LOW-LATENCY TELEOPERATIONS FOR MARS PLANETARY PROTECTION. M. L. Lupisella[1], M. Bobskill[2], M. Rucker[3], M. Gernhardt[4], B. Glass[5], [1]NASA Goddard Space Flight Center, Exploration Systems Projects, 8800 Greenbelt Rd., Greenbelt Md. 20771. Mark.L.Lupisella@nasa.gov. [2]NASA Langley Research Center, Space Missions Analysis Branch, 1 North Dryden Street, Hampton, VA. 23681, marianne.r.bobskill@nasa.gov, [3]NASA Johnson Space Center, Exploration Mission Planning Office, [4]NASA Johnson Space Center, Engineering Directorate, [5]NASA Ames Research Center, Intelligent Systems Division.

Introduction: Low-latency teleoperations has the potential to help address a number of planetary protection concerns associated with human exploration missions to Mars. Based on present conceptions of potential special regions on Mars, it may be prudent to find and explore such regions telerobotically in order to address contamination control concerns for those regions and to mitigate potential biohazards to crew members and possibly to terrestrial life when crew members return to earth. Depending on how special regions are ultimately defined and understood in their actual environments (e.g. through precursor mission data, modeling, etc.), and depending on what kinds of contamination control technologies may be implemented with crew assets (such as suits, rovers, sample acquisition systems, drills, etc.) it may also be prudent to explore these regions for long periods of time without humans in the immediate environment of interest. Similarly, if there is sufficient uncertainty about the biological or chemical nature of Mars samples, it may be wise to explore strategies for telerobotically conducting sample operations for long periods of time. Teleoperations may also be useful for addressing other operations related to planetary protection such as suit and other asset operations (e.g. cleaning, maintenance, etc.) and "end of life" mission operations.

The Human Spaceflight Architecture Team (HAT) Mars Destination Operations Team (DOT) examined these challenges from an integrated operational perspective and noted potentially significant roles for low-latency teleoperations (LLT – used interchangeably with 'teleoperations' and 'telerobotics' in this abstract). The HAT Mars Moons Team is also presently analyzing teleoperations from Mars orbit to assess trades, including potential advantages and implications of telerobotically exploring special regions from Mars orbit.

This presentation will provide background of science operations from the HAT Mars DOT 500-day surface operations concept work and focus primarily, although not exclusively, on 3 domains of Mars operations that are potentially relevant to planetary protection and LLT: (1) Mars orbit to Mars surface, (2) Mars surface location to Mars special regions, and (3) Mars science lab teleoperations.

Mars Orbit to Mars Surface Teleoperations: HAT is presently analyzing missions to the moons of Mars (and Mars orbit generally) prior to landing crew on the surface of Mars. One potential advantage of such missions is that orbit-to-surface teleoperations can be conducted with very short communication delays (e.g. well under .5 seconds). This kind of low-latency teleops can allow crew members to be highly responsive with surface assets on the Mars surface – a form of "real-time" or "near real-time" operations. These surface assets could be pre-deployed (prior to the human mission to Mars) or could be deployed during the human Mars orbit mission. Depending on the capabilities of those assets (e.g. mobility and scientific capabilities), it should be possible to scientifically explore fairly large areas of the surface, and possibly sub-surface, prior to crew landing on the surface. This could allow for previously unknown special regions to be found and for special regions in general to be directly explored thoroughly before crew lands on the surface. In this way, orbit-to-surface teleops can also potentially inform crew landing site selection.

Depending on what is learned about contaminant transport and contaminant impacts to sites of interest, a crewed surface landing may compromise planetary protection protocols. Crew operations of surface assets from Mars orbit would avoid this concern – as long as the telerobotic surface assets were properly cleaned and maintained. An outstanding question is the size of the area (including subsurface) that reconnaissance should cover and the kinds of analysis needed over that area prior to crew landing.

Drilling. Related to the above question, it may be preferable to drill for various reasons – ranging from resource prospecting to biohazard detection to the search for life. If drilling turns out to important, it will be one of the more challenging tasks and so will be an area of focus for this presentation. It may prudent to conduct drilling without having to put humans in the immediate drill zone, at least initially, if not for longer durations while sensitive drilling activities are being conducted. The following paragraphs are taken from a HAT drilling report on Mars drilling associated with human missions [2]:

A fully automated and/or telerobotic drilling system, with no hands-on human interaction, could meet planetary protection constraints but may not be practical, particularly for deep drilling operations which often require hands-on trouble-shooting. Depending on the type of drilling technology selected, automation or telerobotic control could drive the need for specialized equipment manipulators, which in turn would require additional power and thermal conditioning. Adding to the complexity, subsurface sample collection and return to a Science Lab would also have to be fully automated or telerobotic.

A workshop on Planetary Drilling and Sample Acquisition held at the NASA Goddard Space Flight Center in May, 2013 noted significant technology gaps to overcome: "Automated core acquisition and handling, rugged and high-temperature sensor development and placement, automated drilling control software, and software testing and validation are technology gaps." The HAT drilling report built on this and made further recommendations:

Recommendation: If deep drilling operations must be autonomous and/or telerobotic due to planetary protection concerns, technology development emphasis should be placed on automated core and fluid acquisition and handling, low mass borehole stabilization, rugged and high-temperature sensor development and placement, automated drilling control software, and software testing and validation.

Recommendation**:** If deep drilling operations must be completely autonomous and/or telerobotic, a high fidelity mass and operational timeline analysis should be completed to determine whether it makes more sense to perform this activity on a crewed vs. robotic mission. Some of this analysis is underway and will be covered in the presentation.

Recommendation: Mass should be allocated for automated and/or telerobotic control for deep drilling systems (including power).

The time-scale for a drill to encounter difficulties is often on the order of 10 to 20 seconds, making teleoperation from Earth risky. Teleoperation from Mars orbit or Mars surface is feasible, but risk will vary with drill design and drilling conditions.

Mars Surface Location to Mars Special Regions: Much of what is conducted from Mars orbit via LLT could also be performed once the crew has landed on the surface. There is the additional potential advantage that for many scenarios the latency will be lower and potentially less complicated since surface assets may be closer and in direct line of sight at most (or all) times. The HAT Mars Destination Operations Team developed an integrated long-duration 500 day "science-driven" surface operations concept in which low-latency teloeperations was invoked as a possible strategy for exploring potential special regions while the crew is on the Martian surface at a safe distance from special regions. The team reviewed past literature and had invited presentations on planetary protection and contamination control. It was suggested that if the surface assets can be maintained to meet planetary protection protocols, then such assets could be teleoperated to safely explore potential special regions. It may also be that during the initial period of crew acclimation after the crew has landed, that LLT can be conducted from the habitat into the surrounding landing area in order to gain additional detailed understanding of the landing area environment before crew performs the first EVAs or other operations that may be problematic for contamination reasons.

Mars Surface Science Lab Teleoperations: It is also possible that the crew (either from orbit or from a surface location such as a habitat or pressurized rover), using telerobotic assets that are on the surface, could efficiently acquire samples and transport them to a pre-deployed science laboratory to conduct additional detailed analysis on the samples as needed. This additional analysis could be done via low-latency teleoperations of laboratory assets and would benefit from high-precision manipulators and advanced scientific instruments. Similarly, once the crew has landed, a similar strategy can be used when the crew is on the surface since this will allow samples to be relatively isolated from other surface assets and their associated operations (e.g. such as crew habitats).

Additional Considerations: Cleaning and maintenance of surface assets such as suits and rovers is likely to be a key operational activity. Telerobotics has the potential to provide an effective way to safely perform complex tasks of this kind without exposing the crew directly to Mars material or vice-versa. It may also be worth considering potential "end of mission" concerns and the associated operational details such as disassembly applications or "seal up" operations (e.g. hab, rovers, etc.) that may be best done telerobotically either when crew on the surface or from Mars orbit before the crew leaves the Mars system. Disposing of the Mars ascent vehicle (MAV) could be a unique challenge because impacting it somewhere could release contaminants. The MAV could be teleoperated to a state that meets planetary protection requirements (e.g. venting down to vacuum to try to kill organisms, transport to, and/or orientation in, a safe in-space location, or possibly a "controlled" landing to a safe zone if needed).

References: [1] Bobskill, M. and Lupisella, M. L. (2014) Human Mars Science Surface Operations. American Institute of Aeronautics and Astronautics, Presented at SpaceOps 2014, Pasadena, CA.
[2] Rucker, M. et al. (2013) Drilling System Study, Mars Architecture Design Reference Architecture 5.0. Document No: JSC 66635.