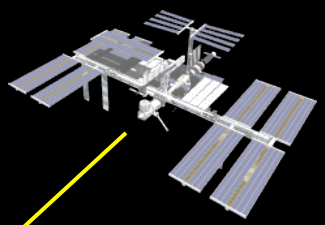
Surface Telerobotics:

Development and Testing of a Crew Controlled Planetary Rover System



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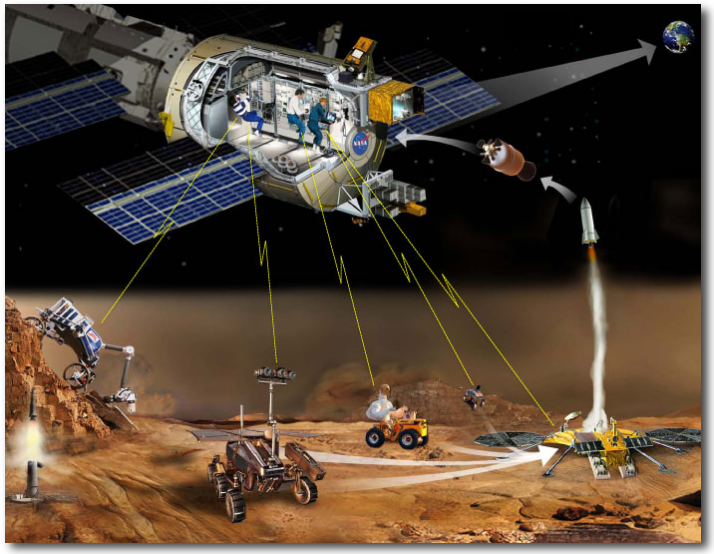
Motivation

Future exploration architecture study teams have made assumptions about how crew can remotely perform work on a planetary surface …

Candidate Exploration Missions

- **L2 Lunar Farside**. Orion "waypoint" mission to Earth-Moon L2 point
- **Near-Earth Asteroid**. NEA dynamics and distance make it impossible to manually control robot from Earth
- **Mars Orbit**. Crew must operate surface robot from orbit when circumstances (contingency, etc.) preclude Earth control



(NASA GSFC)

Assumptions

- Maturity of crew-controlled telerobotics
- Existing technology gaps (and how these can be bridged)
- Operational risks (proficiency, performance, failure modes)

NASA Surface Telerobotics

Objectives

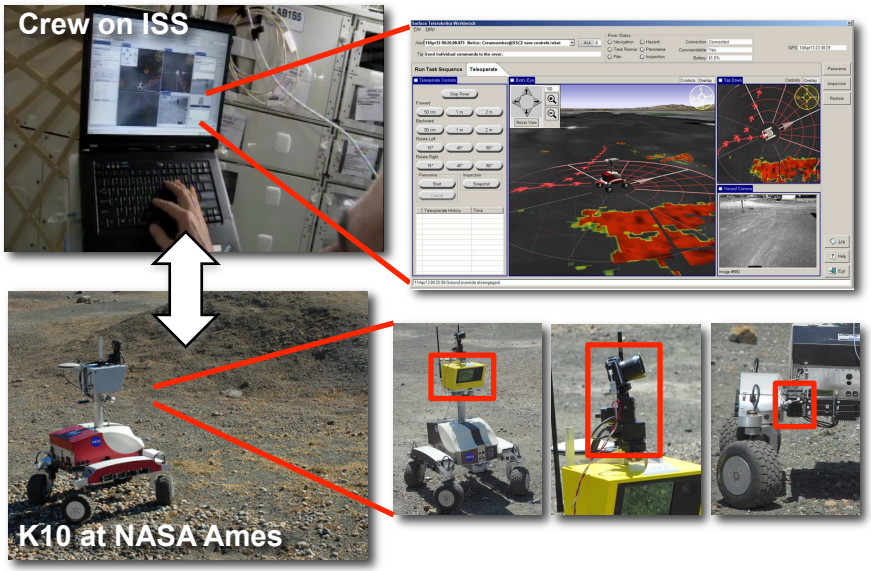
- Demo **crew-centric control** of surface telerobot from ISS
- Test **human-robot "conops"** for future exploration mission
- Obtain **baseline engineering data** of system operation

Approach

- Leverage best practices & findings from **prior ground simulations**
- Record robot telemetry, crew user interfaces, and ops protocols

Implementation

- Astronaut on ISS
- K10 rover in NASA Ames Roverscape
- Waypoint mission simulation (3 crew sessions)

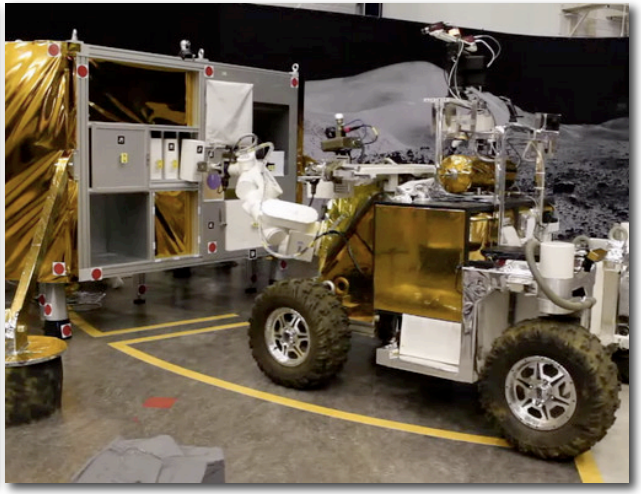


Key Points

- **Complete human-robot mission sim**: site selection, ground survey, telescope deployment, inspection
- **Telescope proxy**: COTS 75 micron polyimide film roll (no antenna traces, no electronics, no receiver)
- **3.5 hr per crew session** ("just in time" training, system checkout, telerobot ops, & crew debrief)
- **Two control modes**: basic teleop and pre-planned command sequencing (with continuous monitoring)
- **Limited crew user interface**: no sequence planning, no science ops capability, no robot engineering data

Surface Telerobotics

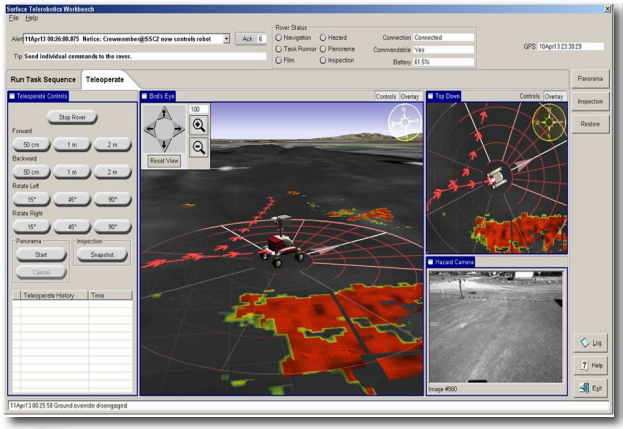
Comparison with Avatar Explore & METERON

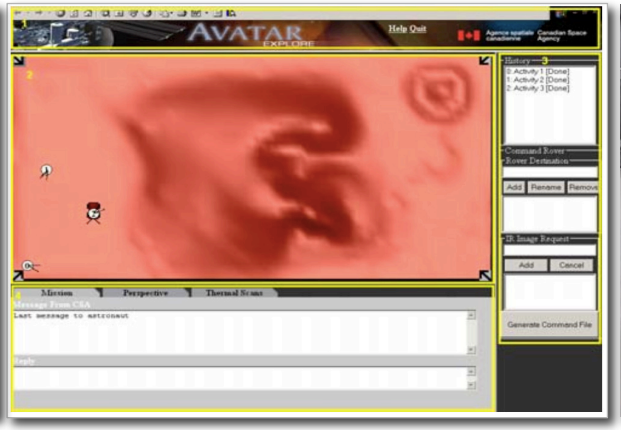


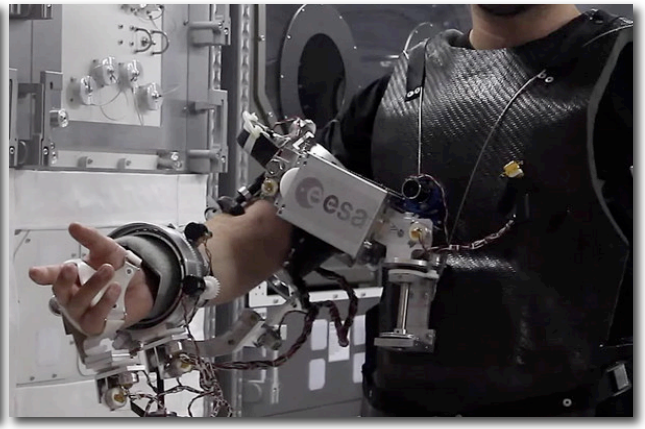
Surface Telerobotics (2012 - 2014)

Avatar Explore (2009)

METERON (2014+ ?)







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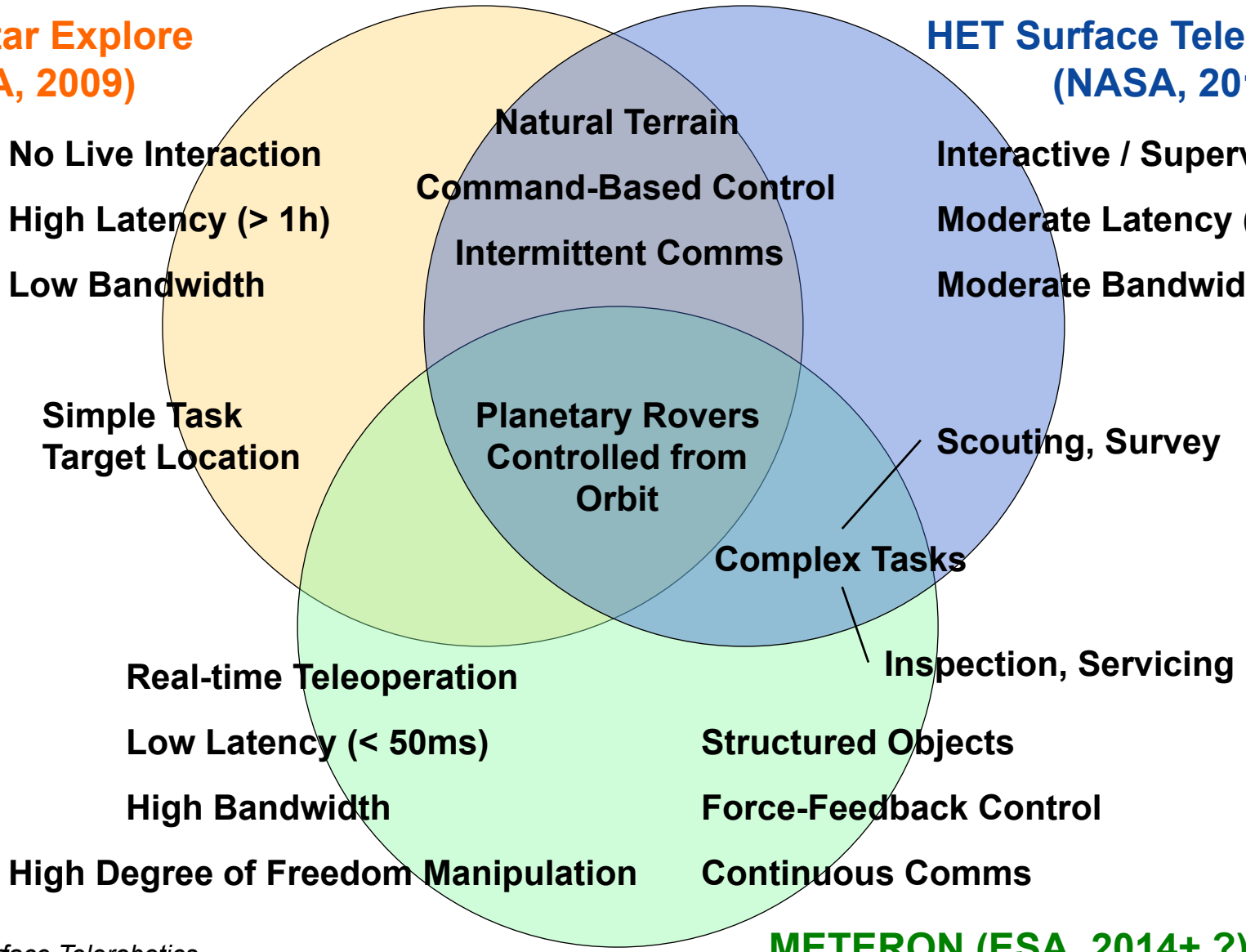


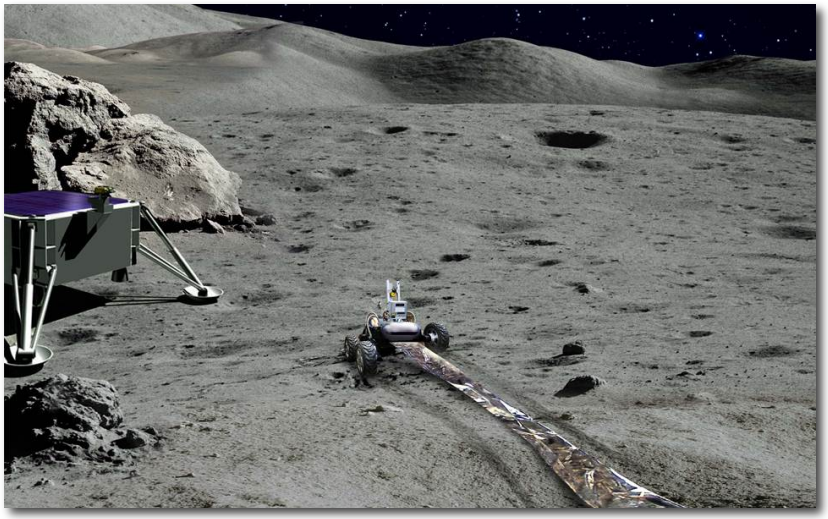
L2 Lunar Farside (Waypoint) Mission Concept

Orion at Earth-Moon L2 Lagrange point

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

Lunar telescope deployment

- Requires surface survey, antenna/receiver deployment, and inspection/documentation
- Lunar farside provides radio quiet zone for low-freq measurements cosmic dawn



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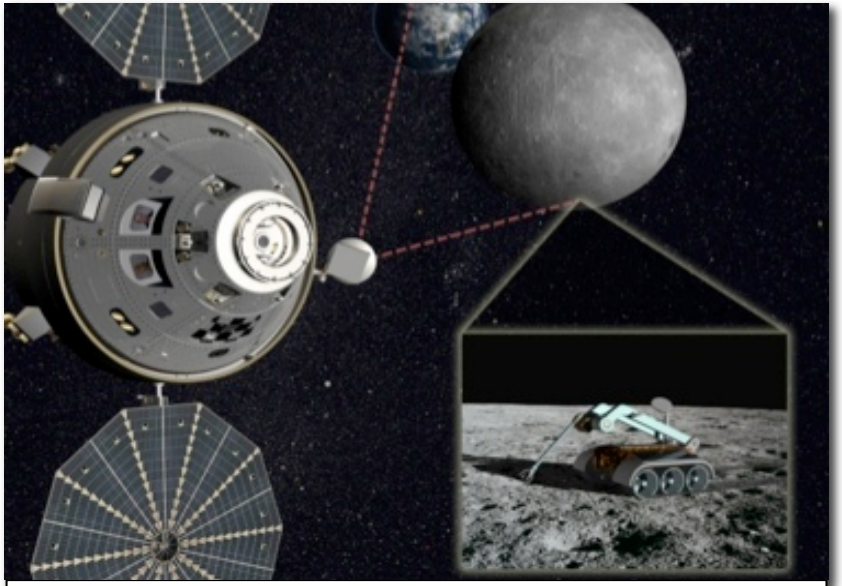
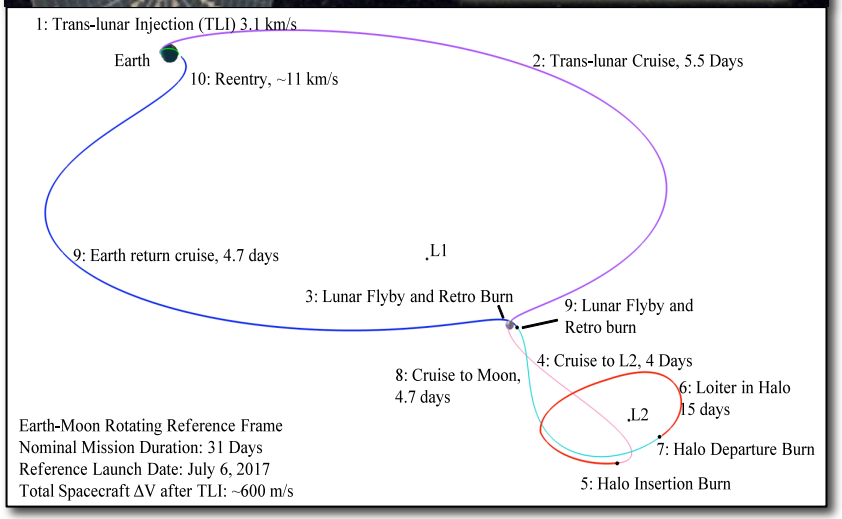
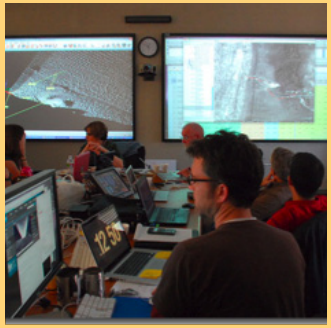
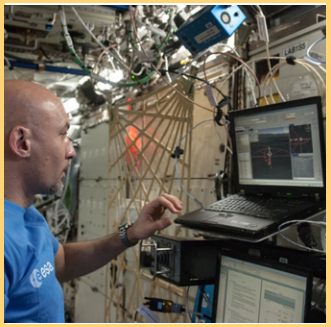




(Lockheed Martin / LUNAR)

Waypoint Mission Simulation (2013)

Phase 0	Phase 1	Phase 2	Phase 3
Pre-Mission Planning	**Surveying**	**Telescope Deployment**	**Telescope Inspection**
			
Ground teams plan out telescope deployment and initial rover traverses.	Crew gathers information needed to finalize the telescope deployment plan.	Crew monitors the rover as it deploys a single arm of a telescope node.	Crew inspects the deployed telescope node looking for tears and folds.
	Crew Session 1	Crew Session 2	Crew Session 3
Spring	***June 17***	***July 26***	***August 20***

K10 Planetary Rover @ NASA Ames

NASA Ames Roverscape

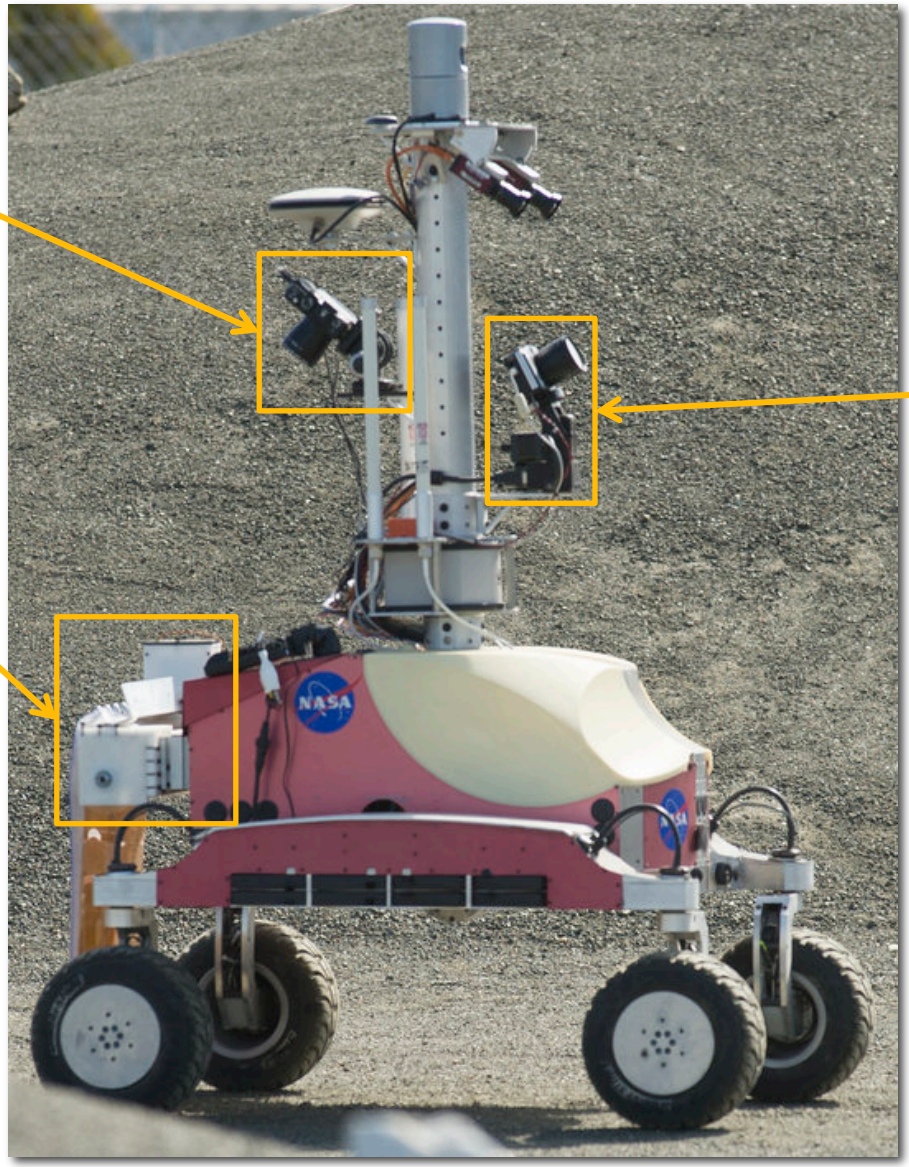
K10 Specifications

- 4-wheel drive, 4-wheel steer
- Split rocker chassis
- Size: 1.3 x 0.9 x 1.0 m (HxWxL)
- Speed: 0.9 m/s (on 10 deg slope)
- Power: 1900 W (Li-ion batteries)
- Weight: 100 kg (with 25 kg payload)

Science Instruments

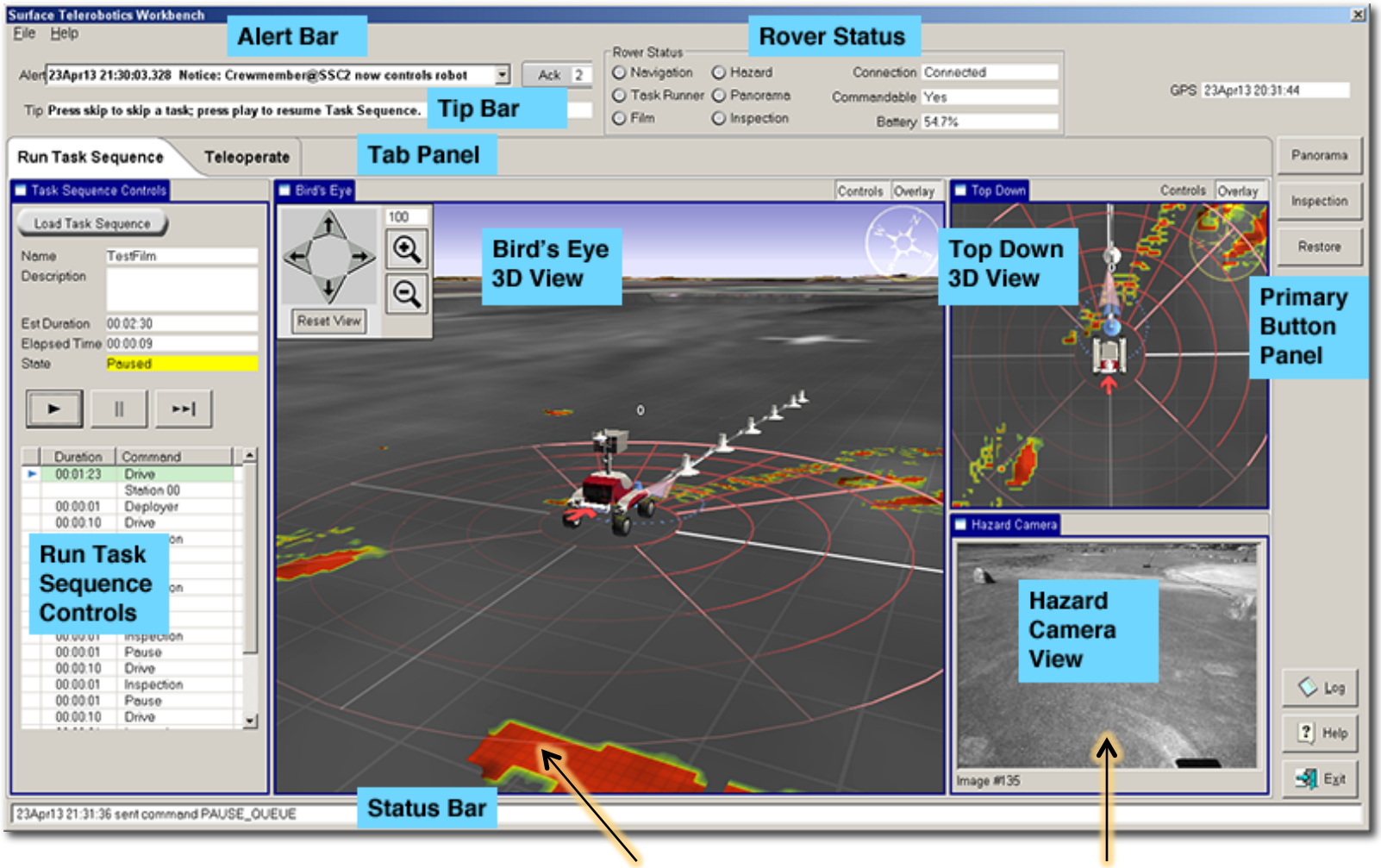
Inspection Camera
- Consumer-grade digital camera
- 12 megapixel
- 350 rad/pixel
- Fixed rear-pointing mount

Film Deployer
- Developed w/ U. of Idaho
- 60-cm wide polyimide film
- Start, stop & tension controlled on-board

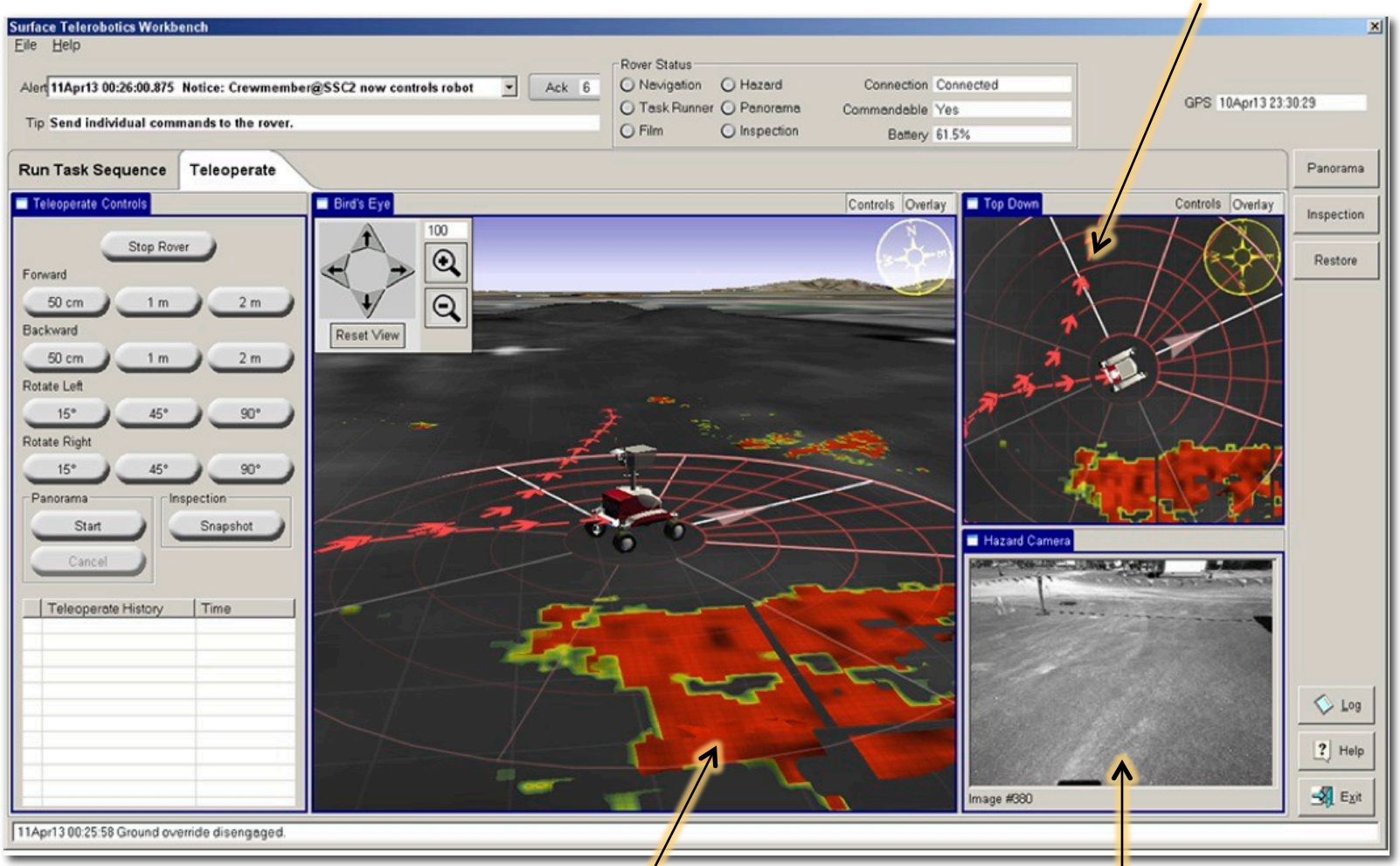


Panoramic Camera
- Consumer-grade digital camera
- 12 megapixel
- 350 rad/pixel
- Pan-tilt unit

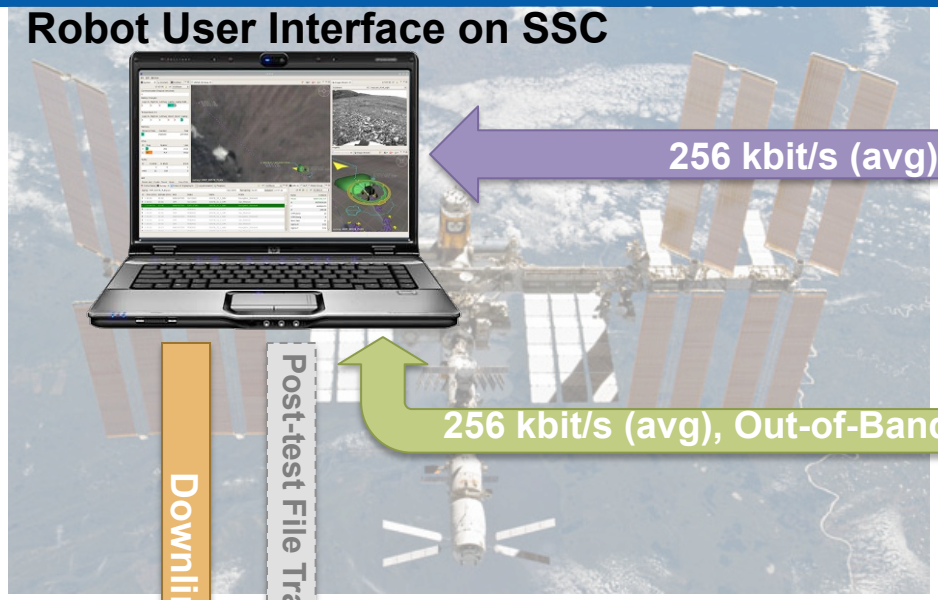
Robot Interface (Supervisory Control)



Robot Interface (Manual Control)



Data Communications



256 kbit/s (avg), 1 sec delay (max)

"Live" Rover Sensor and Instrument Data (telemetry)

256 kbit/s (avg), Out-of-Band

Rover/ Science Data (e.g. imagery)

Downlink

Post-test File Transfer

Uplink, data transfer to laptop storage

Uplink

Note: Normal uplink ~1Mbps, spike after LOS is ~2Mbps for 2 sec

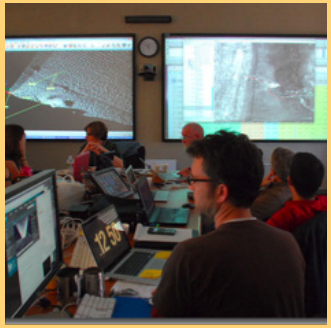
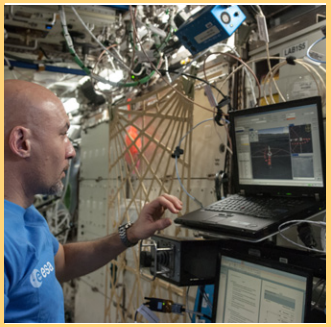
Interface Instrumentation & Evaluation Data

Rover Task Sequence (text file)

1 kbit/sec (avg), 1 sec delay (max)

K10 rover at NASA Ames

Waypoint Mission Simulation (2013)

Phase 0	Phase 1	Phase 2	Phase 3
Pre-Mission Planning	**Surveying**	**Telescope Deployment**	**Telescope Inspection**
			
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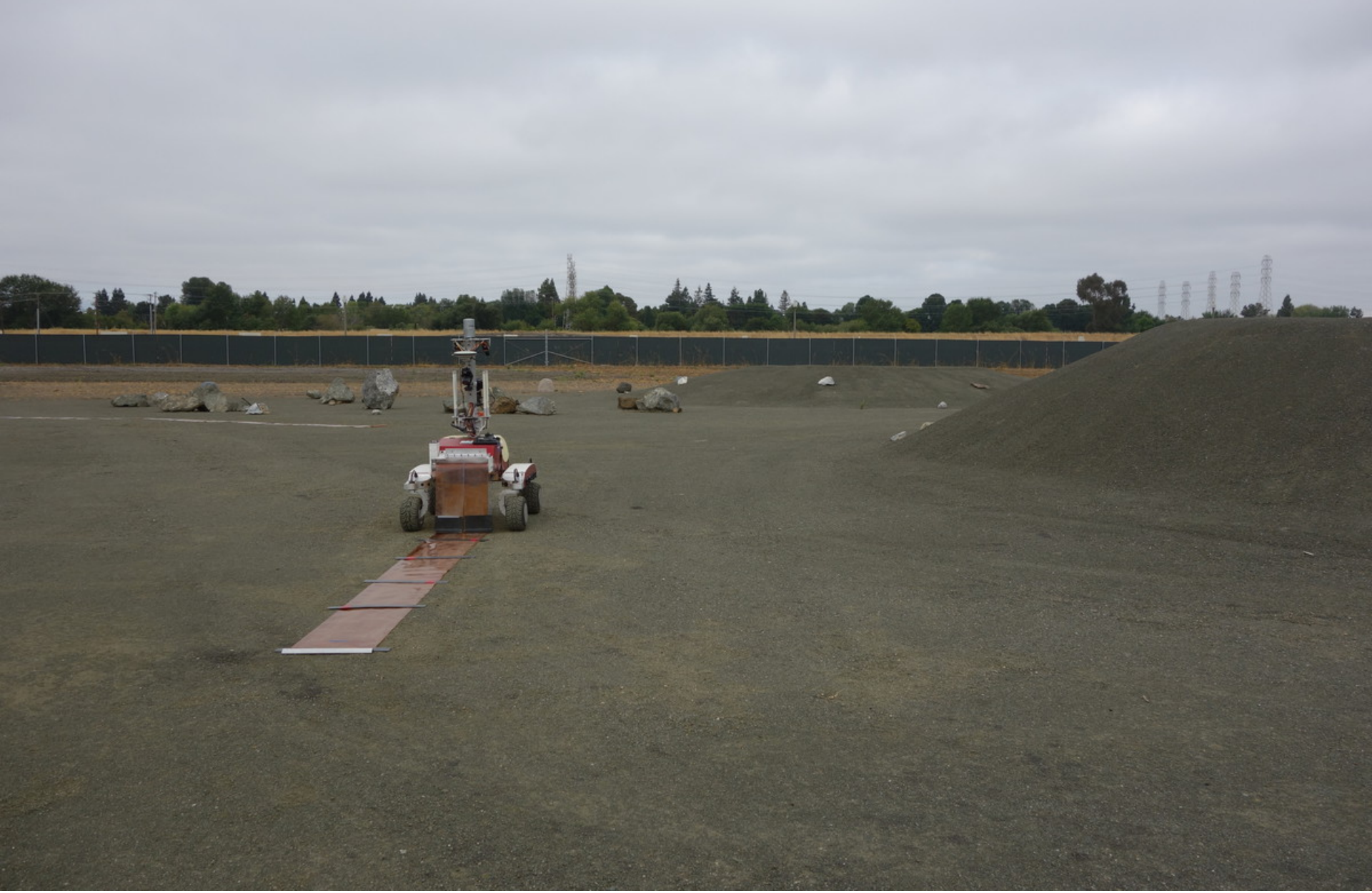
Crew Session #1 – K10 performing surface survey (2013-06-17)

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

“PLUTO” Multi-Purpose Support Room at JSC: provides data comm & crew laptop support



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

Luca Parmitano works with the “Surface Telerobotics Workbench”

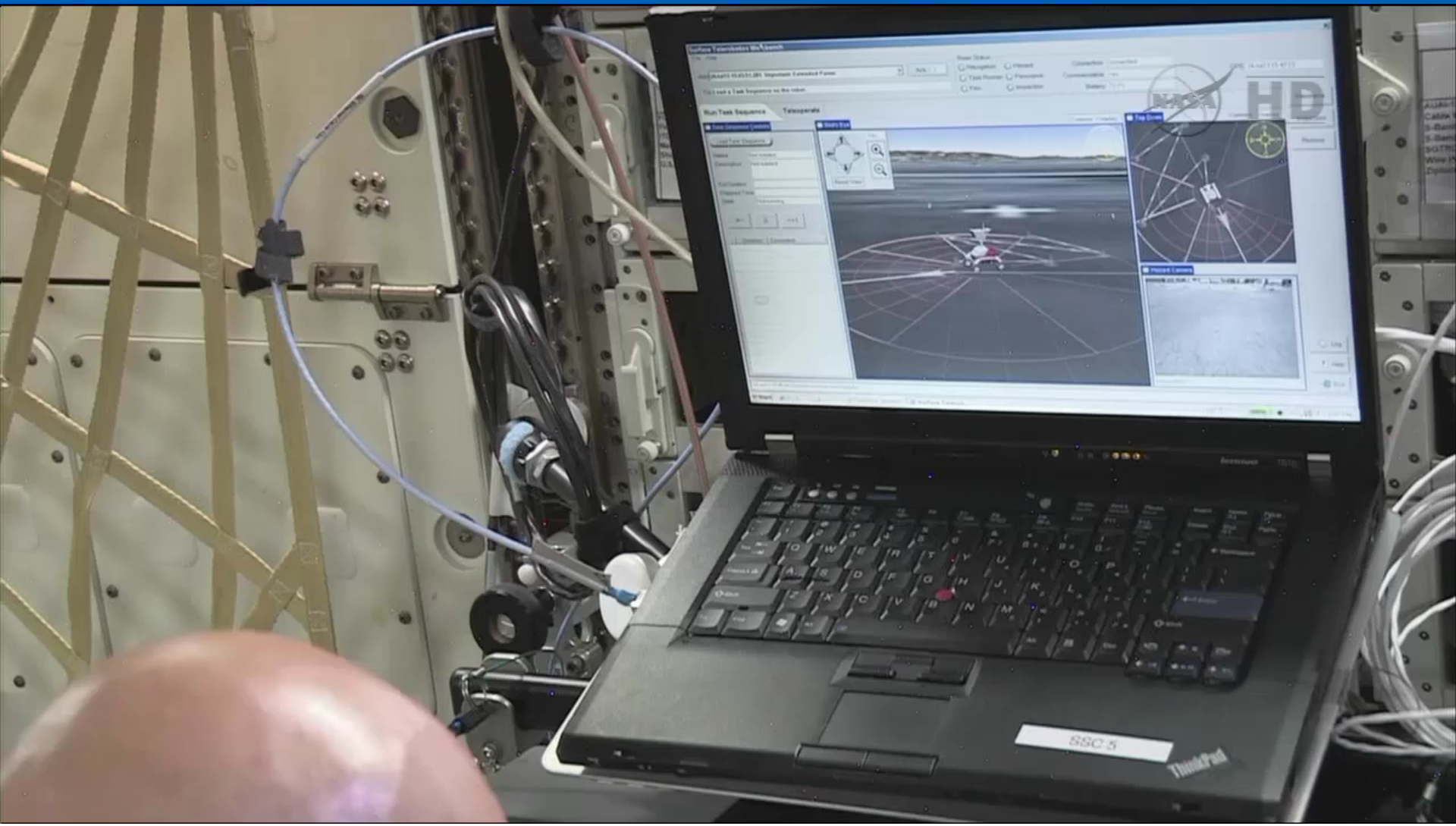
ISS Mission Control (MCC-H) during Surface Telerobotics test
View of robot interface and K10 at ARC

Deployed simulated polymide antenna (three “arms”)

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

K10 documenting simulated polymide antenna

Surface Telerobotics



Assessment Approach

Situation Awareness (SA)

- Level 1 SA (Perception): What are the status, attributes, and dynamics of the elements relating to the environment, system, etc.
- Level 2 SA (Comprehension): What is the impact of the perceptions?
- Level 3 SA (Projection): How are future states affected?

Categories

- Location awareness
- Activity awareness
- Surroundings awareness
- Status awareness
- Overall mission awareness

Data Collection

- Crew questionnaires: SAGAT & Bedford Workload Scale
- Crew debrief interview

Assessment Approach

Metrics

- **Mission Success:** % task sequences: completed normally, ended abnormally or not attempted; % task sequences scheduled vs. unscheduled
- **Robot Asset Utilization:** % time robot spent on different types of tasks (traverse, panoramic imaging, inspection imaging); 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 in vs. unscheduled task sequences
- **System Problems:** Mean Time To Intervene (MTTI), Mean Time Between Interventions (MTBI)
- **Robot Performance:** expected vs. actual execution time on tasks and task sequences

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

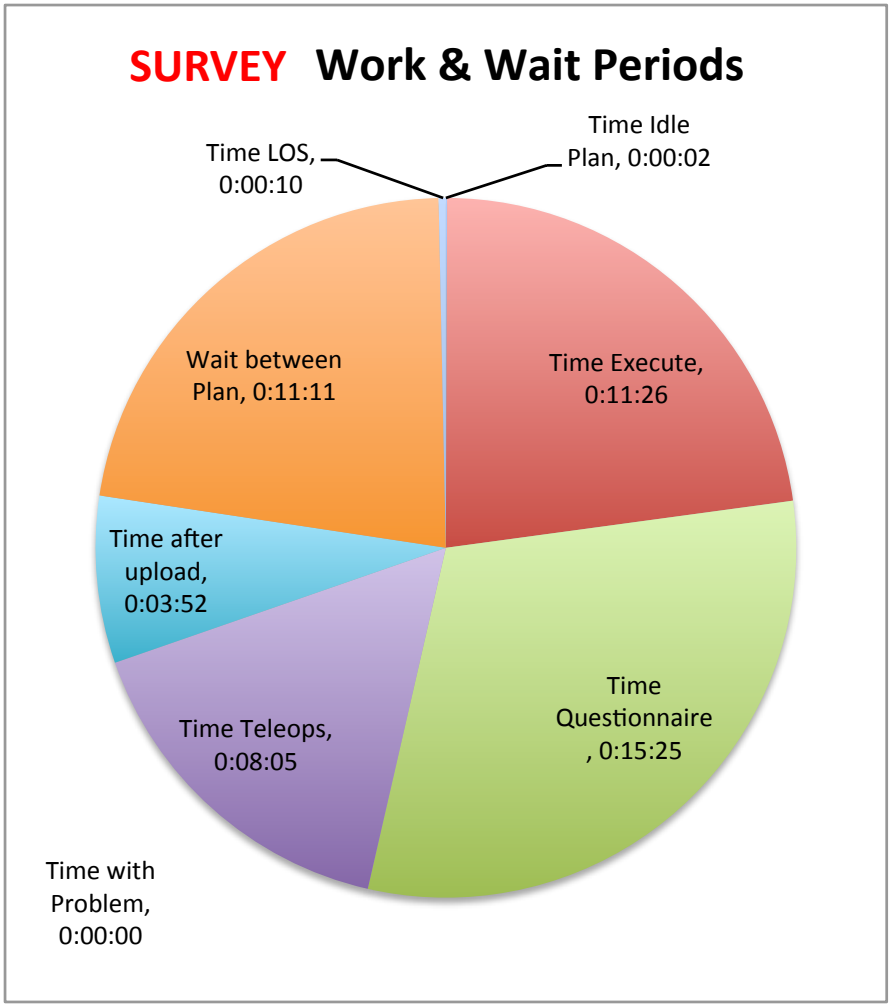
Preliminary Results

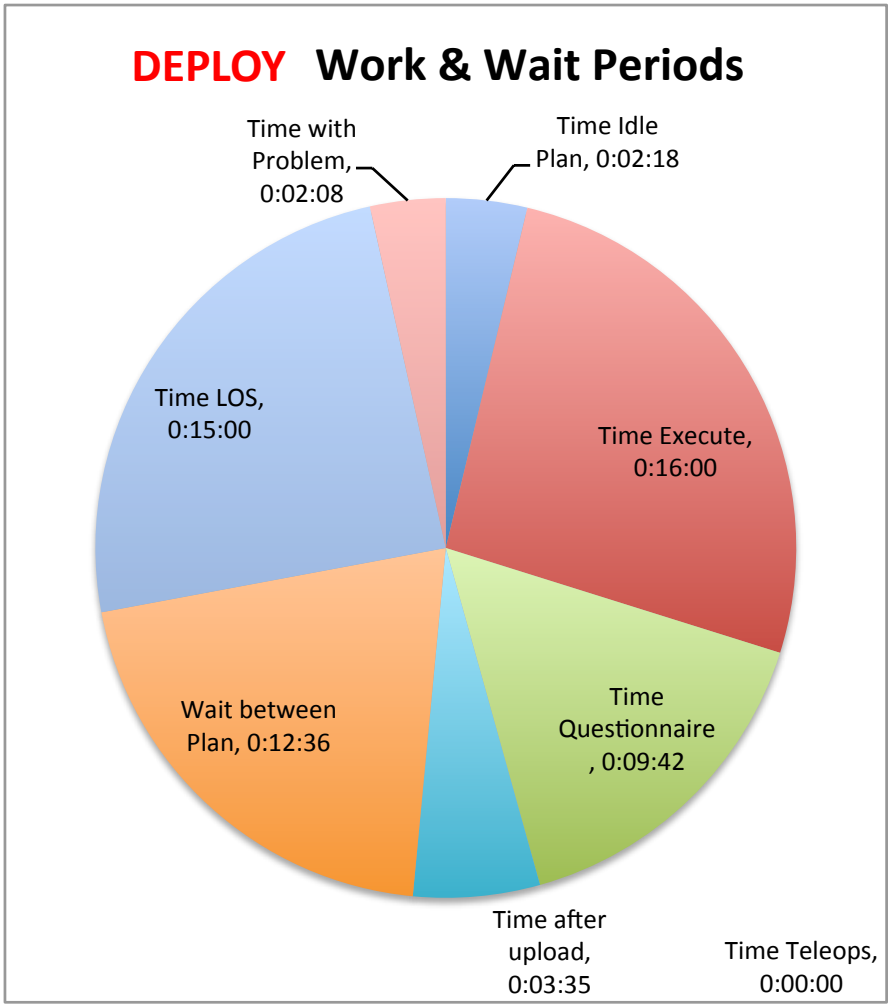
Robot Utilization

- Work Periods
  - **Execute**: work done during planned autonomous rover task. Astronaut may perform supervisory tasks in parallel
  - **Teleops**: work done when astronaut manually teleoperates the rover
  - **Idle_in_Plan**: work done by astronaut in support of rover's planned tasks (e.g. rover is paused while astronaut inspects)
  - **Questionnaire**: astronaut answering questions

- Wait Periods
  - **Time_before_Start**: time after a task sequence is selected but before 1st task is executed
  - **Wait_between_Plans**: time when rover has no task sequence to perform
  - **LOS**: work is paused due to a loss of comm signal
  - **Time_in_Problem**: rover is paused due to a problem

Robot Utilization





Preliminary Results

Productivity

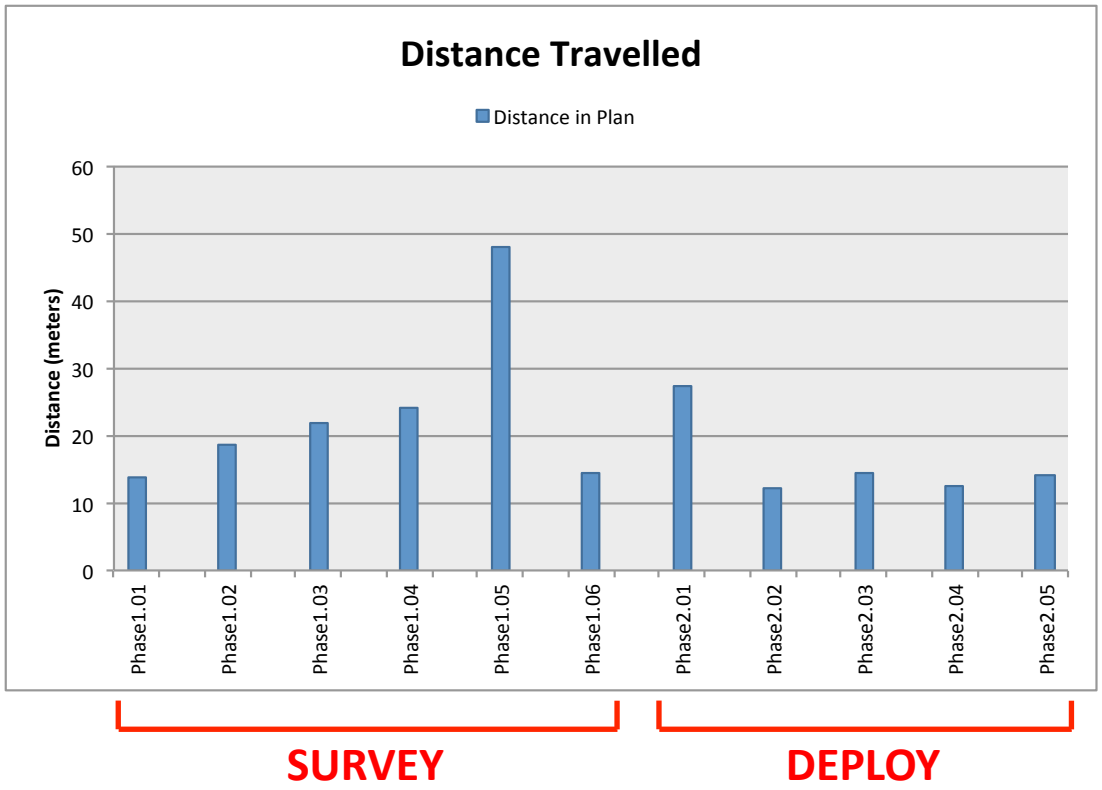
- Productive Time (PT) = astronaut and rover performing tasks contributing to mission objectives
- Overhead Time (OT) = astronaut and rover are waiting
- %PT = percentage productive time
- %OT = percentage overhead time
- Work Efficiency Index (WEI) = PT / OT

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

Preliminary Results

Distance Traveled

- Total distance driven by K10
- Rover covered an average distance of 20 m per task sequence
- Under supervisory control, K10 average speed was 40 cm/s



Conclusion

Successfully completed 3 test sessions in Summer 2013

- 3 ISS astronauts remotely operated K10 rover for approx. 10.5 hrs
- Astronauts used combination of **supervisory control** (task sequencing) and **manual control** (discrete commanding)
- **500-750 msec comm latency** and intermittent LOS periods

Collected wide range of engineering data

Telerobotics technologies

- **Rover autonomy** enhanced operational efficiency and robot utilization (particularly hazard detection and safeguarding)
- **Interactive 3-D visualization** of robot state and activity reduced operator workload and increased situation awareness
- **Supervisory control** was a highly effective strategy for crew-centric surface telerobotics

Acknowledgements

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- Susan Spencer

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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