

Interactive Exploration Robots

Human-robotic collaboration and interactions

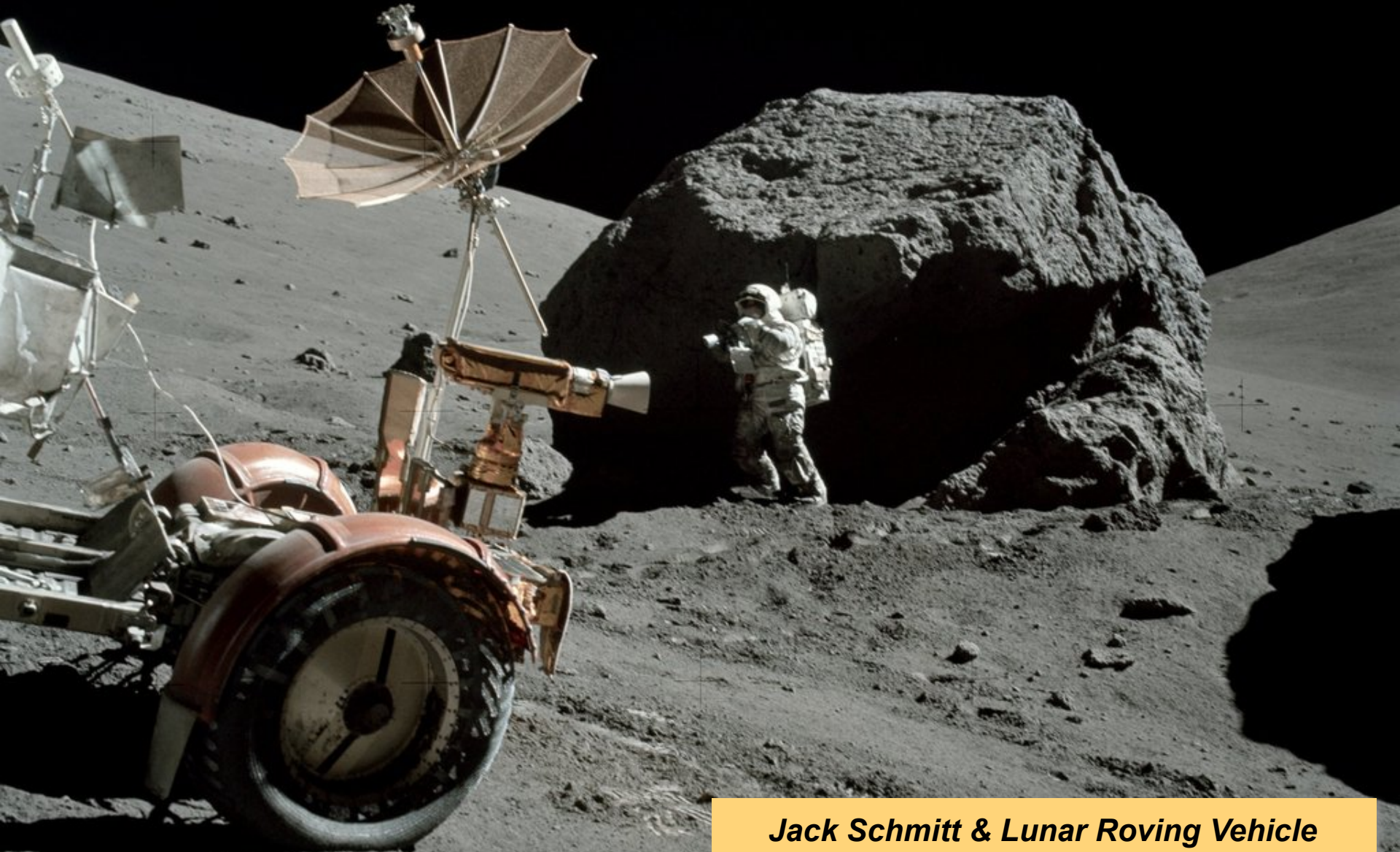


Terry Fong

Intelligent Robotics Group
NASA Ames Research Center
terry.fong@nasa.gov

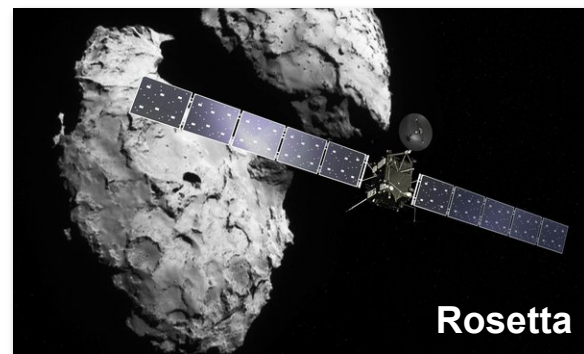
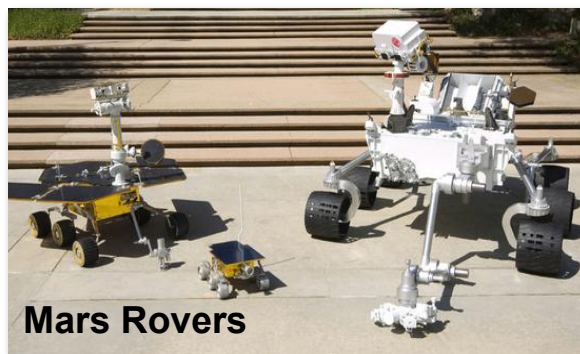
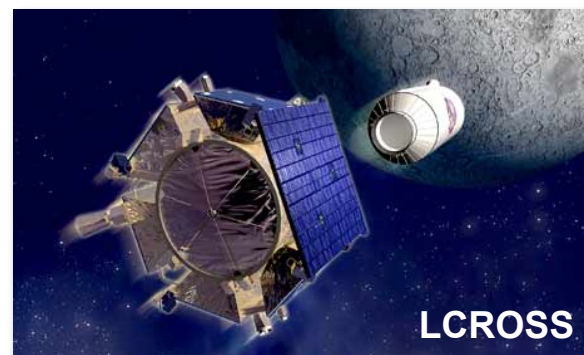
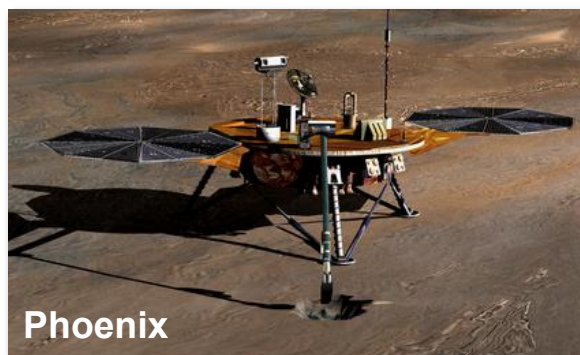
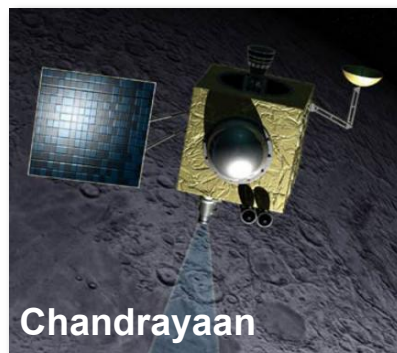
irg.arc.nasa.gov

Human Planetary Exploration



*Jack Schmitt & Lunar Roving Vehicle
Apollo 17 (December 1972)*

What's changed since Apollo?



Human-Robot Teams

Many forms of human-robot teaming

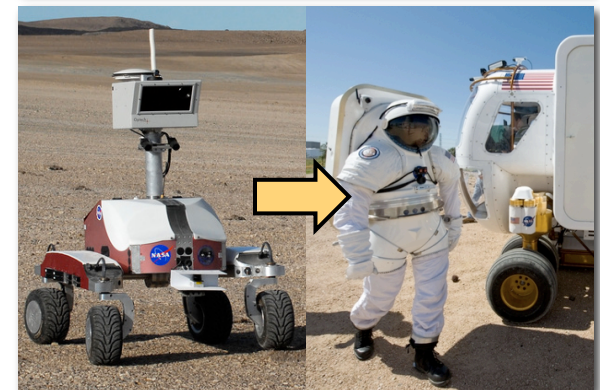
- “Robot as tool” is only **one** model
- Humans and robots do **not** need to be just co-located or closely coupled
- ▶ **Distributed teaming is also important**

Concurrent, interdependent operations

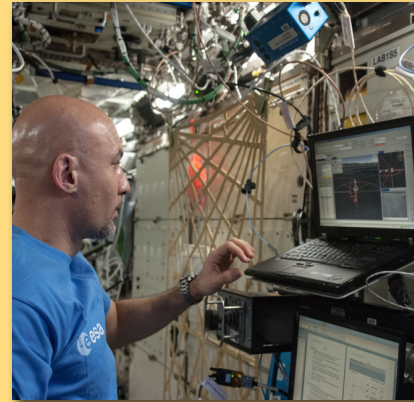
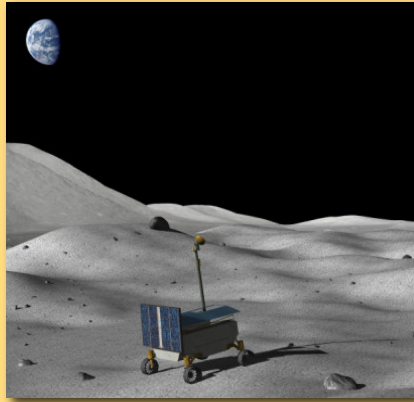
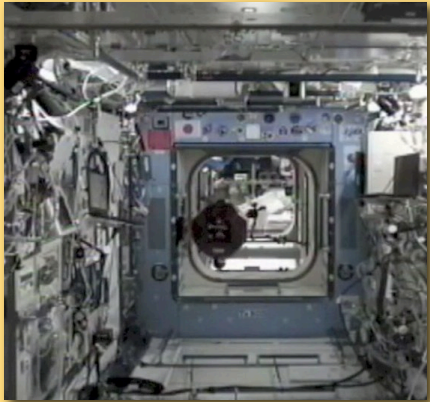
- Human-robot interaction is still **slow** and **mismatched** (compared to human teams)
- Easy for robots to slow down the human
- ▶ **Loosely-coupled teaming (in time and space) should also be employed**

Distributed teams

- Require **coordination** and **info exchange**
- Require understanding of (and planning for) each teammate’s **capabilities**



Interactive Exploration Robots



PART 1

Humans on Earth
Robot in space

PART 2

Humans on Earth
Robot on the Moon

PART 3

Humans in orbit
Robot on planet

PART 4

Real-time
telerobotics



A person is holding a red, octagonal satellite component. The component has a black label in the center with the word "SPHERES" written in white, a star symbol, and the text "MATT SELL" and "OWS". There are two white labels with barcodes on the top of the component. A small white label with "+Y" is visible near the bottom. The background is blurred, showing a person's face and a white wall.

Humans on Earth / Robot in space

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.



Space Station Robots



Space Station Remote Manipulator System (Canadarm2)



Space Station Robots



Special Purpose Dexterous Manipulator (“Dextre”)



Space Station Robots



Robonaut 2



SPHERES



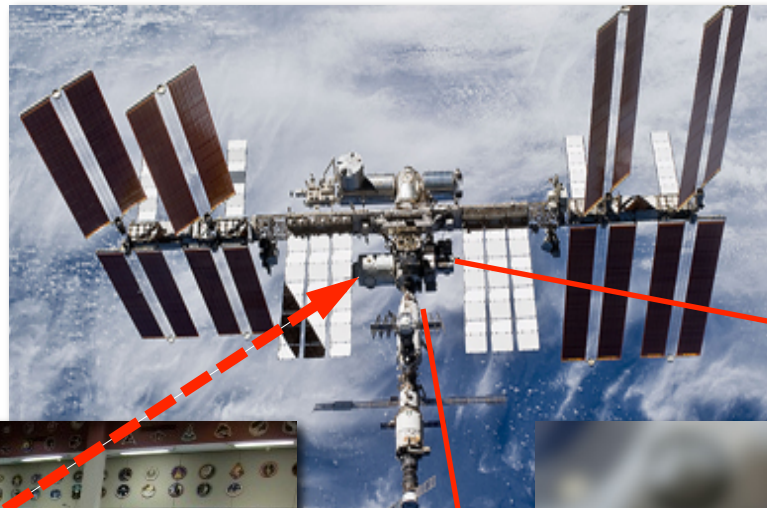
Astrobee (concept)



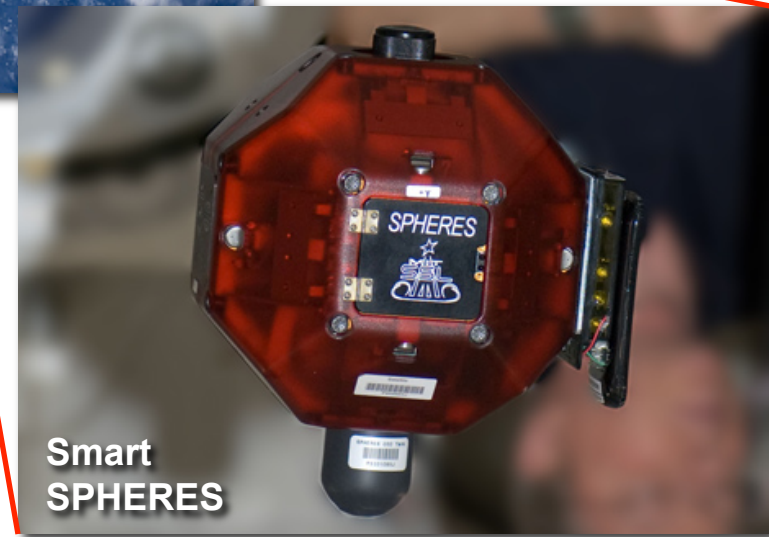
SPHERES



Smart SPHERES



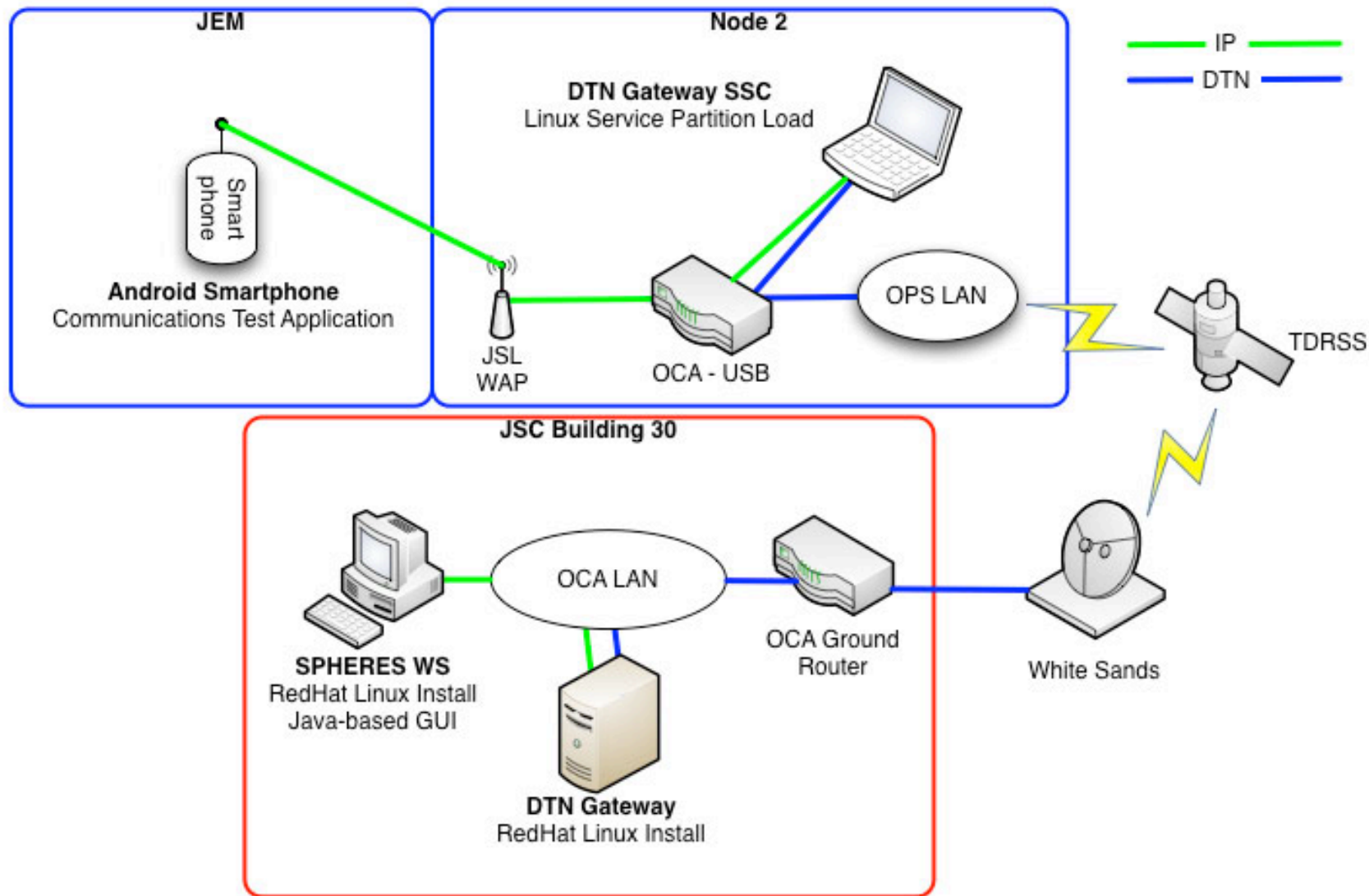
ISS Mission Control
(Houston)



Smart
SPHERES

T. Fong, M. Micire, et al. (2013) “Smart SPHERES: a telerobotic free-flyer for intravehicular activities in space”. Proc. of AIAA Space 2013 (Pasadena, CA).

Smart SPHERES Network Setup



Space Station Interior Survey (2012)



December 12, 2012
Crew: Kevin Ford, Expedition 33 Commander

2x speed



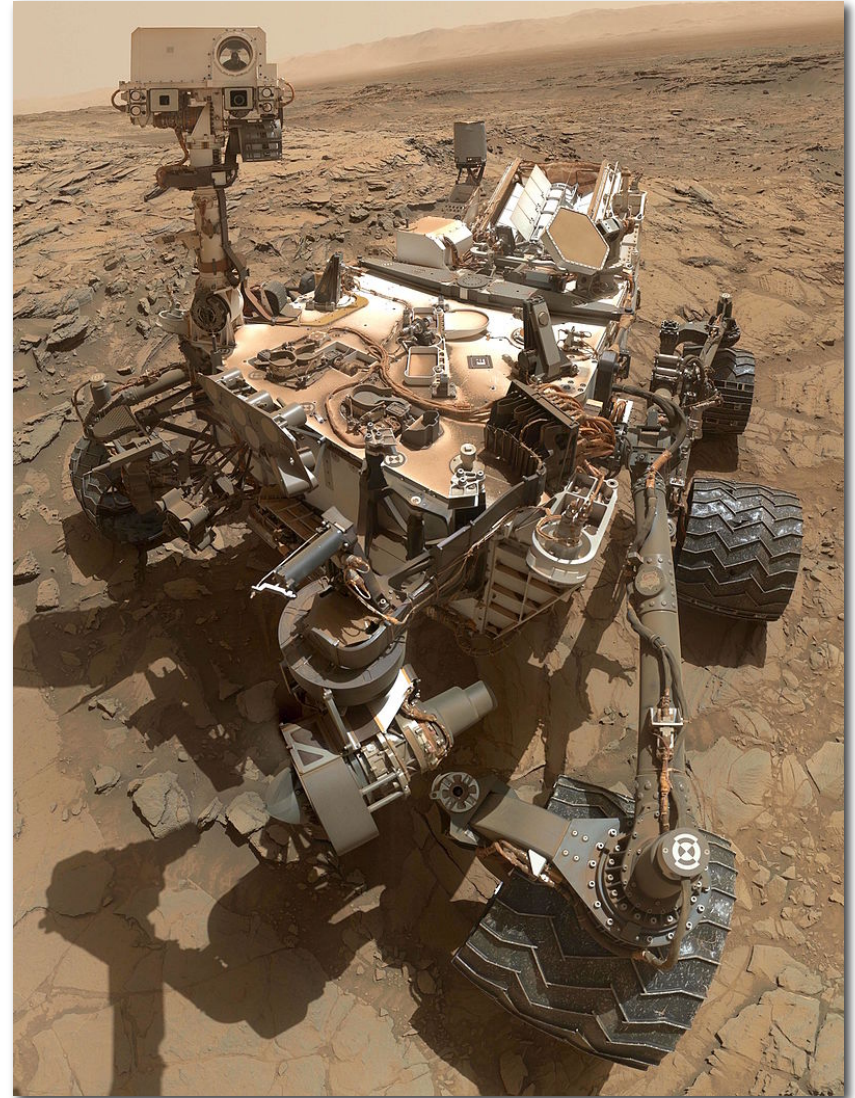


Humans on Earth / Robot on another world

Mars Rovers



**Mars Exploration Rover on Mars
(artist concept)**



Curiosity at "Big Sky"

Resource Prospector Mission

Mission

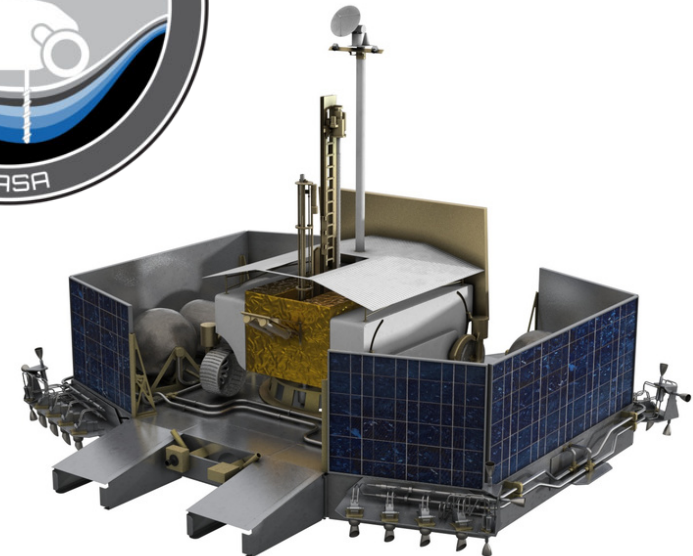
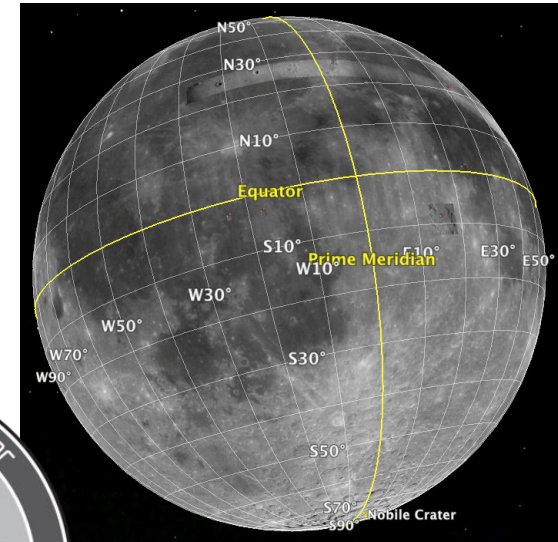
- Characterize the nature and distribution of **lunar polar volatiles**
- Demonstrate **in-situ resource utilization**: process lunar regolith

Key Points

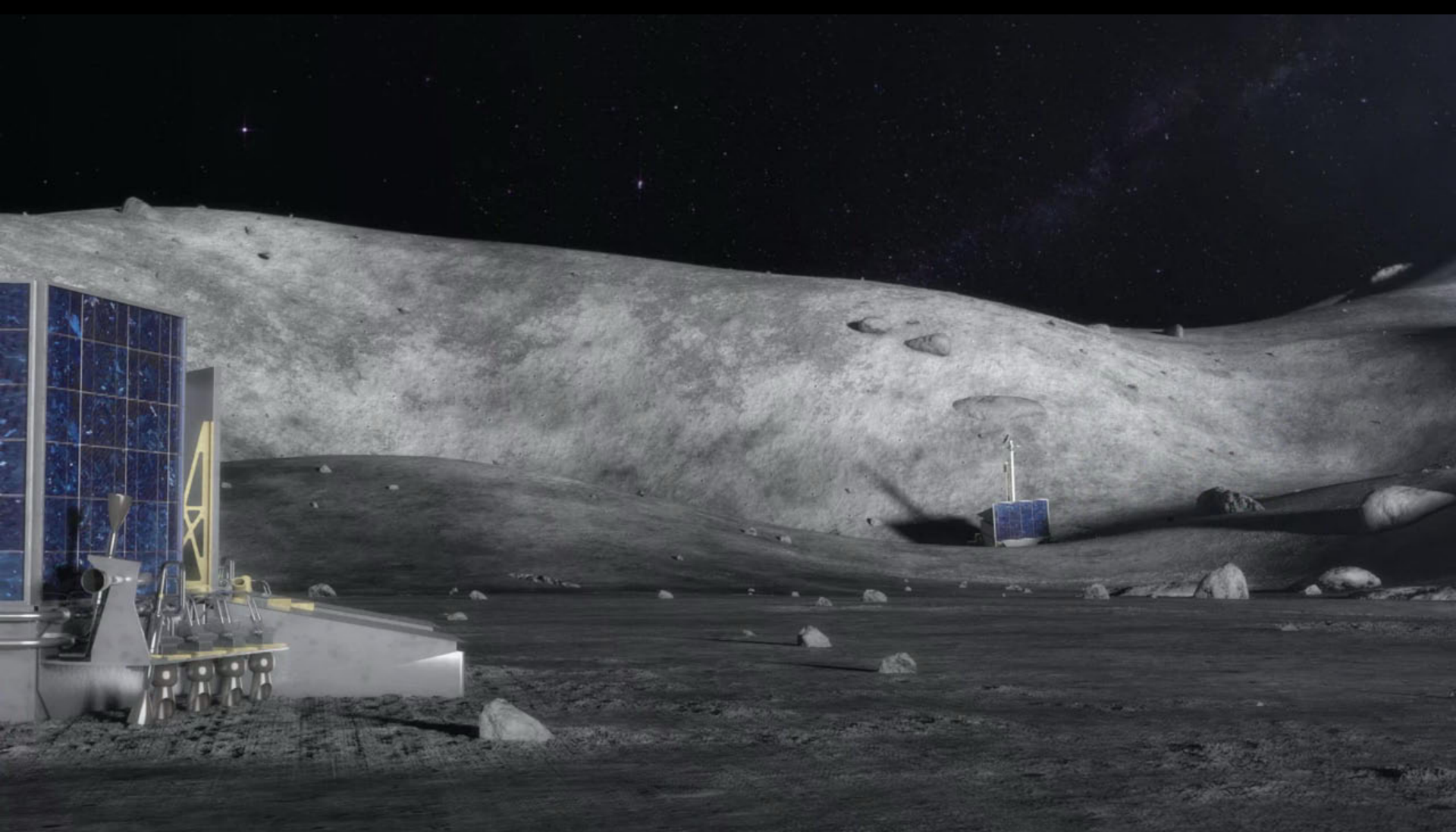
- Class D / Category 3 Mission
- Launch: ~2021
- Duration: 6-14 Earth days
- Direct-to-Earth communications
- **Real-time subsurface prospecting**

Rover

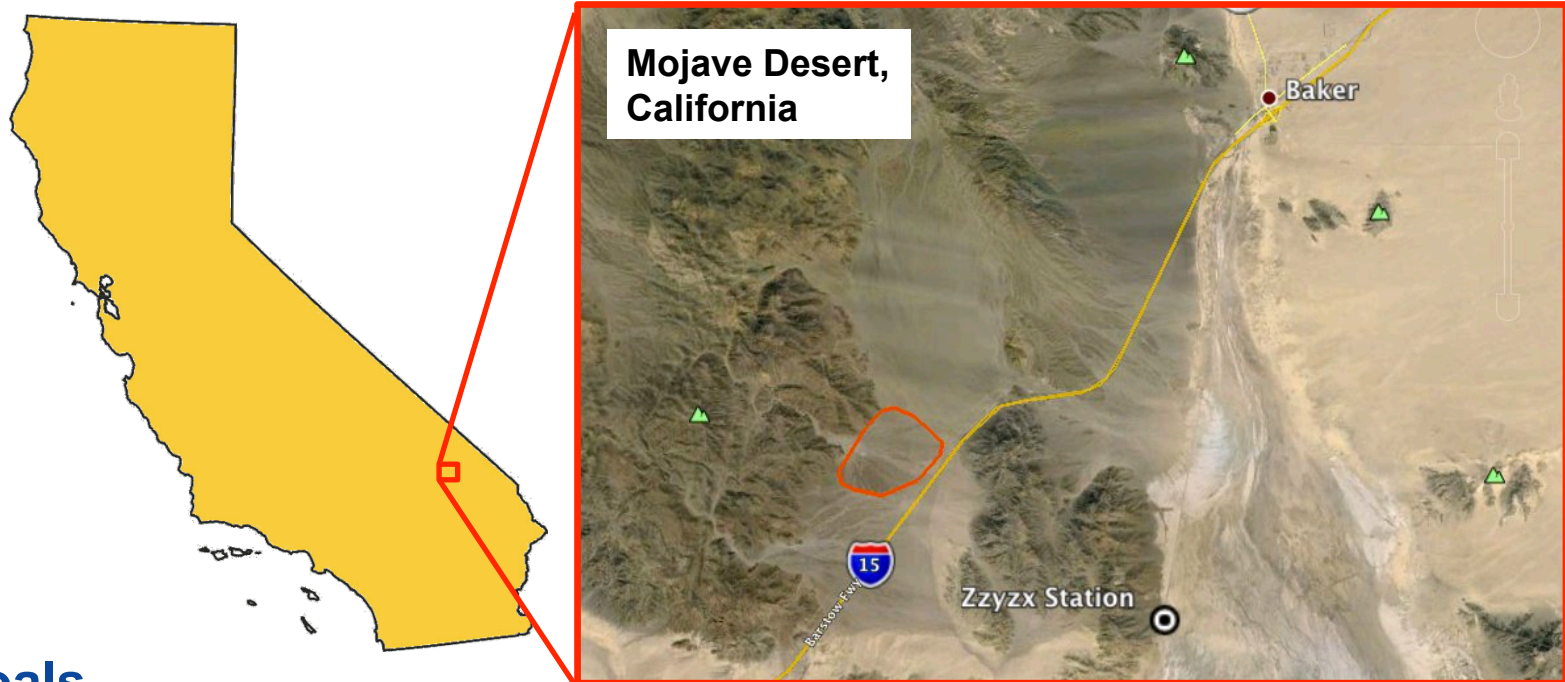
- Mass: 300 kg (including payload)
- Size: 1.4m x 1.4m x 2m
- Max speed: **10 cm/s**
- Speed made good: **0.5 cm/s**



RP Mission Animation



Real-time Prospecting Field Test (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

Prospecting Rover and Instruments



Sample Evaluation
Near Infrared Volatiles
Spectrometer System

Resource Localization
Neutron Spectrometer
System



Real-time Operations (NASA Ames)



Mojave Volatiles Prospector

Mojave Desert, California

October 2014



Rover Operator Interface (VERVE)

The screenshot displays the VERVE for RAPID software interface, which is used for controlling a rover. The main window shows a 3D simulation of a rover on a planetary surface, with a path and various data points visible. The interface is divided into several panels:

- Plans on the rover:** A table listing plans with columns for Name, ID, Version, and Duration. The table contains the following data:

Name	ID	Version	Duration
MVP_2151_A_P21_ASOC	MVP2151_A_PLAN	A	02:2
Checkpoint Basic	MVP2151_B_PLAN	B	00:5
MVP_2168_A_P21_ASOC	MVP2168_A_PLAN	A	01:4
- Plans on the local file system:** A table listing plans with columns for Name, ID, Version, and Duration. The table contains the following data:

Name	ID	Version	Duration
MVP_2150_A_P21_AS1	MVP2150_A_PLAN	A	00:52:06
MVP_2151_A_P21_AS1	MVP2151_A_PLAN	A	02:38:03
Checkpoint Basic	MVP2151_B_PLAN	B	00:08:38
Checkpoint Traverse	MVP2152_A_PLAN	A	00:09:08
MVP_2168_A_P21_AS1	MVP2168_A_PLAN	A	00:27:25
- Run Plan:** A panel showing the details of the selected plan (MVP_2168_A_P21_ASOC). It includes fields for Name, ID, Version, Description (Optional raster), Est Duration (0:14:38), and State (Running). There are buttons for Run, Stop, and Refresh.
- Process Manager:** A panel showing the status of various processes. The table contains the following data:

Duration	Command	ID
00:01:30	Drive	MVP2168_A_STN01_0_RP
00:00:20	Drive	MVP2168_A_STN01_0_RP
00:01:30	Drive	MVP2168_A_STN01_0_RP
00:00:03	Drive	MVP2168_A_STN01_0_RP
00:01:30	Drive	MVP2168_A_STN01_0_RP
- Log Monitor:** A panel showing the log output of the KRx2_Controller. The log contains the following data:

```
4445 [ CTRL_TRAPEZOID, POS_ABS, -77.967deg, 177.617deg/s, 332.473deg/(s^2) ]
4446 [ CTRL_TRAPEZOID, POS_ABS, -24.935deg, 98.583deg/s, 204.766deg/(s^2) ]
4447 [ CTRL_TRAPEZOID, POS_ABS, 76.495deg, 315.553deg/s, 348.095deg/(s^2) ]
4448 @sving_profiles:
4449 [ CTRL_TRAPEZOID, POS_REL, +678.344deg, 25.02deg/s, 658.901deg/(s^2) ]
4450 [ CTRL_TRAPEZOID, POS_REL, 286.407deg, 34.991deg/s, 374.791deg/(s^2) ]
4451 [ CTRL_TRAPEZOID, POS_REL, -473.445deg, 34.775deg/s, 652.451deg/(s^2) ]
4452 [ CTRL_TRAPEZOID, POS_REL, 278.729deg, 14.579deg/s, 383.929deg/(s^2) ]
```
- Access Control View:** A panel showing the control status for the KRx2 rover. It includes buttons for Request Control, Release Control, Grab Control, and Transfer Control. It also shows the current controller (all1andee) and the current pose (RAP...).
- Image Sensor View:** Two panels showing the current image from the KRx2 rover. The top panel shows the image from the GroundCam (Image #2028) and the bottom panel shows the image from the HazCamLeft (Image #18660).



Science Operations Interface (xGDS)

xGDS Exploration Ground Data Systems
NASA MVP

Intelligent Robotics Group
National Aeronautics and Space Administration

Home Maps Console Log Plans Instruments Images Notebook System Status Search Beta Logout

List Plans Manage Schedule Planner Help Edit MVP_2163_B_PZ1_ASOC

Navigate Edit Stations Add Stations Auto until Google Earth Cut Copy Paste Delete Reverse Undo Redo Save As Save

Meta **Sequence** Layers Tools Links

Stations/Segments

Start	00:00
63 meters	+10:52
1	10:52
97 meters	+16:26
2	27:18
103 meters	+17:29
3	44:48
119 meters	+20:07
4	01:09:56
43 meters	+07:34
5	01:17:30
105 meters	+17:49
6	01:35:19
41 meters	+07:05
End	01:42:25

Station Start

Station Properties

Station Properties

- GroundCam_Start 00:00
- Nirvss_Start 00:00
- Nss_Start 00:00

Add commands

Name

Notes

Id MVP2163_B_STN00

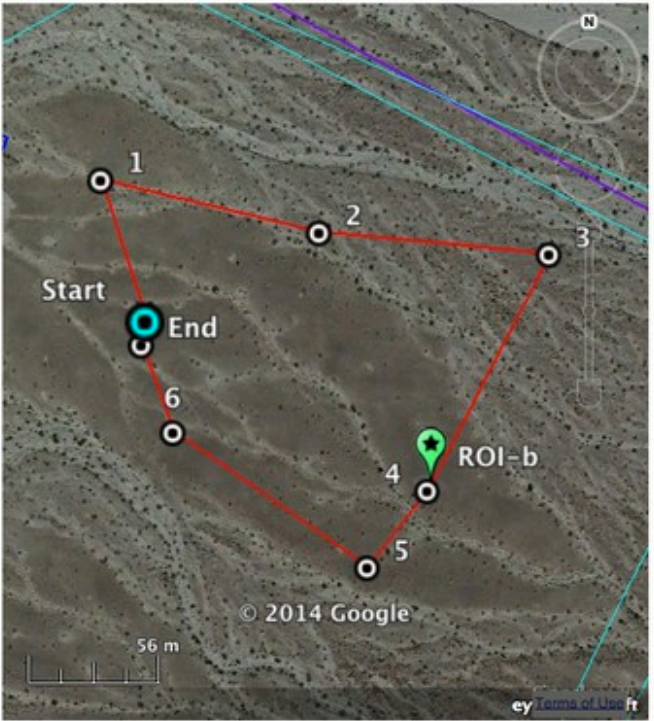
Coordinate System Lng, Lat

Lon, Lat -116.1902567, 35.1807235

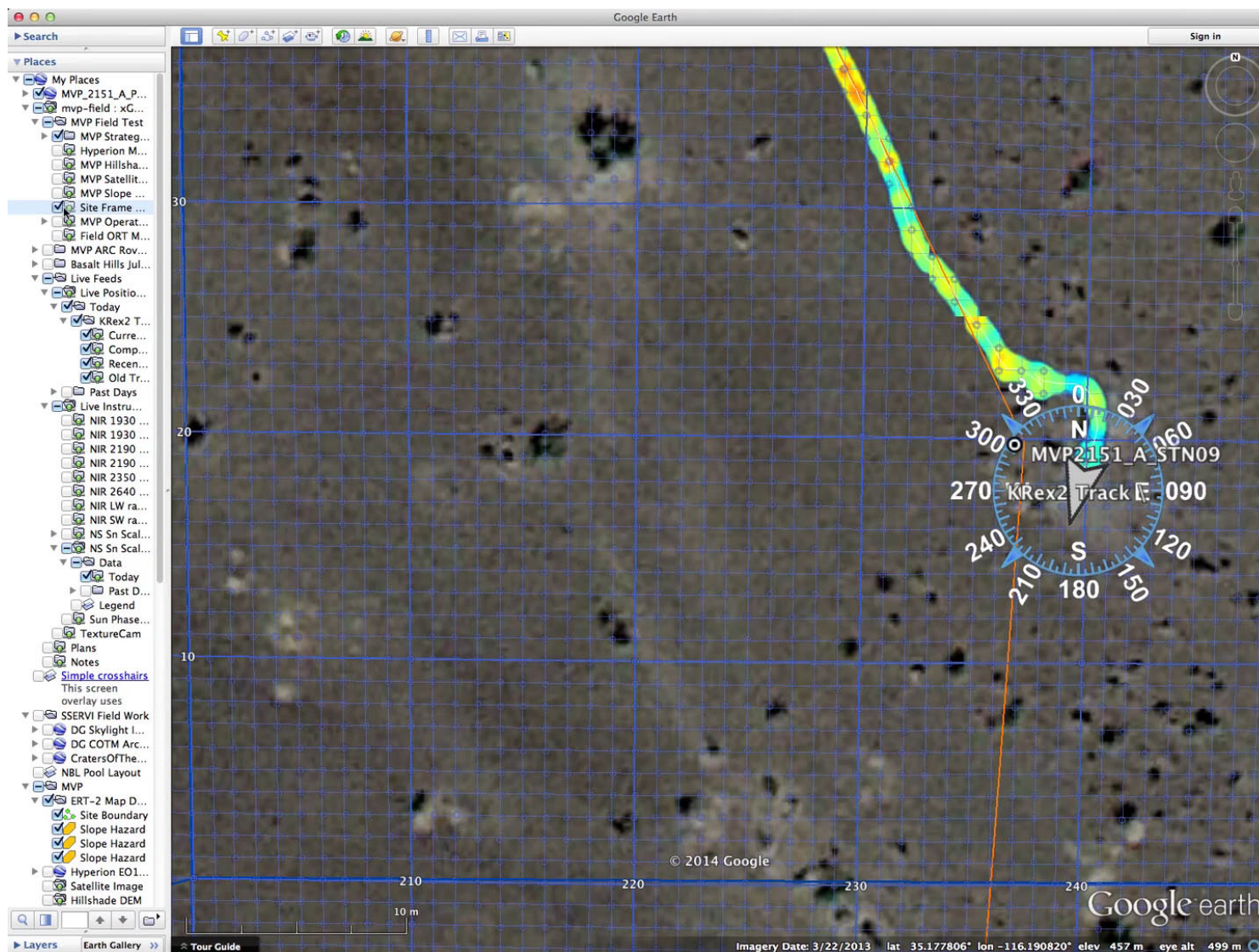
Lon, Lat

tolerance 0.6

isDirectional If true, the rover should try to arrive at the station with its chassis oriented to the



Exploration Ground Data System (xGDS)





Humans in space / Robot on the ground



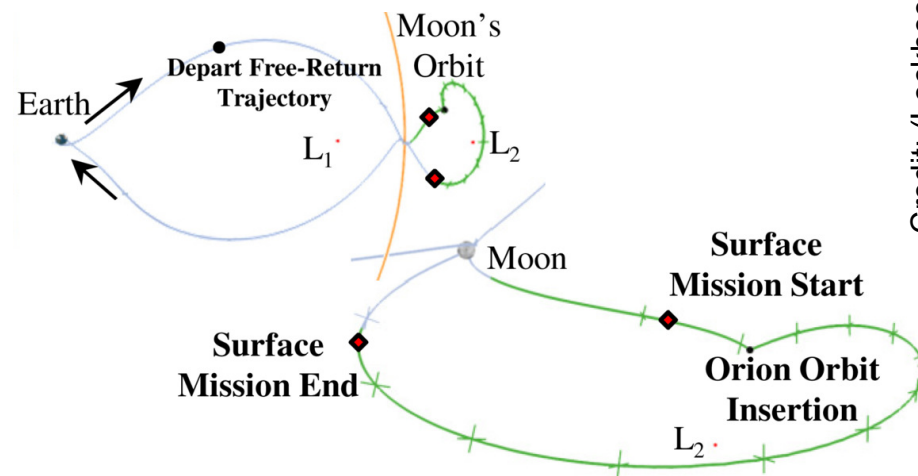
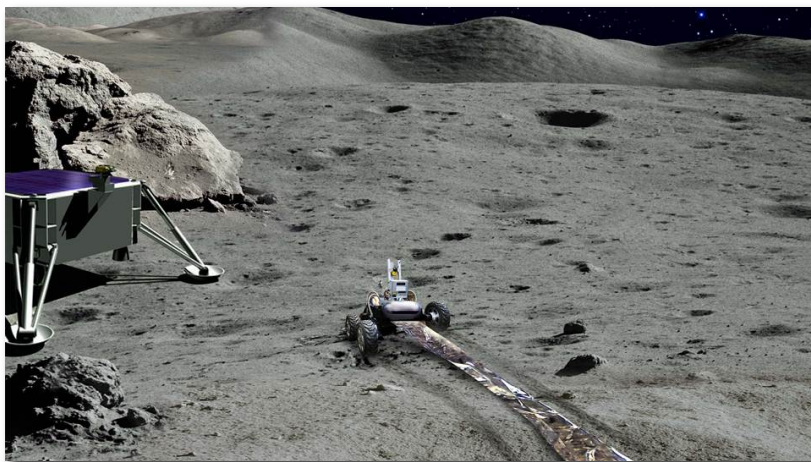
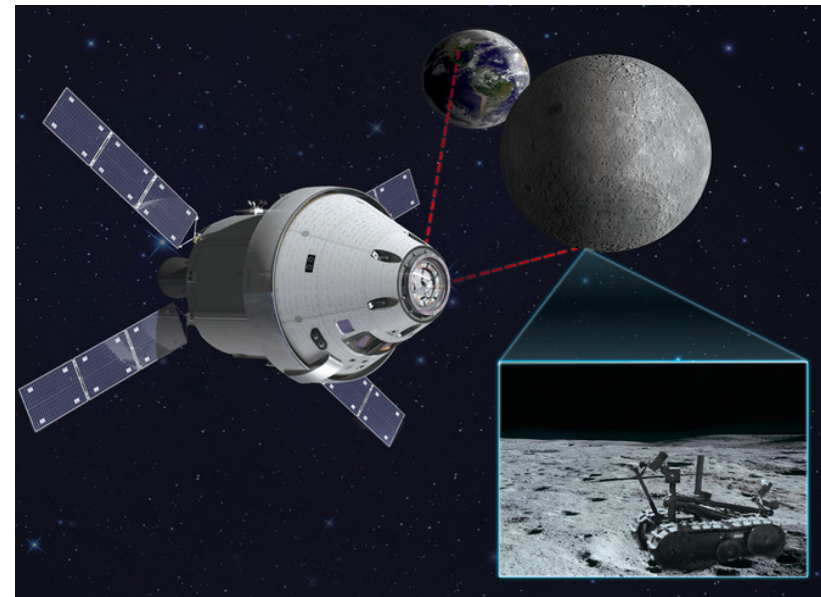
“Fastnet” Lunar Libration Point Mission

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

ISS Expedition 36

Pre-Mission Planning



Ground teams plan out telescope deployment and initial rover traverses.

Surveying



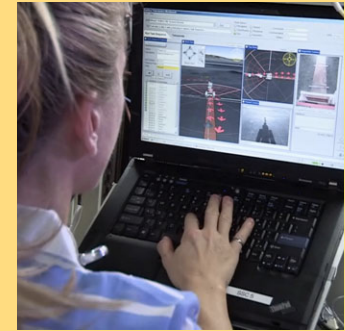
Crew gathers information needed to finalize the telescope deployment plan.

Telescope Deployment



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

Telescope Inspection



Crew inspects and documents the deployed telescope for possible damage.

Chris Cassidy

Luca Parmitano

Karen Nyberg

Spring 2013

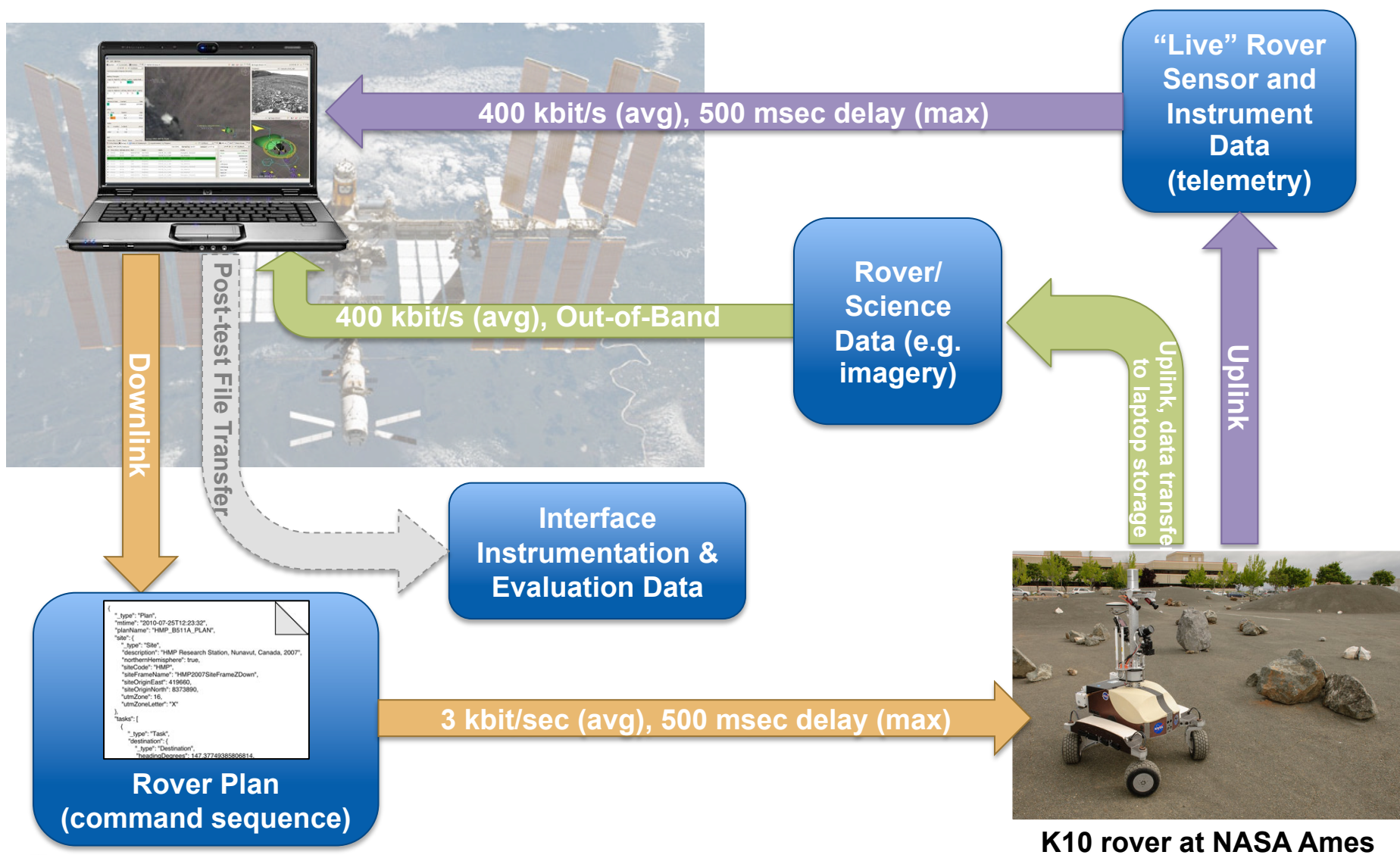
17 June 2013

26 July 2013

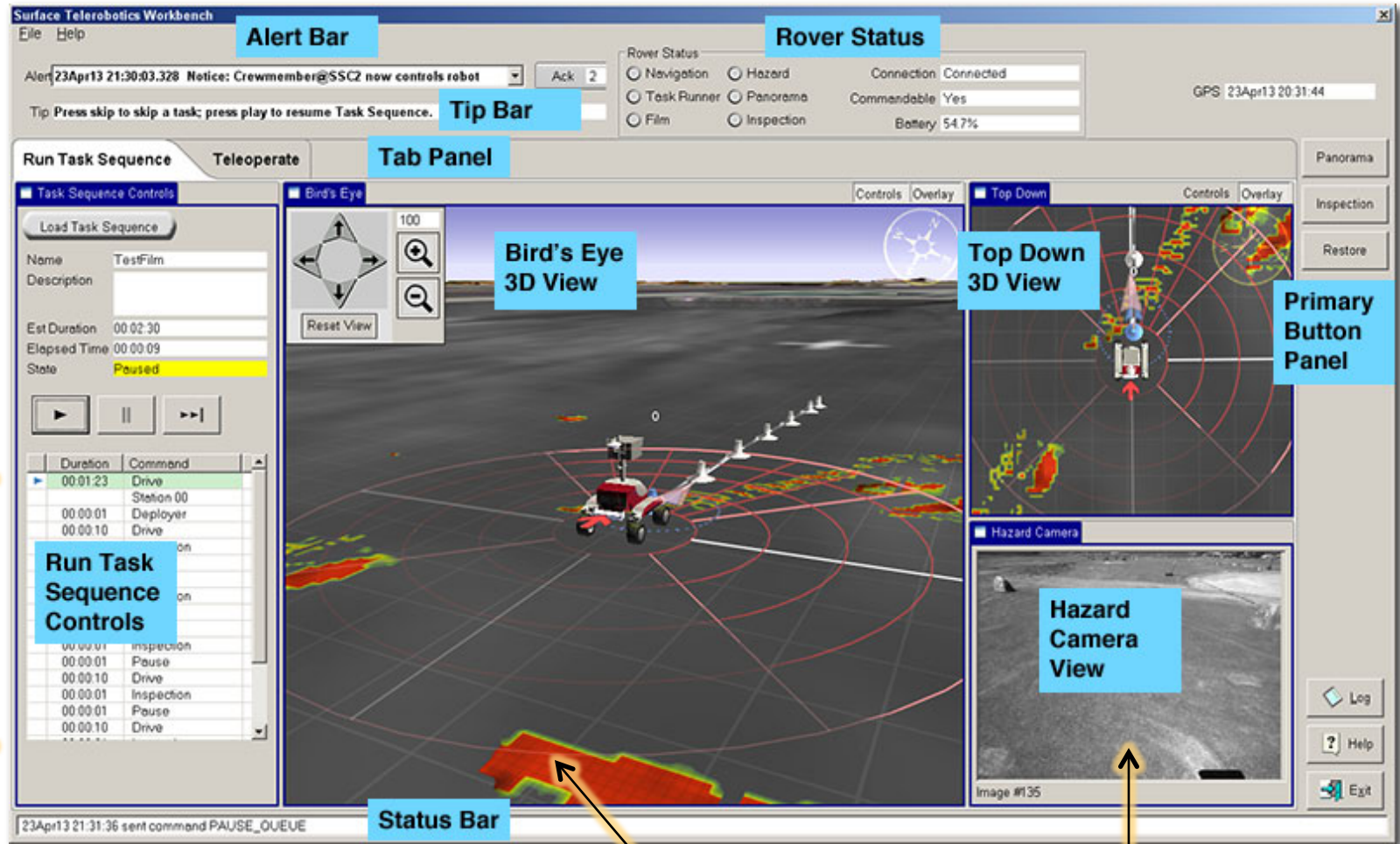
20 August 2013



ISS Test Setup



Robot Interface (Supervisory Control)



Task Sequence

Run Task Sequence Controls

Bird's Eye 3D View

Top Down 3D View

Primary Button Panel

Hazard Camera View

Status Bar

Terrain hazards

Rover camera display



Crew-controlled Telerobotics (2013)

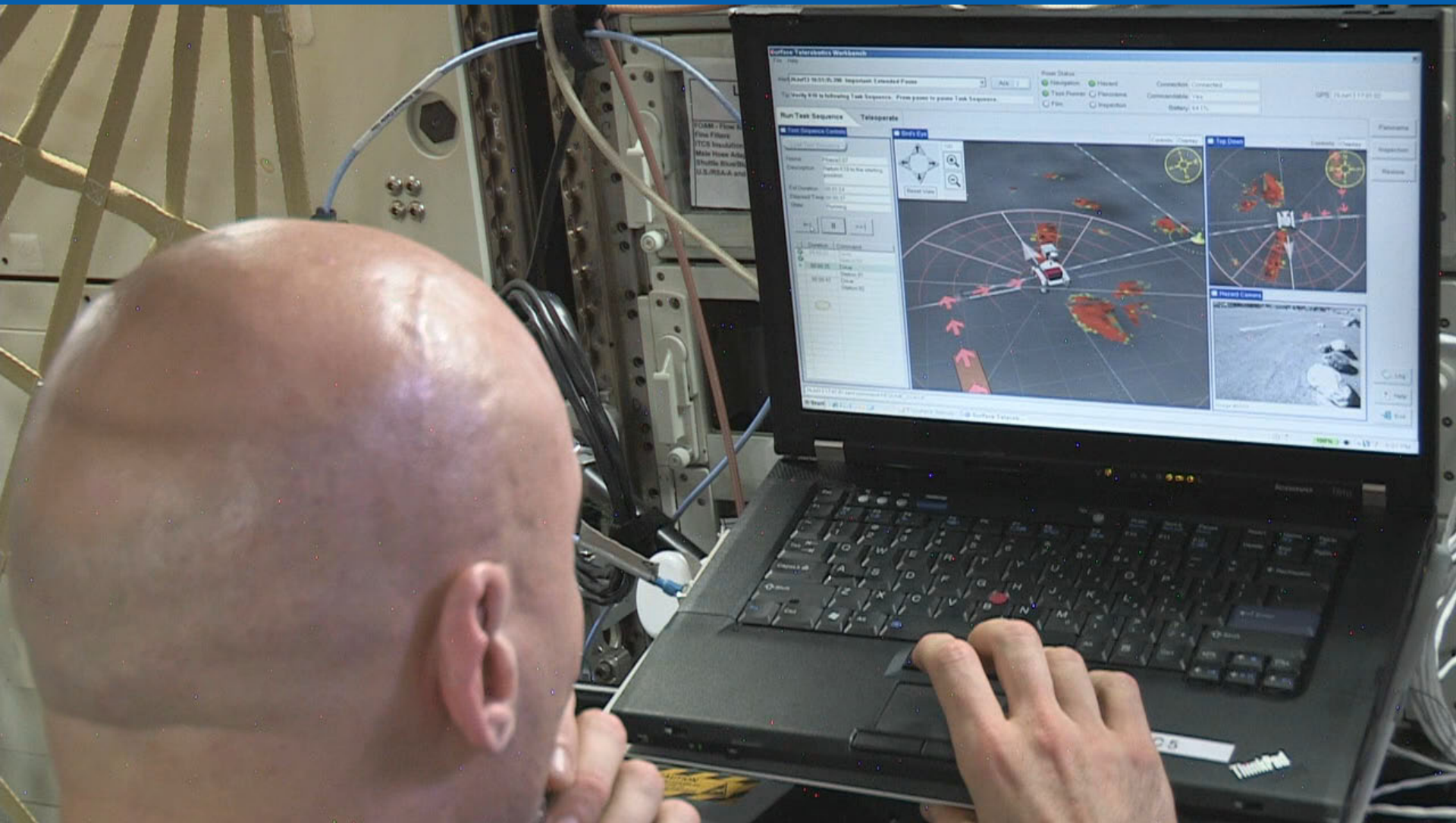
IDG



Mountain View, California



Crew-controlled Telerobotics (2013)



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)



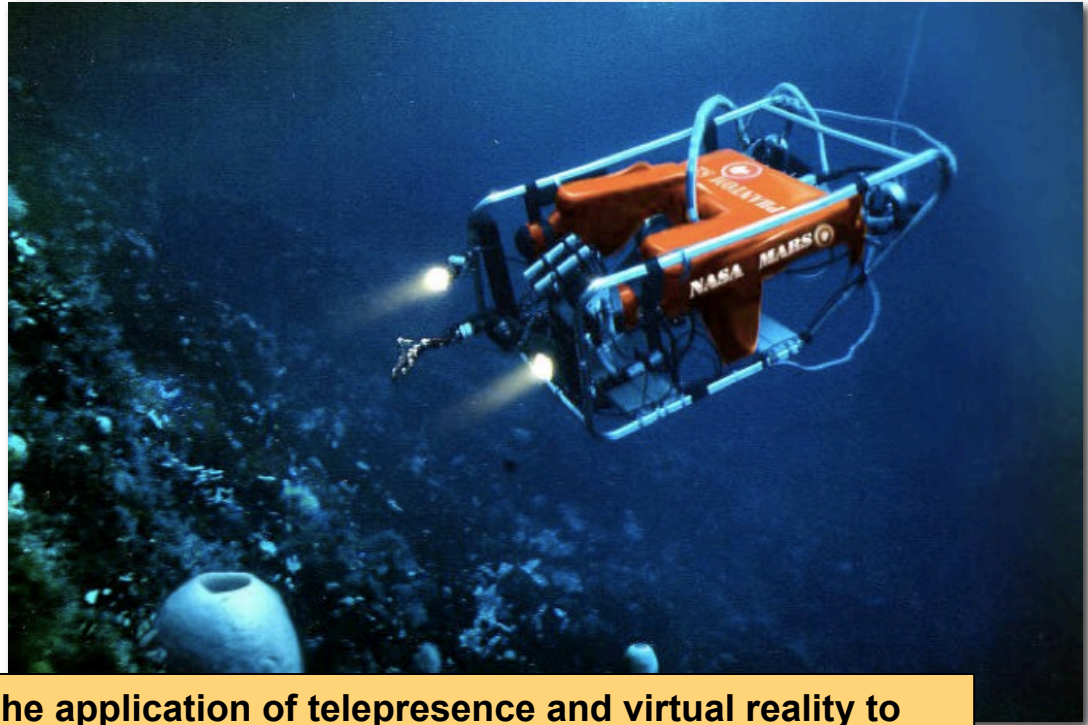
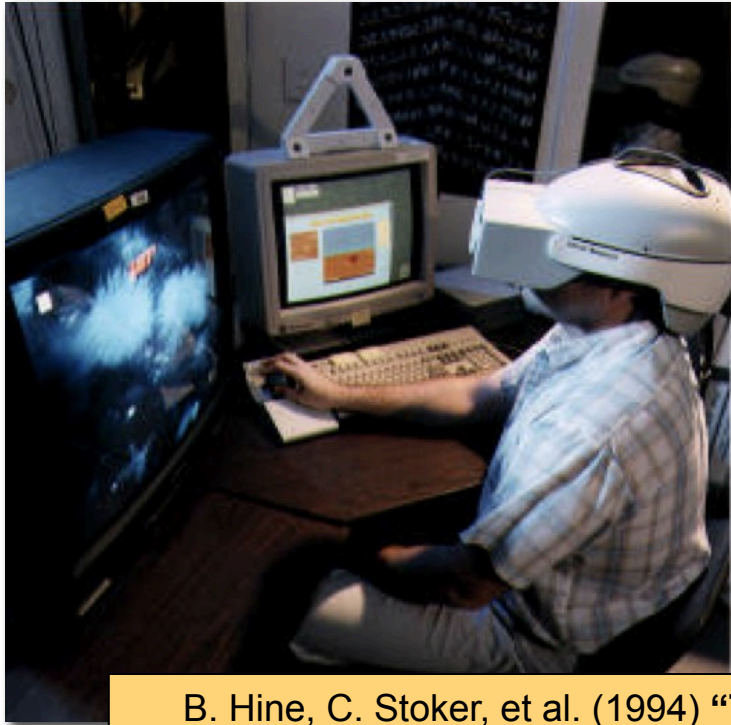
A person is shown from the side, wearing a white VR headset. They are looking at a large monitor. The monitor displays a 3D model of a structure, possibly a robot or a piece of machinery, with a red '118' label on it. The scene is dimly lit, with the primary light source being the monitor. The text 'Virtual Research' is visible on the side of the VR headset.

Real-time Exploration Telerobotics

Real-time Exploration Telerobotics

Telepresence Remotely Operated Vehicle (TROV)

- Benthic ecology survey of McMurdo Sound (Nov-Dec 1993)
- Remote operations from NASA Ames via satellite (832 kbps downlink)
- Virtual environment + telepresence video (head tracked stereo display)



B. Hine, C. Stoker, et al. (1994) **“The application of telepresence and virtual reality to subsea exploration”**. Proc. of IARP workshop on mobile robots for subsea environments.

Telepresence ROV (1993)



Real-time Exploration Telerobotics

Marsokhod at Kilauea

- Geologic mapping of Southwest Desert at Kilauea (Feb 1995)
- Remote operations from NASA Ames via satellite (T1 link)
- Virtual environment + telepresence video (stereo display)



C. Stoker and B. Hine. (1996) **“Telepresence control of mobile robots – Kilauea Marsokhod experiment”**. Proc. of AIAA 34th Aerospace Sciences Meeting.

Marsokhod at Kilauea (1995)



Lessons from TROV & Marsokhod

Latency

- Latency is **only one factor** for remote exploration: type of science, instruments & data, cost, risk, staffing, robot capabilities, etc.
- Remote (robotic) exploration is not dominated by control latency. **Data collection** (with instruments), **analysis** (many steps), and **decision making** (strategic and tactical planning) are all far more significant.

Spatial displays

- 3D visualizations is essential for most field studies
- **Head-mounted** and **stereo video** displays are **pseudo 3D**, not true 3D, which leads to many issues (accommodation errors, etc)
- High levels of **presence** can be achieved even with limited data.

Real-time telerobotics

- Telepresence (immersive real-time presence) is **not a panacea**
- **Manual control** is imprecise and highly coupled to human performance (skills, experience, training)
- **Minimizing risk** is often (far more) important than efficiency.



Questions?



Intelligent Robotics Group
Intelligent Systems Division
NASA Ames Research Center

irg.arc.nasa.gov

