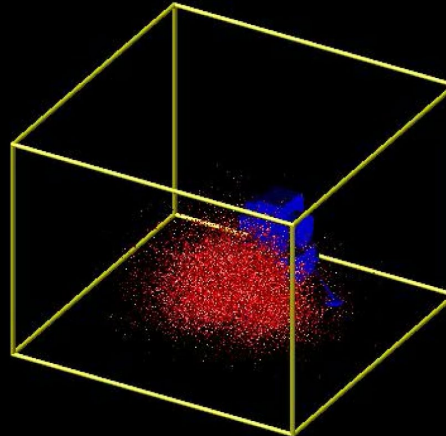
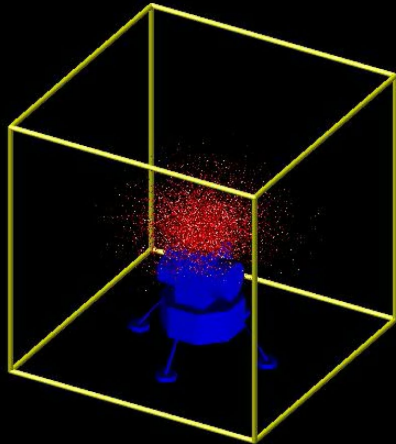
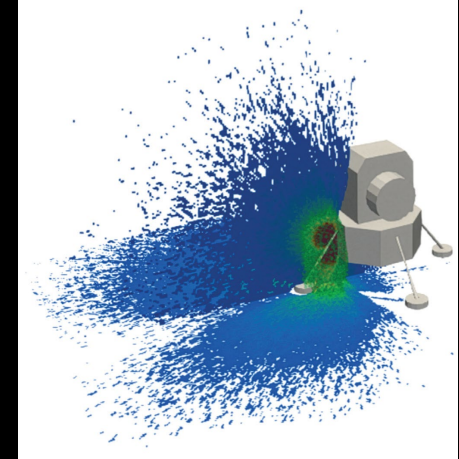
Alred, J.M., Martin, M.G., Hoey, W.A., Soares, C.E., "Outgassing Contaminant Species Extraction, Characterization and Modeling," Planetary Protection Organic Inventory and Archiving Workshop, NASA Headquarters, Washington D.C., February 27-28, 2024.

Source Terms: Venting

Vacuum venting plumes can be multiphase (gas/liquid/solid) and produce both molecular and particulate contamination

- Vacuum venting in crewed systems are significant source of organic contamination
- Mitigation options can be effective in lowering contamination (i.e., preferential venting and filters); however, will not eliminate contamination.

Gutierrez-Cascales, P, et al.
"Vacuum venting Contaminant
Transport for Moon Landers,"
JVS RP Final Presentation,
Pasadena, CA, 2024.



Source Terms: Venting

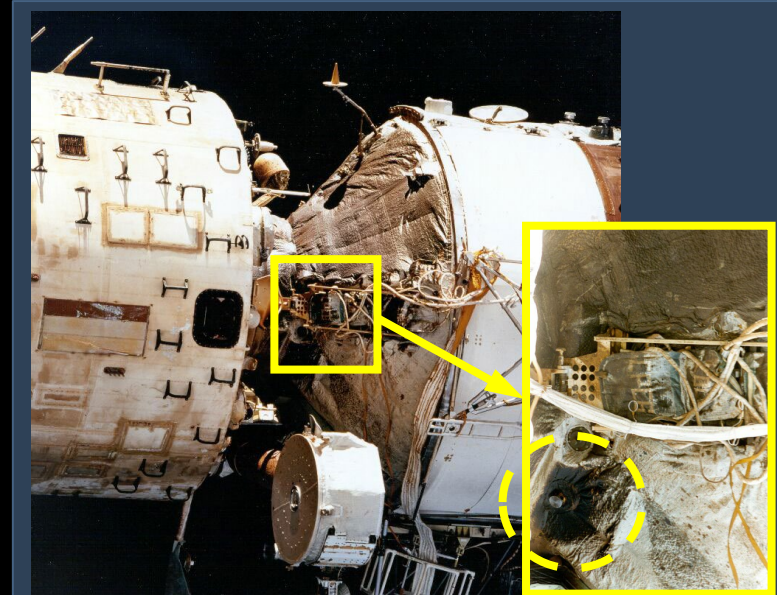
Crewed vehicles release high amounts of organic contaminant from venting systems.

Figures by co-author C. Soares, derived from: Soares, C. 2024. "Organic Contamination From Venting and Leakage (Environmental Control, Life Support Systems, IVA Science and Spacecraft Systems) - The ISS Experience," Invited presentation to the NASA Office of Planetary Protection – PP Organic Inventory Workshop. [See also: our RGD 33 talk!](#)



Release of Organics from Life Support System Vents:

'On-orbit observations show darkening in the area around the Vozdukh vent caused by amine compounds released by the CO₂ scrub system.'

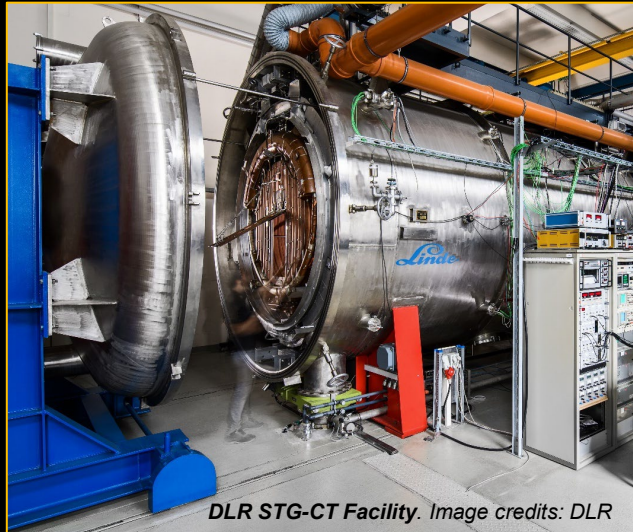


'The Mir Space station had the highest recorded levels of **organic contamination** from vacuum venting causing >10,000 Angstrom depositions and impacts to thermo-optical properties.'

Source Terms: Engine Plumes

Spacecraft descent engine and attitude control thruster plumes generate gas- and liquid-phase contaminants that can alter landing and science-sampling environments.

- We have applied RGD and empirical methods to simulate plume effects, including experimental materials compatibility and plume testing with DLR.

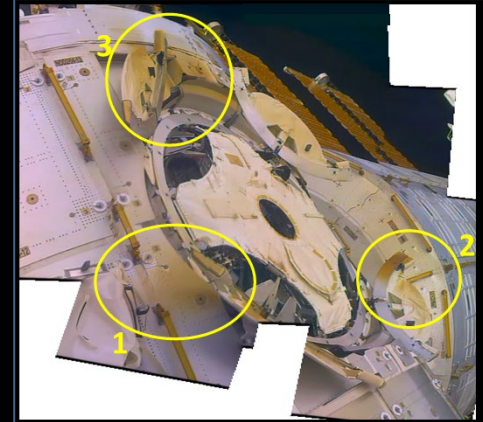


DLR STG-CT Facility. Image credits: DLR

Plume free expansion computed with CFD/DSMC.
Image credit: JPL JVS RP fellow Antonietta Conte.



DLR STG-CT test section; thruster pack at center.
Image credit: DLR



See also: Hoey, W., Soares, C., 2024. "Engineering Models: Thruster Plume-Surface Interactions, Landing Site Alteration, Organic Footprint and Acceleration / Dispersion of Dust and Regolith," Invited presentation, NASA Office of Planetary Protection Organic Inventory Workshop. [Link](https://doi.org/10.48577/jpl.QCQ97L)

Source Terms: Engine Plumes

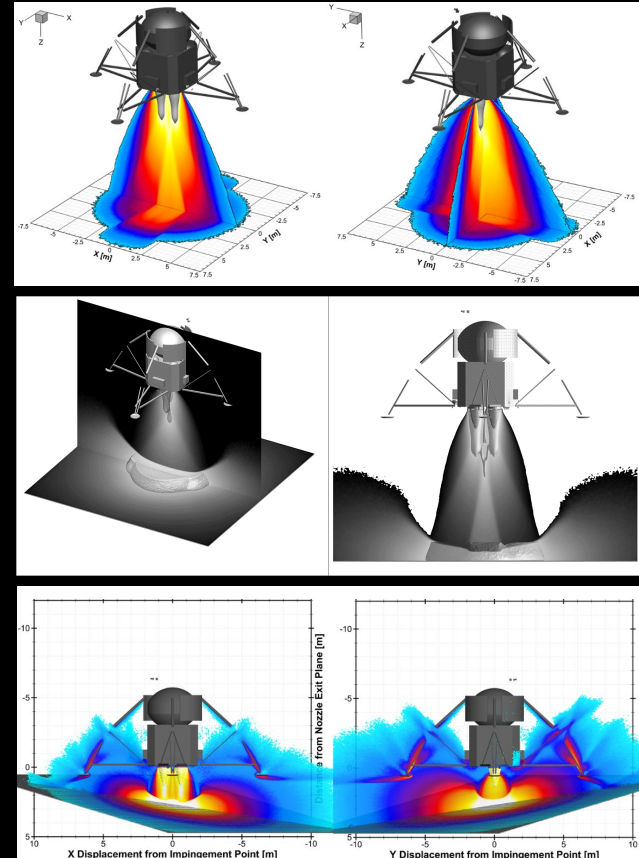
Highly dependent on thruster type and propellant combination

- Monopropellant hydrazine systems
- Bipropellant hydrazine systems
- LOX/hydrocarbon
- Cold gas

Source of both contamination and alteration of landing site (see William Hoey's presentation on Day 1)

- Contamination with organic compounds from FORP (fuel/oxidizer reaction products)
- Penetration of contaminants in the dust/regolith layer
- Erosion of landing site
- Acceleration and dispersion of contaminated dust/regolith

Hoey, W.A., Martin, M.G., Alred, J.M., Soares, C.E., Ababneh, M.; "Analyses of Blue Origin Blue Moon Lunar Landing Descent Engine Plume Effects," ICES 2023 - 52nd International Conference on Environmental Systems, Calgary, Canada, July 16-20, 2023.



Comparing and Contrasting Source Terms

Hoey, W., et al. "The Contaminant Footprint of Landed Spacecraft: Toward A Modeling Framework." Manuscript in draft.

	Materials Outgassing	Chemical Propulsion System Plumbing	Venting Uncrewed Systems, e.g., Passivation	Venting Crewed Systems: e.g., ECLSS, Airlock Cycling
Contaminant Phase	<u>Molecular</u>	Primarily <u>molecular</u> May contaminate regolith <u>particulate</u> , may release <u>droplet</u> or <u>soot</u> products	<u>Molecular</u> <u>Droplet</u> or particulate waste	<u>Molecular</u> <u>Droplet</u> or particulate waste
Driver of Total Source	Vehicle dry mass of nonmetallic and vacuum-exposed materials	Vehicle propellant mass (fuel and oxidizer), as used in descent, landing, and ascent operations	Unspent vehicle propellant mass ejected at end-of-life; ejected waste from instrument or vehicle processes	Total crew count and duration of operations on the solar system body
Nature of Release	Spontaneously and gradually while exposed to vacuum; could span years	Continuous periods of engine firing in descent, landing, and ascent; could span minutes-to-hours	Discrete events to deplete reservoirs, each could span seconds-to-minutes.	May include continuous gas-phase venting from ECLSS, discrete airlock cycling events, or ejections of waste
Rate of Contaminant Release	Driven by local temperatures; time of vacuum exposure; material selection and pre-conditioning.	Driven by total thrust, therefore by vehicle total mass during descent, landing, and ascent operations	Open-ended; driven by the design, requirements, and operation of venting systems	Driven by crew count and mission duration (ECLSS) and operations (EVAs, waste ejections, etc.)
Organic Contaminants?	Typical spacecraft materials will contain some organic molecules that outgas in near-vacuum	Generated as combustion products, dependent on propellant choice and engine operation	May be present in vented propellant and instrument or vehicle waste	Present in ECLSS venting, cabin atmospheres and crew waste
Potential Mitigations of Organic Component	Standard approaches exist for sensitive missions – material screening and selection of low-organic-outgassing materials; pre-conditioning of materials and spacecraft with bake-outs	Unlikely – could relate to choice of propellant, engine firing modes, landing site selection	Mission-dependent – vehicles could plan to retain or scrub certain waste	Mission-dependent – vehicles could plan to retain or scrub certain waste

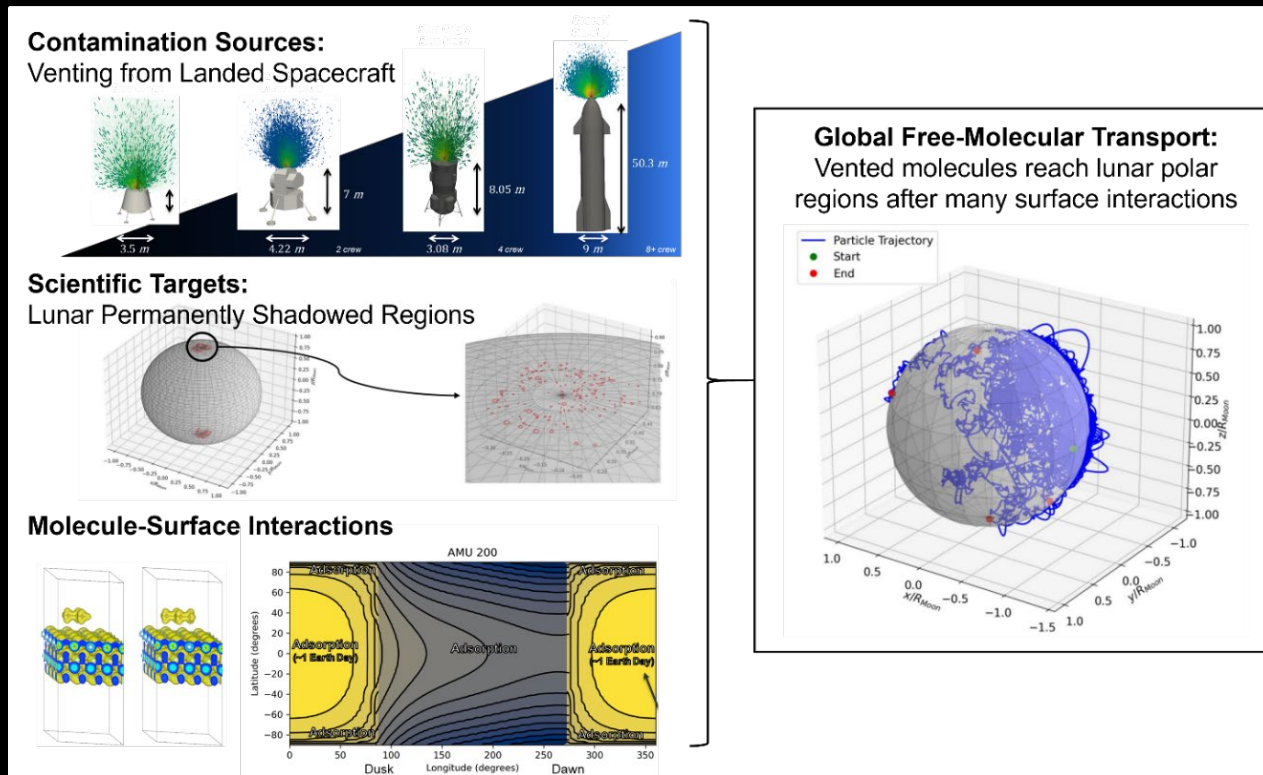
Comparing and Contrasting Source Terms

Hoey, W., et al. "The Contaminant Footprint of Landed Spacecraft: Toward A Modeling Framework." Manuscript in draft.

	Blue Ghost M1 Firefly Aerospace; NASA CLPS (2025)	Chang'e 5 CNSA Lunar Exploration (2020)	Apollo Landing Module NASA; Apollo 17 (1972)	Blue Moon Blue Origin (TBD)	Starship HLS SpaceX (TBD)
Propellant	Bipropellant: MMH fuel, MON-3 oxidizer	Bipropellant: MMH fuel, NTO oxidizer	Aerozine 50 fuel, NTO oxidizer	Liquid hydrogen fuel, liquid oxygen oxidizer	Liquid methane fuel, liquid oxygen oxidizer
Main Engines	×1 Descent (Nammo LEROS-4)	×1 Descent ×1 Ascent	×1 Descent (LMDE) ×1 Ascent (LMAE)	BE-7; May use multiple engines in descent and ascent.	Raptor Vacuum (RVAC); May use multiple engines in descent and ascent.
Max Thrust (Descent)	≥ 1.0 kN	~ 7.5 kN	~ 47 kN (throttlable)	TBD	TBD
Max Thrust (Ascent)	--	3 kN	16 kN	TBD	TBD
Lander Total Mass	1,500 kg	3,200 kg (lander) 700 kg (ascent element)	16,000 kg	TBD	TBD
Propellant Mass	1,000 kg (launch)	1,900 kg (used in descent) 390 kg (used in ascent)	8,200 kg (total for descent) 2,400 kg (total for ascent)	+ Added complexity of crewed vehicles: need to account for airlock cycling, ECLSS, crew waste, etc.!	
Dry Mass	469 kg	1,200 kg	4,920 kg	TBD	TBD
Nominal Crew Capacity	0	0	2	2	2 – 4+

All inputs are estimated from publicly available data.

Modeling Long-Distance Free Molecular Transport



Modeling Global Free-Molecular Transport for Organic Molecules

(*Top Left*): Molecular contaminants vented from lunar landed spacecraft are simulated with DSMC.

(*Center Left*): Lunar permanently shadowed regions (PSRs) of high science and ISRU value are modeled as sinks for contaminant.

(*Bottom Left*): Simulations of molecular-surface interactions, combined with a time-variant lunar surface map, provide insight into the residence time of certain *n*-alkane species on the lunar surface.

(*Right*): In combination, these elements are incorporated into a simulation for the transport of organic molecular contaminant from a landing site to distant regions of the Moon.

Venting analyses and figures by JPL JVSRR P. Gutierrez Cascales, 2024.

Lunar-scale free molecular transport analyses and figures by JPL JVSRR R. Alves Hailer, 2024.

See also: Hoey, W., Anderson, J., Alred, J., Soares, C., Gutierrez Cascales, P., Alves Hailer, R. "Modeling the Contaminant Footprint of Spacecraft Operating in Near-Vacuum." 56th Lunar and Planetary Science Conference, The Woodlands, TX; Mar. 2025. [Link](#)

2nd June 2026

Organic Inventory

Future Work and Developments – NASA EHP Perspective

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Current Organic Inventory and Archive Framework

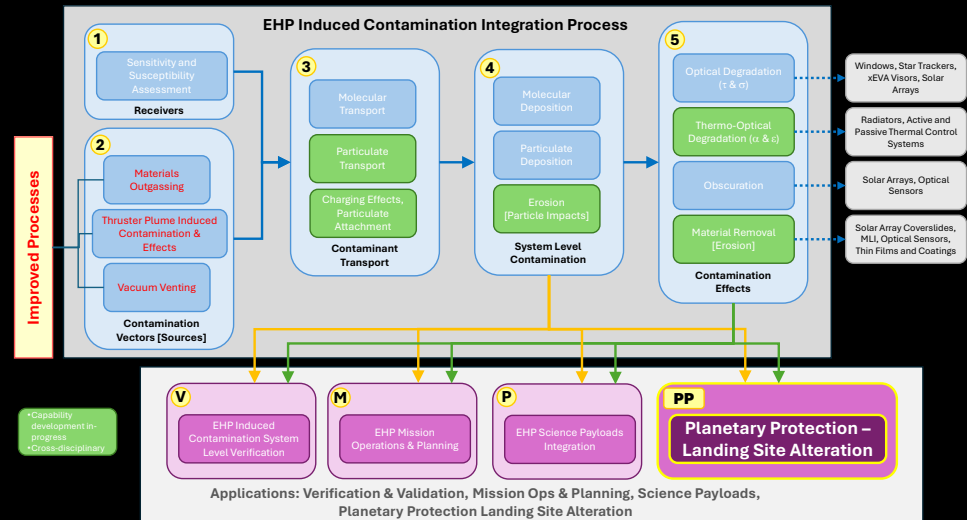
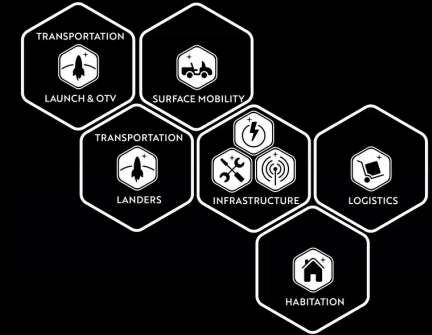
A composite image featuring two astronauts on the lunar surface. In the foreground, an astronaut's helmet and gloved hand holding a tool are visible. In the background, another astronaut stands on the dark, rocky terrain under a bright light source.

Lunar Surface Plans

- Review and approval of EHP Proposed Induced Environments Integration Process
- Creation of a multi-agency (ESA, JAXA, NASA) Working Group dedicated to Planetary Protection topics of the organic inventory and characterization of landing site alteration
- Collaboration and coordination with our international partners (ESA, JAXA NASA) on collecting, analyzing and sharing data from TVAC activities
- Protect current and future mission Planetary Protection and Science requirements

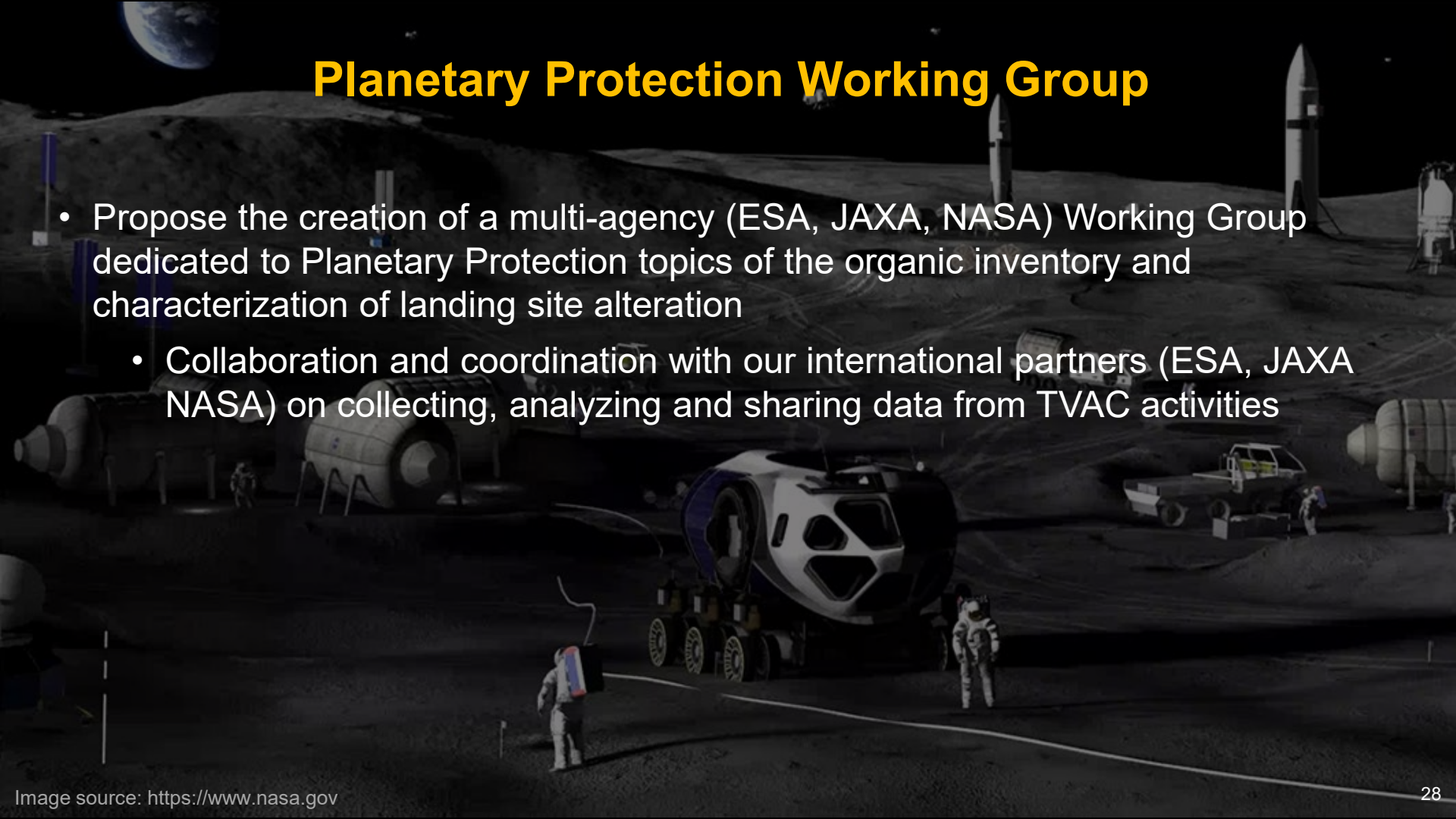
EHP Activity In-Progress

- NASA internal review of EHP Proposed Induced Environments Integration Process is in progress



Planetary Protection Working Group

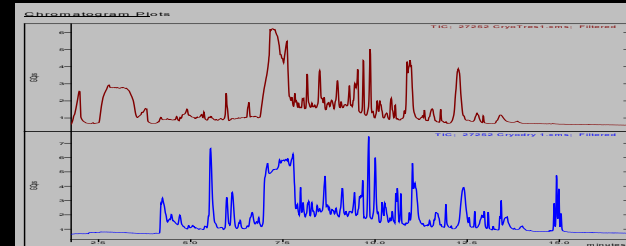
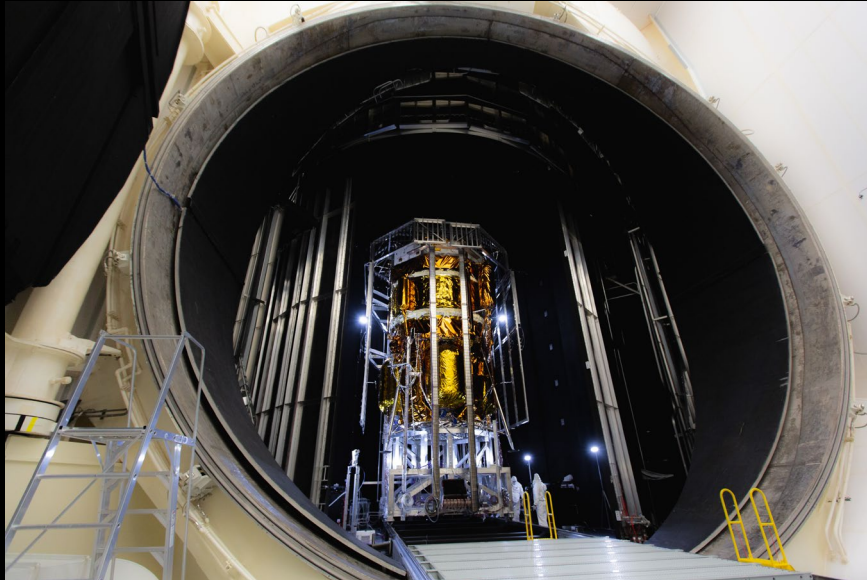
- Propose the creation of a multi-agency (ESA, JAXA, NASA) Working Group dedicated to Planetary Protection topics of the organic inventory and characterization of landing site alteration
 - Collaboration and coordination with our international partners (ESA, JAXA, NASA) on collecting, analyzing and sharing data from TVAC activities



Insights from EHP

Improved Characterization of Materials Outgassing

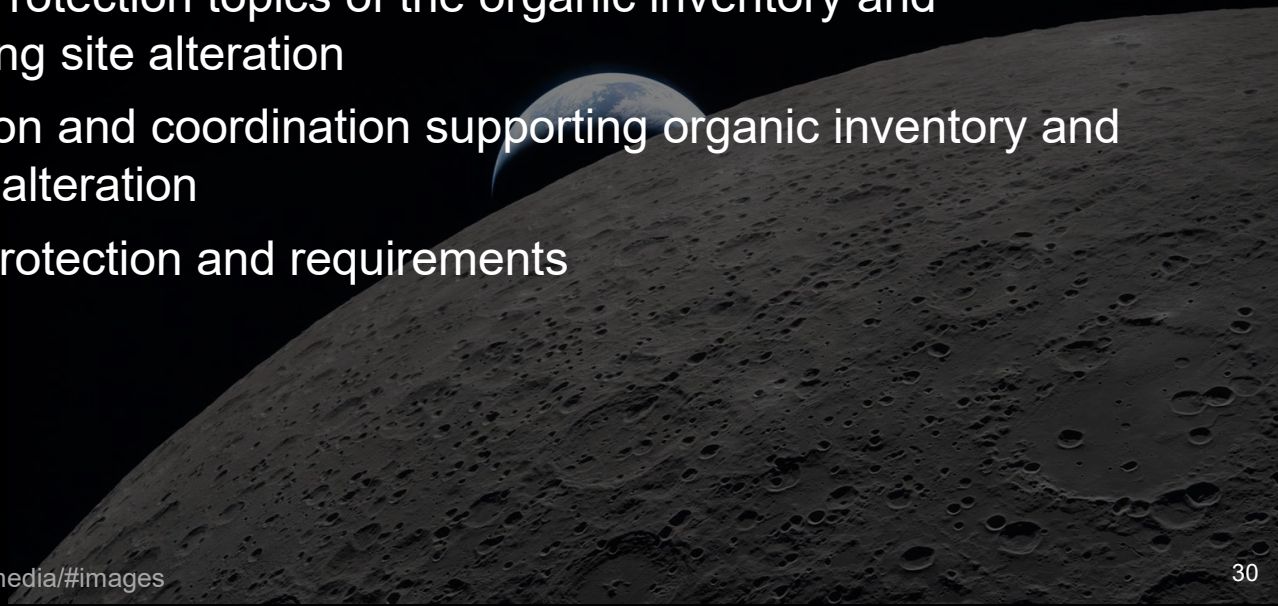
- The EHP Induced Environments Team can assist and collaborate on the measurement, analysis and characterization of materials outgassing during TVAC opportunities



Protecting Current and Future Mission

Planetary Protection and Science requirements

- Future multi-agency meeting opportunities
- Advocate for the creation of a multi-agency (ESA, JAXA, NASA) Working Group dedicated to Planetary Protection topics of the organic inventory and characterization of landing site alteration
- Multi-agency collaboration and coordination supporting organic inventory and definition of landing site alteration
- Evolution of Planetary Protection and requirements



Acknowledgements

This research was carried out under the direction of the Planetary Protection Office at NASA HQ.





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Backup Material

Current Organic Inventory and Archive Framework

- NASA Procedural Requirement document NPR 8020.12: “An inventory of bulk constituent organics is required if the probability of impact is considered significant.”
 - The intent of archiving organic materials is to characterize Earth contamination sources in preparation for returned sample science investigations and analyses.
 - A “false-positive” indication of life via life-detection instruments on board the spacecraft, or in the sample after it is returned to Earth, impacts successful completion of mission science objectives and could lead to increased Planetary Protection requirements for future missions.
- For all launched hardware, if the bulk organic constituents are greater than 1kg, an organic materials inventory is required.
 - The current inventory framework consists of materials usage & identification lists (MIULs), parts lists, and data relevant to organic material identification.
 - Also included are locations of landing sites and condition of the landing spacecraft to assess spread of organic contamination.
 - This requirement also applies to the Moon. If the bulk organic constituents are greater than 25kg, then 50g samples of all organic materials is required for archiving.
- A database provides information on the materials collected and their physical location at the archive.
 - The archive currently has organic samples from the following missions: Viking, Mars Pathfinder, Mars Reconnaissance Orbiter, Phoenix Lander, Mars Exploration Rovers, Mars Science Laboratory, Maven, Insight and Perseverance.

Issues with Current Organic Inventory and Archive Framework

- The current framework only addresses one contamination vector, materials outgassing, and only partially
 - Materials Identification & Usage Lists (MIULs) templates are typically deficient in capturing quantities (mass, volume) and location of applications
 - MIUL submissions also contain a large number of blank entries (i.e., lack quantities, location of application and processing)
 - Materials used in quantities lower than the specified threshold may be significant sources of organic contamination
- Other significant contamination vectors and sources of landing site alteration are not a part of the current framework:
 - Thruster plumes (descent and landing)
 - Vacuum venting
 - Leakage

How can we evolve the existing framework into a Comprehensive Organic Inventory?

- Characterize all contamination vectors and sources of landing site alteration:
 - Materials outgassing
 - Thruster plumes (descent and landing)
 - Vacuum venting
 - Leakage
- Initial study: leverage existing experience in conjunction with modeling and analysis capabilities to define relative contributions for each vector
- Joint review of study results (Planetary Protection, Contamination Control, Planetary Science)
- Develop Comprehensive Organic Inventory strategy and framework
 - Establish policy based on technical rationale that accounts for all organic contamination vectors
 - Protect current and future mission science requirements

Current Organic Inventory and Archive Framework

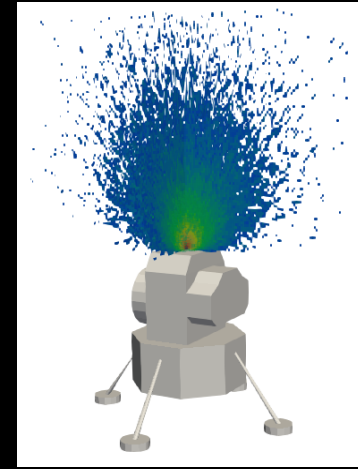
Engineering Source Terms

- **Rocket engine and thruster plumes** (lunar lander descent, landing and ascent)
- **Materials outgassing**
- **Vacuum venting** (crewed systems environmental control and life support, propellant purging, science payloads)

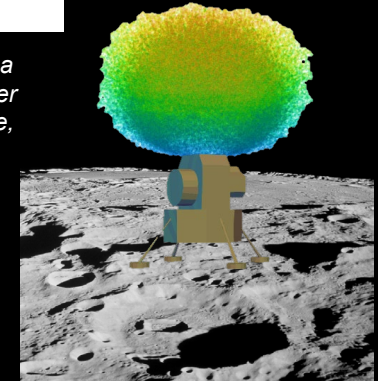
How is molecular contaminant released from a landed spacecraft as it vents, and how can this contaminant alter the vehicle-local environment?

Figures at right show a vehicle-local model of gaseous water venting for an Apollo lander, simulated with the SPARTA DSMC code for a generic set of water vapor venting inputs derived from International Space Station experience.

- Models for several varieties of vent have been examined under this study varying source species, flow rates, vent locations and shapes (e.g. straight vs. T-vent).
- Properties investigated include fluxes of condensable gas species to the lunar surface.
- A framework has also been developed to pass the results of vehicle-local simulations into long-distance, free-molecular transport models using a Python code.



Representative example of a vent releasing gaseous water from an Apollo lunar module, modeled with DSMC.

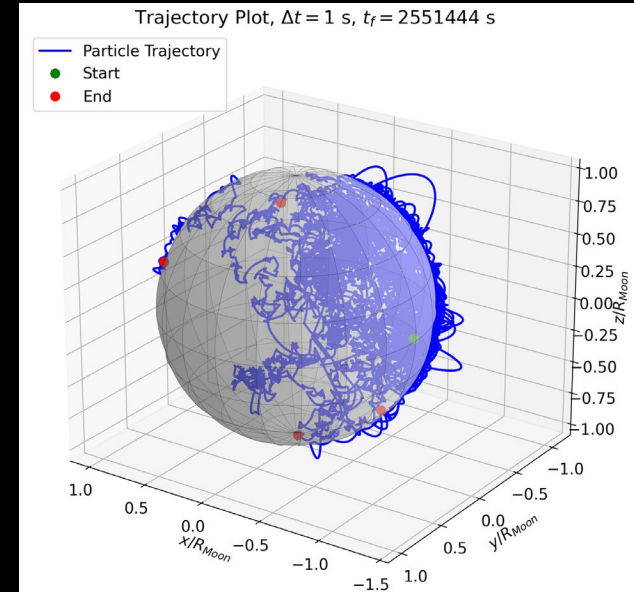


Figures by JPL JVS RP **P. Gutierrez Cascales**, 2024: "Gas Dynamic Simulations of Lunar Landed Spacecraft Venting Processes." See also: [Hoey et al., 2025, "Modeling the Contaminant Footprint of Spacecraft Operating in Near-Vacuum."](#)

How does contaminant reach from a specific lunar lander and its landing site to distant sites, including permanently shadowed regions (PSRs)?

- Long-distance (global) free-molecular simulations may then study transport away from landing sites, e.g., to lunar permanently shadowed regions: **figures at right** show an example of global results generated with a tool that can take input from vehicle-local simulations and simulate a 'hopping' process of molecular transport across a solar system body with near-vacuum surface conditions.
- Currently this model incorporates a time-variant lunar surface temperature map, a library of lunar PSR locations as cold-traps, a surface adsorption / desorption model for water, and permits molecular loss by gravitational escape.
- Future work may investigate non-water contaminant species and other significant physics including photo-dissociative loss processes.

Figures by JPL JVS RP **R. Alves Hailer**, 2024: "Free Molecular Monte Carlo Model for Lunar Contaminant Transport and Deposition in Permanently Shadowed Regions." See also: [Hoey et al., 2025, "Modeling the Contaminant Footprint of Spacecraft Operating in Near-Vacuum."](#)



Examples of long-distance water transport and the surface deposition of water at an arbitrary time during a lunar day.

