Space Science Opportunities Augmented by Exploration Telepresence (ET) - Keck Institute for Space Studies R.C. Anderson[1], K. Hodges[2], and J. Burdick[3], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, [2] Arizona State University, P.O. Box 876004, Tempe, AZ 85287-6004, [3]California Institute of Technology, Pasadena, CA 91109, Robert.C.Anderson@jpl.nasa.gov.

***Workshop*:** The Keck Institute of Space Studies organized a Study Program on "Space Science Opportunities Augmented by Exploration Telepresence". The first workshop in this study was held at California Institute of Technology on October 3-7, 2016 with 28 participants from NASA, space agencies, and industry, providing expertise in planetary science, telerobotics, and human space flight. While the study report will be developed after the second workshop, now scheduled for May 1-3, 2017, below is a brief summary on that first workshop. http://www.kiss.caltech.edu/new_website/workshops/telepresence/telepresence.html#

***Overview**:* The aim of this workshop was to provide the community with a critical review of a potentially new space exploration strategic approach: field scientific research on planetary surfaces conducted by astronaut/scientists using robotic surrogates when the distance from the scientists to the robots is so short as to provide the illusion of being part of the surface environment without requiring humans to be physically at the site. This new paradigm represents a synergistic partnership between humans and robots and will pave the way for eventually putting humans physically on planetary surfaces. We refer to this new approach as "exploration telepresence" (ET-Figure 1).

Current planning at NASA and recent independent studies have noted the potential benefits of ET. However, these reports were primarily developed from individual scientists, engineers, and teleroboticists. To formally address the benefits and/or drawbacks of ET, a multidisciplinary review was essential. For this workshop, world-class representatives of telerobotics, planetary science, and human space flight gathered to evaluate the pros and cons of ET, with a goal to identify research tasks that ET might augment and what obstacles must be overcome for the vision of ET science (e.g., geology and astrobiology) to become a reality. The aim was to evaluate the extent to which ET might help achieve these goals. Overall, we were interested in understanding how rapid progress in telerobotic technology might change the face of space exploration on the timescale foreseen for sending humans to Mars.

Fig. 1 Artist rendecion of "Exploration Telepresence" (ET). *Figure courdacency of Goddradd Space Flight Center.*

***Introcuction to the First Workshop**:* Since the end of the Apollo missions, mankind has conducted scientific studies on planetary surfaces other than Earth exclusively using teleoperated robots. These operations require strategies to mitigate the effects of two issues related to long distances from Earth to the research targets: 1) long communication delays (high latency); and 2) the limited rate of two-way information flow (low bandwidth). Despite the proven successes of science done using assets such as *Curiosity*, it is as yet unclear what penalties might be associated with the use of current teleoperation modes for planetary field research as compared to alternative strategies that involve placing scientists more proximal to research targets so as to drastically reduce latencies and minimize the effects of bandwidth limitations. To what extent may low latencies improve the efficiency and effectiveness of telerobotic science? What

planetary processes that are high-value research targets cannot be effectively studied using telerobotics at high latencies? Is there special value to placing scientists in a position to teleoperate robots with communication latencies less than a few hundred milliseconds, such that the scientists could effectively conduct "real-time" research as if they were there on a planetary surface?

Early in the workshop, a consensus emerged that, despite the fact that planetary field science has employed an increasingly sophisticated array of robotic technologies over the past four decades; the planetary science community still largely regards the research accomplishments of scientists on site as the standard against which the success of robotic field science must be measured. As a consequence, there are reasons to believe that new strategies may accelerate the pace of robotic field science and yield even greater scientific returns approaching those possible with scientists on site. These include the use of fully autonomous robotic agents, variably supervised robotic agents, and robotic agents teleoperated by scientists sufficiently proximal to the study site so as to achieve telepresence. Of these, given the current state of autonomous robotics, science by telepresence (SBT) offers many attractive, near-term opportunities to improve robotic planetary field science.

SBT more readily enables opportunistic science, encouraging the kind of real-time adaptive approaches that characterize the highest-quality field research on Earth. SBT also would lead to a dramatic improvement in the efficiency with which a set of research tasks could be completed. This efficiency, in turn, likely increases the realistic geographic scope of research activities on other planetary surfaces.

Participants noted additional factors that might favor SBT instead of on-site field research by landed astronaut scientists. For example, one of the most interesting scientific enterprises on Mars – the search for signs of biological activity – will be conducted in regions where there is strong incentive to keep human bodies out until those searches are complete. In addition, participants agreed that low-latency telerobotic control of surface assets from orbit would likely be much less expensive than putting humans on the surface, and would increase crew safety.

SBT may be particularly advantageous for three kinds of planetary field science. First, it may be the only way to do the highest-quality field science in environments, which are so extreme that presently available technology will not offer suitable protection for on-site astronauts. Second, it may be necessary to do research on transient events (e.g., cryovolcanic eruptions, or atmospheric phenomena such as dust devils), the timescales of which preclude effective study by high-latency telerobotics. Finally, SBT may permit more effective teleoperation of multiple, geographically distributed robotic assets on a planetary surface, enabling rapid, large-scale reconnaissance which could guide more detailed future research.

Despite the promise of new robotic strategies for planetary exploration science, the participants felt that many questions needed to be answered before these modes of research can reach their full potential. Many roboticists at the workshop felt confident that there will be dramatic advances in artificial intelligence, autonomy, and haptics between now and the anticipated timeframe human travel to regions in the vicinity of high-value exploration targets like Mars. The harnessing of these advances to produce the next generation of robotic assets (or partners) for planetary field science will require concerted efforts in robotics research with sufficient support from NASA and other funding sources. Similarly, all participants recognized that we really have very little experience in doing planetary field science with low-latency telerobotics, even with a large degree of supervised autonomy. As a consequence, there is an urgent need to create an effective funding stream for research on best practices of science operations under low-latency conditions. In addition, well-designed experiments are needed to compare and contrast the efficiency and effectiveness of high- and low-latency research modalities as we contemplate the role of strategies such as SBT into mission planning. A second workshop is scheduled for Spring 2017 to conceptualize specific research projects to address existing knowledge gaps.