Space Telerobotics

Remote operation of robots in & from space

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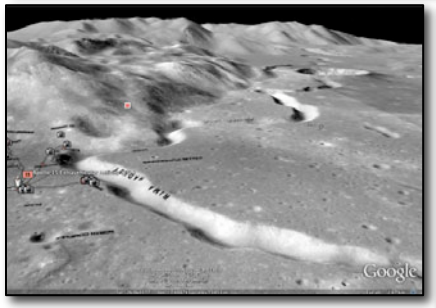
NASA Ames Intelligent Robotics Group

Overview

- 32 researchers (14 Ph.D.'s)
- 25+ student interns yearly
- 80% NASA work
- 20% non-NASA work

Research themes

- **Automated planetary mapping**
  - Base maps & terrain models
  - Geospatial data systems
- **Exploration user interfaces**
  - Robot & science operations
  - Accessible science data
- **Mobile robots**
  - Remotely operated & supervised
  - Free-flyers, lake lander, & rovers



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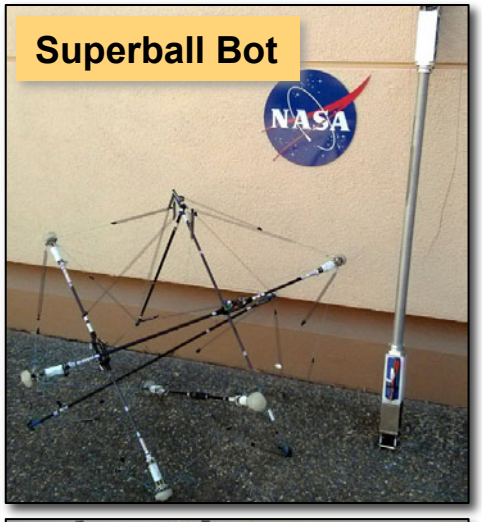
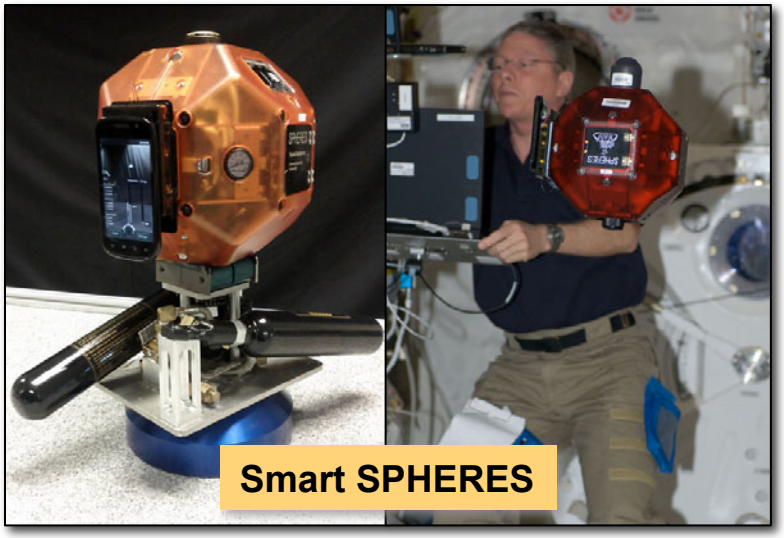
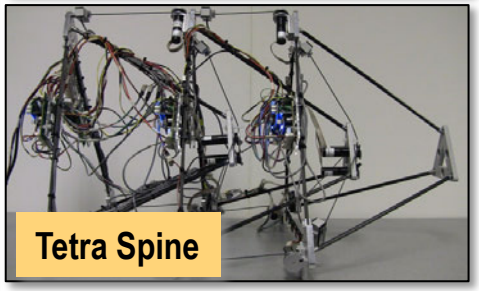
Robots

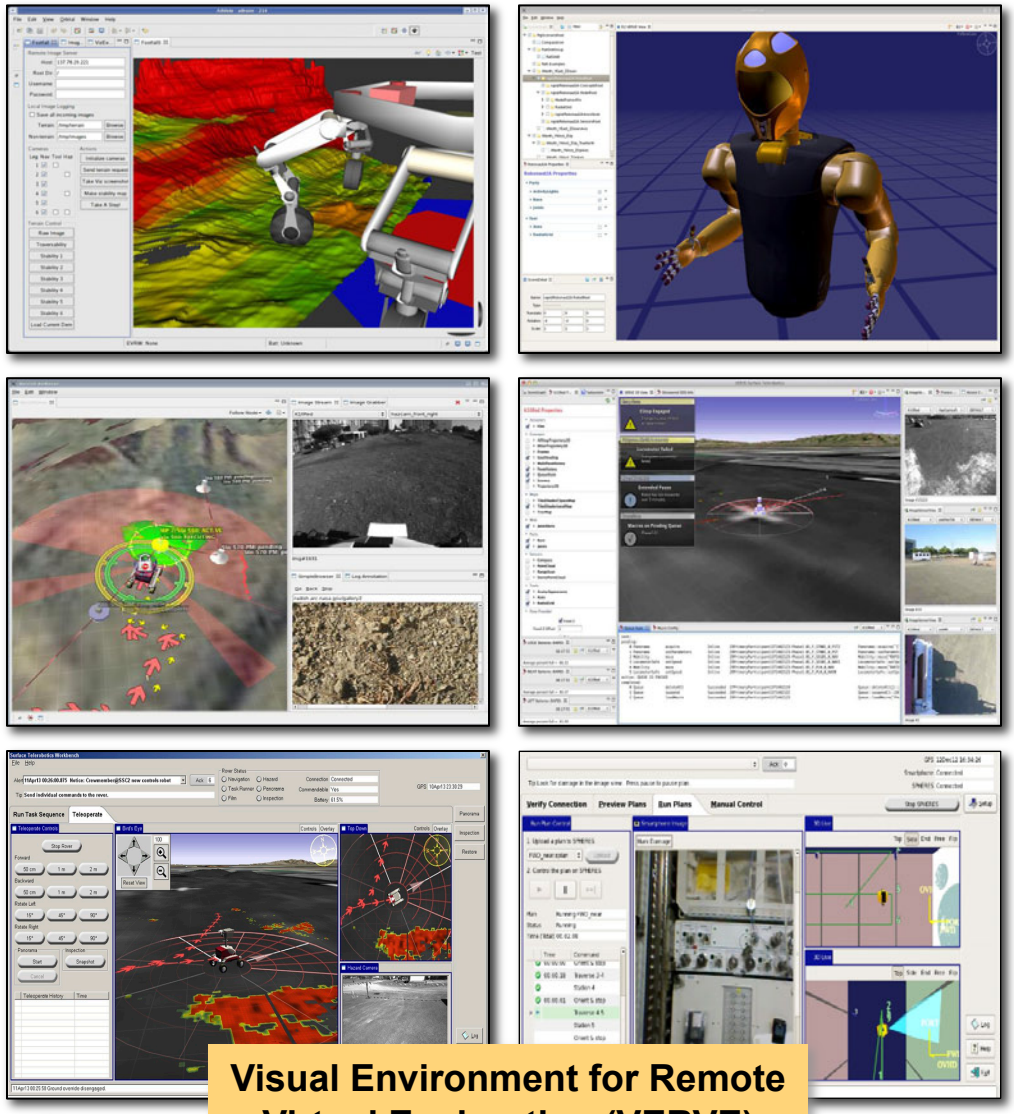




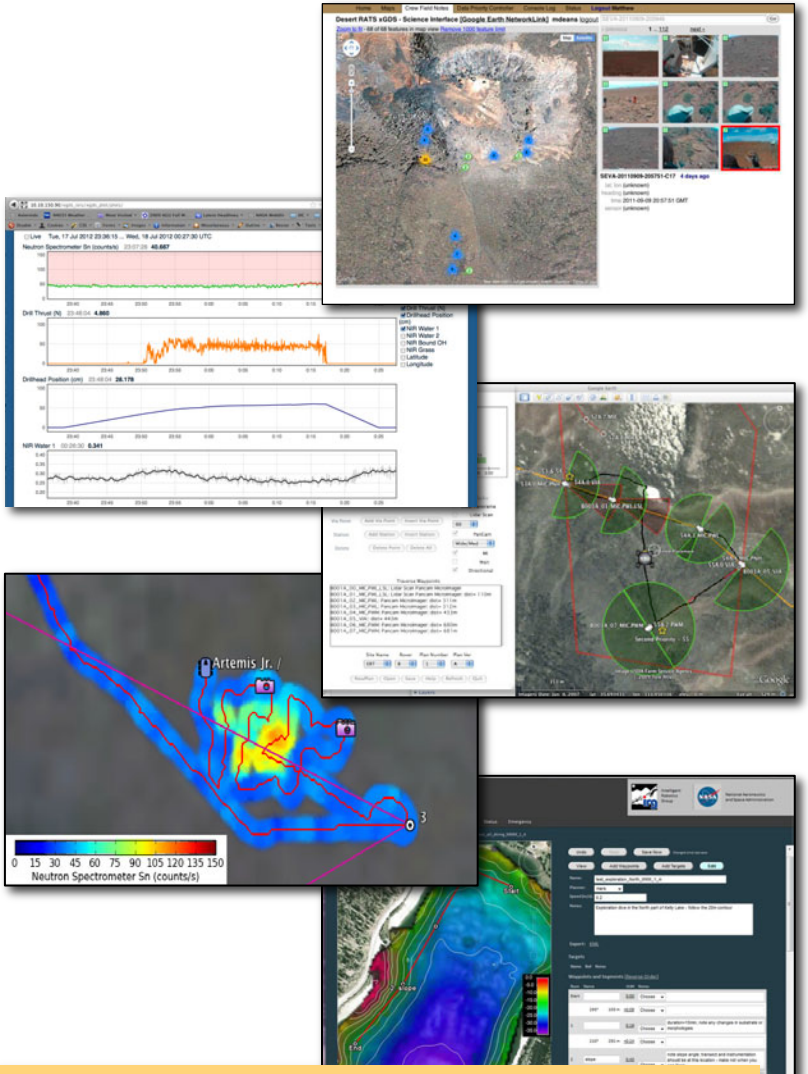


GigaPan

User Interfaces

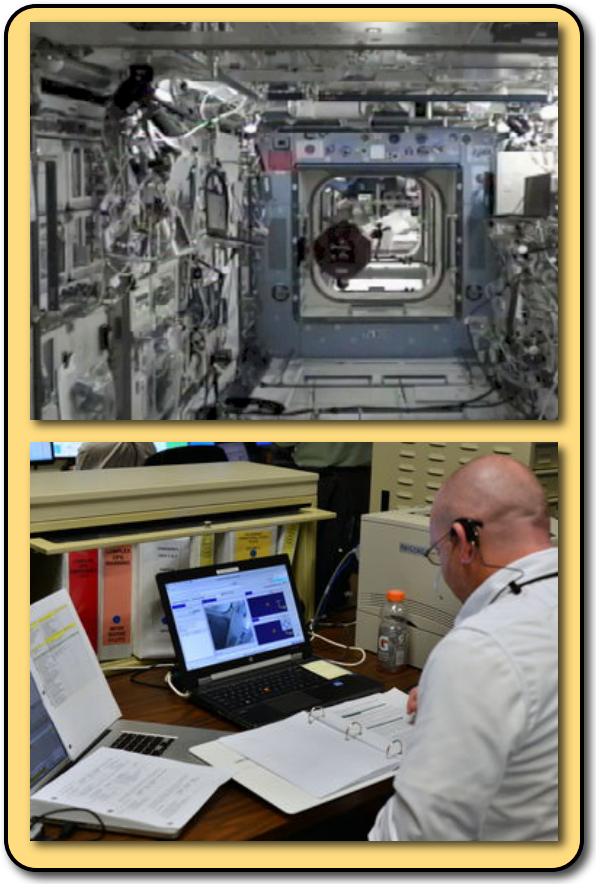


Visual Environment for Remote Virtual Exploration (VERVE)



Exploration Ground Data System (xGDS)

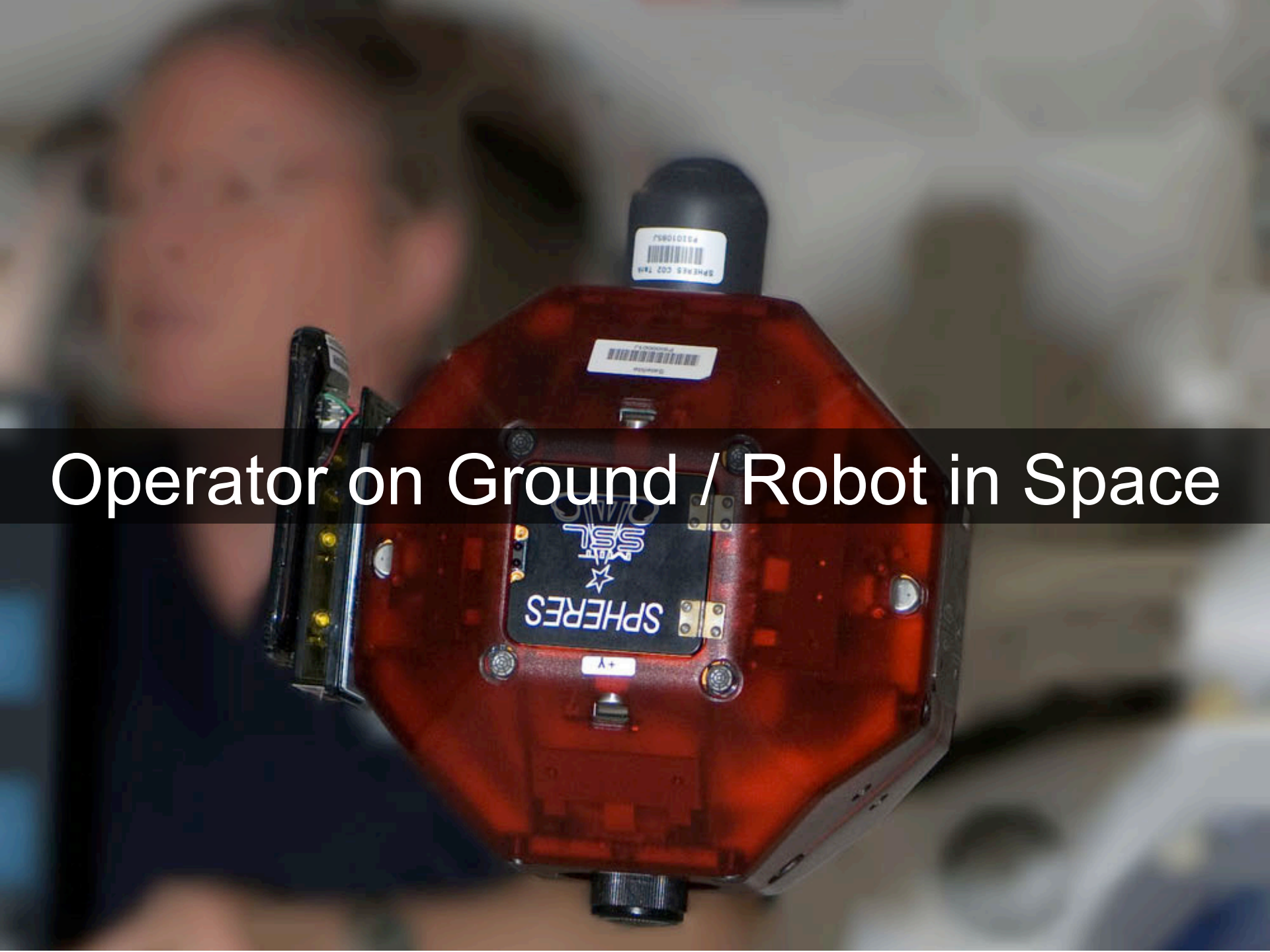
Remote Operation of Space Robots



Part 1
Operator on Ground
Robot in Space

Part 2
Operator in Space
Robot on Ground

Part 3
Operator on Ground
Robot on the Moon



Operator on Ground / Robot in Space

Robots for Human Exploration

Motivation

- Help maintain spacecraft
- Enhance crew productivity
- Perform work before, in support, and after humans

In-Flight Maintenance (IFM)

- Must perform IFM to keep spacecraft in a safe, habitable configuration
- Many IFM tasks are tedious, time-consuming, repetitive & routine
- Many IFM tasks cannot be done using only fixed sensors / actuators

Unmanned mission phases

- Setup spacecraft prior to human arrival (e.g., Mars exploration)
- Contingency situations

IN-FLIGHT MAINTENANCE TASKS

Inspect & monitor
- Provide mobile camera views
- Routine surveys and inventory
- Check payload status / health

Routine maintenance
- Change air/water filters
- Perform water draw/input on ECLSS
- Payload adjustment & trouble shooting

Contingency response
- Assess environment after fire event
- Assess & repair Leaks/MMOD damage
- Power cycle/reboot electrical equipment
- Actuate mechanisms (hatches, valves, etc.)

Space Station In-Flight Maintenance

Extra-Vehicular Activity (EVA)

- Not enough crew time to do everything (**only 1-2 EVAs per year**)
- Crew must always carry out “Big 12” contingency EVA’s if needed
  - Maintain electrical power system
  - Maintain thermal control system
- Prep & tear down: up to 3 hr per EVA

Intra-Vehicular Activity (IVA)

- Crew spends a lot of IVA time on maintenance (**40+ hr/month**)
- Routine surveys require 12+ hr/month
  - Air quality, lighting, sound level, video safety, etc.
- Crew must always carry out contingency IVA surveys
  - Find and repair leaks, etc.

Repetitive and Routine Tasks

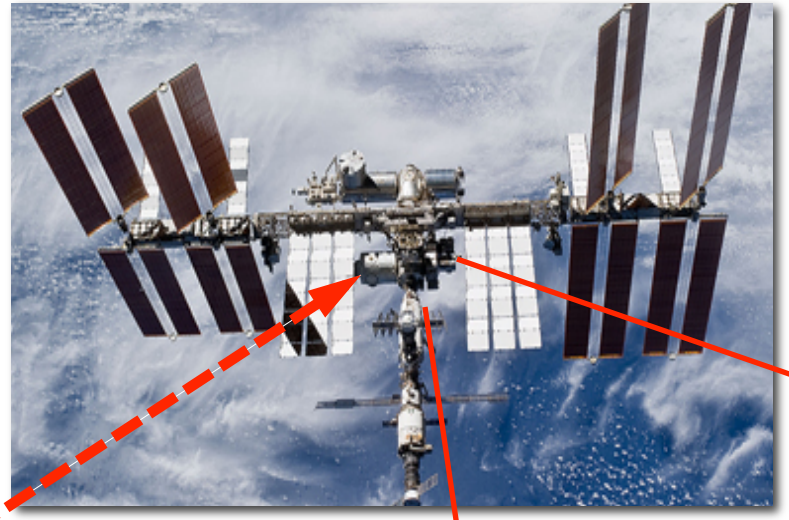
Camera positioning

- **Many** cameras on the Space Station
- Crew has to **manually reposition** cameras monitored by mission control
- Camera are essential for many tasks
  - Safety surveys
  - Equipment and payload inspections
  - Crew “over the shoulder” views during IVA activities

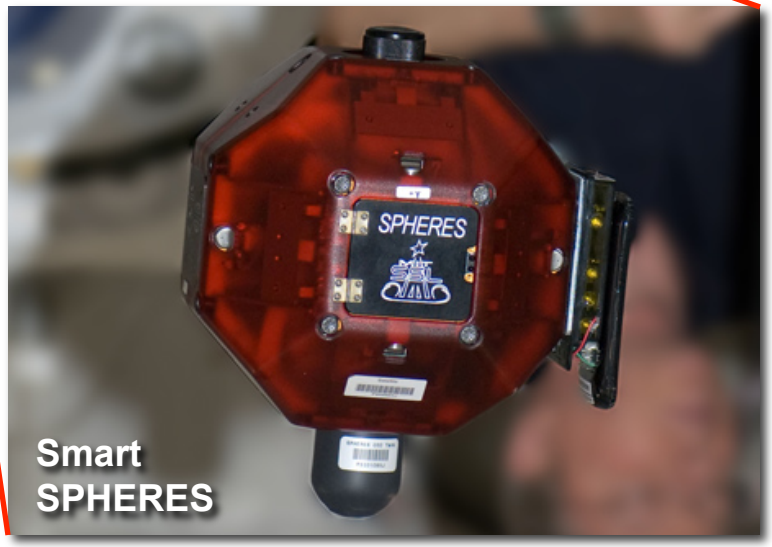
Logistics

- Crew must locate equipment and materials needed for IVA work
  - Crew spends up to 1 hr per day manually searching for items
  - 20,000 items in the inventory database
- Automated logistics is a key NASA priority for future missions

Smart SPHERES

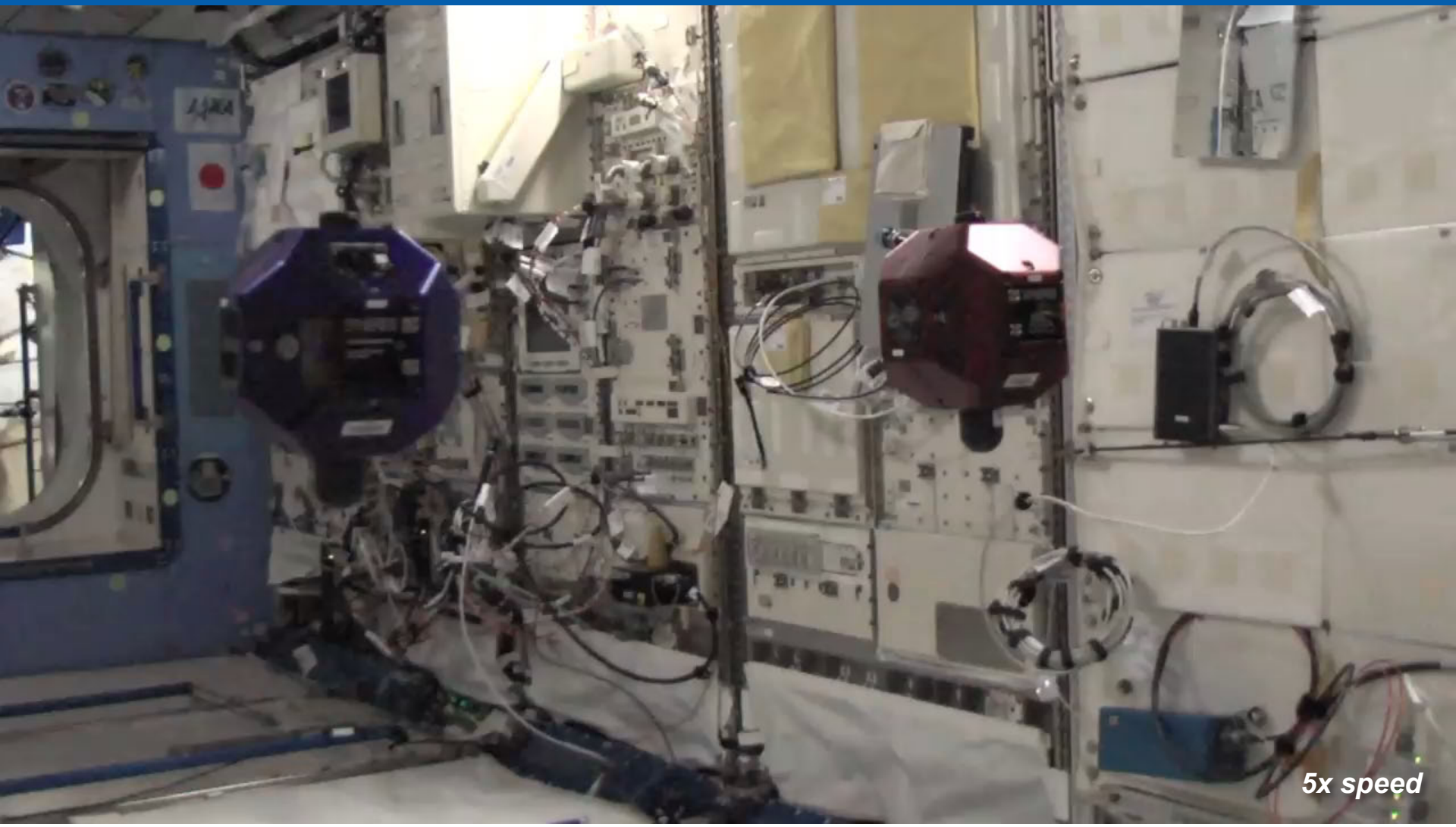


ISS Mission Control
(Houston)



Smart
SPHERES

SPHERES



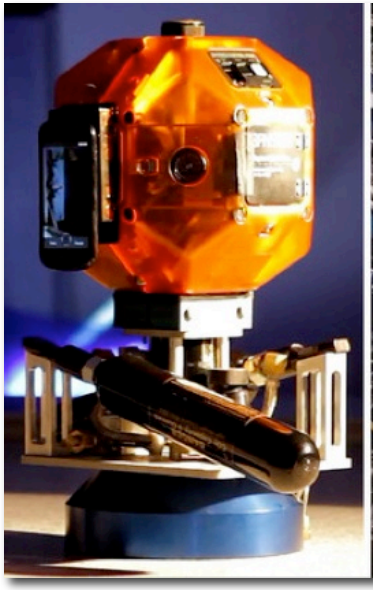
Smart SPHERES

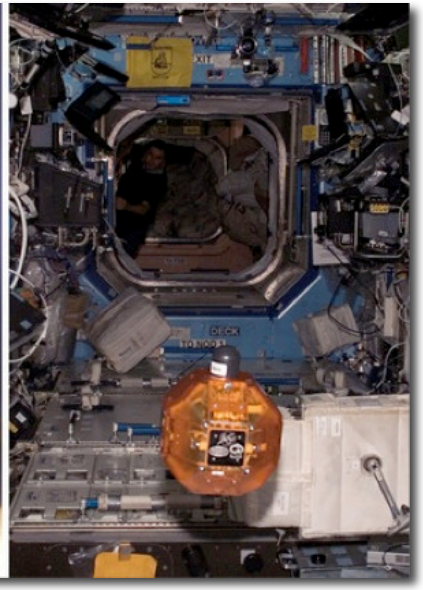
Smartphone Upgrade

- Delivered on STS-135 shuttle flight
- Provides low-cost, off-the-shelf avionics upgrade for SPHERES
- Activiated and initial check-out on November 1, 2011

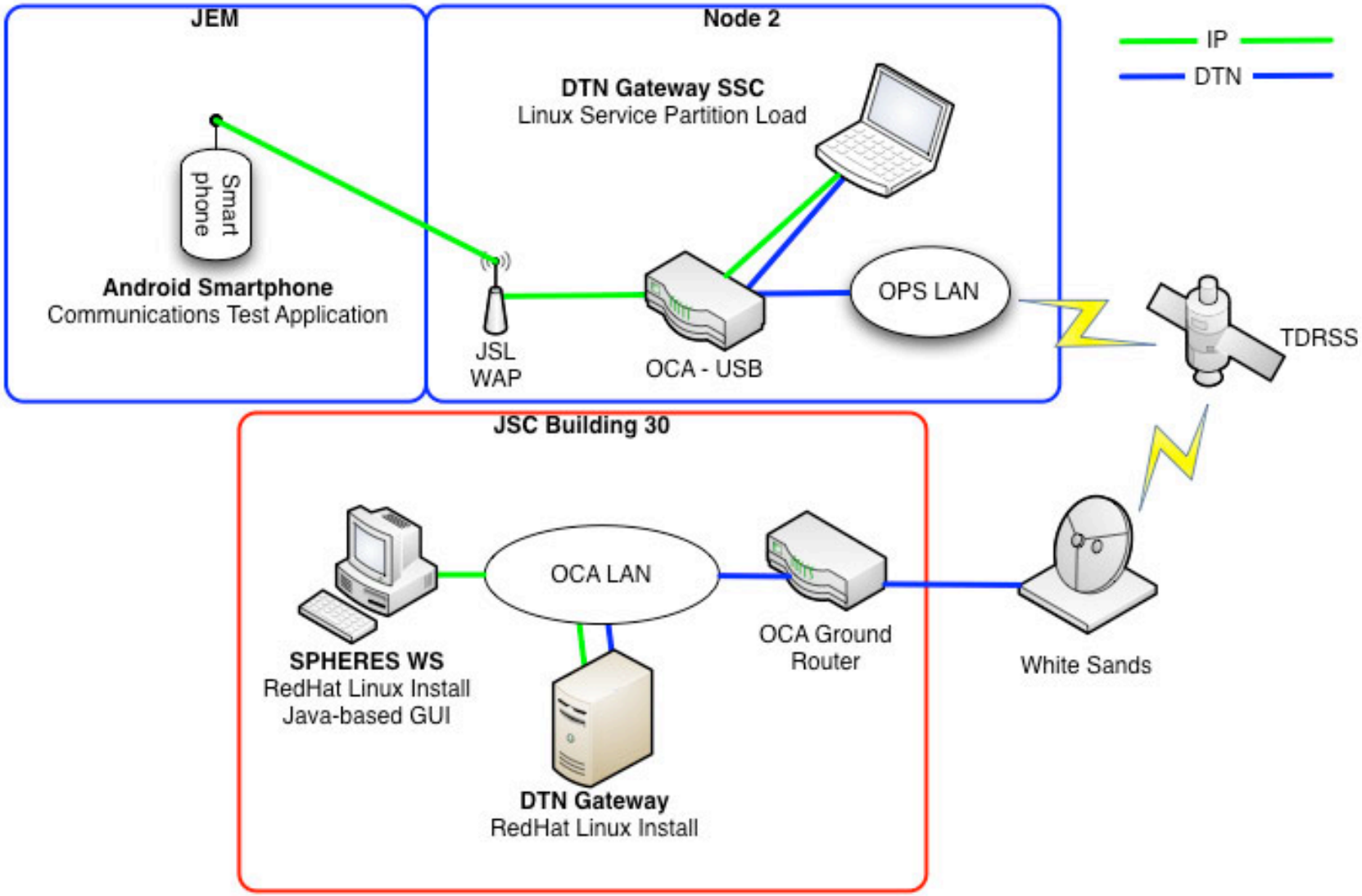
Key Points

- Smartphone was the first commercial smartphone certified for use on the Space Station
- Smartphone enables real-time, remote operation of SPHERES by crew and ground control
- Smartphone provides modern CPU, Wi-Fi, and sensors (camera, magnetometer, etc)





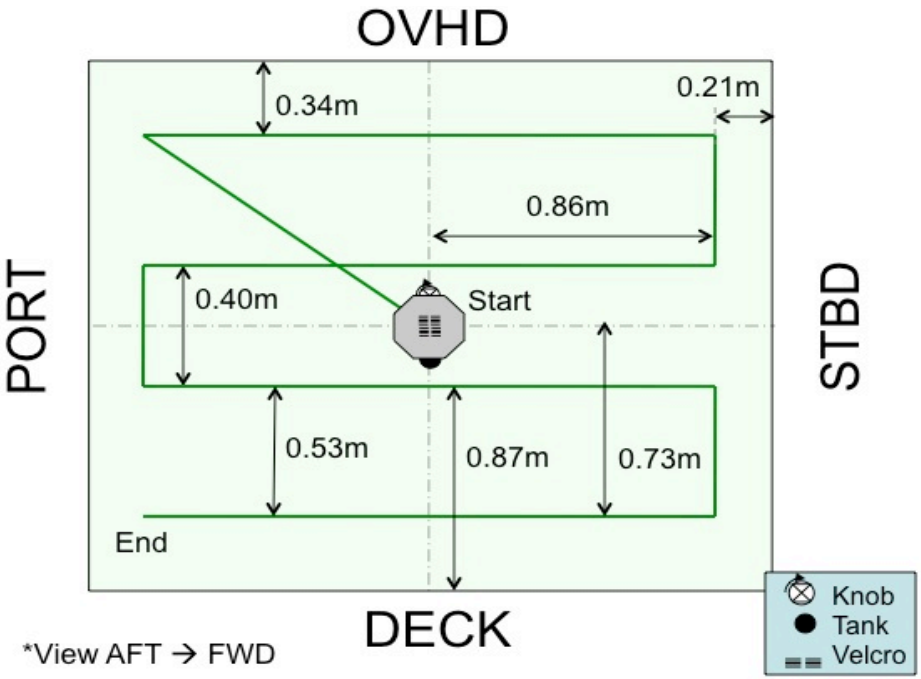
Smart SPHERES Network Setup



Ground Control Test (12 December 2012)

Space Station Interior Survey

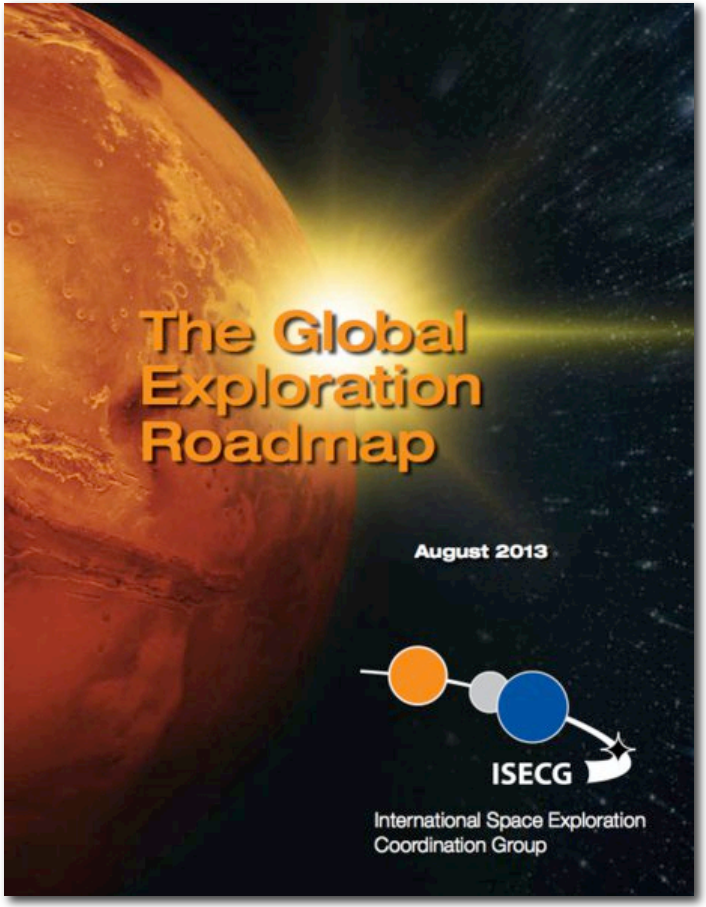
- Demonstrate free-flying video survey within (Kibo Laboratory module)
- Smart SPHERES remotely operated from Mission Control (Houston)
- **Manual control** (discrete commanding) and **supervisory control** (command sequences)



Space Station Interior Survey

Operator in Space / Robot on Ground

Global Exploration Roadmap



Tele-Presence (p. 22)

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

Surface Telerobotics Project

Summary

- 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 Space Station
- K10 rover in NASA Ames Roverscape

ISS Testing (Expedition 36)

17 June 2013 – **C. Cassidy**, survey

26 July 2013 – **L. Parmitano**, deploy

20 August 2013 – **K. Nyberg**, 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)

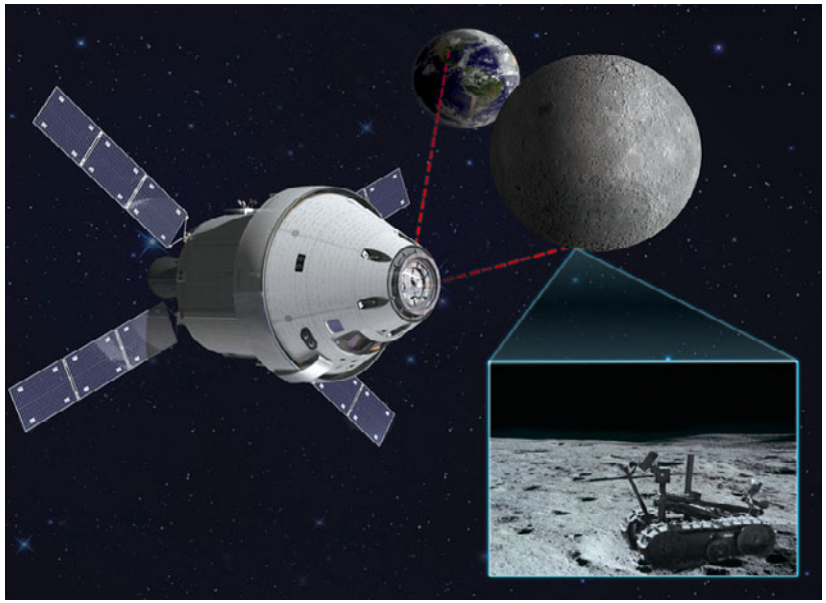
“Fastnet” Lunar Libration Point Mission

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

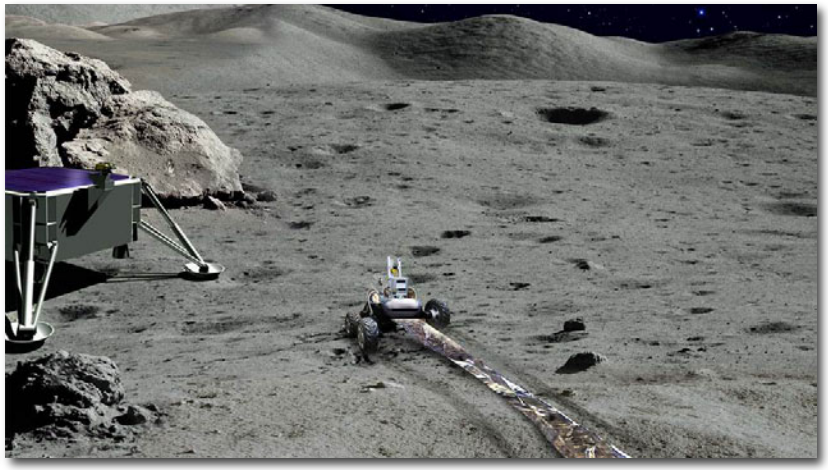
- 60,000 km beyond lunar farside
- Allows station keeping with minimal fuel
- Crew remotely operates robot
- Does not require human-rated lander

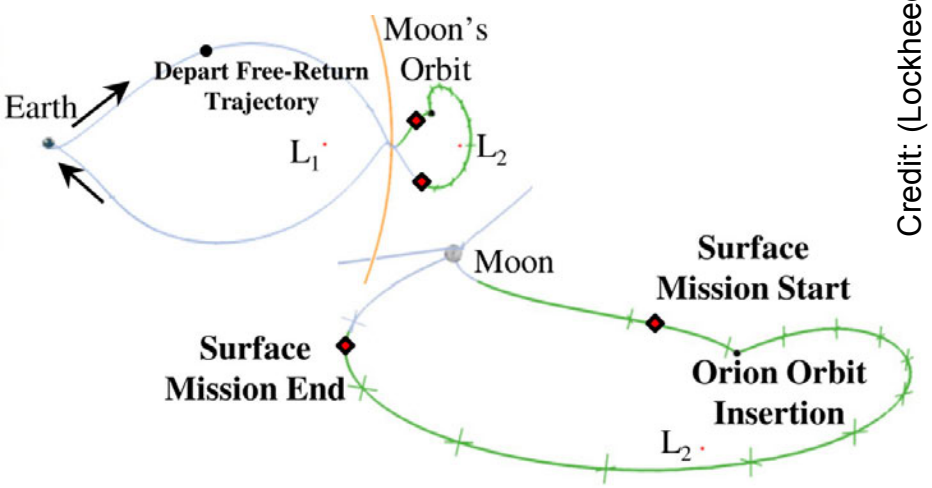
Human-robot conops

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

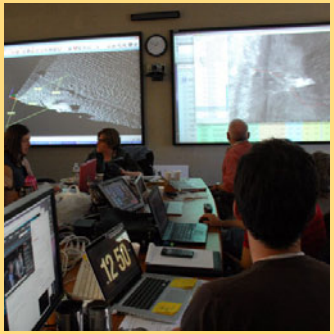
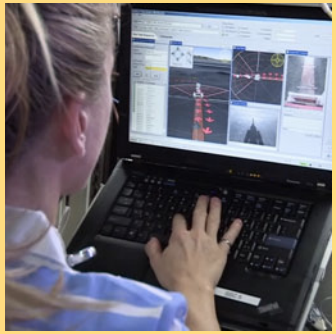


Credit: (Lockheed Martin / LUNAR)

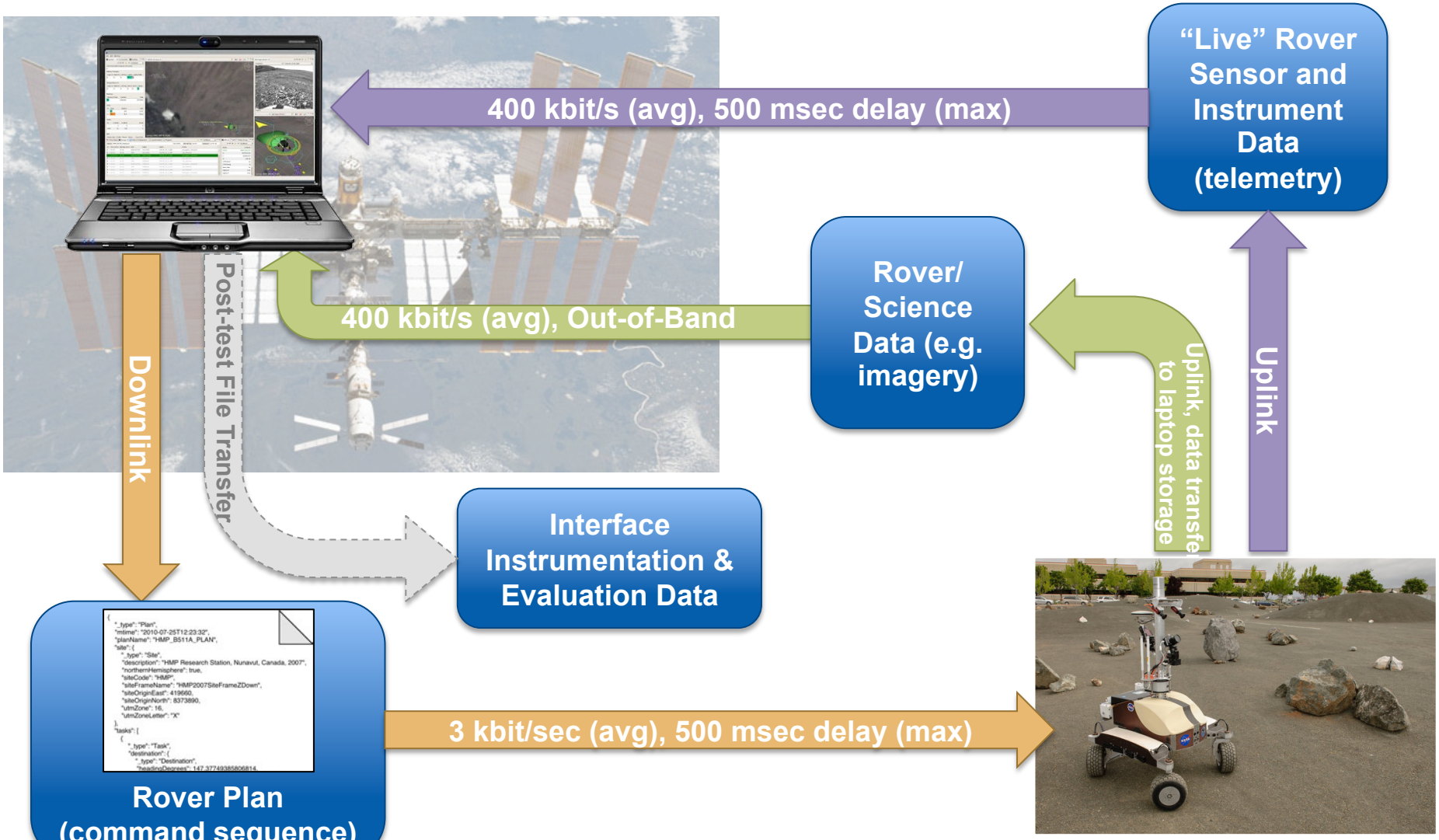




“Fastnet” Mission Simulation with ISS

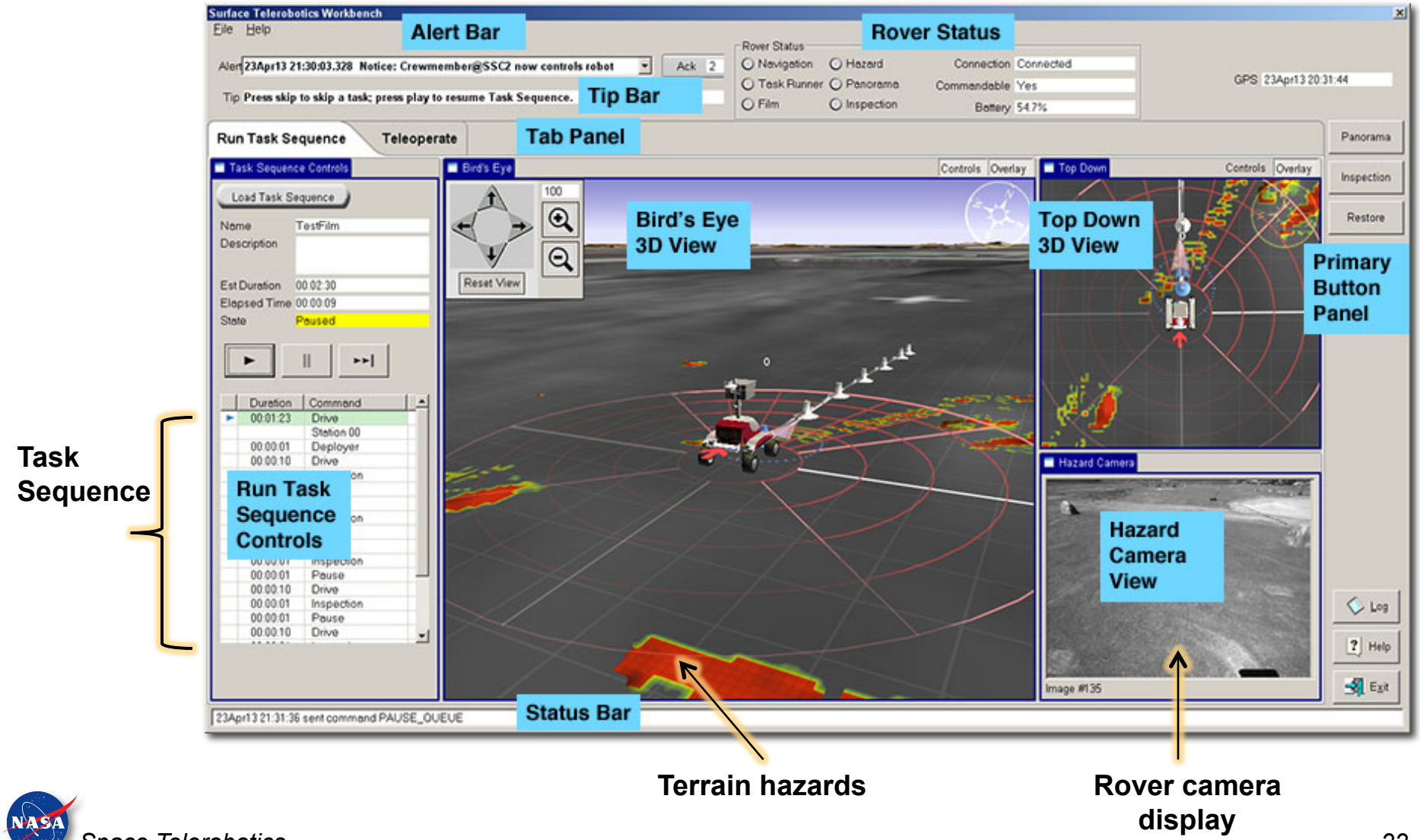
Planning	Phase 1	Phase 2	Phase 3
Pre-Mission Planning	**Surveying**	**Telescope Deployment**	**Telescope Inspection**
			
Ground teams plan out telescope deployment and initial rover traverses.	Crew gathers information needed to finalize the telescope deployment plan.	Crew monitors the rover as it deploys each arm of the telescope array.	Crew inspects and documents the deployed telescope for possible damage.
	Crew Session 1	Crew Session 2	Crew Session 3
Spring 2013	***17 June 2013***	***26 July 2013***	***20 August 2013***

ISS Test Setup



K10 rover at NASA Ames

Robot Interface (Supervisory Control)



Robot Interface (Manual Control)

Rover path

Motion controls

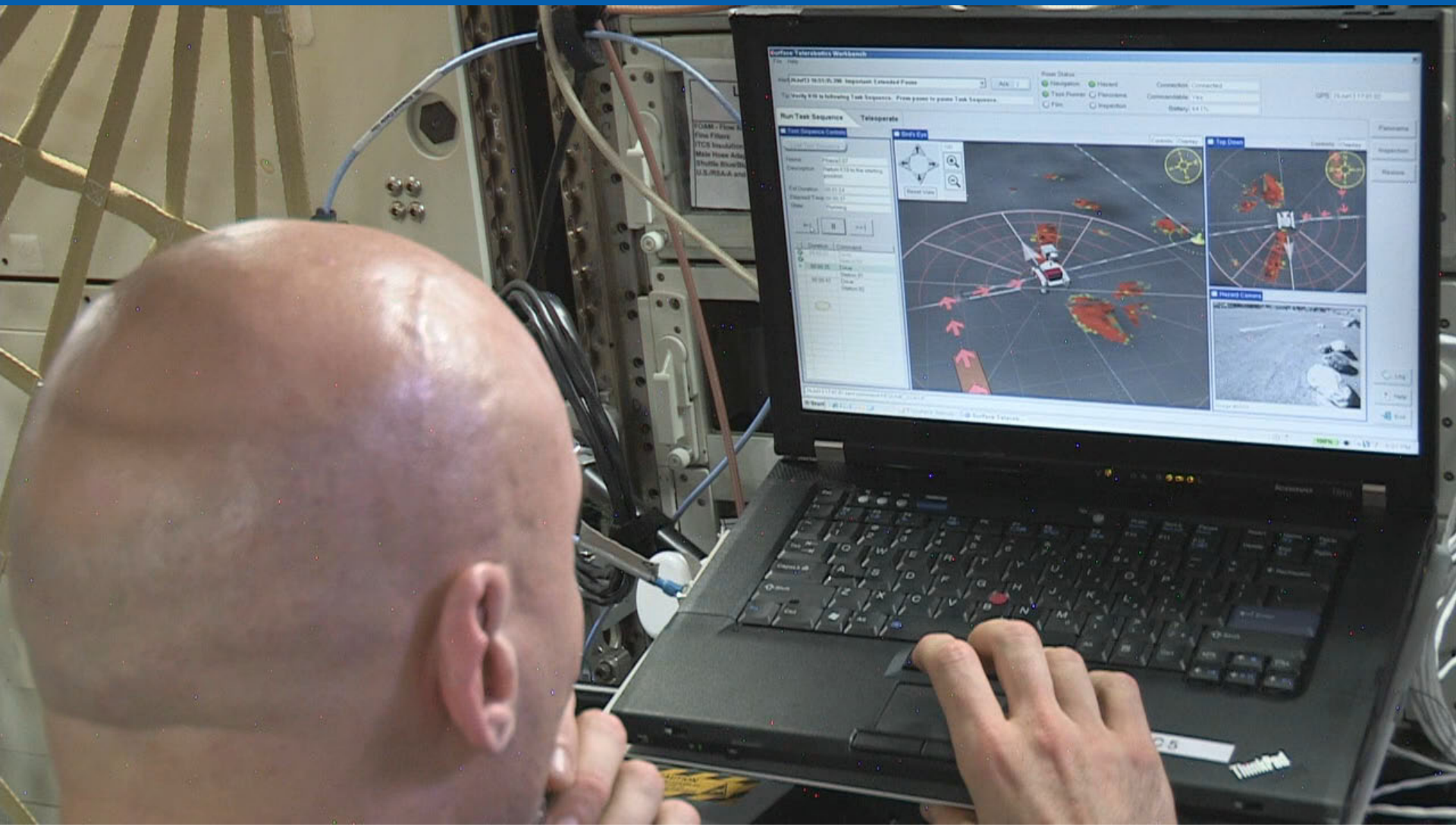
Camera controls

Terrain hazards

Rover camera display

Surface Telerobotics

Surface Telerobotics



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)

Human-Robot Teaming

Productivity Analysis

- **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) = Productive Time / Overhead Time

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

Operator on Ground / Robot on the Moon

Resource Prospector Mission (2020)

NASA led lunar rover mission

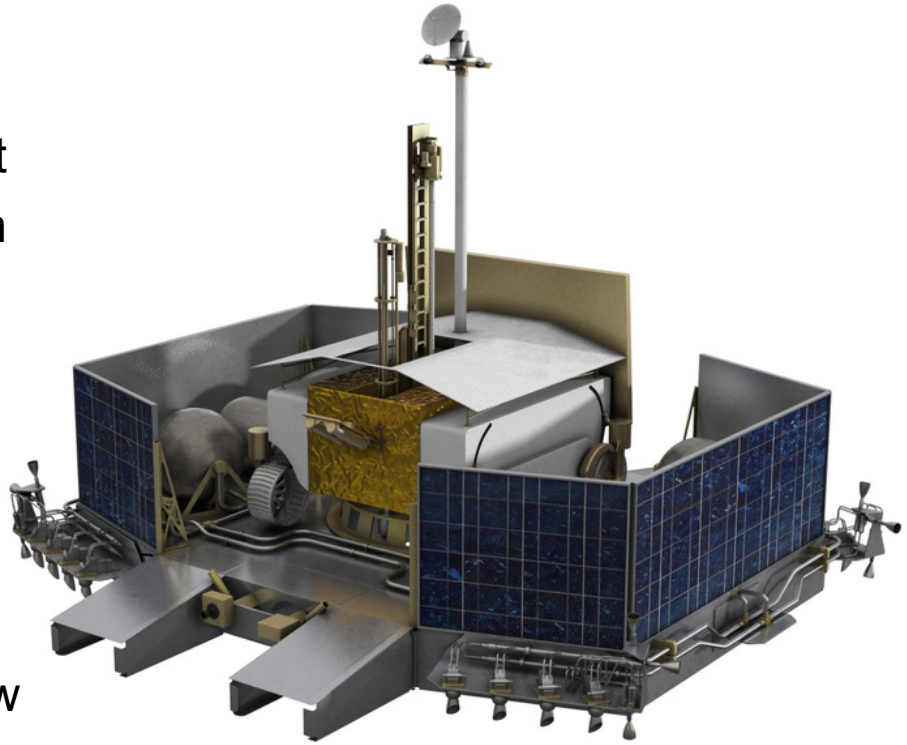
- $200M (plus launch & lander)
- NASA Class D / Category III project
- Risk-tolerant, streamlined approach

Partnerships

- NASA to provide rover and payload
- Detailed discussions and study with multiple partners for lander

Status

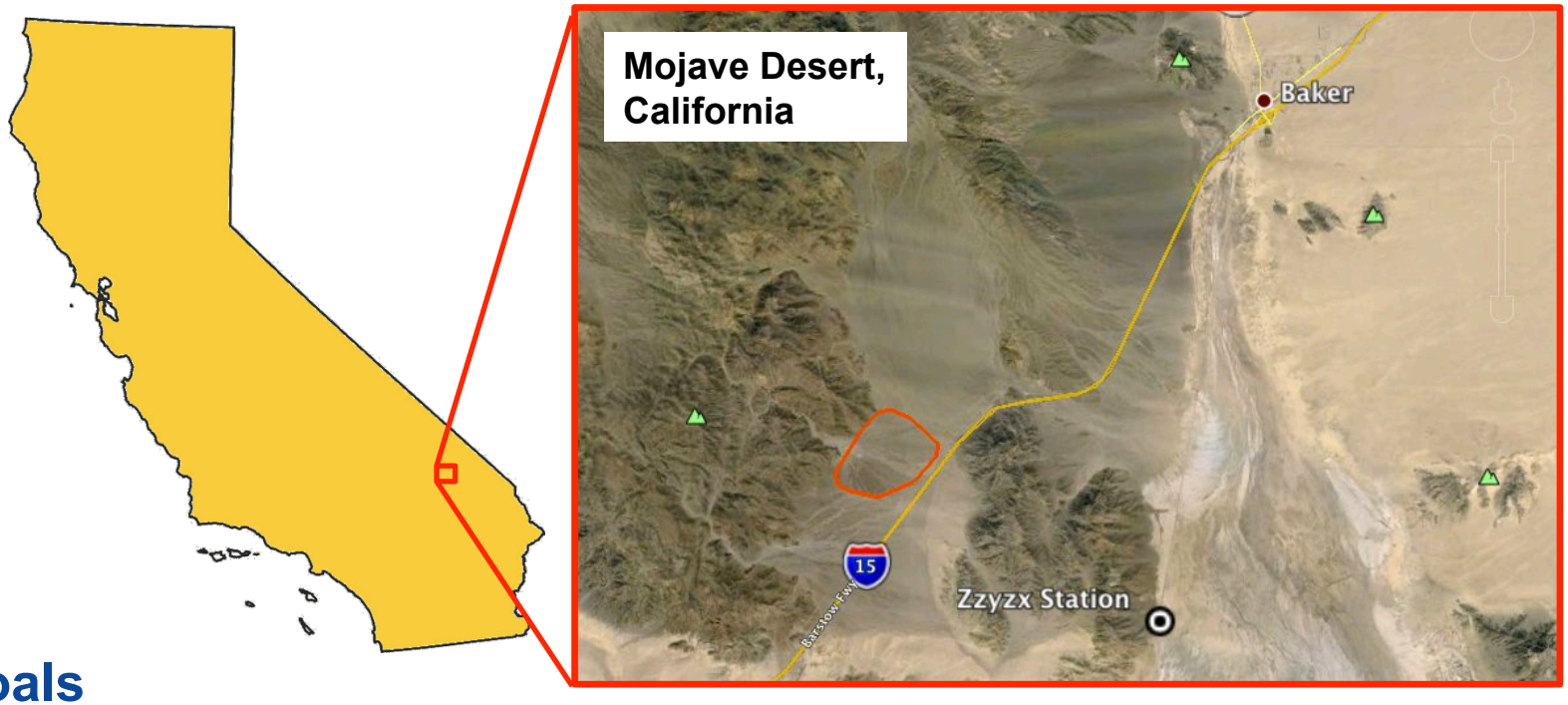
- Completed Mission Concept Review (MCR) in September 2013
- Rover Engineering Test Unit (ETU) completed in August 2015
- Payload Engineering Units in test
- Early 2020 launch date to the Moon



NASA lander concept with rover and ISRU payload

Resource Prospector Mission (2020)

Rover Field Test (October 2014)



Goals

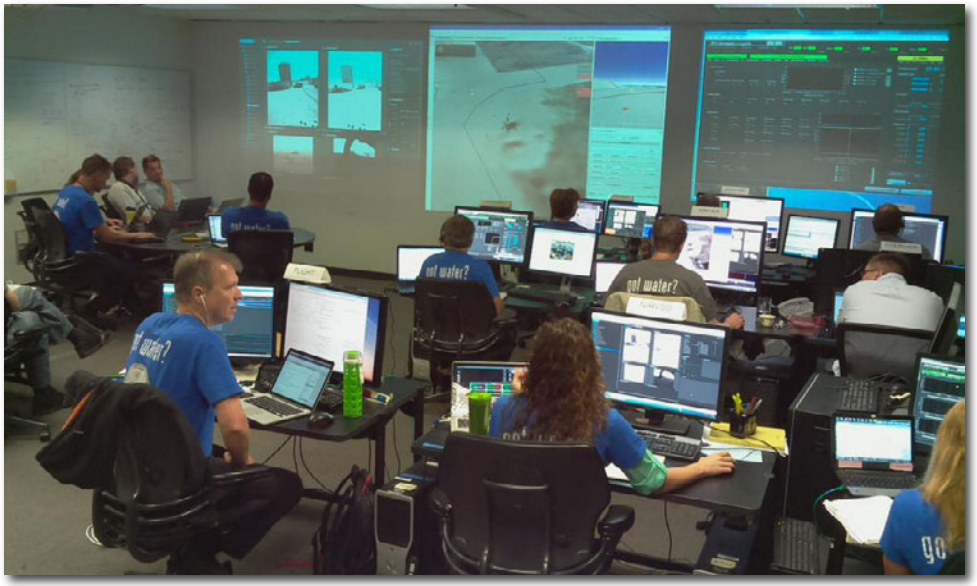
- **Prospecting**. Mature prospecting ops concept for NIRVSS and NSS instruments in a lunar analog field test
- **Real-Time Operations**. Improve support software by testing in a setting where the abundance / distribution of water is not known a priori
- **Science on Earth**. Understand the emplacement and retention of water in the Mojave Desert by mapping water distribution / variability

Real-time Operations (NASA Ames)

Rover and Instruments

Rover Field Test (October 2014)

Current Work



Questions?

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