TESTING FORWARD CONTAMINATION OUTCOMES BY RECOVERING SPACECRAFT DEBRIS FROM IMPACT SITES NEAR THE LUNAR SOUTH POLE. D.J. Smith[1], A.C. Schuerger[2], J.E. Moores[3], G. Reitz[4], P.Boston[5]. [1]NASA Ames Research Center, Space Biosciences Research Branch (david.j.smith-3@nasa.gov), [2]University of Florida (schuerg@ufl.edu), [3]York University (jmoores@yorku.ca), [4]German Aerospace Center (Guenther.Reitz@dlr.de), [5]NASA Ames Research Center, Science Directorate (penelope.j.boston@nasa.gov).

Forward Contamination: Spacecraft leaving Earth carry microbiological contaminants onboard, including vehicles intentionally and inadvertently impacted into the Moon's surface. In fact, since September 1959, approximately 60 missions have delivered upwards of 80 spacecraft, boosters, payloads, rovers, and other structures to the surface of the Moon. Based on previous work evaluating the resistance of terrestrial microorganisms to space extremes for up to 69 months [1], it is worth considering if recently delivered Earth biomass remains viable on the Moon. Previous lunar missions (e.g., Biostack experiments [2] onboard Apollo 16 and Apollo 17) also suggest potentially favorable survival outcomes for microorganisms delivered to the lunar surface.

Using a 16-factor Lunar Microbial Survival (LMS) model [3], we estimated the probable viable bioburdens on all spacecraft components reaching the lunar surface through soft and hard landings. The LMS model tallied an estimated average microbial bioburden of ~$5.47 \cdot 10^8$ viable vegetative cells and spores per individual spacecraft. Most relevant to upcoming Artemis and CLPS missions, the LMS model predicted higher survival outcomes for any spacecraft-delivered bioburden near the lunar poles (**Fig. 1**).

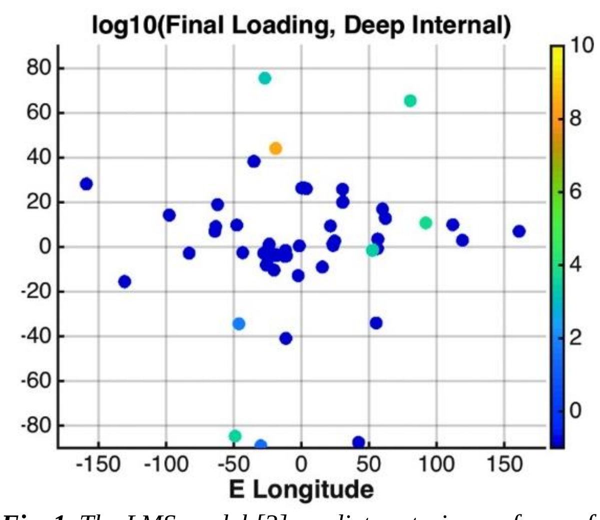

Fig. 1. *The LMS model [3] predicts exterior surfaces of all landed/impacted spacecraft are currently sterile, whereas some bacterial spores might remain in the deep interiors of more recently landed/crashed spacecraft, particularly at polar latitudes where Artemis and CLPS missions are planned.*

Our presentation will review predicted survival outcomes for three recently crashed vehicles near the Moon's South Pole (Lunar Prospector; Chandrayaan-1; and LCROSS) and offer an overarching mission framework for retrieving spacecraft debris that could be used to validate the LMS model. Results from such a mission would provide unique insight for the field of astrobiology and provide the first ever impact survival data for refining planetary protection protocols for solar system exploration.

Biocidal Conditions on the Moon. The Moon possesses no substantial atmosphere, nor planetary magnetic field, so the surface is exposed to the full influx of galactic and solar radiation. Moreover, surface conditions on the Moon are extremely harsh with high doses of ultraviolet (UV) irradiation (26.8 $W \cdot m^{-2}$ UVC/UVB), wide temperature extremes (–171°C to 140°C), and low pressure (10^{-10} Pa). When the biocidal factors of solar UV, vacuum, high-temperature, and ionizing radiation were combined into an integrated LMS model, a –231 $\log_{10}$ reduction in viable bioburden was predicted for external spacecraft surfaces per lunation at the equator [3].

While that degradation rate makes the likelihood of microbes remaining viable on the Moon low, the LMS model also predicted that deep internal spacecraft surfaces would be affected only by vacuum with a degradation rate of –0.02 logs per lunation. A similar rate would be expected for permanently shadowed craters at the lunar South Pole. Sun-exposed crater rims at the lunar poles had an inactivation rate predicted by the LMS model at –4 logs per lunation [3]. A key takeaway from the LMS model: recently flown lunar spacecraft containing bioburden buried deep within the vehicle, or at the bottoms of shadowed craters, may still have some viable microorganisms onboard.

Impact Forces. Fundamentally, how impact forces reduce spacecraft bioburden is unknown and the Moon can be used as the first real case study. More research is needed into how kinetic energy and heat dissipate in the process of a spacecraft structure crashing, collapsing and breaking apart [3]. Related studies [4] concluded that compression forces on bacteria during simulated impact events into regolith-like materials yielded an overall reduction of approximately –4 logs if traveling at velocities near 2.6 $km \cdot s^{-1}$. Estimates for bacterial spore survival in the genus *Bacillus* for bolide impact velocities of 1.0–5 $km \cdot s^{-1}$ have yielded survival rates in the range of 0.1% to $<10^{-6}$ of the starting spore densities per impact event [5,6].

Motivation for Retrieval Mission at Known Impact Sites near South Pole: The Moon is not a protected exploration target in planetary protection, but its accessibility and planned human missions on the surface offers an opportunity to determine if spacecraft carrying bioburdens result in viable forward contamination; or, alternatively, if impact forces and subsequent radiation effects sterilize contaminants. Such knowledge would help refine planetary protection approaches for spacecraft heading to other solar system targets, sometimes resulting in hard impacts (purposeful or accidental).

Within 6° of the South Pole, we have identified three high priority target locations that could be visited by teams of astronauts in order to retrieve debris from recently crashed spacecraft and test LMS model predictions:

Lunar Prospector – orbiter's crash site

- Location (lat/long): 87.5° S/42.3° E
- Impact date: 31 January 1999
- Dry mass (kg): 158
- Probable bioburden at contact: $4.0 \cdot 10^4$

Chandrayaan-1 – impact probe's site

- Location (lat/long): ~89° S/330° E
- Impact date: 14 November 2008
- Dry mass (kg): 35
- Probable bioburden at contact: $8.86 \cdot 10^3$

LCROSS – impact site for shepherding spacecraft and Centaur upper stage

- Location (lat/long): 84.7° S/311° E
- Impact date: 09 October 2009
- Dry mass (kg): 866 (shepherding vehicle) and 2305 (Centaur)
- Probable bioburden at contact: $8.02 \cdot 10^5$

Mission Architecture: A precursor mission would be required to identify the most accessible debris field for Lunar Prospector, Chandrayaan-1 and LCROSS. Lunar orbiters with high-resolution cameras (**Fig. 2**) or future CLPS landers could both acquire debris field images for surface mission planning purposes. With an EVA designed to operate within the most accessible of the candidate debris fields, recovered spacecraft debris could be bagged and returned to Earth with a high degree of confidence.

There is precedent for this proposed mission architecture on the Moon. During the Apollo 12 mission, astronauts retrieved a portion of the Surveyor III's camera during a surface EVA in November 1969. Back on Earth, scientists reported that a single pure culture of *Streptomyces mitis* was recovered from circuit board foam insulation that was deeply embedded within the camera body [7]. However, that claim was likely due to contamination (see Schuerger et al. [3]) and there is a need for repeating such an experiment at other landing/impact sites, applying more modern, stringent, and sensitive methods in microbiology back on Earth.

Only a few kg of material would be required for the proposed debris retrieval mission at the South Pole, with minimal crew training. Unlike other conceivable surface science investigations, an untrained eye could probably identify metallic spacecraft debris amongst lunar rocks/regolith, and crewmembers could place samples in pre-sterilized containers that would not require additional steps for maintaining aseptic conditions.

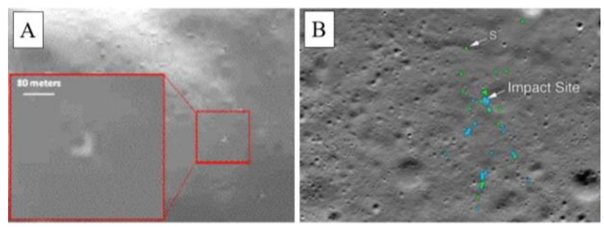

Fig. 2. *(A) LCROSS mission's Centaur stage impact site near the lunar South Pole as seen by shepherding spacecraft; (B) A more clearly imaged debris site by Lunar Reconnaissance Orbiter (LRO) from a crashed lander (Vikram; ~71° S, ~23° E) to demonstrate how a precursor mission could be done for candidate South Pole locations. Image credits: NASA.*

Acknowledgments: We thank NASA Space Science Data Coordinated Archive (NSSDCA) curator Dr. Dave Williams at NASA Goddard Space Flight Center. Research efforts were supported by grants from NASA's Planetary Protection Office.

References: [1] G. Horneck (1998) *Adv Space Res, 22*, 317–326. [2] H. Bücker et al. (1974) *Life Sci Space Res, 7*, 209–213. [3] A.C. Schuerger, J.E. Moores, D.J. Smith and G. Reitz (2019) *Astrobiology, 19(6)*, 730-756. [4] J.B. Plescia et al. (2016) *Planet Space Sci, 124*, 15–35. [5] P. Fajardo-Cavazos, et al. (2005) *Astrobiology, 5*, 726–736. [6] B.L. Barney, et al. (2016) *Planet Space Sci, 12*, 20–26. [7] F.J. Mitchell and W.L. Ellis (1971) *Proceedings of the 2nd Lunar Science Conference*, Vol. 3, 2721–2733.