SPACE SCIENCE AND EXPLORATION ON THE LUNAR FARSIDE FACILITATED BY SURFACE TELEROBOTICS FROM THE DEEP SPACE GATEWAY. J. O. Burns[1], T. Fong[2], D. A. Kring[3], and J. B. Hopkins[4]. [1]Center for Astrophysics and Space Astronomy, University of Colorado, UCB 391, Boulder, CO 80516 jack.burns@colorado.edu;, [2]NASA Ames Research Center, Moffat Field, CA 94043, terry.fong@nasa.gov; [3]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston 77058, kring@lpi.usra.edu; [4]Lockheed Martin Space Systems Company, P.O. Box 179, MS: H3005, Denver, CO 80201, josh.b.hopkins@lmco.com.

Introduction: During the early phases of development of cis-lunar infrastructure, there is an exciting opportunity to begin a new era of space science and exploration on the lunar farside facilitated by telepresence from NASA's planned Deep Space Gateway (DSG) [1]. Surface telerobotics (i.e., astronauts in orbit remotely operating planetary rovers or other robots on the lunar surface) can be used to collect geological samples from the Moon's farside and to deploy a low frequency radio telescope to study the unexplored Cosmic Dawn epoch of the early Universe. During the time when the DSG is not occupied by astronauts, it can serve as a telecommunications relay to operators on Earth. This is a necessary and enabling capability for affordable missions to the lunar farside.

Surface Telerobotics Simulations: Our laboratory experiments with surface telerobotics are beginning to provide requirements on bandwidth, video frame rates, and latency for effective scientific exploration on the lunar surface [2]. In addition, we previously conducted a series of NASA-funded tests involving astronauts aboard the International Space Station (Figure 1) that demonstrated the viability of surface telerobotics using a high-fidelity operational environment [3]. The ISS served as a proxy for Orion/DSG. NASA's K10 planetary rover was operated by ISS astronauts over a simulated lunar terrain at the NASA Ames Research Center to deploy an engineering prototype of a radio telescope array. More recently, ESA conducted a similar experiment to operate a ground-based rover from the ISS.

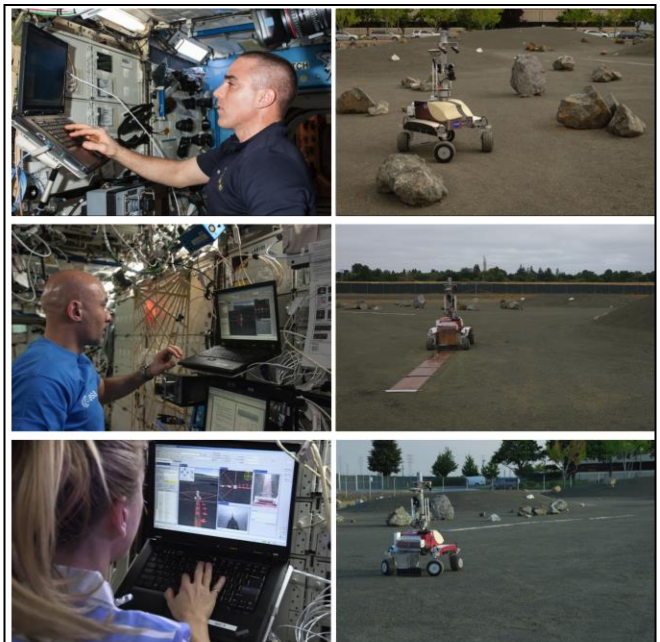

Figure 1. Surface telerobotics testing aboard the International Space Station during three crew sessions. *Top:* NASA astronaut Chris Cassidy surveys the NASA Ames "roverscape" site; *Middle:* ESA astronaut Luca Parmitano uses the K10 rover to deploy three "arms" of a simulated radio telescope array; *Bottom:* NASA astronaut Karen Nyberg remotely operates K10 to document the deployed radio telescope array.

Planetary Science and Cosmology on the Lunar Farside: Cutting edge science (e.g., National Academy Decadal Surveys) can be conducted from the lunar farside using surface telerobotics as a precursor to a human return to the Moon [4].

A teleoperated lunar rover remotely operated by astronauts in the DSG could be used to collect and return rock samples from the Moon's South Pole Aitken (SPA) Basin, as recommended by the NRC Planetary Sciences Decadal Survey [5] and the NRC-2007 report [6]. The highest priority science is to test the lunar cataclysm hypothesis which posits that the Moon and Earth were exposed to heavy bombardment via solar system debris ~4 billion years ago. The Schrodinger impact basin within the SPA basin may be ideal to investigate this science goal, and most other science goals of [6], including age-dating the SPA basin, with short-duration [7] and long-duration [8] missions.

This lunar rover could also be used to deploy a low frequency radio telescope array to observe the redshifted 21-cm power spectrum originating from structure within the intergalactic medium surrounding the first stars and galaxies [4]. The array would operate at frequencies from 20-80 MHz (corresponding to redshifts of 70-17). At frequencies down to 20 MHz, the lunar farside is the best location in the inner solar system to perform these observations because it is free of human-generated radio frequency interference and distortions from the Earth's ionosphere [9]. The hyperfine line of neutral hydrogen probes the gas surrounding the first stars and galaxies, allowing us to infer their properties (e.g., ignition times, masses, stellar populations) for the first time [10]. Such an array, labeled the Cosmic Dawn Mapper in the NASA Astrophysics Roadmap [11], allows us to investigate the nature and evolution of the first structures in the Universe in a way not possible with any other planned ground or space mission. One approach to deploy such a low frequency array is to unroll a polyimide substrate, with electrically-conducting antennas embedded. An artist's impression of this rover-based deployment is shown in Fig. 2.

Requirements for Surface Telerobotics from the Deep Space Gateway: For science and exploration missions using telerobotics, the preferred location of the DSG would be a compact halo orbit about the Earth-Moon L2 Lagrange Point, which sits ~65,000 km above the lunar farside. This would provide uninterrupted line of sight to most of the farside [12]. If an orbit providing continuous telecom is not selected, an orbit that allows uninterrupted communications for one lunar daylight period (~12-14 Earth days) or an orbit that minimizes the duration of loss of contact would be best; such a location for the DSG might be within a Near-Rectilinear Polar Halo Orbit [13].

In general, the DSG can provide a valuable communciations relay between Earth and landed assets on the lunar farside. In Table 1, we present estimates of requirements for data communication equipment.

Table 1. Communication Equipment Requirements

Requirement	Value
Mass	30-100 kg
Volume	2-6 m^3 external
Power	75-150 W
Temperature	Some heat rejection depending upon power level
DSG location	External, lunar-pointing to accuracy of ~1°
Operational Frequency	S, X, K, or Ka band subject to ITU allocation
Data Rate Relayed to Earth	• 64 kbps for a stationary lander • 1 Mbps for a rover with realtime operations • 16 Mbps for data generated by a radio astronomy array

Feed-forward to Mars: Such surface telerobotics support "off-board" autonomy and also prepare for human Mars missions. Cis-lunar experiments will train astronaut crews to virtually explore the surface of Mars from orbit using robots as avatars. Such teleoperation could enable multiple rovers to be used for exploring tens to hundreds of kilometers of Mars' terrain - even before the first humans set foot on the surface.

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Figure 2. Surface teleoperation of a rover from the Deep Space Gateway is a key technology for astronaut-assisted deployment of a lunar farside polyimide antenna and the collection of geological samples. Image is courtesy of R. MacDowell and NASA GSFC.

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