DEVELOPING SCIENCE OPERATIONS CONCEPTS FOR THE FUTURE OF PLANETARY SURFACE EXPLORATION. K. E. Young[1], J. E. Bleacher[2], A. D. Rogers[3], A. McAdam[2], C. A. Evans[4], T. G. Graff[5], W. B. Garry[2], P. Whelley[6], S. Scheidt[7], L. Carter[7], D. Coan[7], M. Reagan[4], T. Glotch[3], and R. Lewis[2]; [1]University of Texas, El Paso ï Jacobs/JETS Contract, NASA Johnson Space Center (JSC), 2101 NASA Parkway, Houston, TX, 77058 (corresponding email: kelsey.e.young@nasa.gov); [2]NASA GSFC, Greenbelt, MD, 20771; ; [3]Stony Brook University, Stony Brook, NY, 11794; [4]NASA JSC, Houston, TX, 77058; [5]Jacobs/JETS Contract, NASA JSC, Houston, TX, 77058; [6]USRA at NASA GSFC, Greenbelt, MD, 20771; [7]University of Arizona, Tucson, AZ, 85721; [8]SGT, NASA JSC, Houston, TX, 77058.

Introduction: Through fly-by, orbiter, rover, and even crewed missions, National Aeronautics and Space Administration (NASA) has been extremely successful in exploring planetary bodies throughout our Solar System. The focus on increasingly complex Mars orbiter and rover missions has helped us understand how Mars has evolved over time and whether life has ever existed on the red planet. However, large strategic knowledge gaps (SKGs) still exist in our understanding of the evolution of the Solar System (e.g. the Lunar Exploration Analysis Group, Small Bodies Analysis Group, and Mars Exploration Program Analysis Group). Sending humans to these bodies is a critical part of addressing these SKGs in order to transition to a new era of planetary exploration by 2050.

Background: The Apollo missions are the only example of conducting crewed in situ science on another planetary body. These were characterized by careful traverse planning and execution, sample collection with basic technologies (e.g. scoops, rakes, bags, etc.) and deployment of in situ science experiments (e.g. Apollo Lunar Surface Experiment Package). Although these missions were a resounding success by collecting samples and other data that improved our understanding of the lunar geologic history, multiple technological advancements in the four decades since Apollo will enable higher-resolution analyses in situ during future exploration missions.

These technology developments will enable increased mobility, communications structures, and real-time data processing and viewing capability. All of these factors introduce not only the potential for increased science return, but also operational complexity that must be accounted for and incorporated into mission concept and procedure development. Technology development and the associated procedural development for future science operations is already underway through multiple operational campaigns that build off both Apollo and ongoing integrated operational tests, and it is these tests which will close outstanding SKGs (for Science, Technology, and Science Operations) and enable human planetary exploration before 2050.

RATS (Research and Technology Studies) and NEEMO (Extreme Environments Mission Operations (NEEMO) testing have identified crucial Science Operations knowledge and technology gaps that must be closed prior to future planetary exploration. The complementary RIS[4]E (Remote, In Situ and Synchrotron Studies for Science and Exploration) project focuses in on one important area: the use of high-resolution field portable instruments in crewed exploration.

Planetary Surface Mission Operational Testing: The RATS tests (1997-2012) provided an ongoing testing platform for technology (e.g. habitat rovers, space suits, tools, etc.), operational concepts development, and science operations procedures. From 1997-2011, RATS testing took place in the San Francisco Volcanic Field, AZ, testing procedures for the exploration of both Mars and the Moon. In 2012, RATS testing moved to NASA Johnson Space Center (JSC) to the Space Vehicle Mockup Facility, testing technology and procedures for the exploration of small bodies. Major lessons were learned from the RATS tests:

(a) A science backroom is crucial for supporting scientifically-driven Extravehicular Activities (EVAs);
(b) A crew combining both astronauts (or operational engineers) and geologists is valuable for testing exploration technologies and operational procedures;
(c) It is extremely valuable during EVA to have a crewmember supporting the surface operations from an IV (intravehicular) capacity. However, more work is needed to determine exactly what assets are needed for the intravehicular activity (IVA) crew and how the communications pathways are structured and governed between the EVA crew, the IVA crew, and any terrestrial science support;
(d) Field portable instruments are highly valuable in a planetary exploration mission. Arizona RATS testing included instrumentation in a habitat laboratory to support crews on long duration missions and indicated that field portable instruments can play a valuable role during an EVA to inform scientific discovery.

Science Operational Concepts Development: 21 NEEMO missions have taken place off the coast of the

Florida Keys at Aquarius Reef Base. Crews have lived in Aquarius for as many as 18 days at a time, testing both IVA and EVA objectives as an analog for the exploration of the Moon, Mars, and small bodies. Most recently, NEEMO 21 was run in July/August 2016, and tested a variety of objectives that will have implications for the future of planetary exploration:

(a) It is possible to conduct scientifically-motivated EVA operations under a Mars-appropriate communications latency, with the crew receiving actionable intelligence about science sampling priorities during a single EVA;

(b) The IV crewmember workload is extensive, it is therefore crucial to develop appropriate supporting technologies for an IV crewmember supporting an EV crew;

(c) A ñflexible executionò methodology provides the crew with enough latitude to make deviations from an original traverse plan if real-time feedback indicates added-value, thereby enhancing the science return of an exploration EVA.

Field Portable Technology on EVA: The RIS^{4}E project is a Solar System Exploration Research Virtual Institute (SSERVI) team led by Dr. Timothy Glotch at Stony Brook University. A primary goal of the RIS^{4}E project is to investigate the utility of field portable instruments for planetary surface exploration and provide recommendations to NASAôs Human Exploration Operations Mission Directorate (HEOMD). RATS and NEEMO testing indicated that portable technologies could play a valuable role in exploration, but the logistics of integrating high-resolution instruments are poorly understood. RIS^{4}E is working to close this SKG by identifying a science question of interest, selecting an instrumentation suite to collect critical data, answer the science question, and providing recommendations to HEOMD on how portable instruments are best incorporated into an EVA timeline (Figure 1).

The instrumentation suite chosen for future exploration missions has not yet been determined, so RIS^{4}E has chosen a suite comparable to the types of data and instruments that are likely candidates: an x-ray diffraction instrument, a handheld x-ray fluorescence spectrometer, a multispectral imager, a light detection and ranging instrument, ground penetrating radar, and an aerial-based imager for context and terrain modeling. Field deployment of these instruments is modeled after the 2010 RATS test and is analogous to a likely architecture to be used in future surface exploration:

1. Crewed rover parks at target of interest.
2. Crew initiates remote measurements (including LiDAR, visual imaging, and multispectral imaging). These will be used as context for all other in situ data collected on EVA.
3. Crew egresses and conducts an EVA, deploying portable instruments, and assimilates new data into future EVA and real-time mission planning.
4. Crew ingresses rover, analyzes all collected data from EVAs, and discusses future plans for subsequent EVAs as impacted by real-time data.

While the future science operations architecture has not been finalized, it is probable that the operational concept will look like what is described here, regardless of the target body being explored.

Figure 1: The RIS^{4}E Methodology, focusing on answering science questions about planetary processes through the use of field portable instrumentation, as well as seeks to understand how these technologies would fit into an Exploration EVA architecture.

Conclusions and Moving Forward: Human exploration will be a crucial part of planetary exploration by 2050. While work has begun exploring science operations architectures for a crewed expedition, much more work is needed to test these architectures and develop both the technologies and the operational procedures needed to implement them. One crucial role that has been identified and needs more investigating is the role of an IVA crewmember in support of EVA operations, especially when integrating field portable technologies. Real-time data analysis will be critical and figuring out the crew time and assets needed to do this is a critical knowledge gap that must be closed. Additionally, the range of crew autonomy in exploration scenarios must be considered, with varying degrees of interaction with science support teams playing a potential role in a missionôs science return. Only when these various science operations gaps are closed will we as a community be ready to send human crews out in the Journey to Mars, as is the hope by 2050.