

### Low-Latency Telerobotic Sample Return and Biomolecular Sequencing for Deep Space Gateway

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**Introduction:** A cislunar Deep Space Gateway (DSG) can provide opportunities to integrate mission concepts leveraging lunar surface operations, sample return, data collection, and scientific research and analysis. The presentation will provide integrated mission concepts that utilize low-latency robotics, crew-assisted sample return, and biomolecular sequencing to obtain and evaluate lunar samples and inform future similar Mars activities. Resources envisioned for the DSG and related infrastructure will also be presented.

The Human Spaceflight Architecture Team (HAT) has explored a number of strategies and mission concepts for how a “Deep Space Gateway” in cislunar space could be utilized for science. Analyses were conducted several years ago by the HAT “Cis-Lunar Destination Team” [1] and then subsequently by a “Translunar Supported Missions Task” [2] that included two separate but related tasks investigating: (1) the use of low-latency teleoperations/tele robotics (LLT) in cislunar space, and (2) crew-assisted sample return in cislunar space (often referred to as Human-Assisted Sample Return as noted in the International Space Exploration Coordination Group Global Exploration Roadmap.

In the summer of 2016, DNA was successfully sequenced in space for the first time by Kate Rubins on the International Space Station using a miniature low-power molecular sequencer [3]. This demonstration showed that a small-scale nanopore sequencer could be reliably used to sequence DNA in a micro-gravity environment.

This presentation will cover the three areas noted above (LLT from a DSG, crew-assisted sample return, and biomolecular sequencing), integrating them into notional mission concepts that leverage the use of LLT from a DSG to obtain samples from the lunar farside and Apollo landing sites and returning them to the DSG for analysis, including biomolecular sequencing for Apollo site samples, with possible return to earth. We will also touch on broader biomolecular sequencing uses on a DSG for crew health and environmental purposes. Technical and operational implications of these concepts for the DSG will be explored, including potential implications for mass, volume, power, communications and crew-time.

**LLT Lunar Sample Return:** The HAT LLT analyses included concepts involving crew tele-

operating lunar surface rovers to perform surface science, sample acquisition and return to a DSG, and science system maintenance and repair of surface assets. Crew-assisted sample return involves the possibility of using cis-lunar facility such as a DSG to capture, store, analyze and help return a variety of planetary samples back to earth with the crew or a dedicated sample return vehicle.

A “LLT lunar sample return” concept combines LLT with crew-assisted sample return by having DSG crew members use LLT for sample prospecting, acquisition, and return of samples to a cislunar DSG which can then be returned to earth with or without crew – the former of which has the potential to allow more sample mass to be returned to earth (perhaps a factor of 10 or more) [4]. We will touch on details of a notional LLT lunar farside sample return from the South Pole-Aitken Basin, taking advantage of long time periods afforded by a Deep Space Gateway. The South Pole-Aitken basin is one of the oldest impact basins in the solar system and exploring it is a key science objective from the 2011 Planetary Science Decadal Survey [5].

Although many untouched “pristine” samples could be returned to earth from the DSG to ensure sample integrity, a DSG would allow for some degree of sample analysis on the DSG – which would then allow for an assessment of which samples may be best to return to earth for more in-depth analysis. Such a scenario could also be relevant for Mars samples, for which on-orbit analysis could be more important [6]. A LLT lunar sample return mission could also feed forward to Mars if LLT is needed to analyze a sample containment unit before bringing it inside a DSG or Mars orbiting science facility – which could be tested and practiced with lunar samples using the cislunar DSG. The greater communications distances to Mars, potentially strict planetary protection requirements, and possible requirements to analyze samples in the Mars vicinity, suggest it would be wise to develop and prepare for an effective Mars orbital LLT sampling strategy [7].

LLT from an orbiting DSG is not necessary to obtain samples from the lunar surface, however, surveying, prospecting and sample acquisition could be performed faster via LLT and would help prepare for similar mission scenarios at Mars where exploring large

regions in a relatively short time, could be a valuable capability – especially “special regions” of possible biological interest [8].

*Apollo Contamination Environment (ACE) Sample Return.* The LLT lunar sample return concept can be applied to sampling the Apollo landing sites and returning those samples to a DSG to analyze contamination. Such data could contribute to a better understanding of the overall contamination “foot print” of the Apollo missions, including performing molecular sequencing that could shed light on the effects on biological sources (such as waste) that have been on the lunar surface for almost 50 years. This can then help inform potential future contamination dynamics, including numerous planetary protection knowledge gaps for human extraterrestrial missions noted in a NASA planetary protection workshop report [9], suggesting it would be important to sample the Apollo sites before new contamination is introduced [10]. An Apollo contamination environment sample return mission could also help address strategic knowledge gap (SKG) II-B-4 on radiation shielding effects of lunar material, and such a mission would also need to be compliant with NASA’s recommendations on how to protect the historic and scientific value of Apollo landing sites [11].

Some level of robotic in-situ (i.e. on-surface) biomolecular sequencing before returning samples to a DSG might be possible and would have benefits such as (a) increasing the probability of not compromising sample integrity through ascent and human interactions with the sample onboard DSG, (b) reducing any potential biohazard risks to crew, and (c) allowing for effective high-grading before returning samples to a DSG. However, requirements for sample preparation and other factors associated with rigorous biomolecular sequencing may make robotic on-surface LLT/robotic sequencing insufficient or unfeasible, suggesting that sequencing may be more effectively accomplished by astronauts on a nearby orbiting DSG with proper analytical capabilities and biohazard protections.

**Biomolecular Sequencing for DSG:** This presentation will also address the importance of biomolecular sequencing for DSG environmental monitoring and crew health. For example, in-situ spacecraft microbial analysis will be needed for (a) real-time monitoring of the DSG microbiome, (b) longitudinal studies of new vehicle microbial seeding through long-term population studies, and (c) onboard dependent clinical analysis. Long-term culture equipment for sample growth, collection, and analysis will be beneficial for multi-generational microbial evolution studies and will inform human missions to Mars, including effects of and mitigation strategies for radiation. Our presentation will link to a number of science and HRP (Human Re-

search Program) objectives as well SKGs such as II-D (Maintaining Peak Human Health). Discussion of options for on-station sequencing data analytics will include a review of current and emerging bioinformatics platforms that contain turn-key Graphical User Interface (GUI) workflows for sequence taxonomy classification and functional genomics analysis.

A Deep Space Gateway offers unique opportunities to integrate LLT with crew-assisted sample return and biomolecular sequencing into mission concepts that can address a variety of SKGs and science objectives – possibly with relatively low impact to DSG capabilities, particularly when compared to the potential science and Mars feed-forward value that could result.

**References:** [1] Lupisella, M.L. and M. Bobskill (2012) NASA Human Spaceflight Architecture Team: Cis-Lunar Analysis, *Proceedings of Earth and Space 2012*. pp. 1515-1524. [2] Bobskill, M.R., and M. L. Lupisella et al. (2015) Preparing for Mars: Evolvable Mars Campaign Proving Ground Approach, 2015 IEEE Aerospace Conference, Paper No. 2662. [3] Castro-Wallace, S. L and Burton, A. et al. (2017) In press. Nanopore DNA Sequencing and Genome Assembly on the International Space Station.” *Scientific Reports–Nature*. [4] Pratt W. and Alkalai L. et al. (2014) Human-Assisted Sample Return from the Moon and Mars Using the Orion Spacecraft, *Proceedings of the 65<sup>th</sup> International Astronautical Congress*. [5] Burns, J. O. and Kring, D. et al. (2013) A Lunar L2-Farside Exploration and Science Mission Concept with the Orion Multi-Purpose Crew Vehicle and a Teleoperated Lander/Rover, *Adv. Space Res.* 52, 306-320. [6] Bobskill, M. and Lupisella, M.L. (2012) The Role of Cis-Lunar Space in Future Global Space Exploration, *Global Space Exploration Conference*, May 2012; Washington D.C., GLEX-2012.05.5.4x12270. [7] Lupisella, M.L. and Wright M.R. et al. (2017) Low-Latency Telerobotics and Teleoperations for the Evolvable Mars Campaign, *IEEE Aerospace Conference*. [8] Lupisella, M.L. and Race, M.S. (2017) Low-Latency Teleoperations, Planetary Protection, and Astrobiology, *International Journal of Astrobiology*. [9] Race, M. et al. (2015) NASA Workshop Report: Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions. [10] Glavin D.P, Dworkin J.P., Lupisella M.L., Kminek G., Rummel, J.D. (2004) Biological contamination studies of lunar landing sites: implications for future planetary protection and life detection on the Moon and Mars. *International Journal of Astrobiology* 3 (3): 265–271. [11] NASA, July 20, 2011. NASA’s Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts.