LUNAR AVATAR: THE OTHER ARTEMIS ASTRONAUT. K. D. Runyon, K. D. Seelos, A. Matiella Novak, C. A. Hibbitts. M.E. Nord, A.M. Stickle, D.A. Handelman, K. L. Craft, H. M. Meyer, A.O.Tucker IV, J. I. Núñez, and the Lunar Avatar Team. Johns Hopkins APL, Laurel, MD, 20723, USA

Introduction: Astronauts who will conduct geologic exploration and other science on the lunar surface during the early Artemis missions will be highly time-constrained and possibly mobility-limited. As an augmentation and assistant to help maximize astronaut scientific productivity on the Moon, the Space Exploration Sector at Johns Hopkins APL is developing the "Lunar Avatar." Avatar will combine an all-terrain robot with anthropomorphic manipulators (human-like robotic hands) inspired by APL's Modular Prosthetic Limb (MPL, Figure 1;). Operation will be through an immersive near real-time, latency-tolerant mixed reality environment created with data from sensors on the Avatar. Stereoscopic vision and immersive pseudo real-time remote operation will allow human geologists in mission control (or elsewhere) to "map their mind" (figuratively) onto Avatar. The superior mobility offered by the all-terrain robot will enable access to rugged and dangerous terrain while the anthropomorphic manipulator will enable use of astronaut-compatible EVA tools, allowing for exploration and scientific discovery in regions not accessible to humans. Merging of persistently-updated mixed reality from Avatar's sensors with remote manipulation would remove the most disruptive effects of the ~5-second delay for the Earth-based operator. This means that, effectively, an Earth-based operator could operate Avatar on the Moon with minimal impact from communication delay.

Expanded Surface Capability and Community Participation: Avatar's ability to remotely use EVA tools independently of astronauts creates the opportunity to perform field geology remotely but in near real-time. This means that, in addition to deploying instrument packages or collecting samples, Avatar could be outfitted with sensor packages comparable to those currently reserved for landers or rovers to permit real-time analysis in the field by trained scientists. Such enhanced capabilities would complement field mapping and enable more targeted sample return through robust in situ characterization of observed terrains and outcrops. Possible instruments could include stereo cameras, multi- or hyperspectral imaging, microscopic imagers [Núñez et al., 2019; 2020], alpha particle x-ray or Raman spectroscopy, etc.

Geology Backroom Structure: The geologist operating Avatar from the Flight Control Room (FCR) geology backroom would function as an additional crew member on the Moon (but without human-specific safety constraints).

One potential ConOp ("other astronaut ConOp," or OA) would be for Avatar to travel with the crew to pre-defined stations to conduct detailed exploration in geologically interesting but less-accessible terrain, such as steep slopes, rubbly boulder fields, and permanently shadowed regions (PSRs). A retrospective example could be Avatar walking further down inside Hadley Rille at Apollo 15's Stations 9A and 10 to retrieve samples and make in situ outcrop observations. In addition to expanding the amount and type of explored terrain, Avatar could provide a degree of mission assurance in the event the crew were not able to complete their tasks.

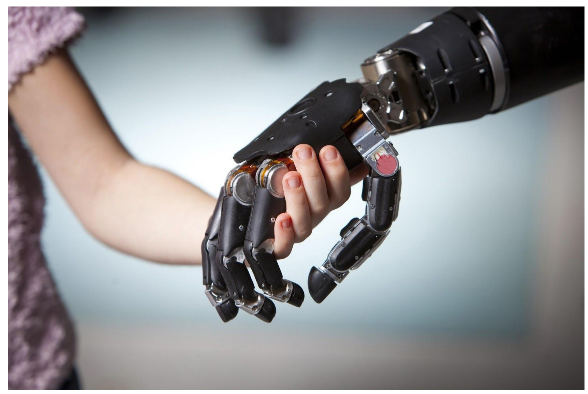

Figure 1. APL's Modular Prosthetic Limb (MPL) is an anthropomorphic robotic end effector. See https://www.jhuapl.edu/prosthetics*. Credit: JHU/APL.*

Avatar would be controlled by its remote (Earth-bound or elsewhere) geologist-operator, functionally acting as "the other astronaut" on the lunar surface. This scenario would place the operator in a unique communications position: besides the CAPCOM or SciCom, he or she could be the only Earth-bound person in voice communication with the astronauts, just as the astronauts are in communication with each other. The Avatar operator could either be isolated from the science backroom and only communicate with the astronauts and the CAPCOM/SciCom (Bell et al., 2013) in order to avoid confusing communication, or could switch to interact with the science backroom for real-time decision making about what to explore, either in conjunction with an on-Moon astronaut or independently, though this would benefit from Earth-analog testing.

Another Science ConOp would be for Avatar to conduct different traverses from the crew and so operate independently of them, and to do so nearly continuously with different operators to maximize efficiency ("24/7 ConOp"). Accordingly, there would be no need to be in contact with the astronauts nor CAPCOM. However, Avatar operators should then be embedded within the science backroom.

A realistic scenario (Figure 2) would be one in which both ConOps are used at different times: OA ConOp when the crew is on EVA and 24/7 when the crew is not on EVA. Practically speaking, this hybrid ConOp may require the Avatar operator to relocate into the science backroom for 24/7 and likely to isolate (to prevent confused communication) during OA.

Training Considerations: Avatar operators should train with crew on Earth by both co-locating in geologic field locations as well as remotely (but with the Avatar in the field). This is especially true for the OA ConOp in which the Avatar controllers should develop rapport and efficient teaming interactions with the astronaut crew.

Additionally, Avatar operators should train with science backroom personnel and the crew for how to maximize the science with Lunar Avatar as well as how to mitigate issues such as anomalous Loss of Signal (LOS) and Loss of Control (LOC). Procedures developed from these simulations would inform crew coordination in such events.

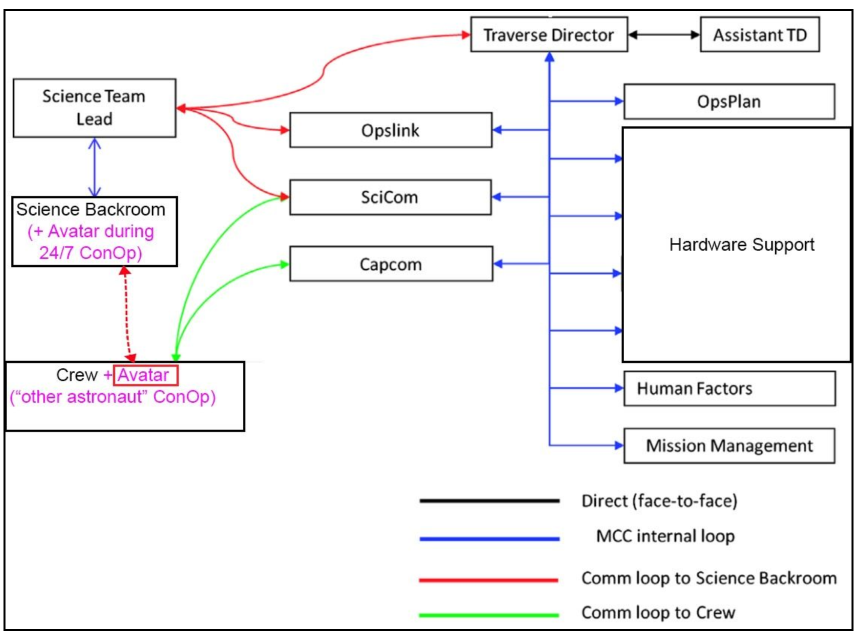

Figure 2. Basic Operations Team Organization and Communications Flow, modified from Bell et al. (2013); Avatar additions in magenta for the two different ConOps ("other astronaut" (OA) and "24/7" ConOps). The dashed red arrow indicates that the Avatar operator could have the option of conferring directly with the backroom, though this would benefit from Earth analog tests.

References: **Bell** Jr, E. R., et al. (2013). Mission control team structure and operational lessons learned from the 2009 and 2010 NASA desert RATS simulated lunar exploration field tests. Acta Astronautica, 90(2), 215-223. **Núñez**, J. I., et al. (2019), The Advanced Multispectral Infrared Microimager for Planetary Surface Exploration, 50th Lunar and Planetary Science Conference, The Woodlands, TX, March 18-22, 2019. Abstract #3004. **Núñez**, J. I., et al. (2020), Enabling Surface Exploration and High-Grading of Lunar Samples with the Advanced Multispectral Infrared Microimager (AMIM), Lunar Surface Science Virtual Workshop #1: Overview and Tools and Instruments, May 28-29, 2020. Abstract #5149.

Appendix: Opportunities for Public Engagement: Developing this technology also provides an exciting opportunity to engage students and young explorers with exploration science. The use of mixed reality lends itself readily to a visual and interactive way to engage the public. We are developing a "virtual field work" scenario that will be web hosted along with a beta version of software for Lunar Avatar that can be downloaded and installed on local VR hardware (such as Oculus or Vive). The scenario will involve the VR representation of an analog field site and ask users to navigate on the surface in order to find geological areas of interest, mark them, and obtain virtual measurements. At the end of the VR session, the software would then save the coordinates of the marked features as well as any measurements. Users could then upload the file to a data sharing site, which would collate data from multiple users and display the data via an interactive webpage. Even members of the public that do not have VR hardware would be able to browse the interactive web page to view data collected by other users. In this way, we may be able to test some of the VR ConOps needed to make Lunar Avatar successful. The scenario can potentially be expanded to "classroom sessions" that can be downloaded by educators and separated into both a VR and non-VR section, so all students can participate in the scenario.