Synergism among Multiple Biocidal Factors on Mars and Interplanetary Space Increases the Lethality of Diverse Space Environments on Spacecraft Bioburdens

Andrew C. Schuerger, Dept. of Plant Pathology,
University of Florida, Gainesville, FL

John E. Moores, Center for Research in Earth and Space
Science, York university, Toronto, Canada

17 Biocidal or Inhibitory Factors on the Surface of Mars

(1) solar UV irradiation
(2) extreme desiccating conditions (i.e., low water activity; a_w)
(3) low pressure (7 mbar)
(4) anoxic CO_2-enriched atmosphere
(5) low temperature
(6) high salts levels [e.g., $MgCl_2$, NaCl, $FeSO_4$, and $MgSO_4$] in surficial soils
(7) galactic cosmic rays
(8) solar particle events
(9) UV-glow discharge from blowing dust
(10) solar UV-induced volatile oxidants [e.g., O_2^-, O^-, H_2O_2, O_3]
(11) globally distributed oxidizing soils
(12) high concentrations of heavy metals in martian soils
(13) acidic or alkaline conditions in martian soils
(14) perchlorates in most soils
(15) lack of defined energy source free of UV irradiation
(16) no sources of available nitrogen and carbon
(17) no obvious redox couples for microbial metabolis

(Schuerger et al., 2013, Astrobiology, 13, 115-131.)

6 Key Biocidal Factors in Interplanetary Space

(1) solar UV irradiation

(2) solar heating

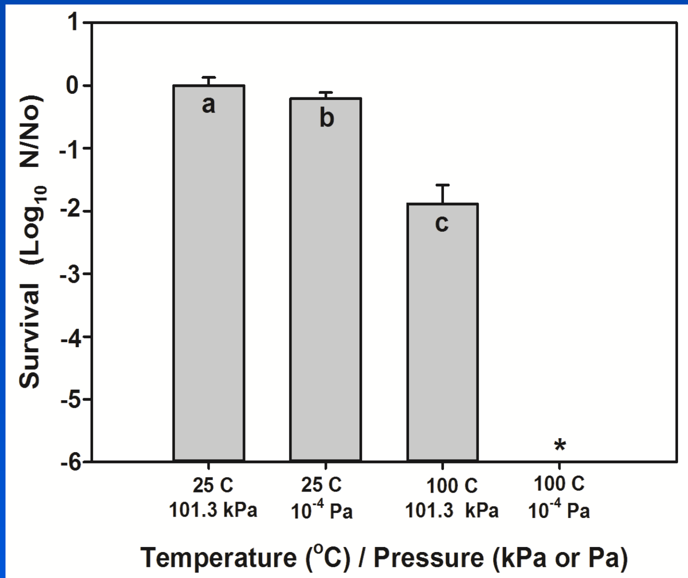
(3) extreme desiccating conditions

(4) extreme low pressure (~ 10^{-9} mbar)

(5) galactic cosmic rays

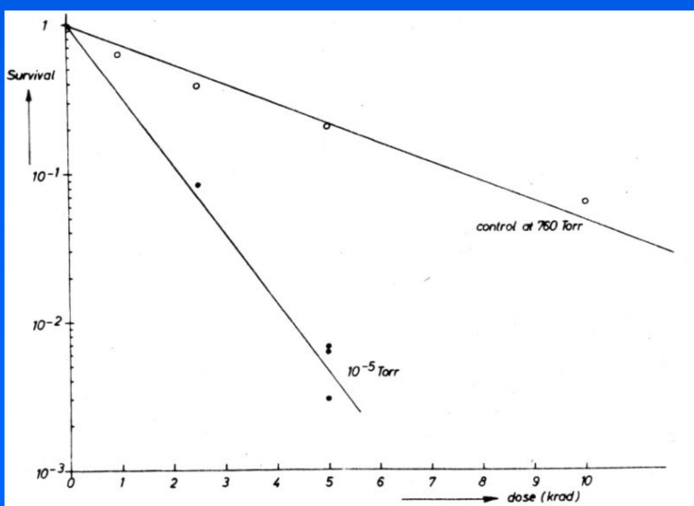
(6) solar particle events

Heat + VAC (*B. subtilis*)



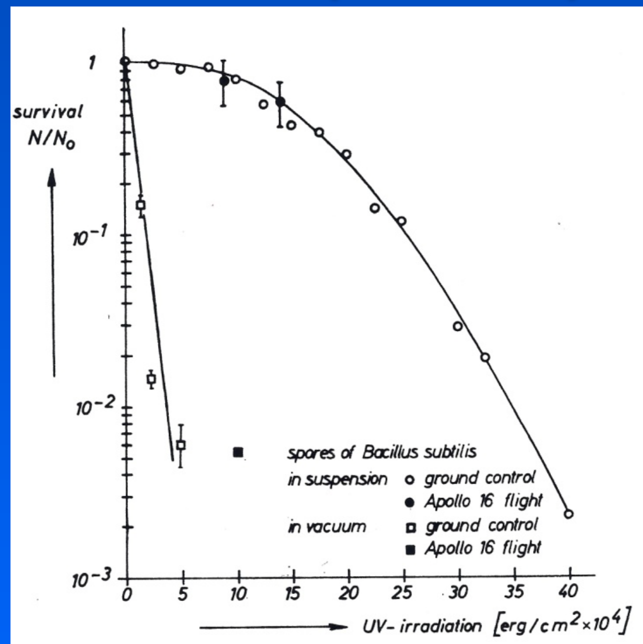
Schuerger et al., 2019

X-rays + VAC (*E. coli*)



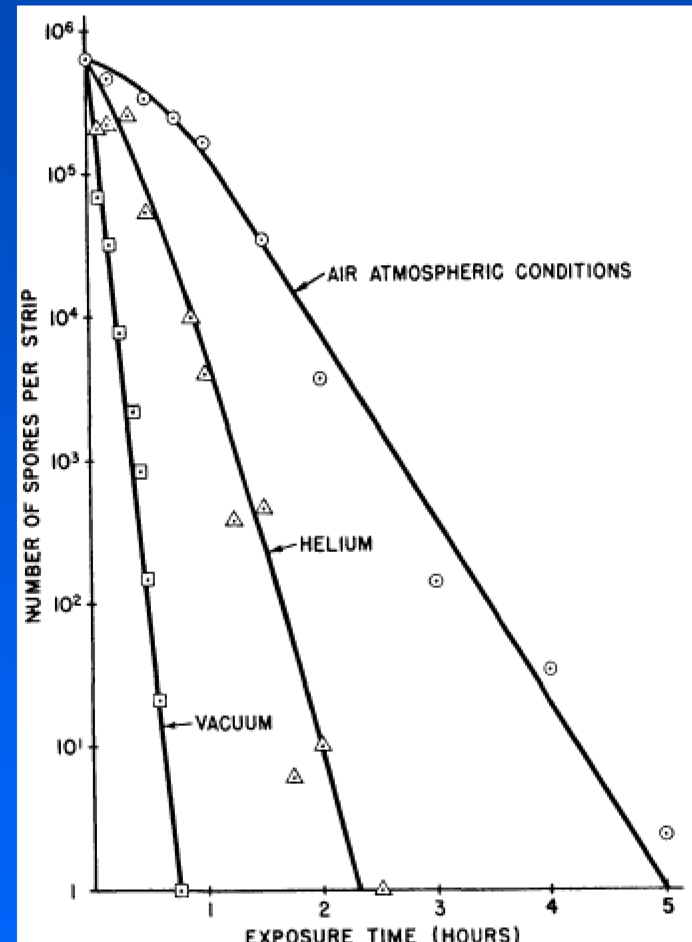
Bucker & Horneck, 1970

UV + VAC (*B. subtilis*)



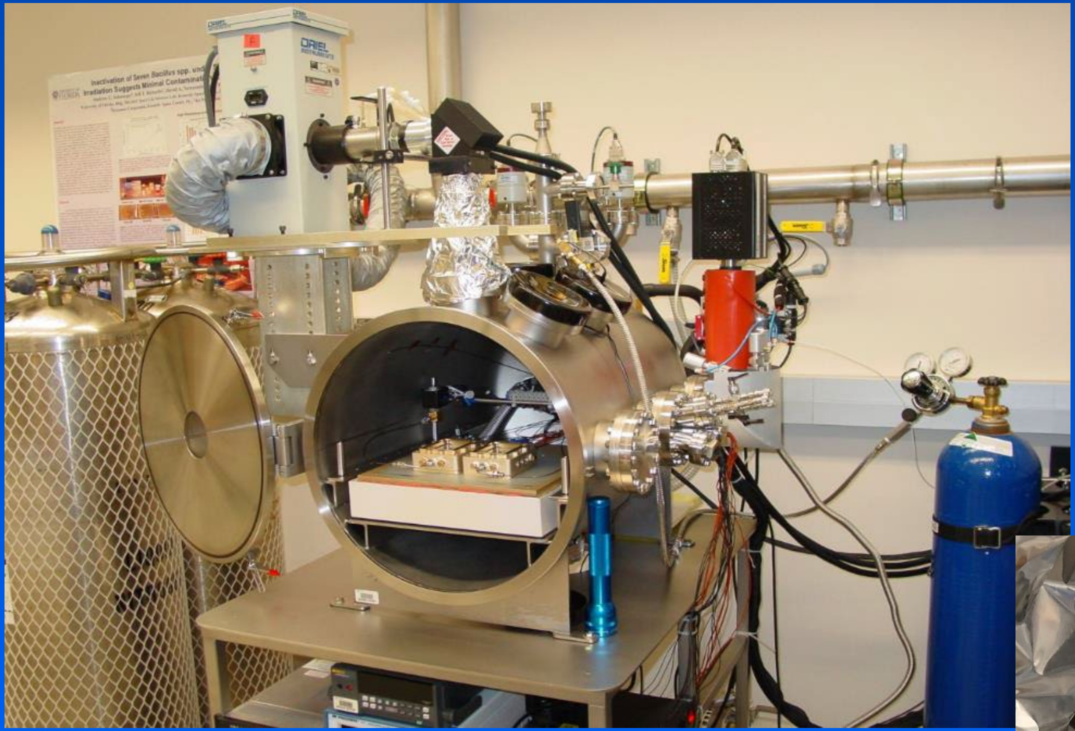
Bucker et al., 1974

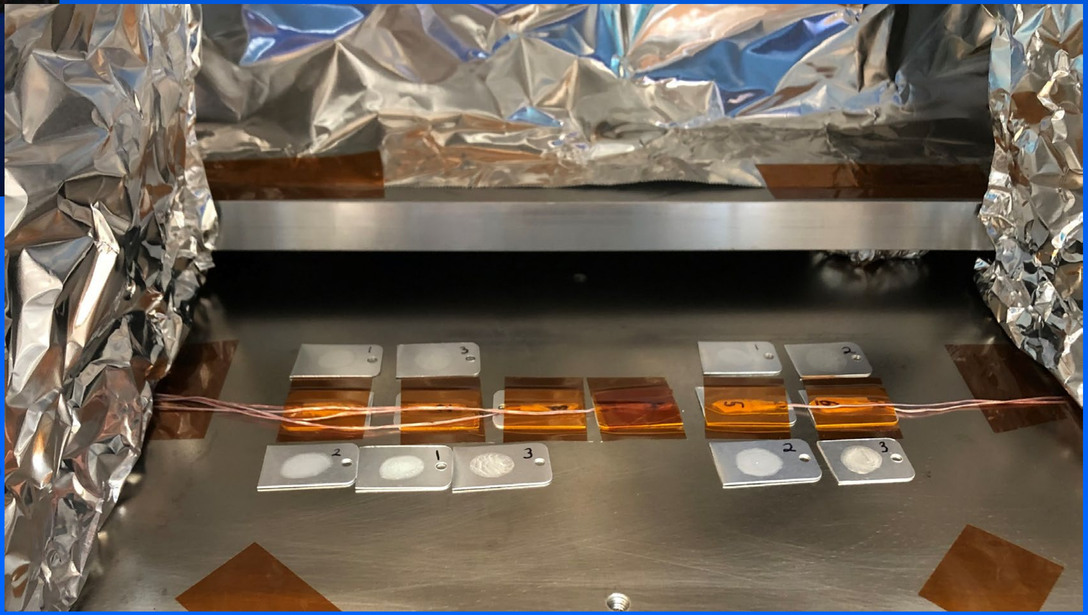
120°C + VAC (*B. subtilis*)



Bruch , 1965, NASA SP-108.

Mars Simulation Chamber (MSC)
Schuerger et al., 2008, *Icarus*, 194, 86-100.

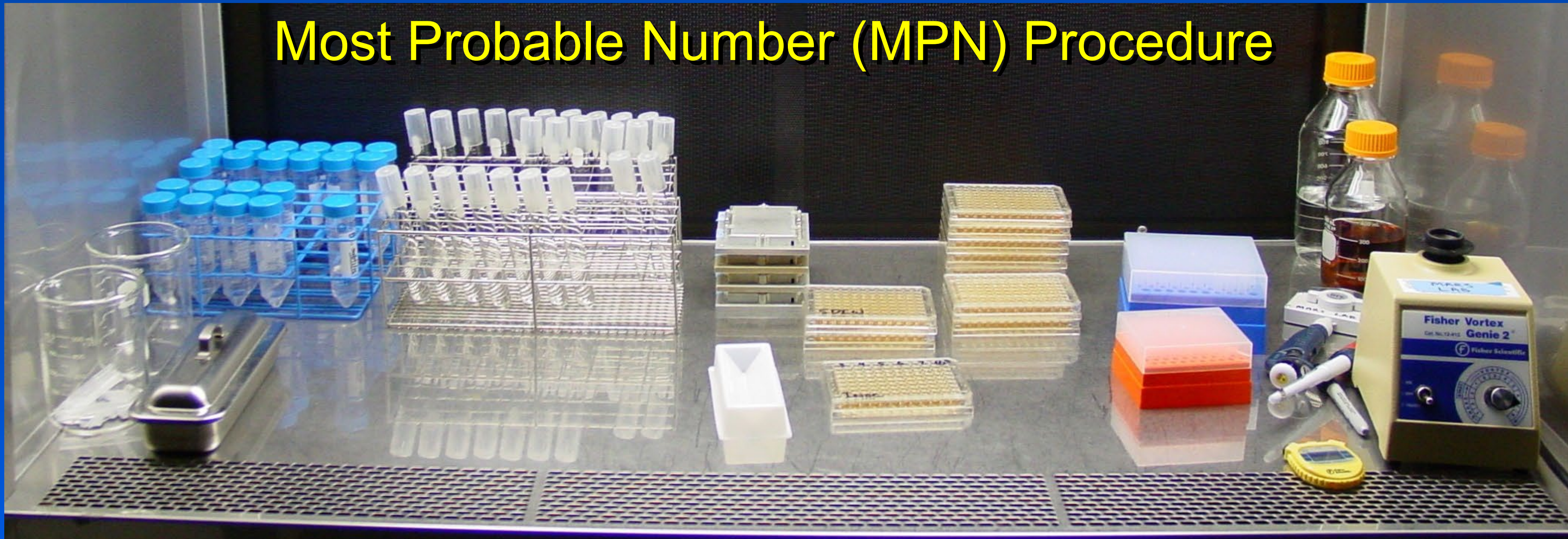




- Pressure: down to 0.01 mbar
- Temp: -100 to +160 °C (programmable)
- Gases: CO_2; O_2/N_2; Mars mix (top 5 gases)
- UV-VIS-NIR: equatorial to polar fluence rates
- Dust loading from *tau* 0.1 to 3.5

(Schuerger, 2024, *doi.org/10.3390/microorganisms12101976*)

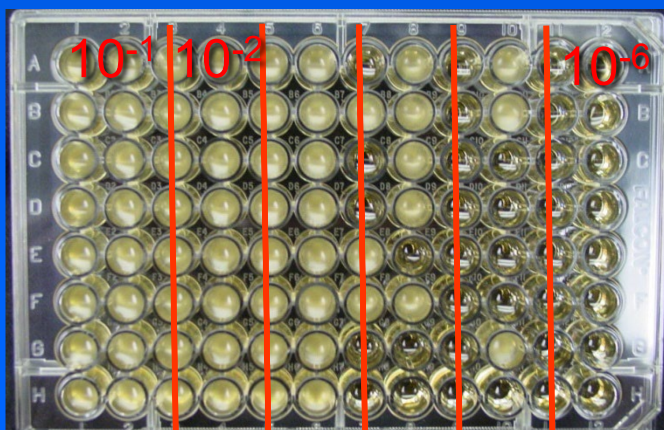
Most Probable Number (MPN) Procedure

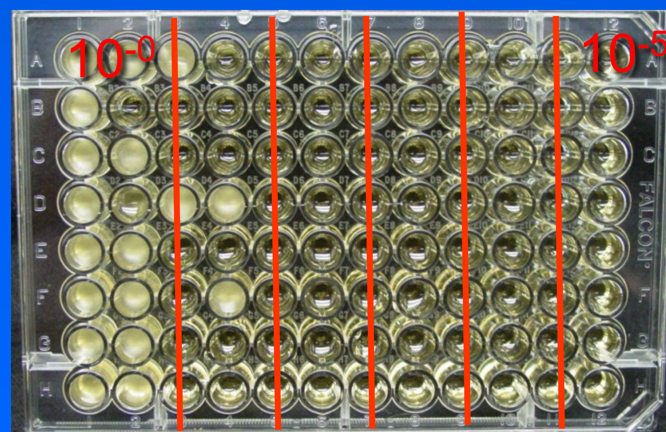


Control = 0 min

Mars UV = 15 min

Mars UV = 120 min





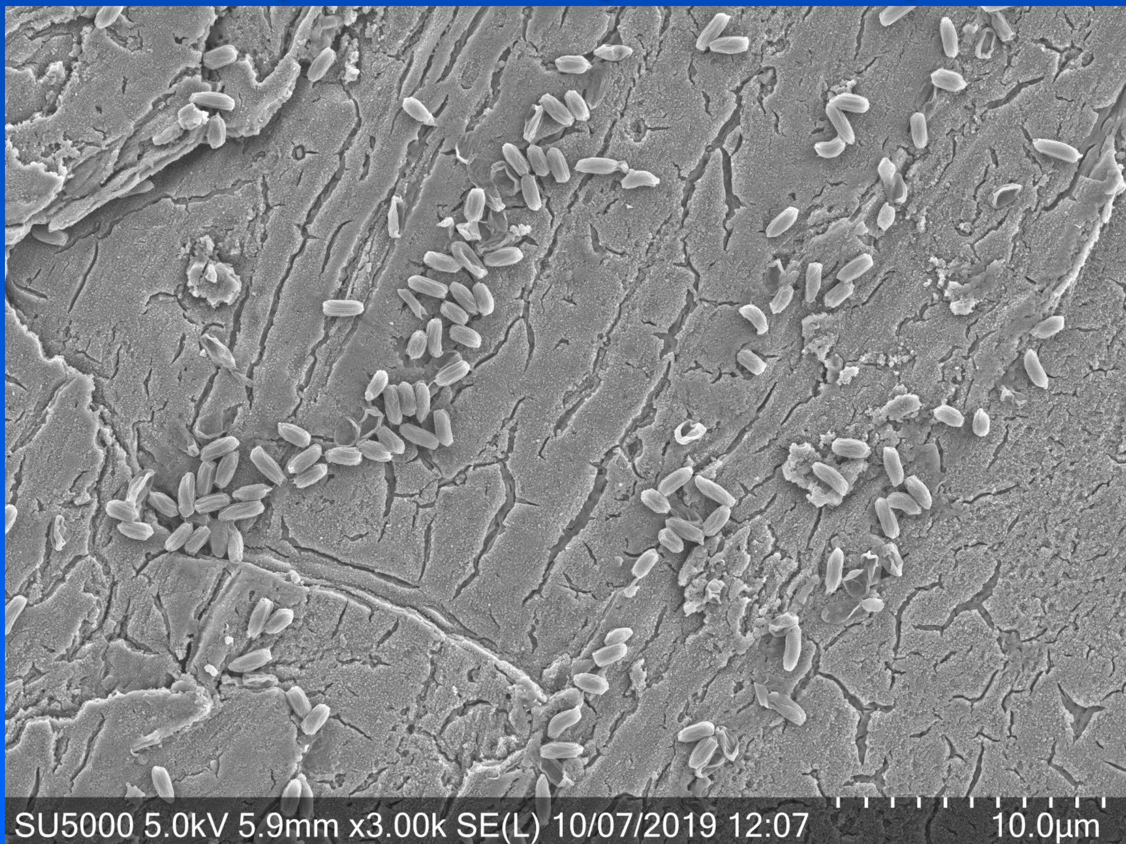
10-5-2 (10^5)

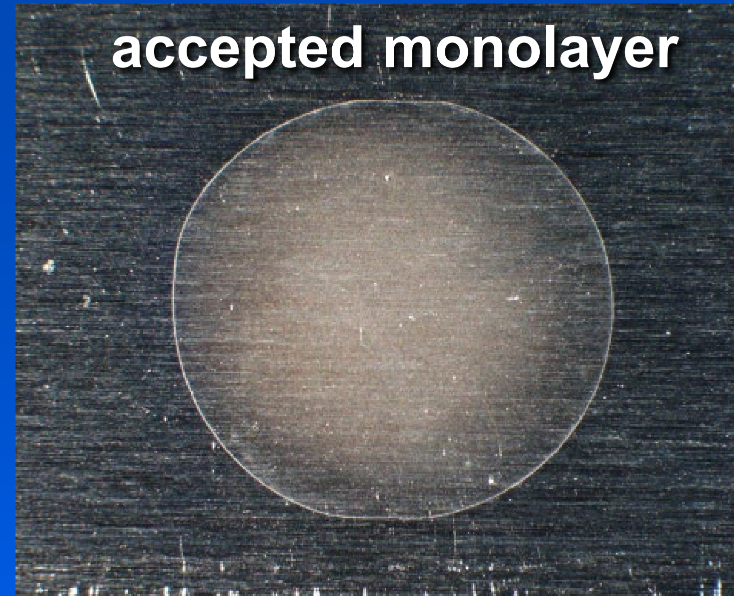
9-3-0 (10^2)

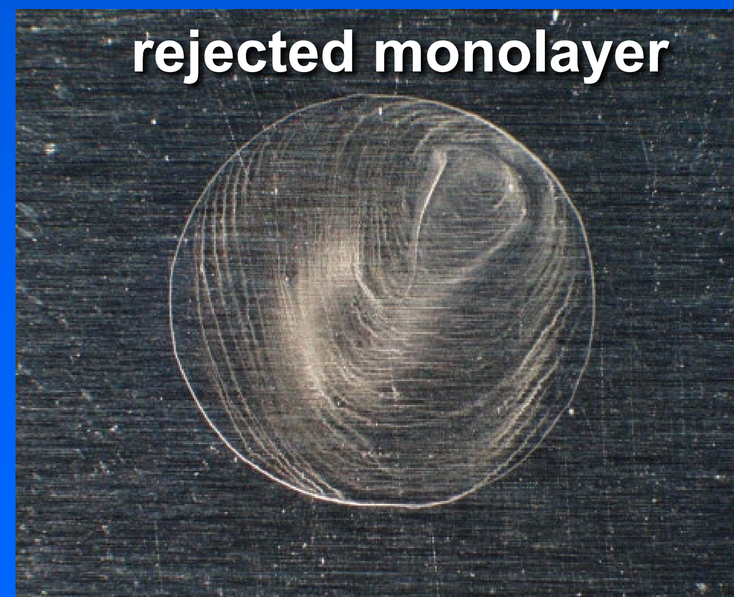
1 [+] / 96 wells

Monolayers vs Multilayers Exposed to Solar UV

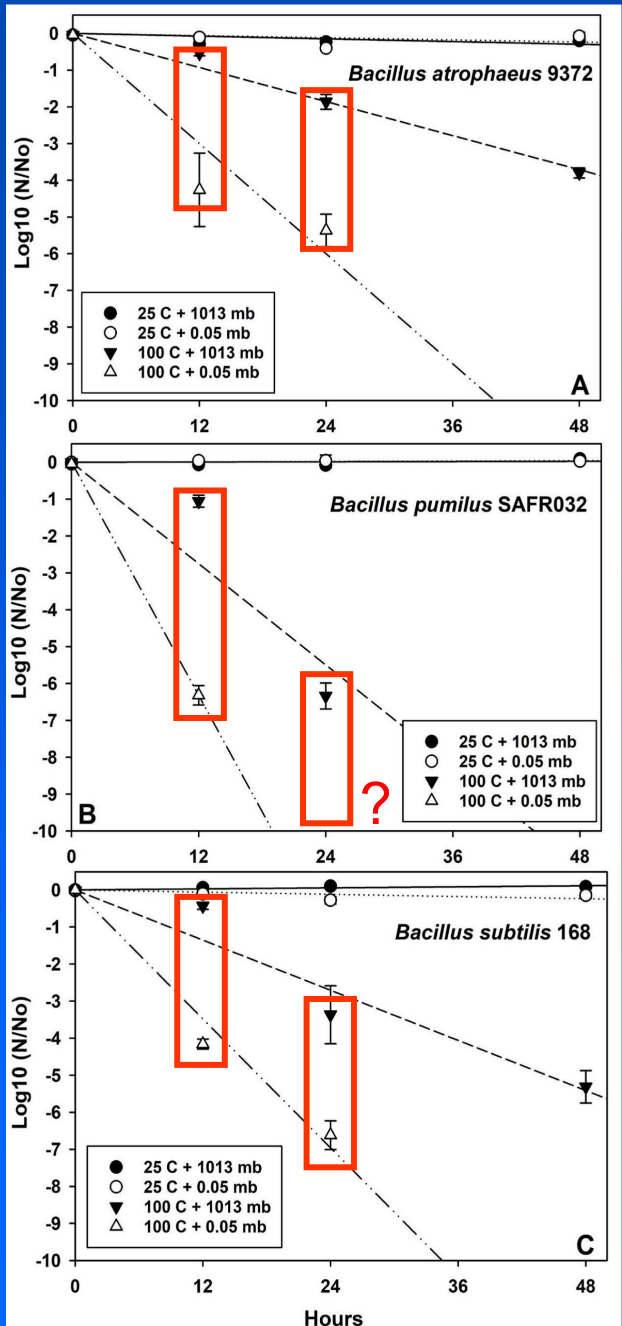
10^6 spores / 100 µL / 1-cm spot



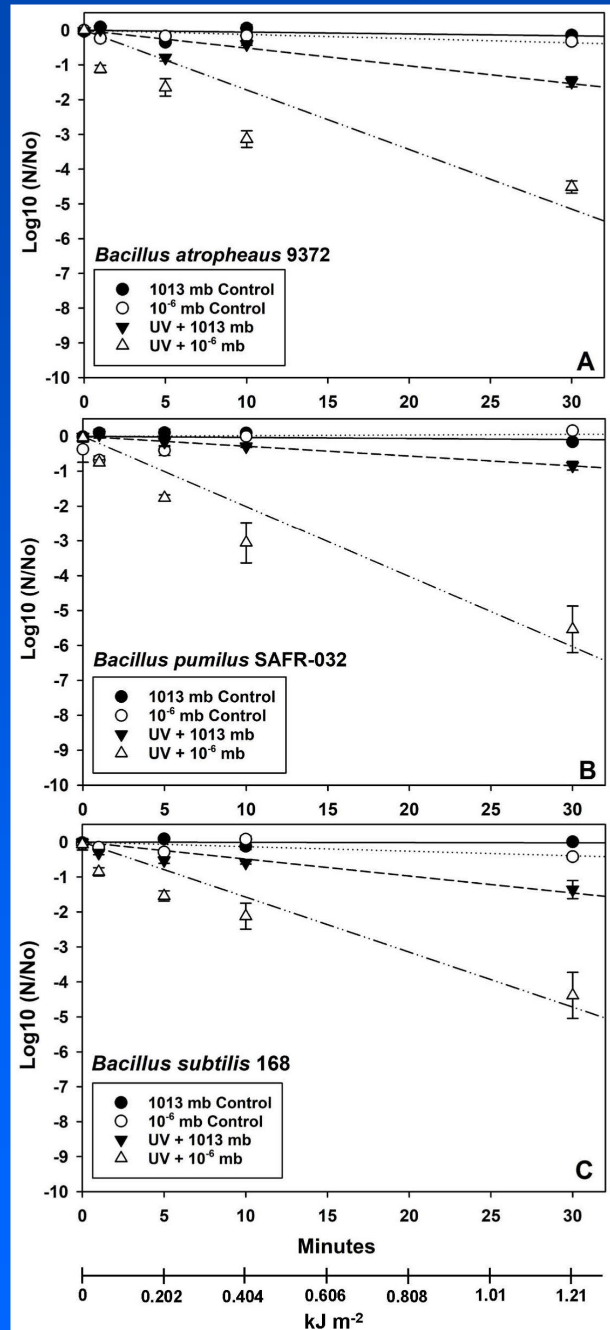




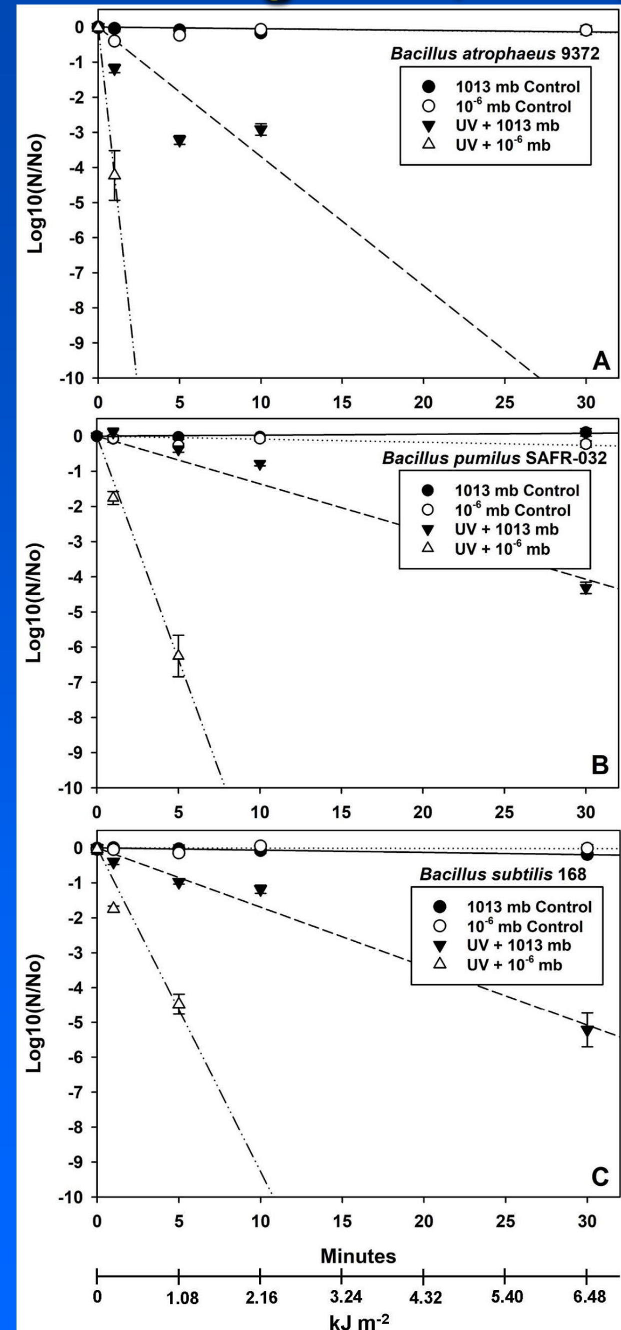
VAC + HEAT



VAC + low-UV (0.672 W/m²)



VAC + high-UV (3.6 W/m²)



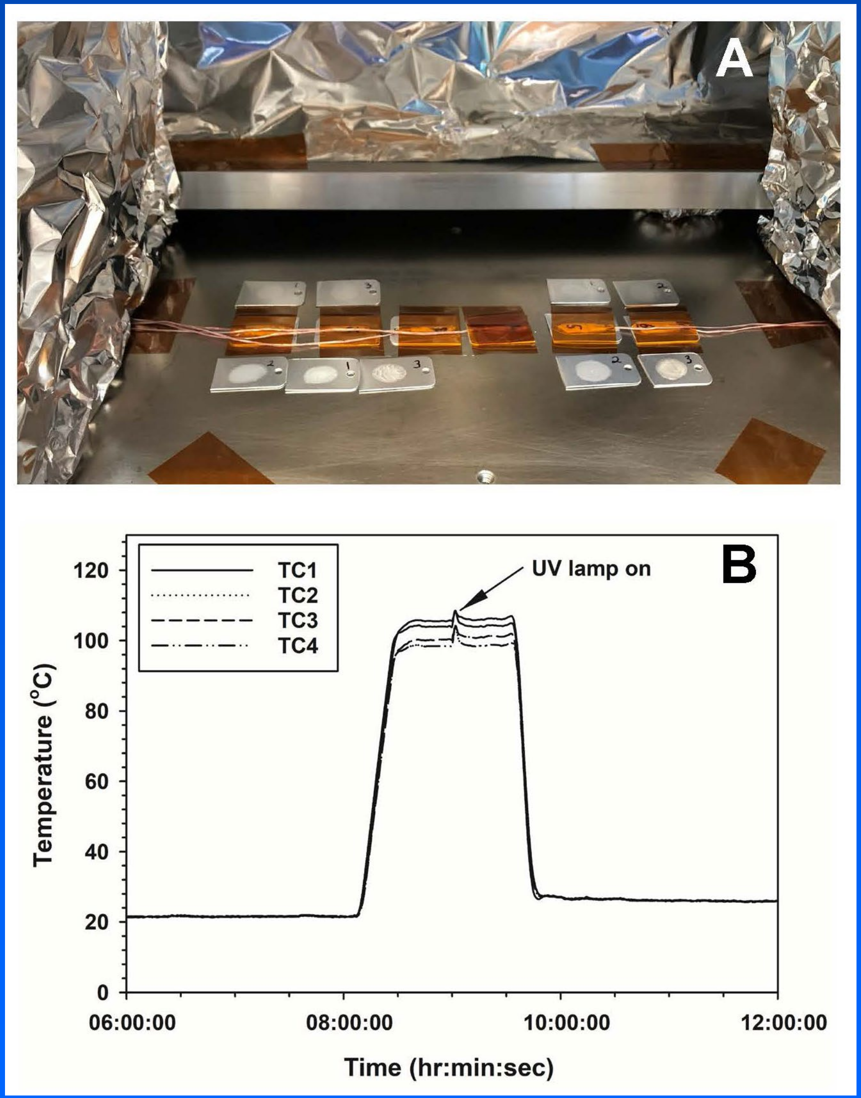
Sterility Assurance Level (SAL; –12 logs)

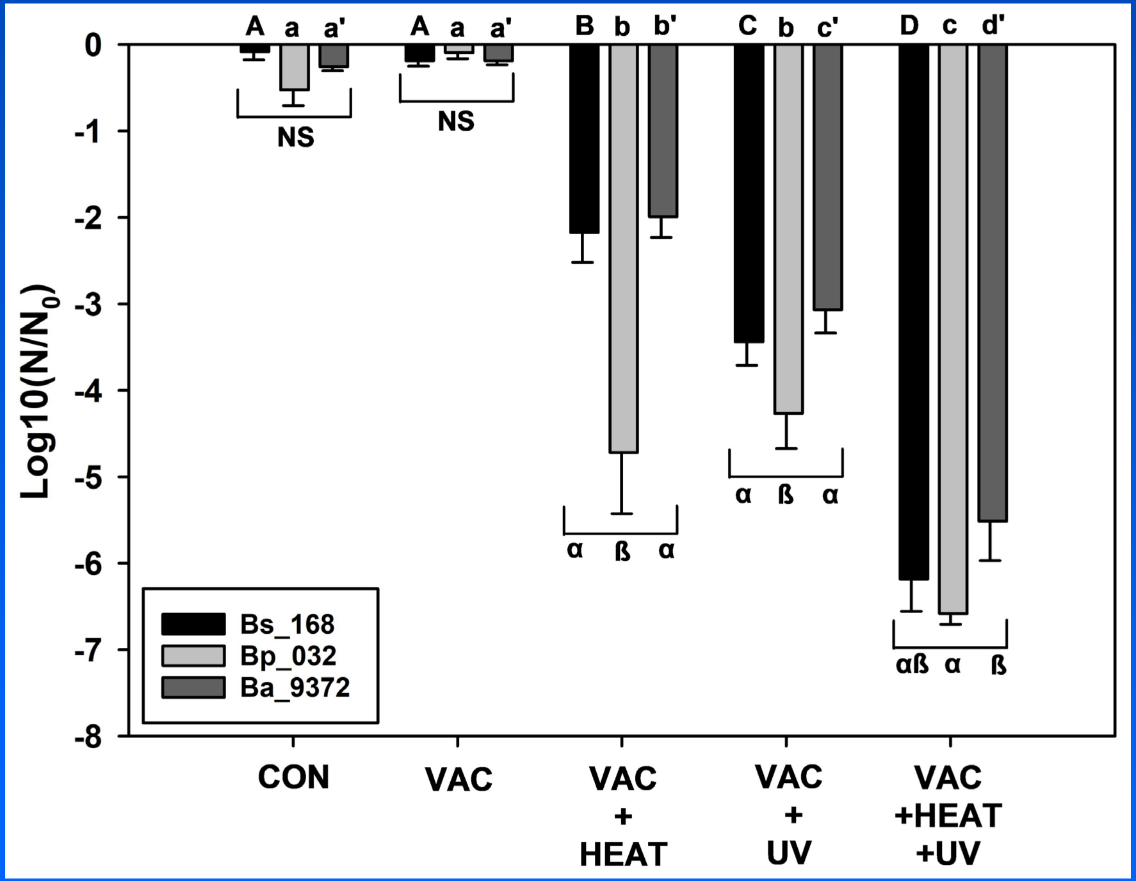
Bacterial species	100C + 0.05 mb linear model (hrs)	VAC + low-UV linear model (min)	VAC + high-UV linear model (min)
B. atrophaeus	48.0	69.9	2.8
B. pumilus	22.8	59.7	9.5
B. subtilis	41.4	76.3	12.9

(Schuerger, 2024, *doi.org/10.3390/microorganisms12101976*)

Synergism for 3 Space Biocidal Conditions

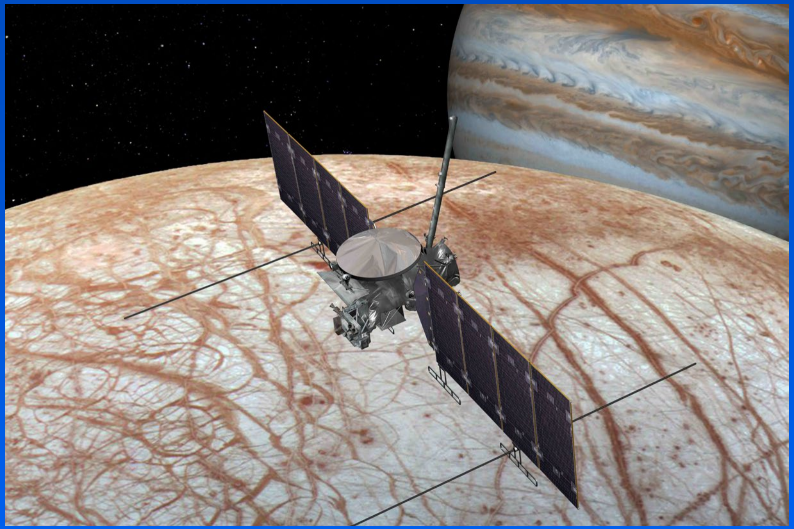
VAC = 48 hrs + HEAT = 2 hrs + high-UV = 2 min

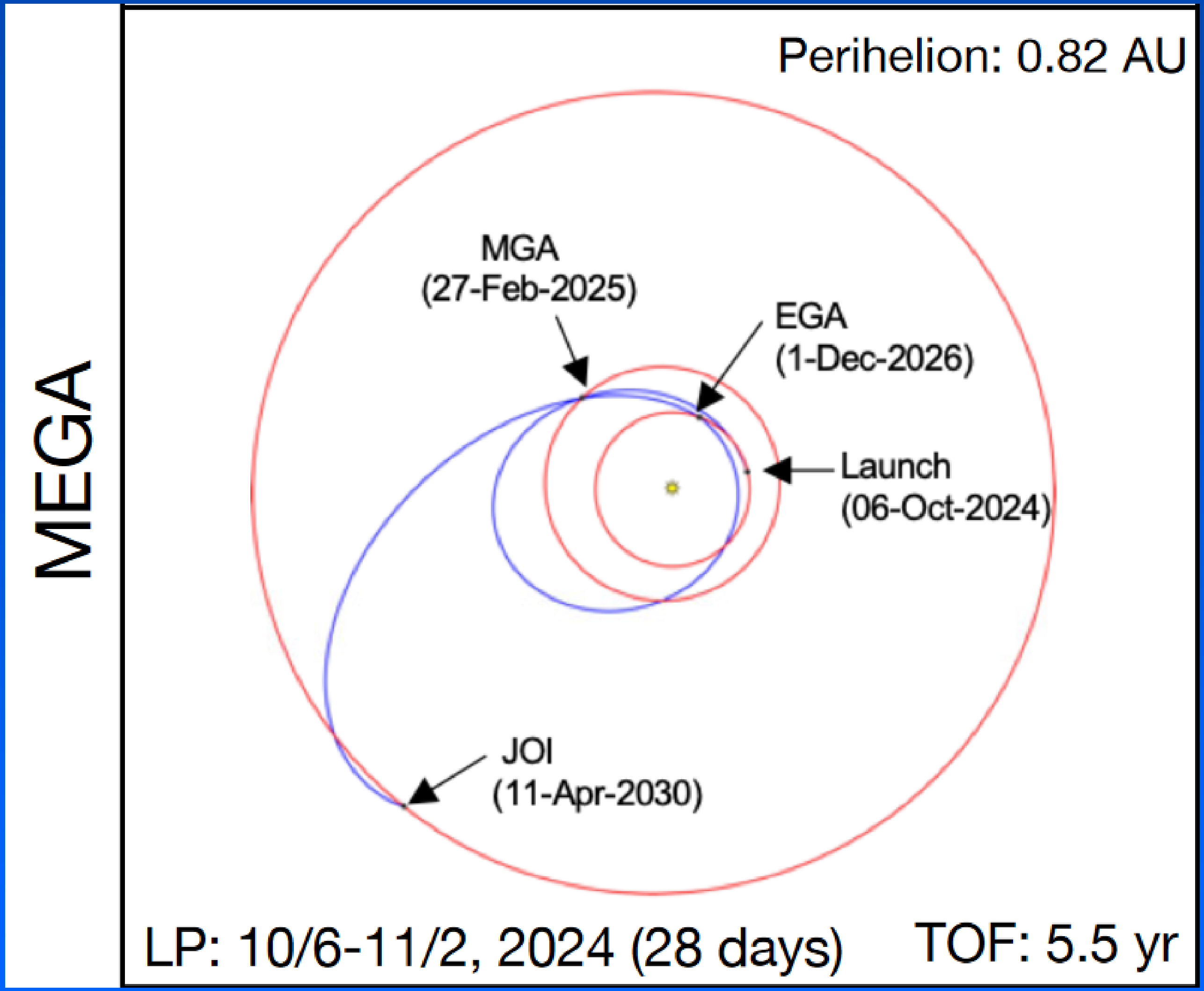




(Schuerger, 2024, *doi.org/10.3390/microorganisms12101976*)

Europa Clipper Jupiter Cruise Trajectory





ASTROBIOLOGY
Volume 19, Number 6, 2019
© Mary Ann Liebert, Inc.
DOI: 10.1089/ast.2018.1952

Research Articles

A Lunar Microbial Survival Model for Predicting the Forward Contamination of the Moon

Andrew C. Schuerger,[1] John E. Moores,[2] David J. Smith,[3] and Günther Reitz[4,5]

ASTROBIOLOGY
Volume 20, Number 12, 2020
© Mary Ann Liebert, Inc.
DOI: 10.1089/ast.2019.2205

A Cruise-Phase Microbial Survival Model for Calculating Bioburden Reductions on Past or Future Spacecraft Throughout Their Missions with Application to Europa Clipper

John E. Moores[1] and Andrew C. Schuerger[2]

JGR Planets

RESEARCH ARTICLE
10.1029/2023JE007975

UV Reflectance of Spacecraft Materials and Analog Soils: Implications for Bioburden Reductions on the Undersides of Mars Rovers

Andrew C. Schuerger[1] and John E. Moores[2]

Key Points:

- Reflected UVC can sterilize the undersides of landed rovers

microorganisms

MDPI

Article

Synergistic Interactions among Vacuum, Solar Heating, and UV Irradiation Enhance the Lethality of Interplanetary Space

Andrew C. Schuerger [1,2]

doi.org/10.3390/microorganisms12101976

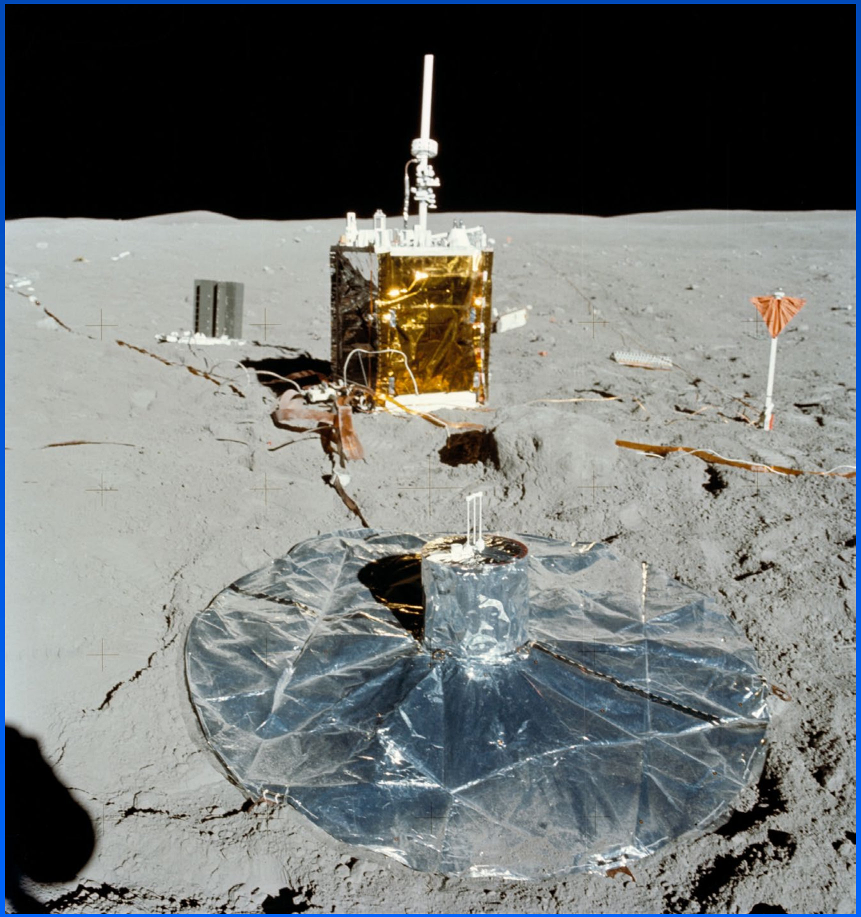
Conclusion

Synergism among the 3 biocidal space conditions tested here significantly increases the lethality of most space environments.

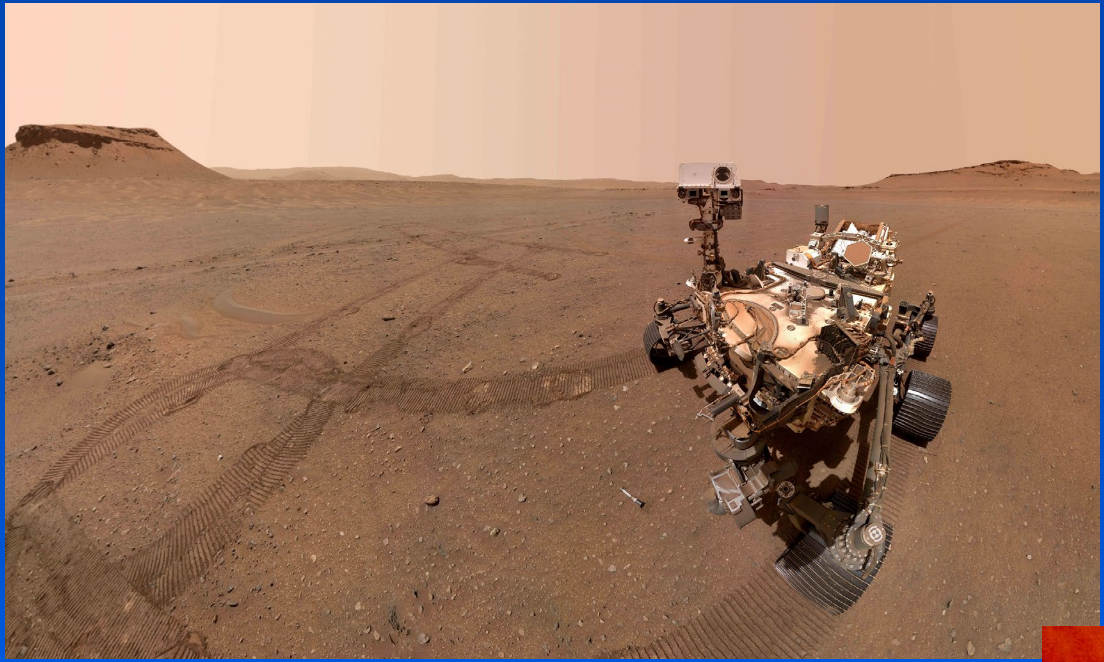
Strategic Knowledge Gaps (SKGs)

SKG #1: nylon JETT bags under Apollo LEMs

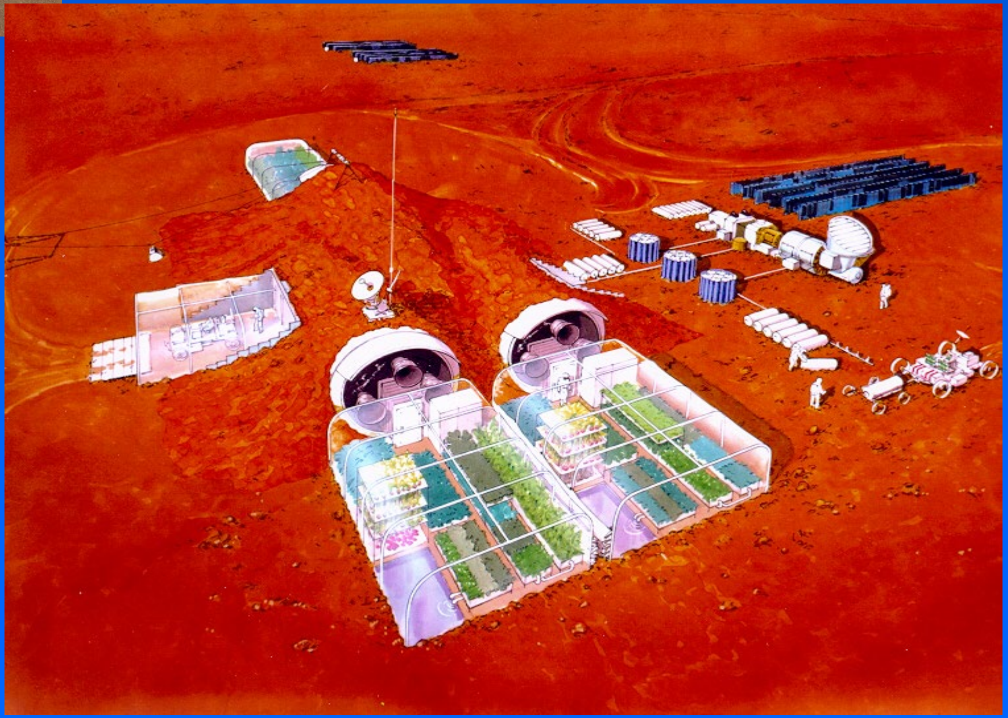
SKG #2: Sample deployed equipment.



SKG-1 and SKG-2 would help validate LMS and CPMS models.



SKG #3: Diffusion of biocidal volatile oxidants into equipment.



SKG #4: Diffusion of biocidal volatile oxidants thru regolith and under habitats.