Ultraviolet Irradiation on the Surface of Mars and the Implications for Robotic and Human Missions

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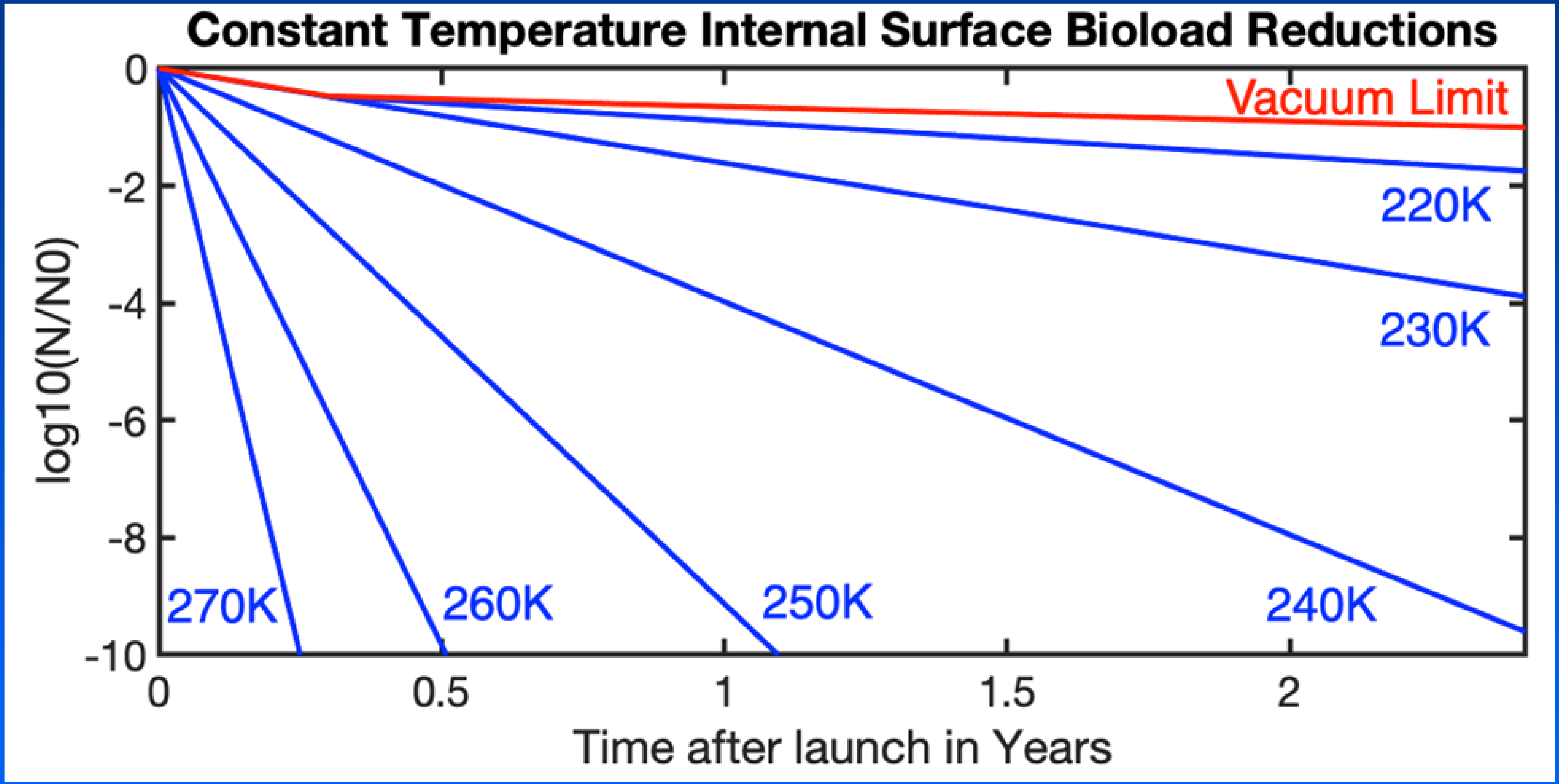
17 Biocidal or Inhibitory Factors on the Surface of Mars

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

(Schuerger et al., 2013, *Astrobiology* 13, 115-131.)
(Stoker et al., 2010, *JGR* 115, E00E2.)
(Beaty et al., 2006, *Astrobiology* 6, 677-732.)

Cruise Phase Microbial Survival Model for Spacecraft



Moores and Schuerger 2020, *Astrobiology* 20, 1450-1464.

UV Models for Mars

(1) UV Mars Models:

- Kuhn and Atreya, 1979, *J. Mol. Evol*., 14, 57-64.
- Cockell et al., 2000, *Icarus*, 146, 343-359.
- Patel et al., 2003, *IJA*, 2, 21-34.
- Schuerger et al., 2003, *Astrobiology*, 165, 253-276.
- Moores et al., 2007, *Icarus*, 192, 417-433.

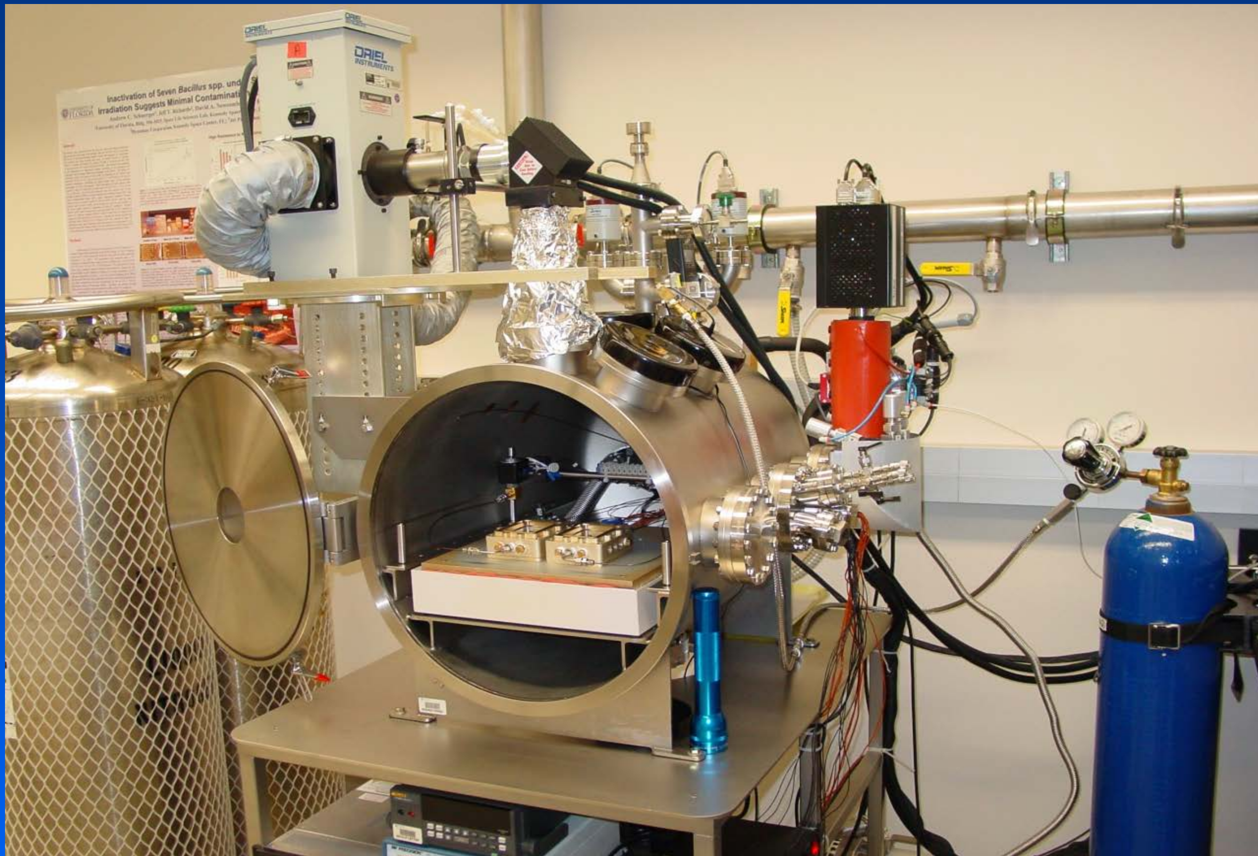
(2) UVA , UVB, & UVC fluence rates equal to ~38, 8, & 3.5 W/m^2.

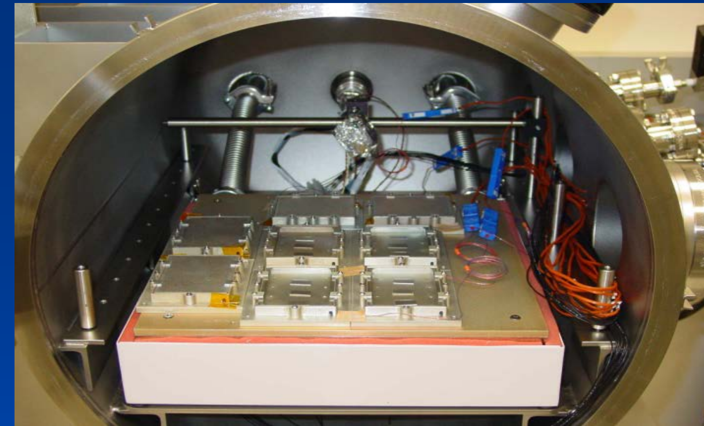
(3) UV attenuated at 190 nm by CO_2 martian atmosphere.

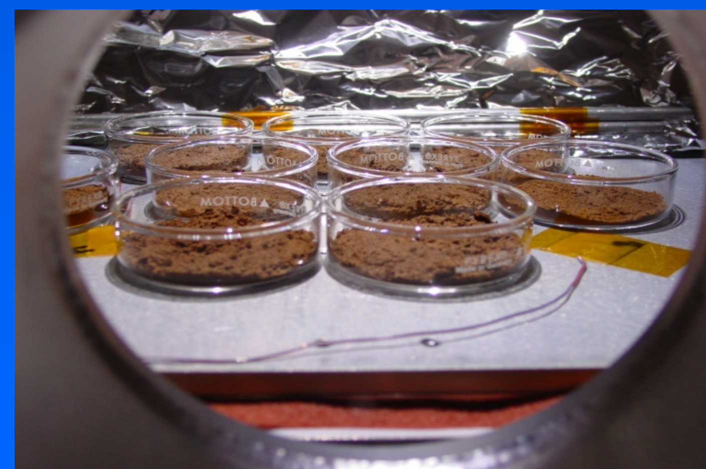
(4) +/- 18% UV dose at aphelion and perihelion.

(5) UV Biocidal effects on the surface of Mars are ~1000x greater than Earth.

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

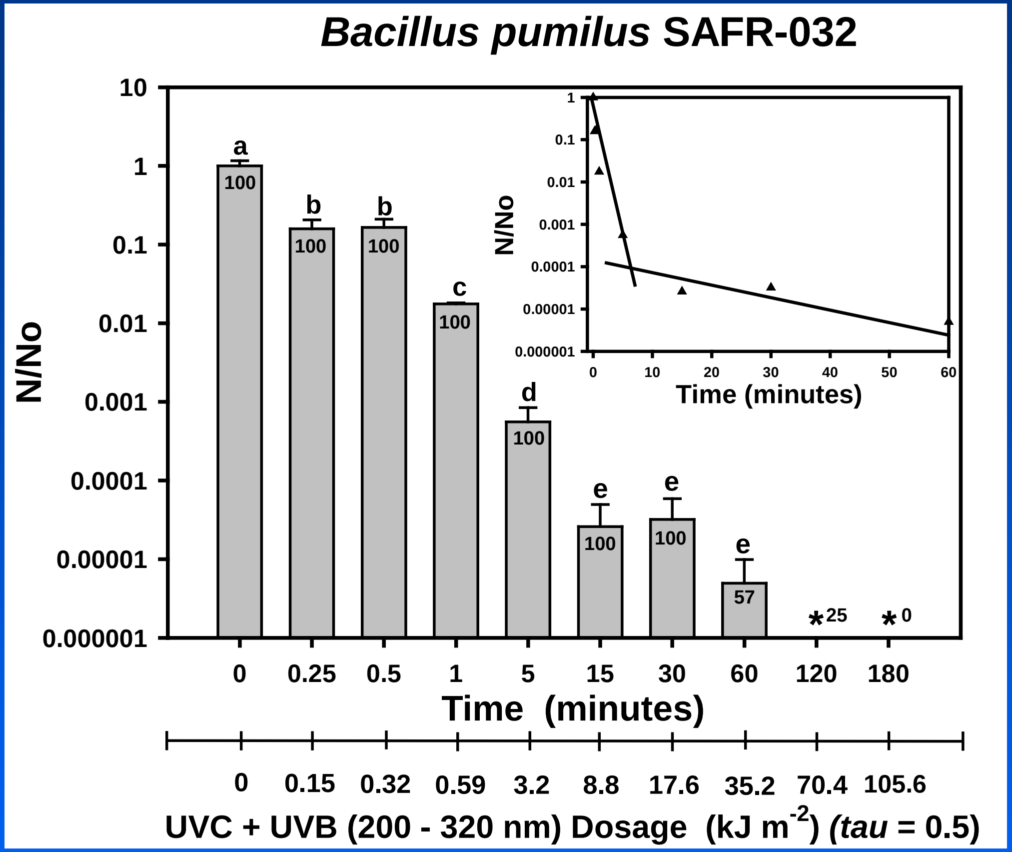


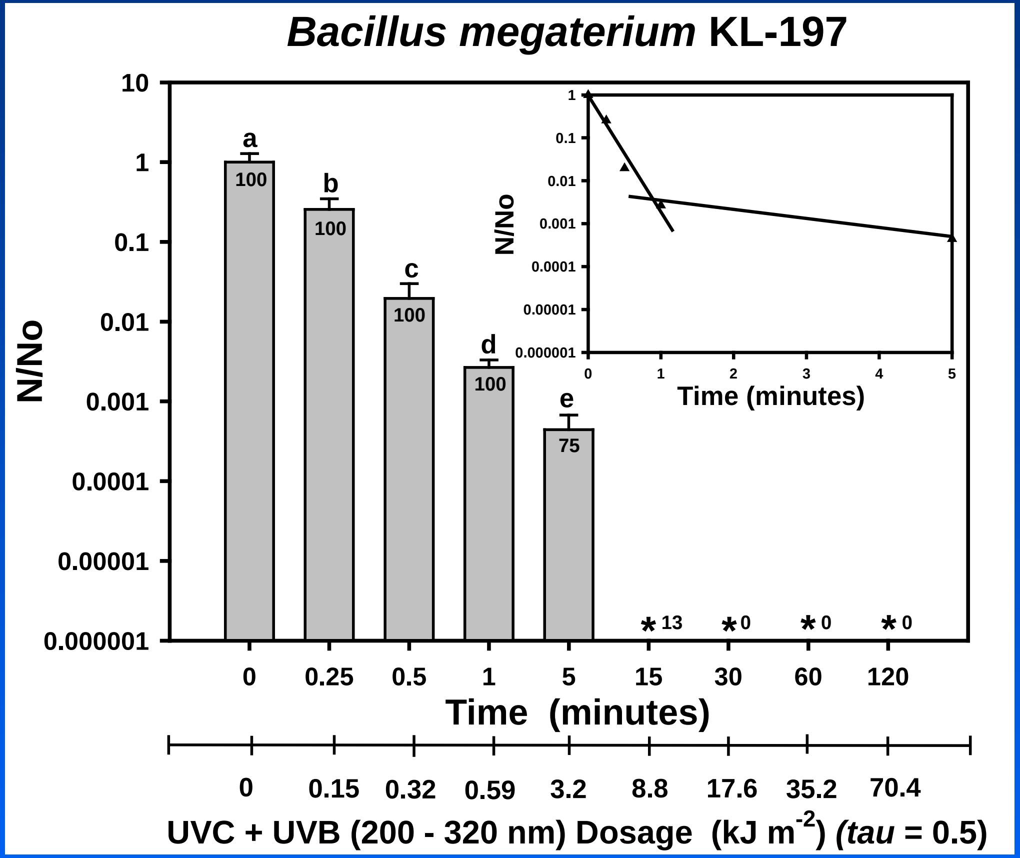




- Pressure: down to 0.1 mbar
- Temp: -100 to +160 ^{o}C (programmable)
- Gases: CO_2; O_2/N_2; Mars mix (top 5 gases)
- UV-VIS-NIR: equatorial to polar fluence rates
- Dust loading from *tau* 0.1 to 3.5

Effects of Mars UV flux on the Survival of *Bacillus* spp.



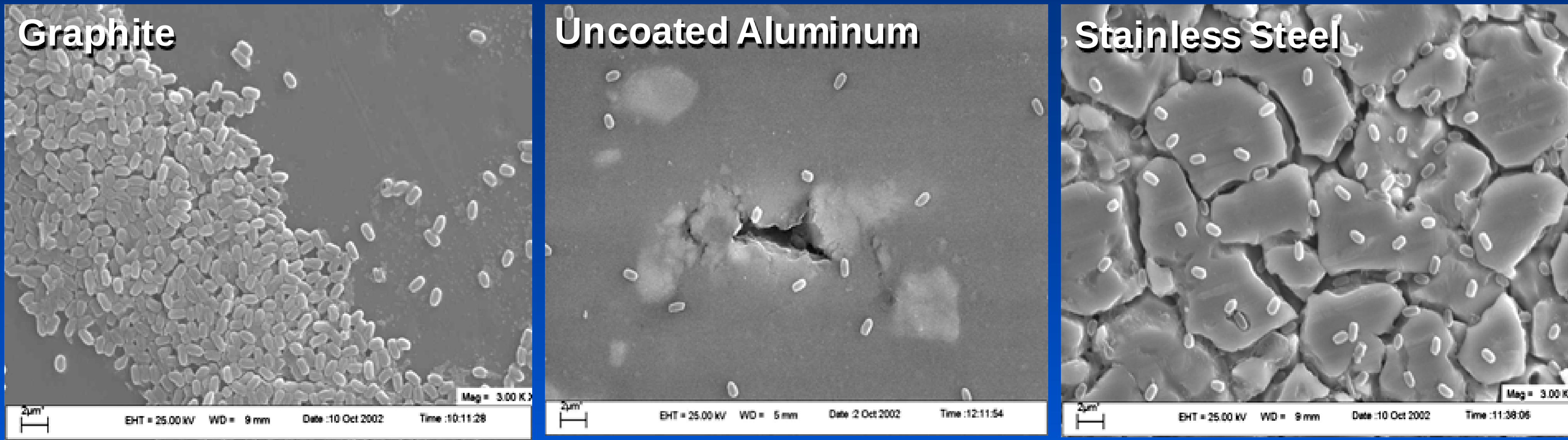


<u>PP Knowledge Gap #1</u>:

- Biocidal UV kill-curves are required for a wider diversity of microorganisms than just *Bacillus* spp. under martian conditions.

(Schuerger et al., 2006, *Icarus* 181, 52-62.)
(Schuerger et al., 2020, Icarus, 340, 113628, corrigendum.)

SEM of *Bacillus subtilis* on Different Spacecraft Components



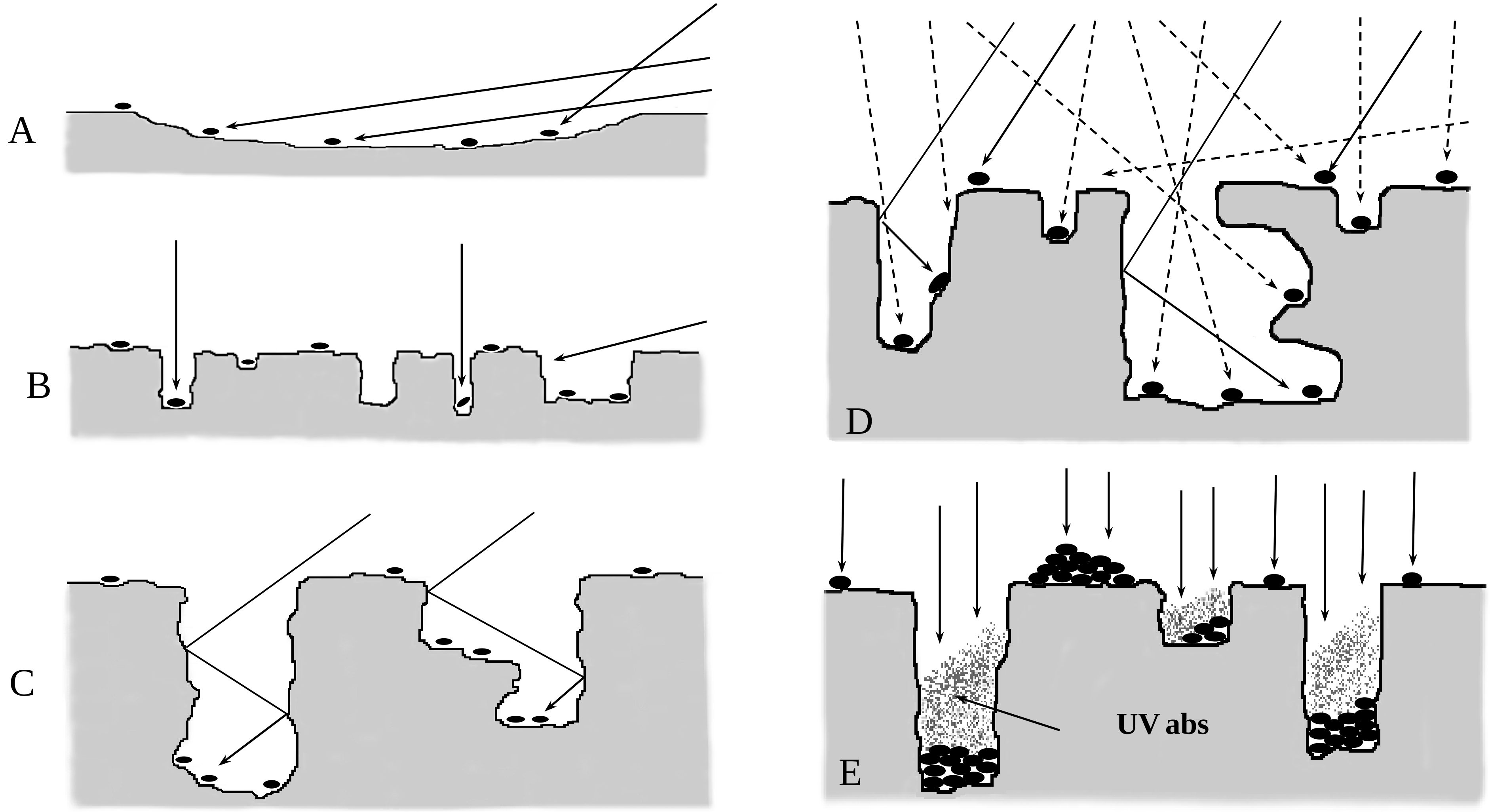
(Schuerger et al., 2005, *Astrobiology*, 5(4), 545-559.)

<u>PP Knowledge Gaps 2 & 3</u>:

- Precisely how do microorganisms adhere to spacecraft materials during pre-launch processing?
- Can spacecraft materials and payload processing protocols be designed to prevent the formation of multicellular aggregates on surfaces?

(Schuerger et al., 2005, *Astrobiology* 5, 545-559.)

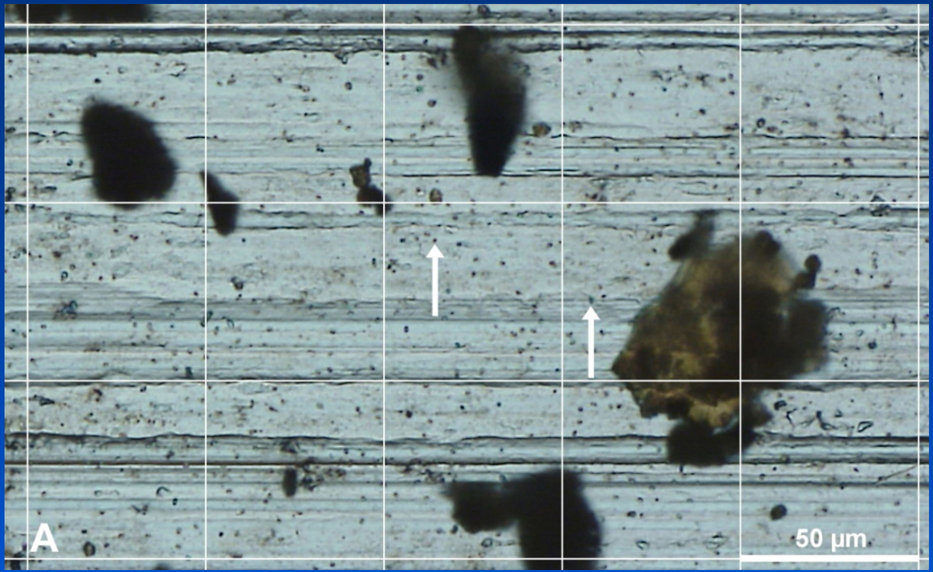
Penetration of UV Irradiation into Spacecraft Materials

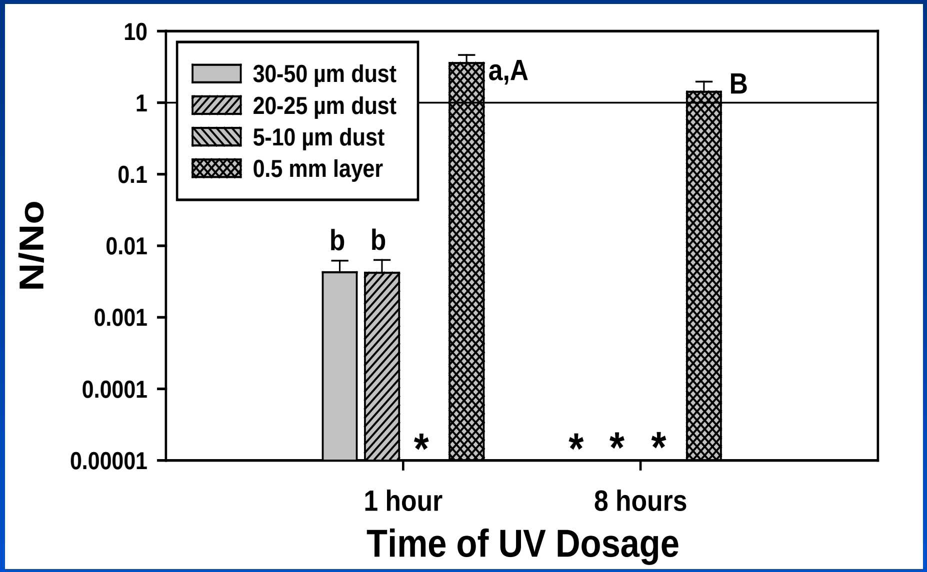


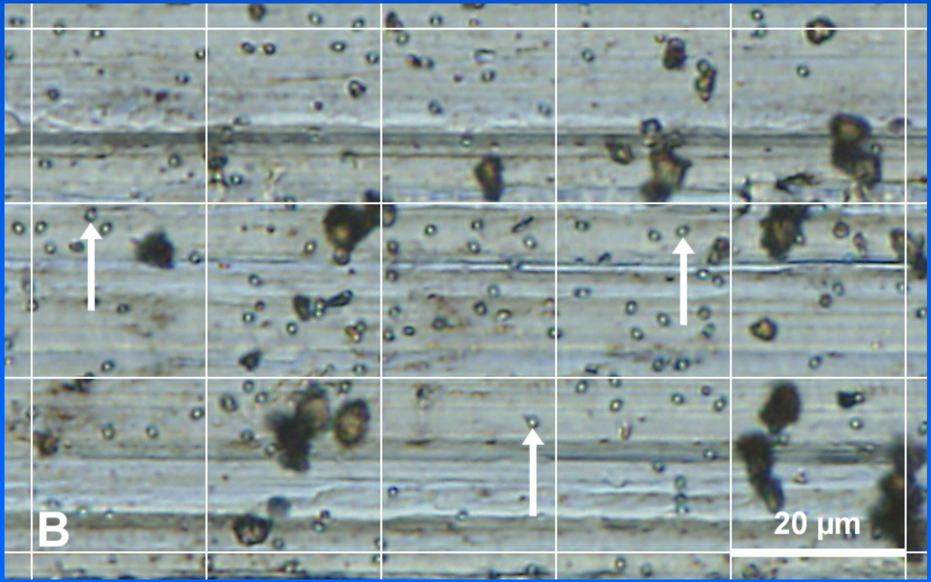
Dashed Line = Diffuse Beam; Solid Line = Direct Beam

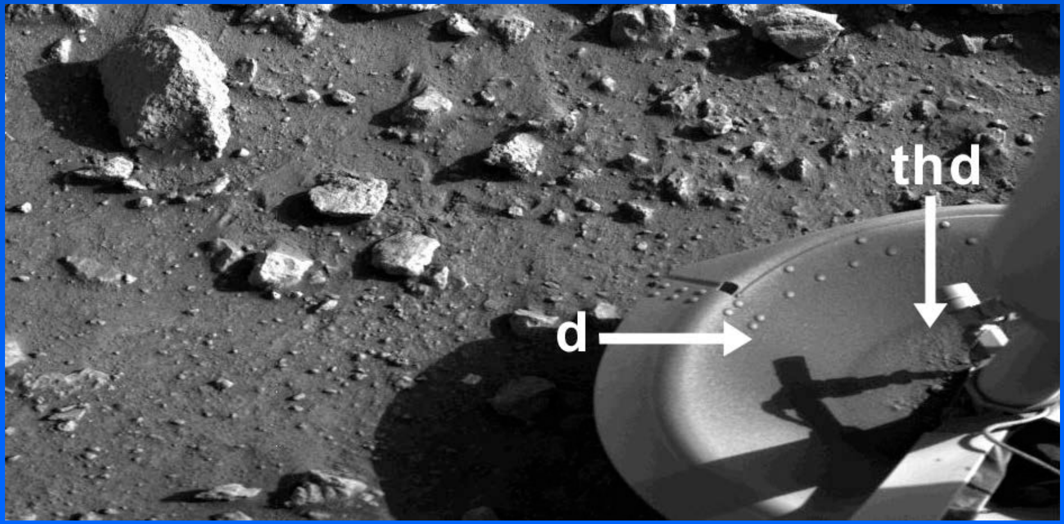
(Schuerger et al., 2005, *Astrobiology* 5, 545-559.)

UV Scattering around Dust Particles on Spacecraft Surfaces



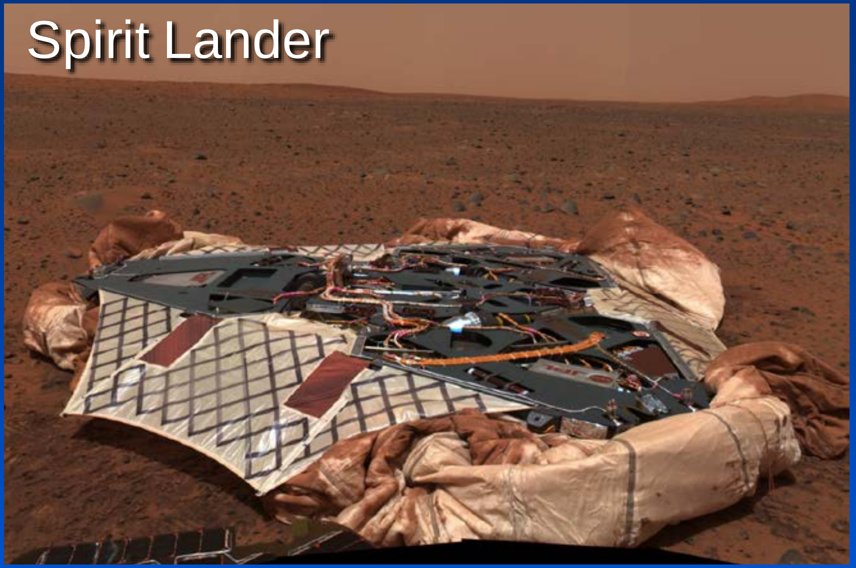






(Schuerger et al., 2003, *Icarus* 165, 253-276.)

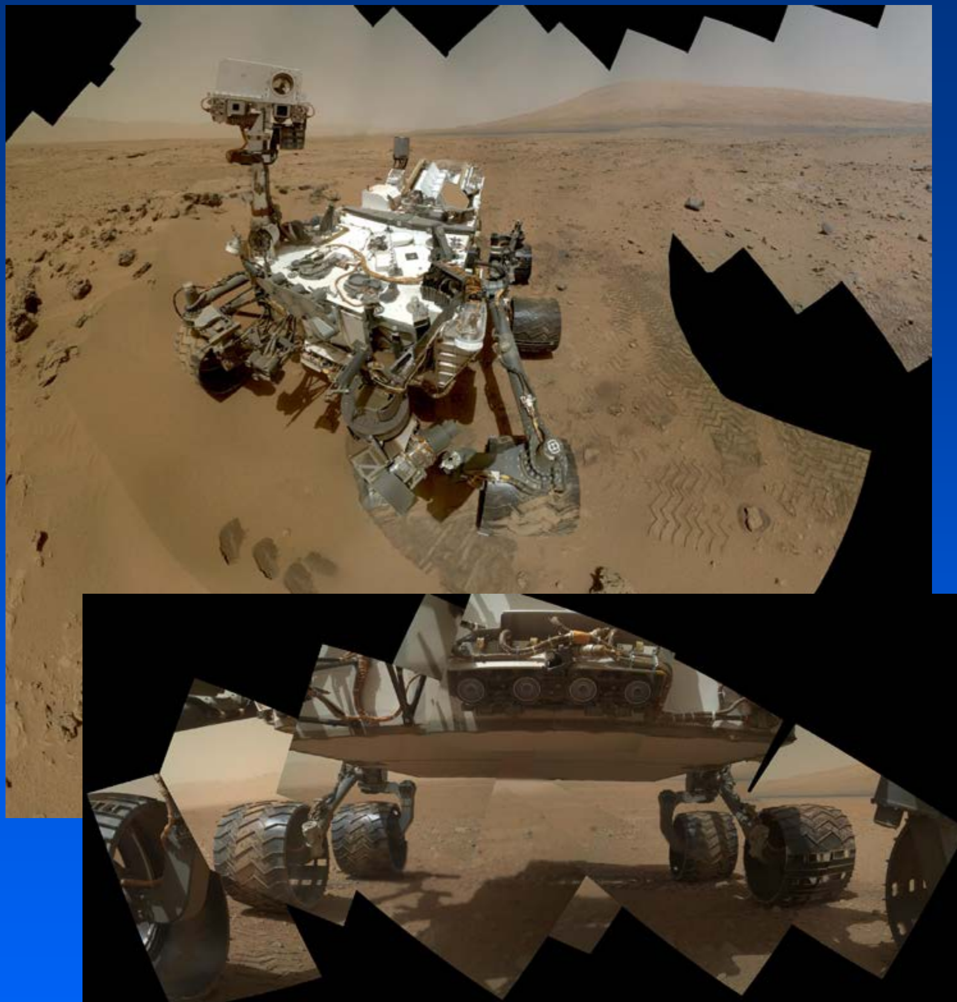
Implications for Air-Bag Landing Systems on Mars



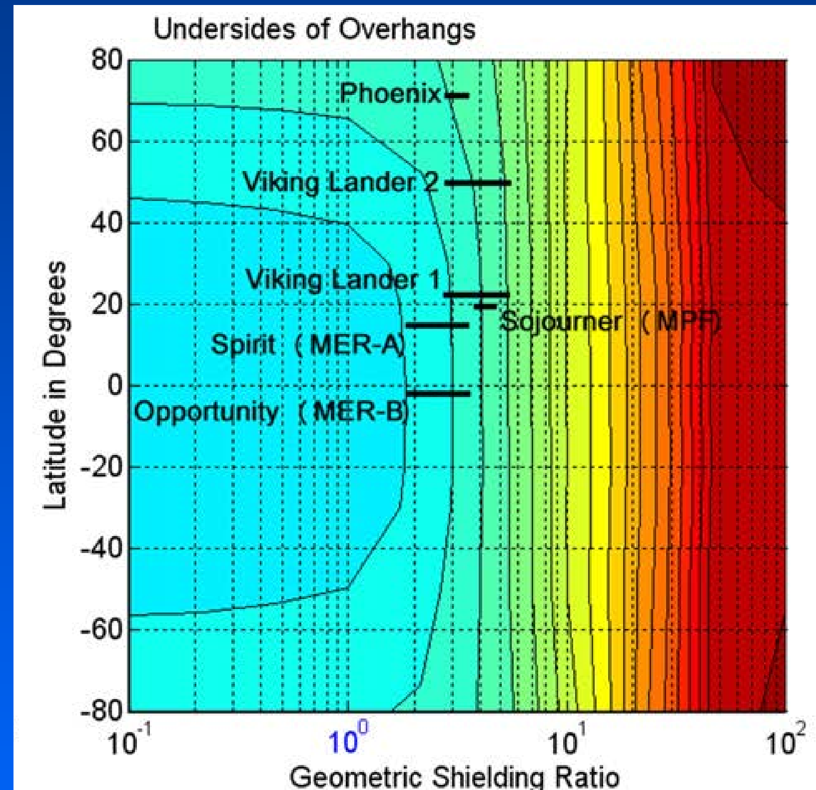
PP Knowledge Gap 5:

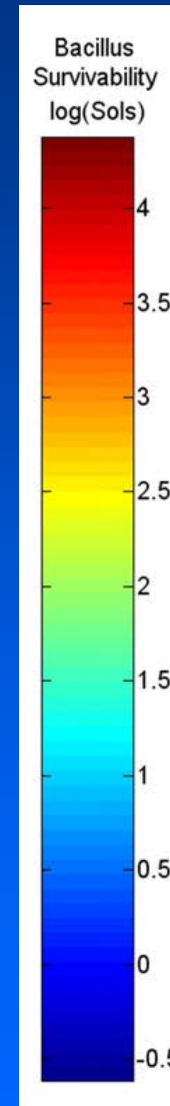
- Can rover wheels be "UV-sterilized" (> 12 log reduction) prior to roll-off from landing pads or initial traverses on regolith?

Implications for Direct-Descent Landing Systems on Mars



B. pumilus SAFR-032; LD_{100} = 105.6 kJ/m^2
(based on Schuerger et al. 2006)



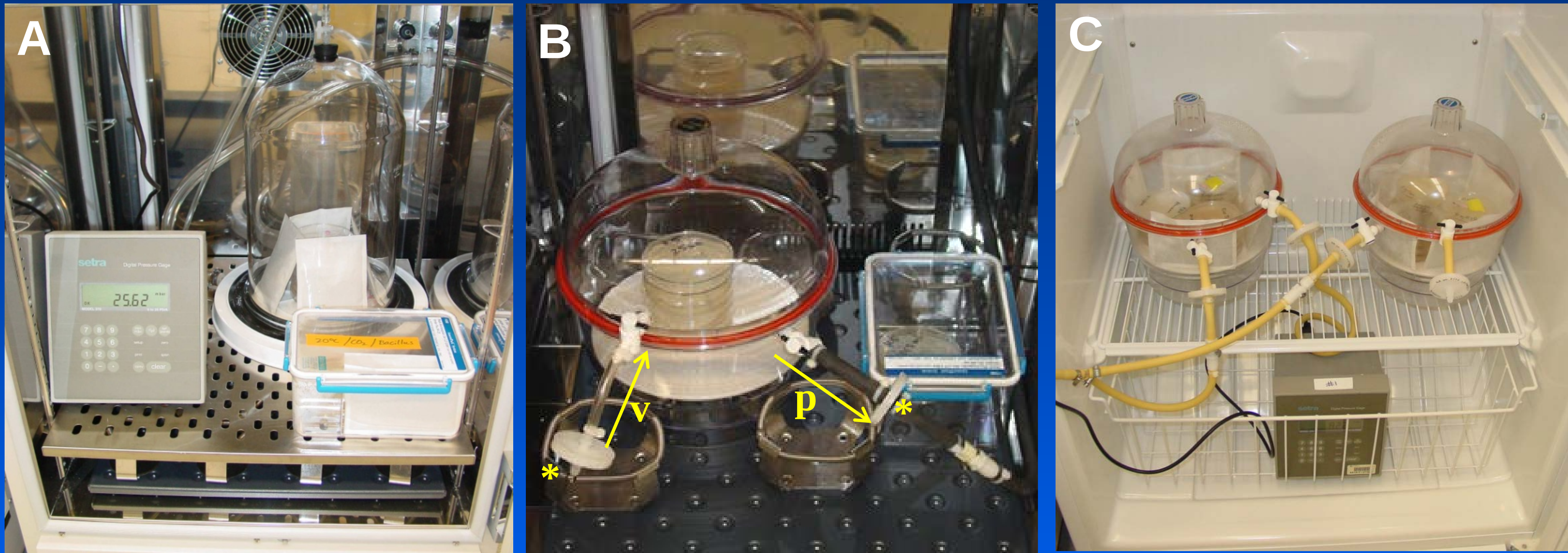


PP Knowledge Gap 6:

- Can surface textures on rovers be managed to promote UV biocidal effects on microbial survival?

Moores et al., 2007, *Icarus*, 192, 417-433.

Microbial Growth under Hypobaric Conditions

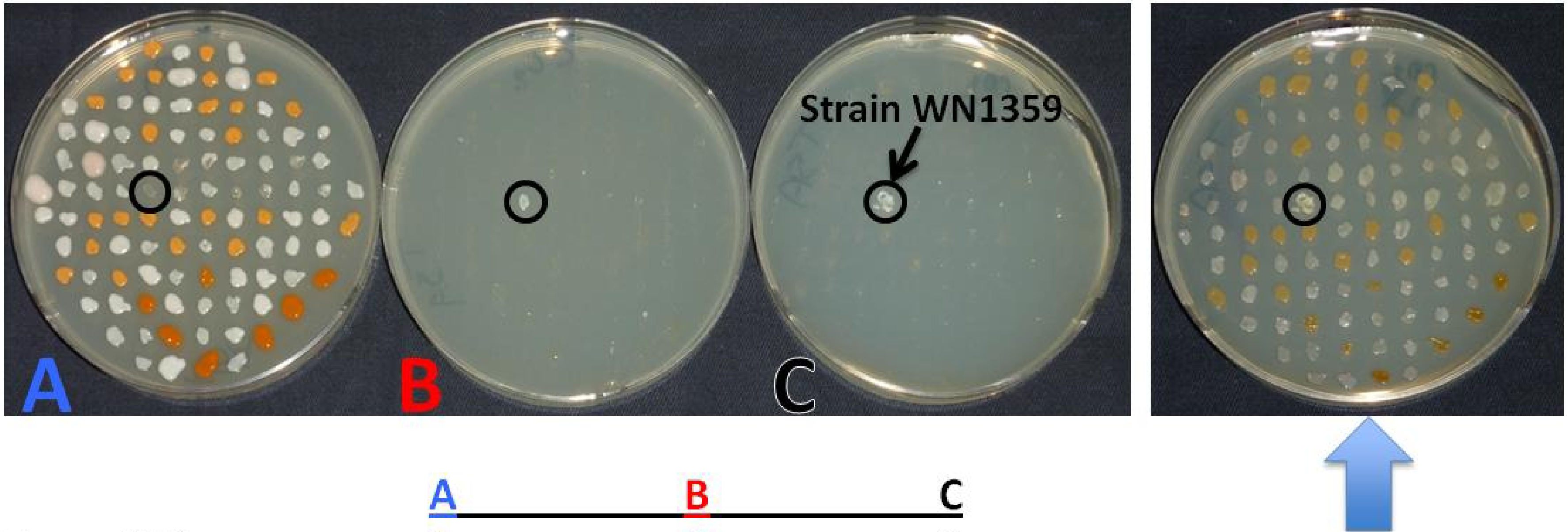


1) TSA = trypticase soy agar; LB = Luria-Bertani broth.
2) 1000's of strains of mesophilic & psychrophilic bacteria.
3) Pressure = 1013, 100, 75, 50, 25, or 7 mbar.
4) Temperature = 30, 25, 15, 10, 5, or 0 °C.
5) Atmosphere = O_2/N_2 or CO_2-enriched anoxic atmosphere.

(Schuerger et al., 2013, Astrobiology, 13, 115-131; Nicholson et al., 2013, PNAS, 110, 666-671.)

10 *Carnobacterium* spp. grew at 7 mbar, 0 °C, and CO_2 anoxic atmo.

Growth of Soil 4-d isolates on 1/2x TSA after 30 days:



	A	B	C
Temp (°C):	0	0	0
Atmosphere:	N_2/O_2	CO_2	CO_2
Pressure (mbar):	1013	1013	7
	Earth		"Mars"

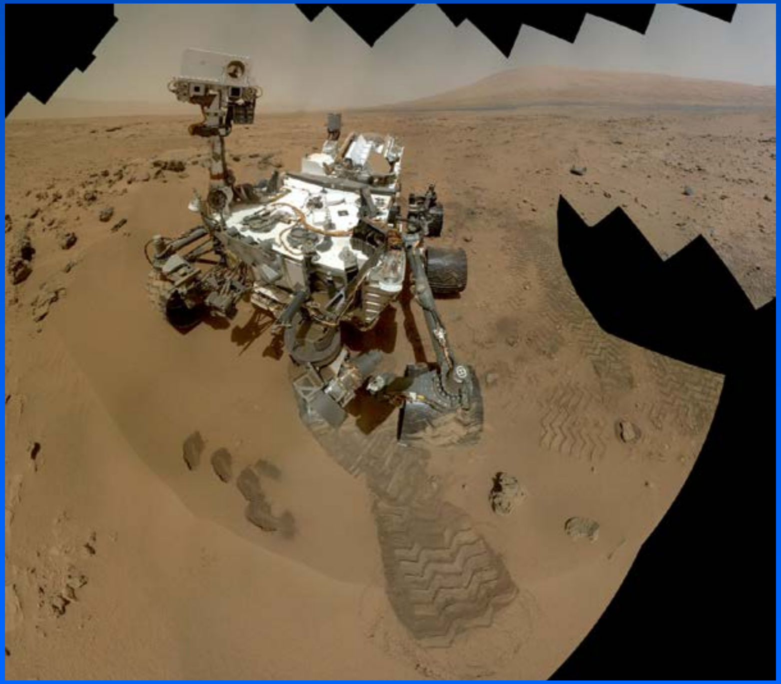
Plate C, after 1 Day at 20°C, N_2/O_2, 1013 mbar:

(Nicholson et al., 2012, PNAS, 110, 666-671.)

Hypobarophiles Grown at 7 mbar, 0 ^{o}C, and CO_2-enriched Atmosphere

29 species in 10 genera

- *Serratia liquefaciens* (6 *Serratia* type-strains confirmed)
- *Carnobacterium* inhibens subsp. gilichinskyi (10 *Carnobacterium* type-strains confirmed)
- *Bacillus sp.* (likely an undescribed species in Bacillaceae)
- *Clostridium vincentii*
- *Cryobacterium arcticum*
- *Exiguobacterium sibiricum*
- *Paenibacillus antarticus*
- *Rhodococcus qingshengii*
- *Streptomyces aureus*
- *Trichococcus pasteurii*



(Schuerger & Nicholson, Astrobiology, 2016, 16, 964-976.)

Implications for Robotic and Human Missions to Mars

Conclusions:

1. Solar UV on Mars is capable of significant biocidal action on terrestrial microorganisms on exposed spacecraft surfaces.

2. External surfaces of spacecraft – directly exposed to solar UV – are likely to see >6 orders-of-magnitude reductions in viable bioloads per sol.

3. Although 29 bacteria have been identified as hypopiezotolerant capable, such hydrated and nutrient-rich niches on Mars are very rare.

Mars Habitability Reviews:

1. Rummel et al. 2014. A new analysis of Mars "Special Regions": Findings of the Second MEPAG Special Regions Science Analysis Group (SR-SAG2). *Astrobiology* 14, 887-968.

2. Craven et al. 2021. Biological safety in the context of backward planetary protection and Mars Sample Return: Conclusions from the Sterilization Working Group. *International J. Astrobiology*, 20, 1-28.