Testing Astronaut Controlled Telerobotic Operation of Rovers from the International Space Station as a Precursor to Lunar Missions

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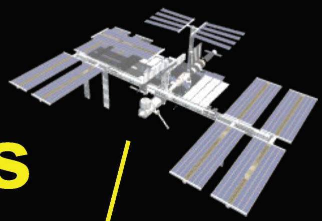
Josh Hopkins, and Bill Pratt



2014 IAC, Toronto, Canada
2014-09-30

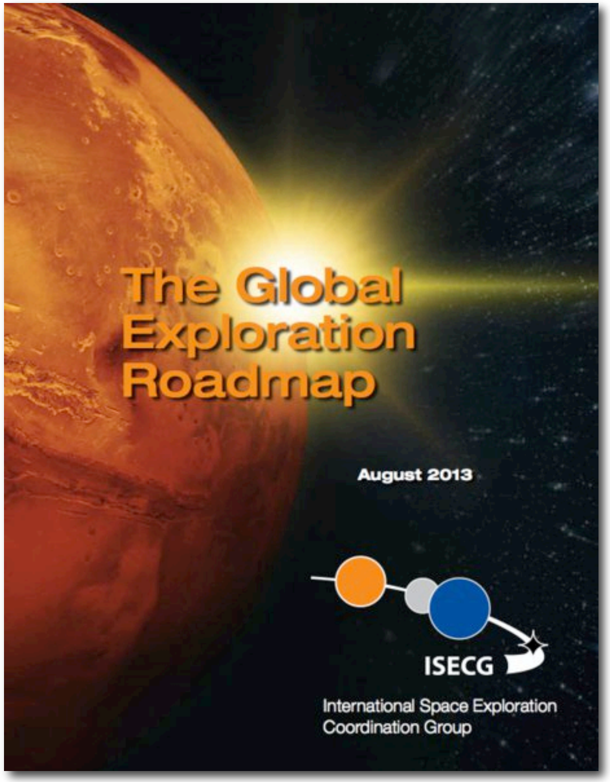
Global Exploration Roadmap (2013)

Human-Robotic Partnership (p. 22)

Tele-Presence

Tele-presence can be defined as tele-operation of a robotic asset on a planetary surface by a person who is relatively close to the planetary surface, perhaps orbiting in a spacecraft or positioned at a suitable Lagrange point. Tele-presence is a capability which could significantly enhance the ability of humans and robots to explore together, where the specific exploration tasks would benefit from this capability. These tasks could be characterized by:

- High-speed mobility
- Short mission durations
- Focused or dexterous tasks with short-time decision-making
- Reduced autonomy or redundancy on the surface asset
- Contingency modes/failure analysis through crew interaction



The Surface Telerobotics project tested the key underlying assumptions and collected engineering data using the ISS …

Surface Telerobotics Project

Key Points

- Demo **crew-control** surface telerobotics (planetary rover) from ISS
- Test **human-robot conops** for future exploration mission
- Obtain **baseline engineering data** (robot, crew, data comm, task, etc)

Implementation

- Lunar libration mission simulation
- Astronaut on ISS (in USOS)
- K10 rover in NASA Ames Roverscape

ISS Testing (Expedition 36)

June 17, 2013 – **C. Cassidy**, survey
July 26, 2013 – **L. Parmitano**, deploy
Aug 20, 2013 – **K. Nyberg**, inspect

SURVEY
DEPLOY
INSPECT

- **Human-robot mission sim**: site survey, telescope deployment, and inspection
- **Telescope proxy**: Kapton polyimide film roll (no antenna traces, electronics, or receiver)
- **3.5 hr per crew session** ("just in time" training, system checkout, ops, & debrief)
- **Robot ops**: manual control (discrete commands) and supervisory control (task sequence)

From Testing to Missions

Ground Analogs

Develop telerobotic systems (autonomy, data comm, interfaces)

Implement and test multiple conops

Simulate future human mission concepts

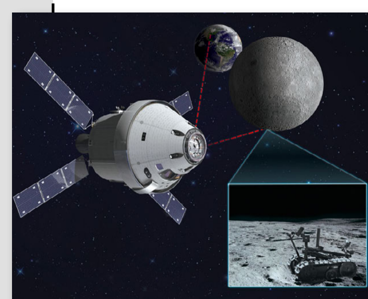
ISS Laboratory

Obtain baseline engineering and operations data

Validate prior ground simulations via high-fidelity ops sims

Reduce risk for future exploration systems (test assumptions)

Lunar Orbit



Enable "off-board" autonomy (use flight vehicle computing as part of robot system)

Use cis-lunar environment to prepare for human Mars missions.

Mars Orbit

Enable crew to explore surface using robot as an "avatar"

Enable "off-board" autonomy and data storage (use flight vehicle computing as part of robot system)

TRL 5 **Surface Telerobotics** TRL 7

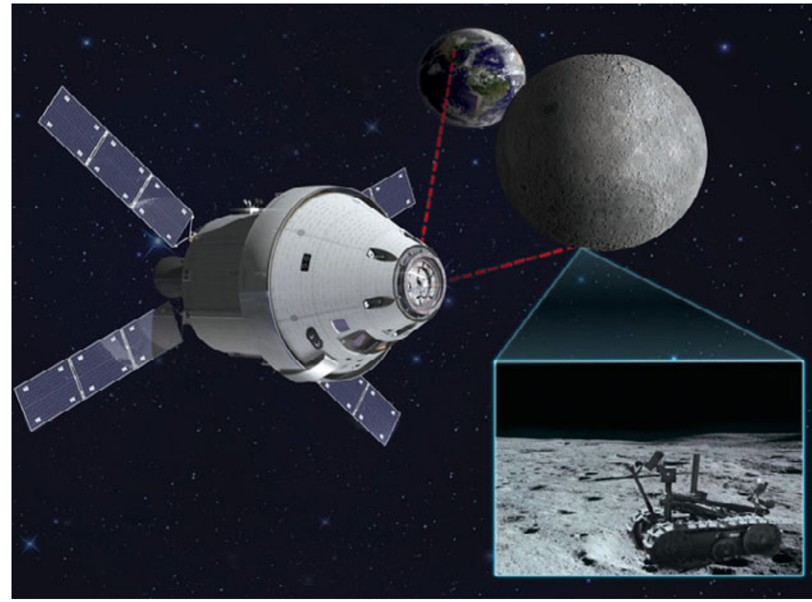
“Fastnet” Lunar Libration Point Mission

Orion MPCV at Earth-Moon L2 (EM-L2)

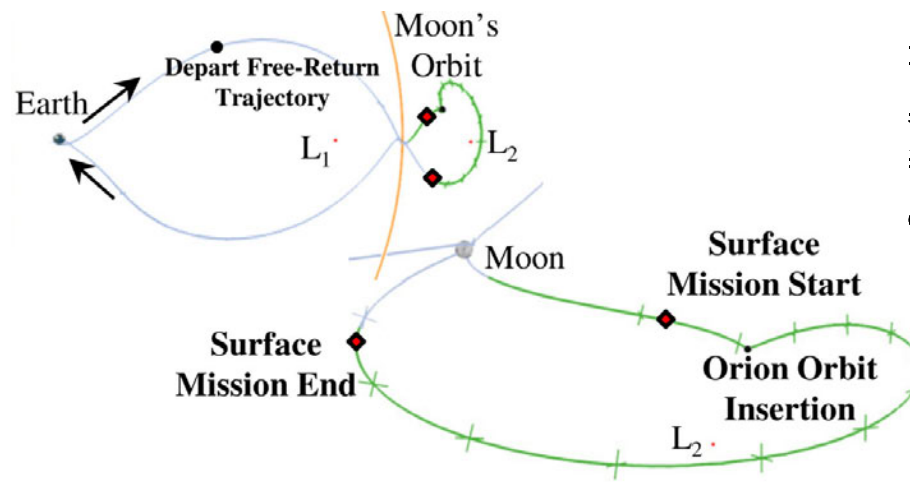
- 60,000 km beyond lunar farside
- Allows station keeping with minimal fuel
- Crew remotely operates robot
- Does not require human-rated lander

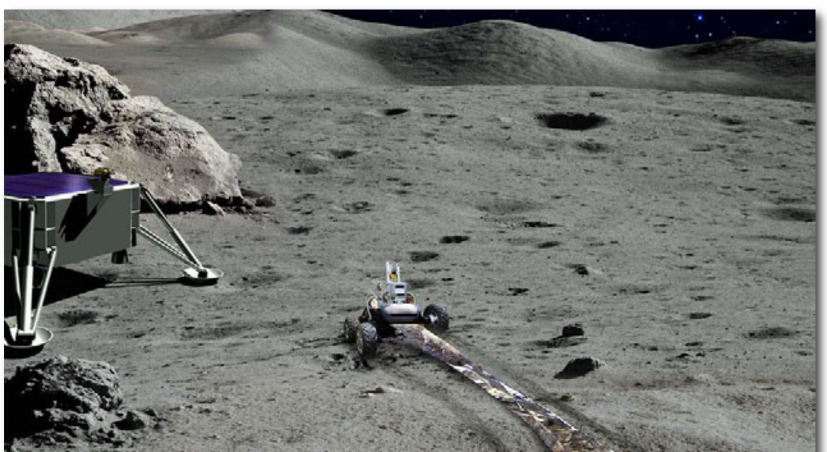
Human-robot conops

- Crew remotely operates surface robot from inside flight vehicle
- Crew works in shirt-sleeve environment
- Multiple robot control modes



Credit: (Lockheed Martin / LUNAR)





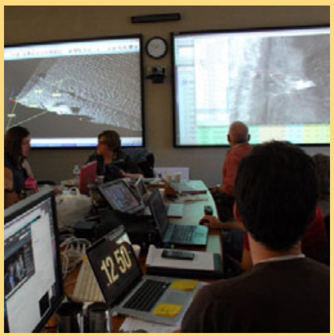
Crew-controlled surface telerobotics from the ISS

Surface Telerobotics

“Fastnet” Mission Simulation with ISS

Planning

Pre-Mission Planning



Ground teams plan out telescope deployment and initial rover traverses.

Spring 2013

Phase 1

Surveying

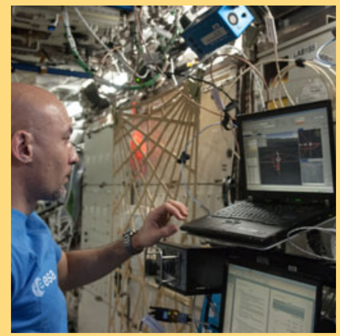
Crew gathers information needed to finalize the telescope deployment plan.

Crew Session 1

June 17, 2013

Phase 2

Telescope Deployment



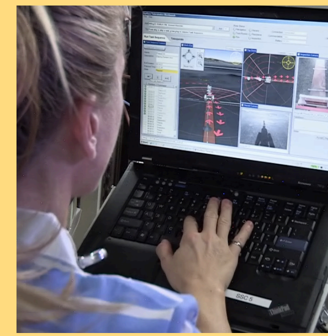
Crew monitors the rover as it deploys each arm of the telescope array.

Crew Session 2

July 26, 2013

Phase 3

Telescope Inspection

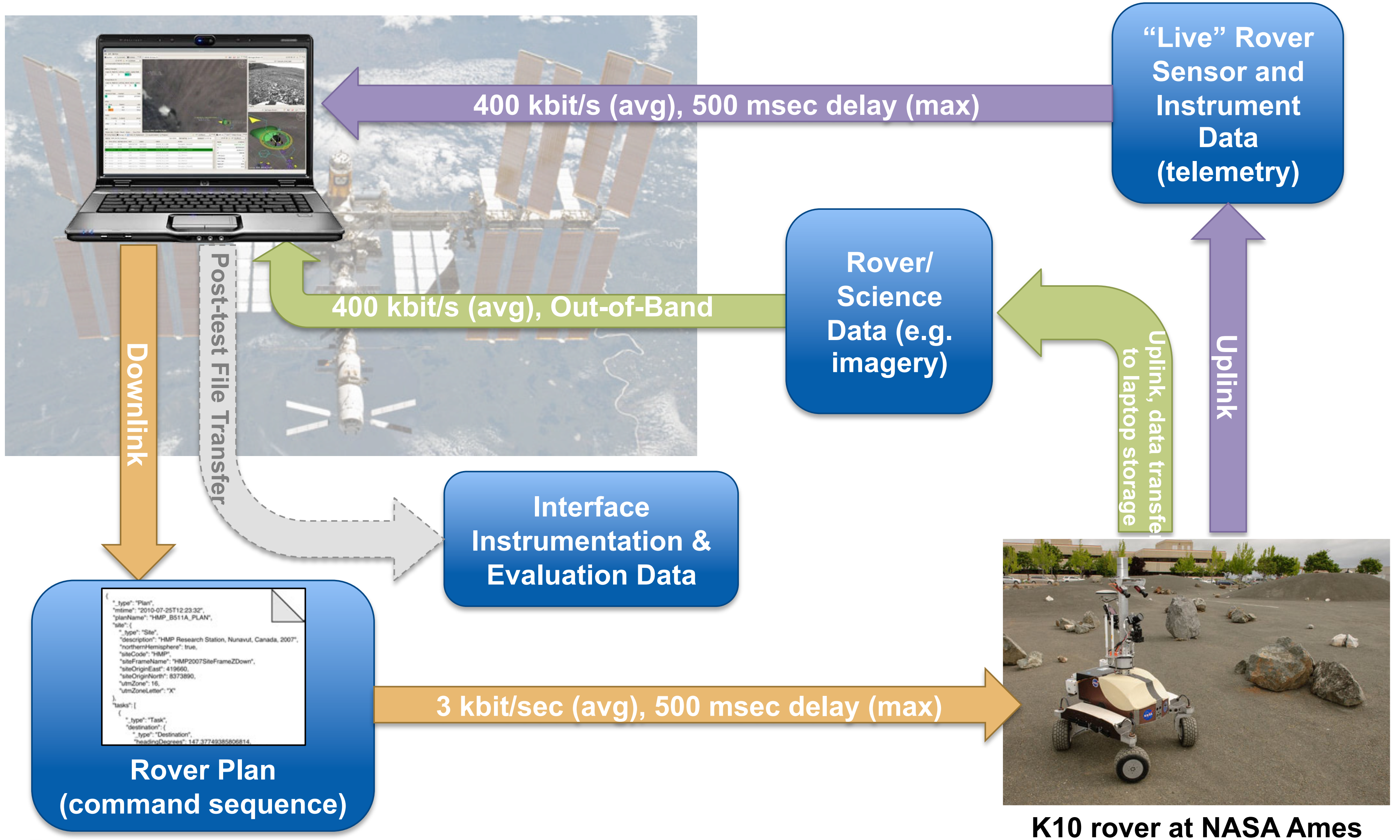


Crew inspects and documents the deployed telescope for possible damage.

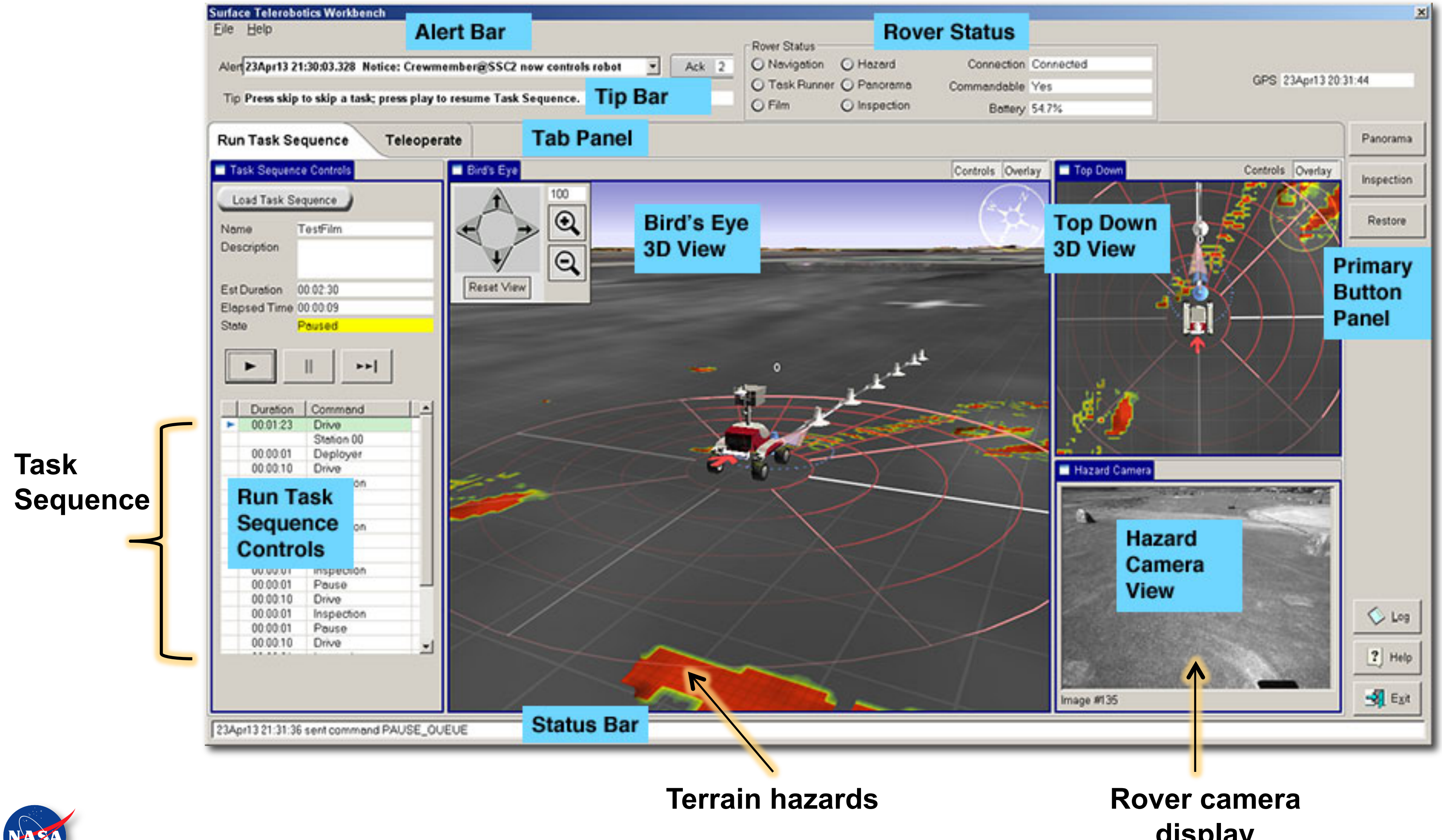
Crew Session 3

August 20, 2013

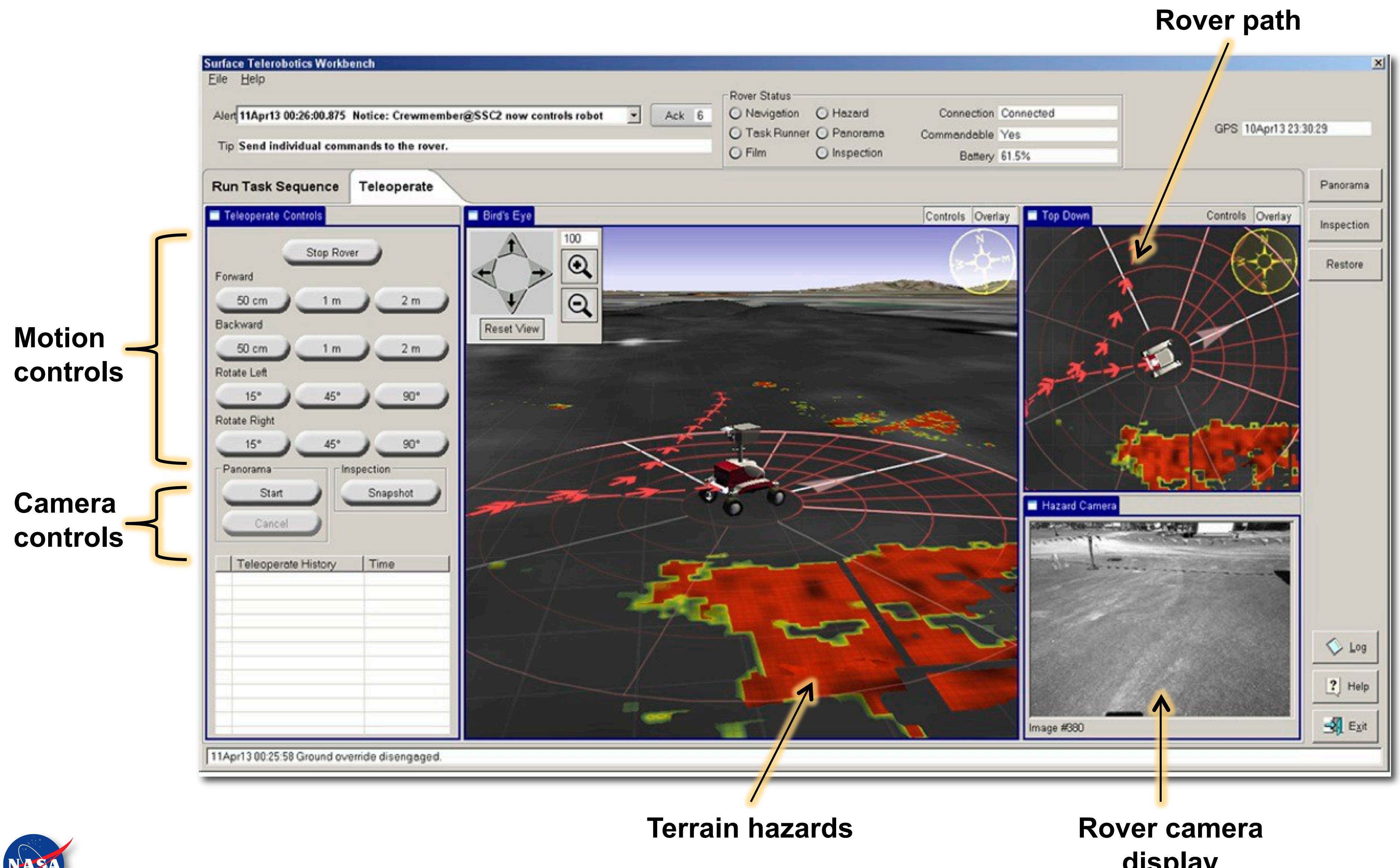
ISS Test Configuration



Robot Interface (Supervisory Control)

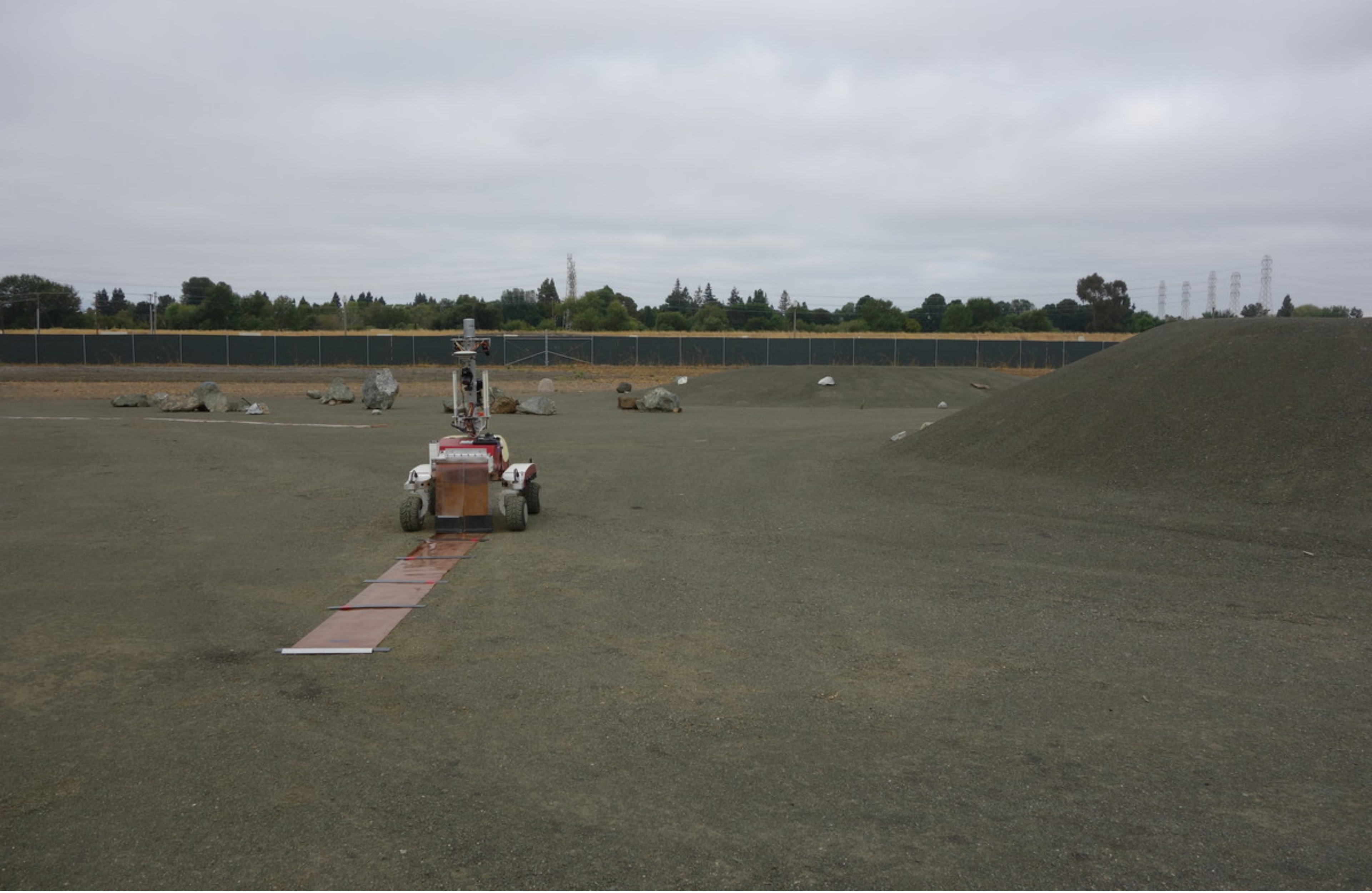


Robot Interface (Manual Control)



Crew Session #1 – K10 performing surface survey (2013-06-17)

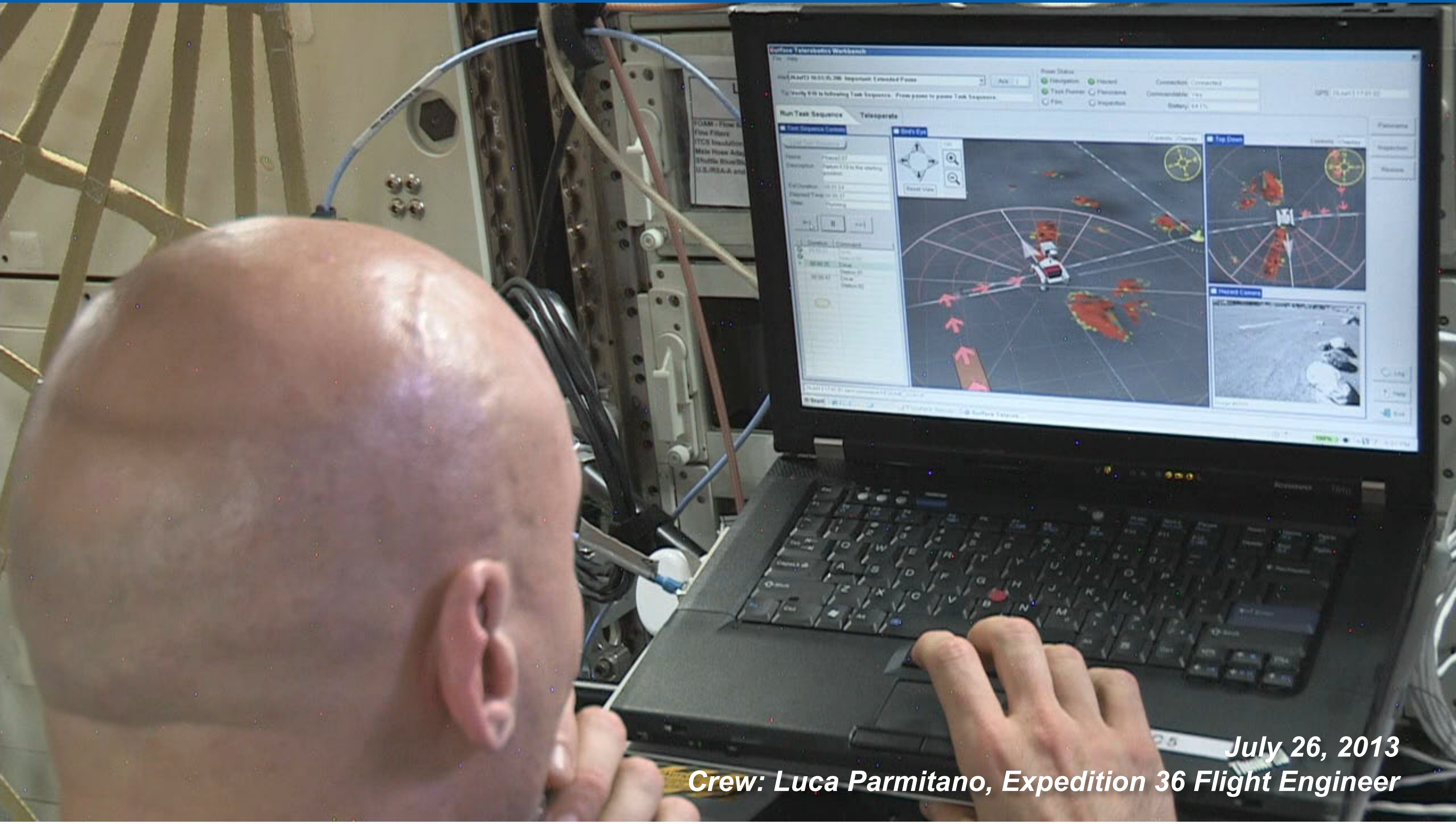
Chris Cassidy uses the "Surface Telerobotics Workbench" to remotely operate K10 from the ISS



Crew Session #2 – K10 deploying simulated polymide antenna (2013-07-26)

ISS Mission Control (MCC-H) during Surface Telerobotics test
View of robot interface and K10 at ARC

Surface Telerobotics



Deployed simulated polymide antenna (three “arms”)

Crew Session #3 – Karen Nyberg remotely operates K10 (2013-08-20)

K10 documenting simulated polymide antenna

Assessment Approach

Metrics

- **Mission Success:** % task sequences: completed normally, ended abnormally or not attempted; % task sequences scheduled vs. unscheduled
- **Robot Utilization:** % time robot spent on different types of tasks; comparison of actual to expected time on; did rover drive expected distance
- **Task Success:** % task sequences per session and per task sequence: completed normally, ended abnormally or not attempted; % that ended abnormally vs. unscheduled task sequences
- **Contingencies:** Mean Time To Intervene, Mean Time Between Interventions
- **Robot Performance:** expected vs. actual execution time on tasks

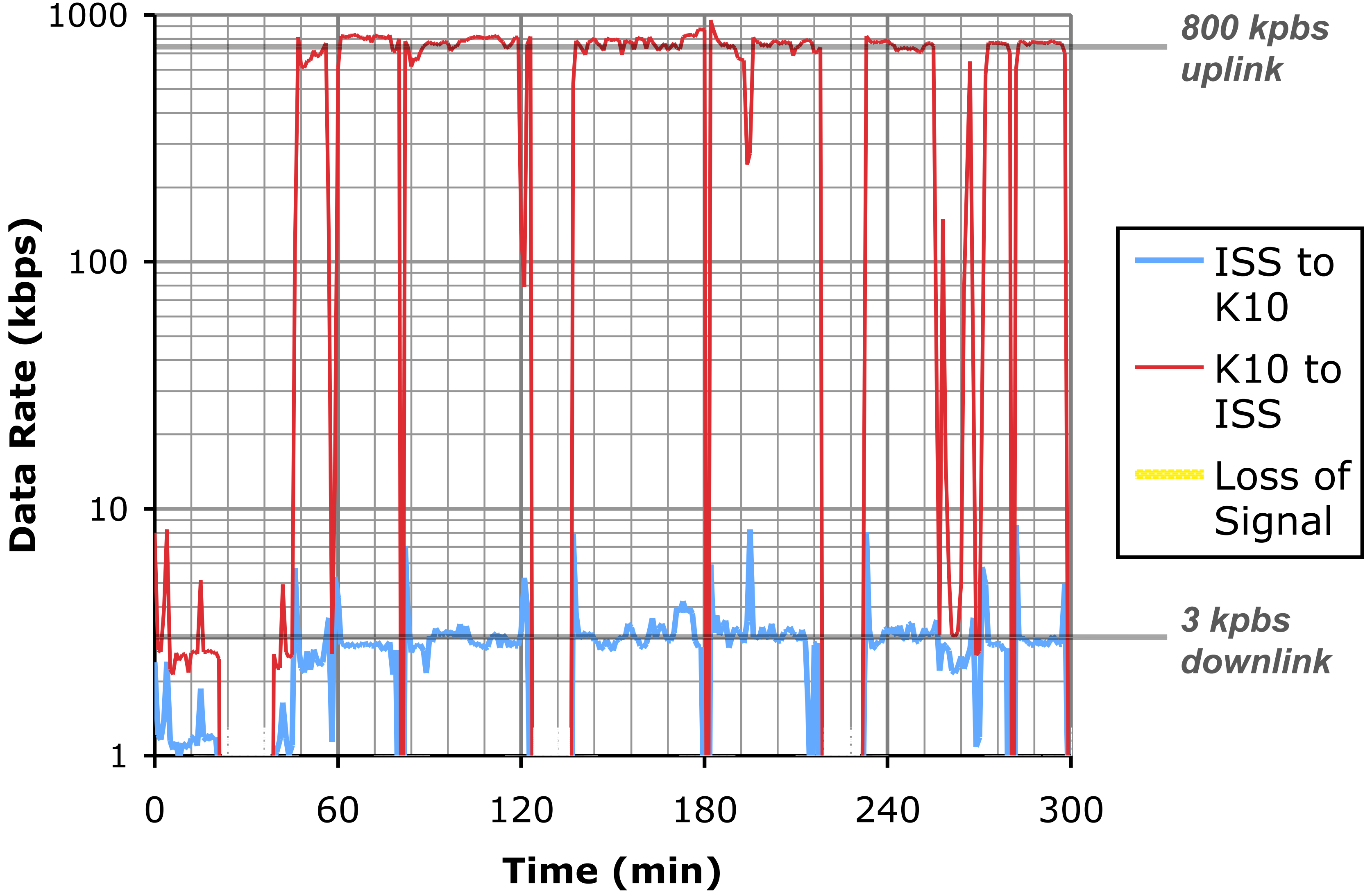
Data Collection

automatic

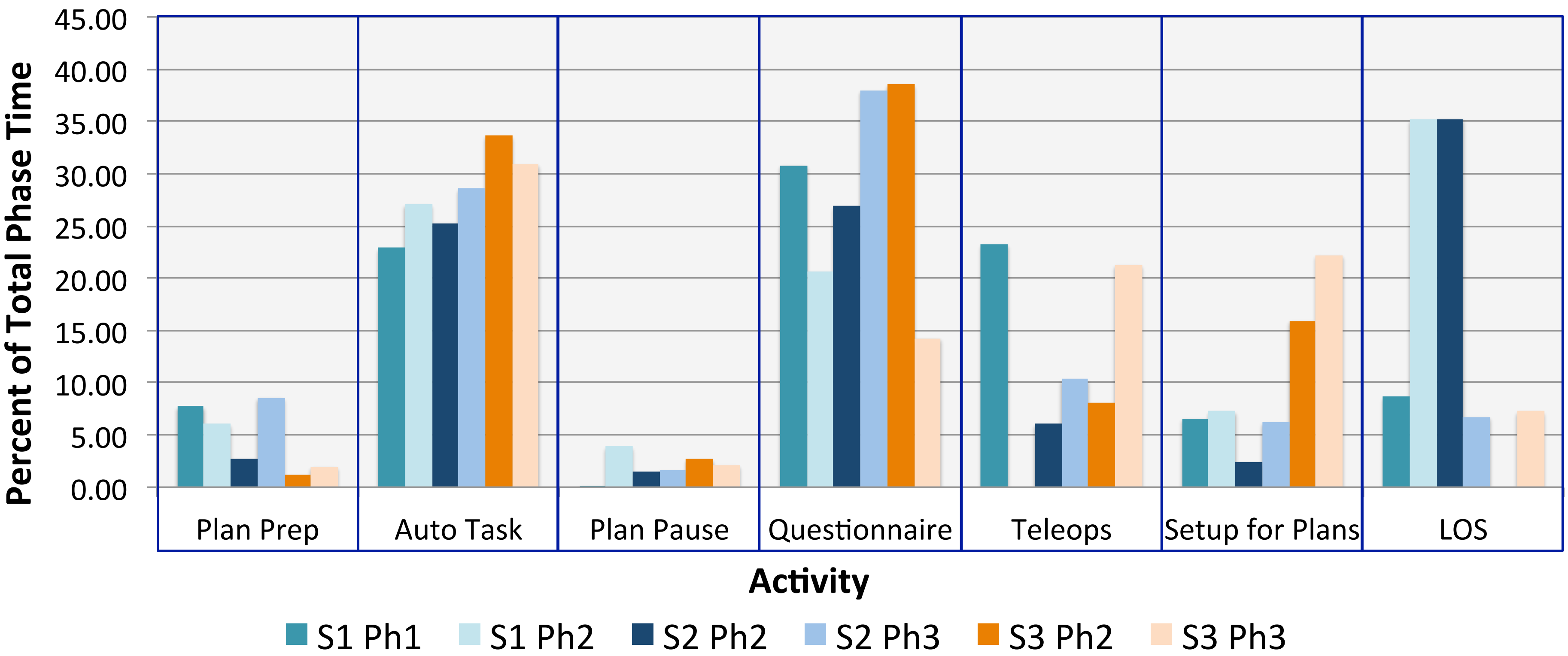
- **Data Communication:** direction (up/down), message type, total volume, etc.
- **Robot Telemetry:** position, orientation, power, health, instrument state, etc.
- **User Interfaces:** mode changes, data input, access to reference data, etc.
- **Robot Operations:** start, end, duration of planning, monitoring, and analysis
- **Crew Questionnaires:** workload (Bedford Scale), situation awareness (SAGAT)

M. Bualat, D. Schreckenghost, et al. (2014) "Results from testing crew-controlled surface telerobotics on the International Space Station". Proc. of 12th I-SAIRAS (Montreal, Canada)

Data Communications



Activities Performed by Phase



- 23% - 34% of phase time spent in autonomous task execution
- Questionnaires took 15% - 38% of total phase operations
- Teleoperations time ranged from 6% - 24% of phase time
- LOS ranged from 0% to 35% of phase time

Human-Robot Teaming

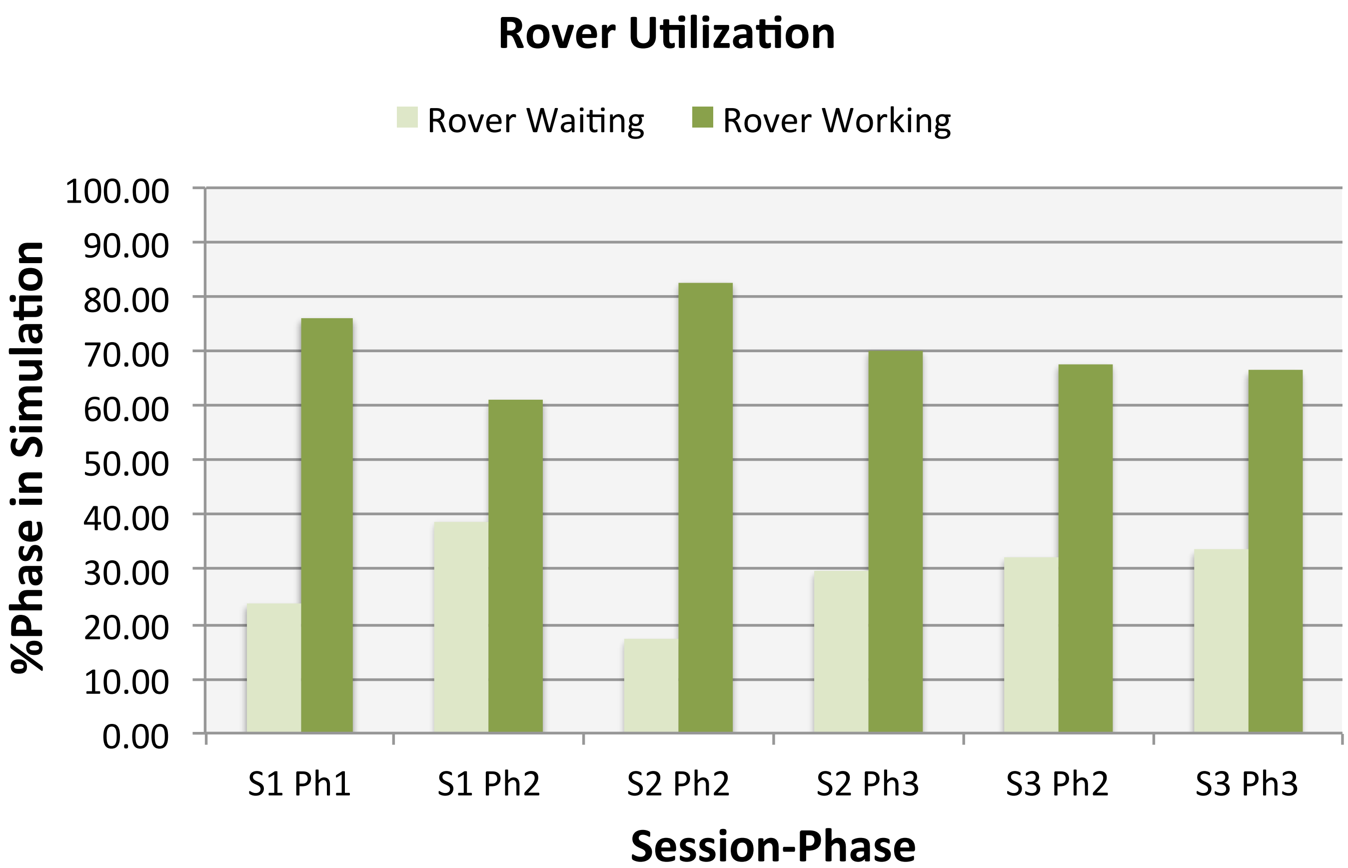
Productivity

- Productive Time (PT) = astronaut and robot performing tasks contributing to mission objectives
- Overhead Time (OT) = astronaut and robot are waiting
- %PT = percentage productive time
- %OT = percentage overhead time
- Work Efficiency Index (WEI) = PT / OT

Productivity	Total Phase Time	PT	OT	%PT	%OT	WEI
Survey	0:50:01	0:34:58	0:15:03	69.90	30.10	2.32
Deploy	0:46:19	0:28:00	0:18:19	60.45	39.55	1.53

Highly productive

Rover Utilization



- Rover spent **65% to 80%** of in-sim time working on tasks

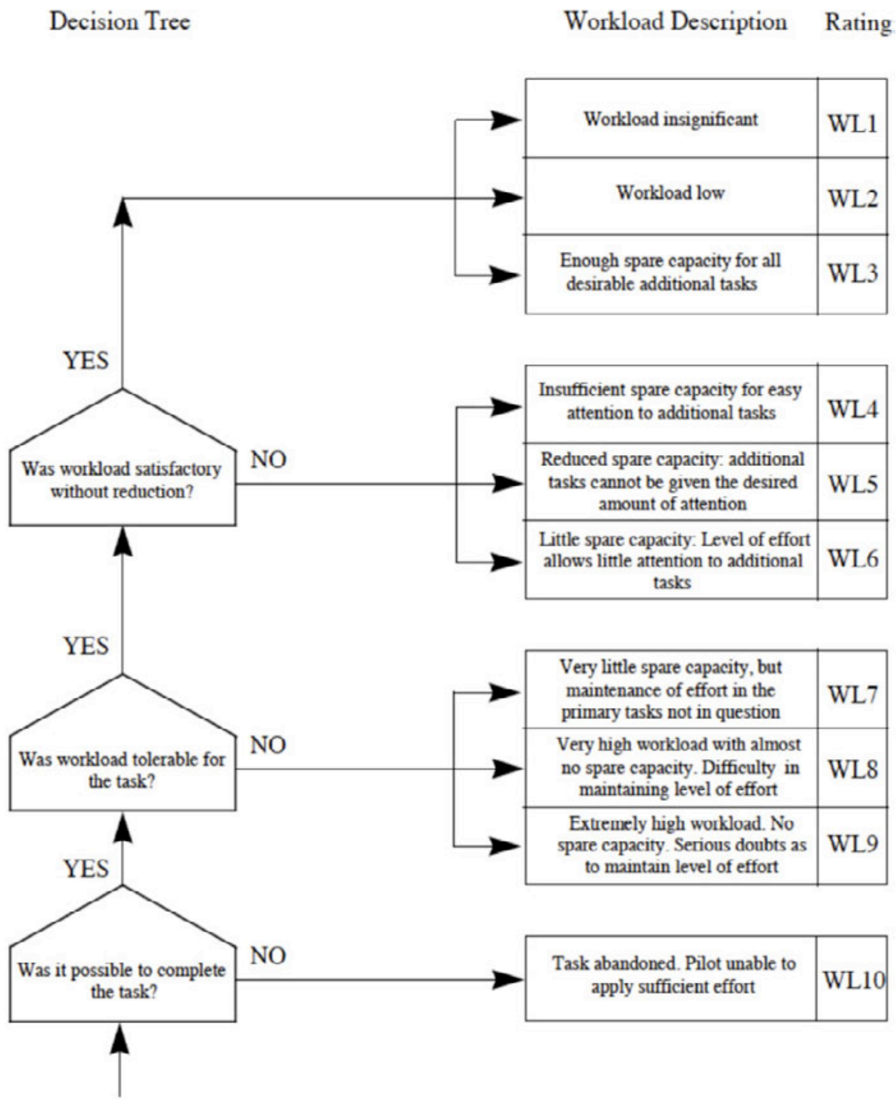
Crew Workload

Bedford Workload Scale (BWS)

- 10-point interval rating scale
- Focus on “spare capacity”
- Subjective rating during task performance

Results

- All crew members reported **consistently low workload**
- Session 1: BWS between 2 (low) and 3 (spare capacity for all additional tasks)
- Session 2: BWS 2 (low)
- Session 3: BWS between 1 (insignificant) to 2 (low)



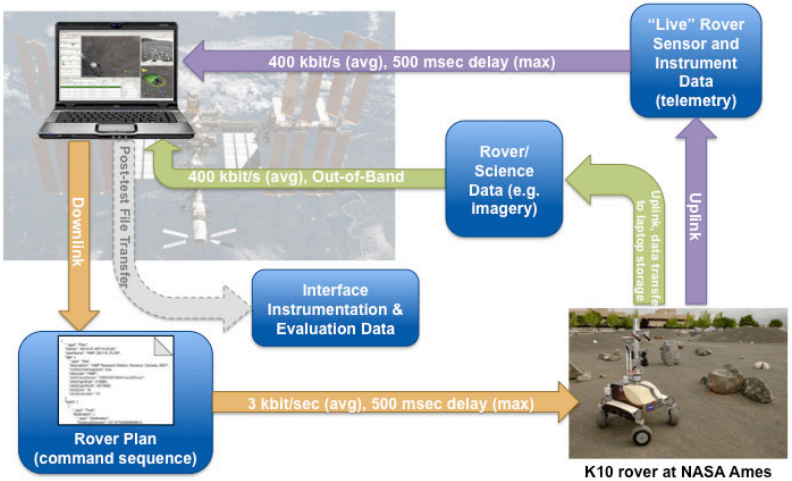
Future Work: Spacecraft Constraints

Objectives

- Study **integration impacts** to spacecraft
- Assess viability of **off-loading rover processing** to spacecraft for certain tasks
- Test crew **real-time decision making**

Approach

- Repeat **prior mission sim** with mods
  - More crew training on robot operations
  - Crew operates with little ground support
  - Human-in-the-loop contingency handling
- Give crew low-level control of rover
- Off-board some rover functions (hazard detection, localization, etc) to spacecraft



K10 rover at NASA Ames

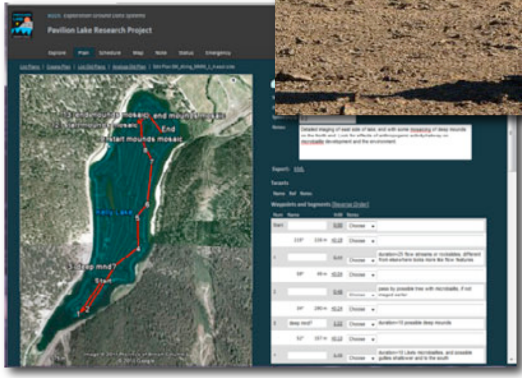
Metrics

- Crew: Work Efficiency Index, Situation Awareness, Bedford Workload Scale
- Robot: Mean time between/to intervention
- CPU load, RAM/disk, bandwidth

Future Work: Different Surface Tasks

Objectives

- Examine **surface tasks** that are more unstructured, complex and unpredictable
- Assess **system capability** to support increased SA and control mode changes
- Enhance **operational knowledge** of crew-controlled surface telerobotics



Approach

- Run **new mission sim** with:
  - Assembly/cabling of a functional instrument
  - Planetary fieldwork
- Enhance user interface for science ops

Metrics

- Crew: Work Efficiency Index, Situation Awareness, Bedford Workload Scale
- Robot: Mean time between/to intervention
- Task: Time on Task, Idle Time, Success rate, % Incomplete

Conclusion

Successfully completed 3 test sessions in Summer 2013

- 3 ISS astronauts remotely operated K10 rover (approx. 10.5 hr)
- Astronauts used combination of **supervisory control** (task sequencing) and **manual control** (discrete commanding)
- **500-750 msec comm latency** and intermittent LOS periods
- Crew consistently had **low workload** and **high SA level**
- Robot utilization was consistently high (**> 50% time in operation**)

Telerobotics technologies

- **Rover autonomy** enhances operational efficiency and robot utilization (particularly hazard detection and safeguarding)
- **Interactive 3-D visualization** of robot state and activity supports low operator workload and good situation awareness
- **Supervisory control with interactive monitoring** is a highly effective strategy for crew-centric surface telerobotics

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Dedicated to the memory of Janice Voss who served as the initial NASA Crew Office liaison for the Surface Telerobotics project