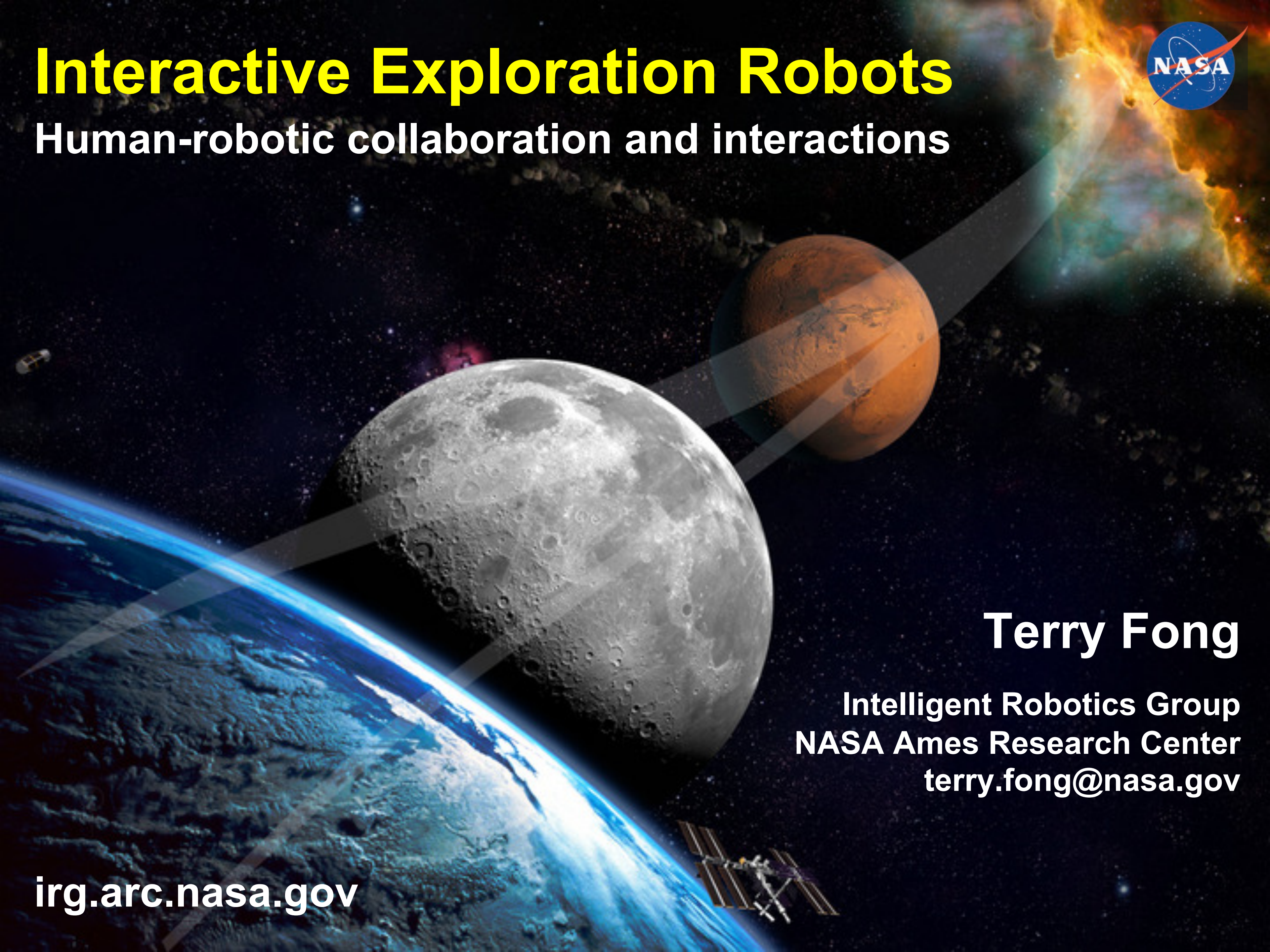
Interactive Exploration Robots

Human-robotic collaboration and interactions



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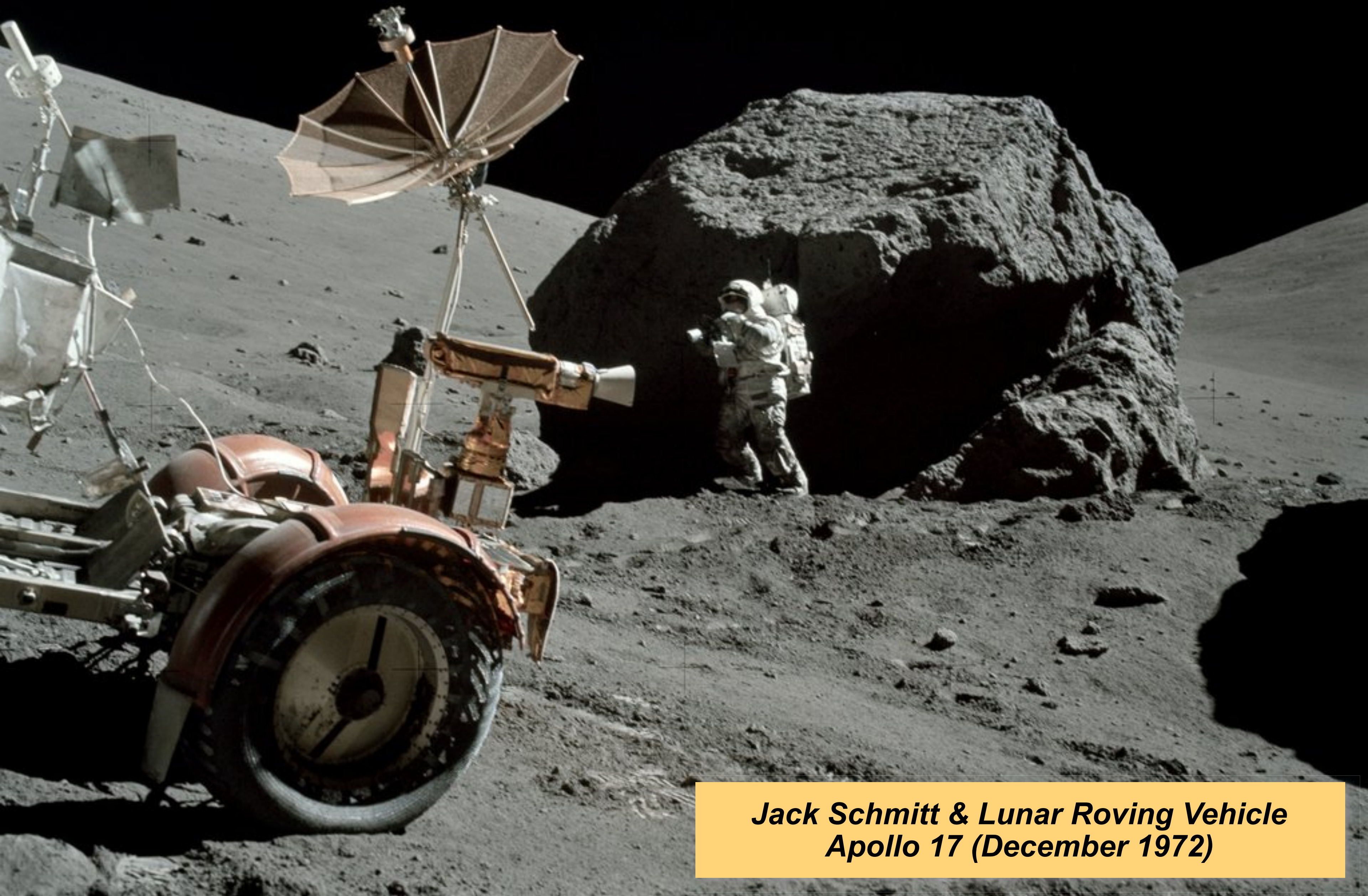
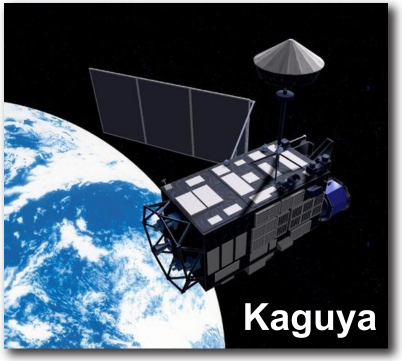
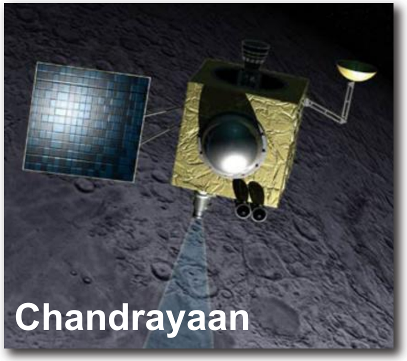
Human Planetary Exploration

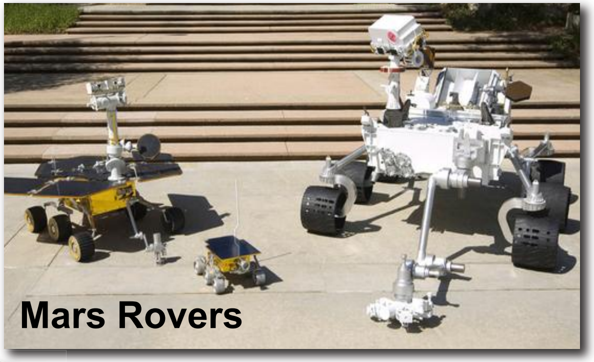


Jack Schmitt & Lunar Roving Vehicle
Apollo 17 (December 1972)

What’s changed since Apollo?







Human-Robot Teams

Many forms of human-robot teaming

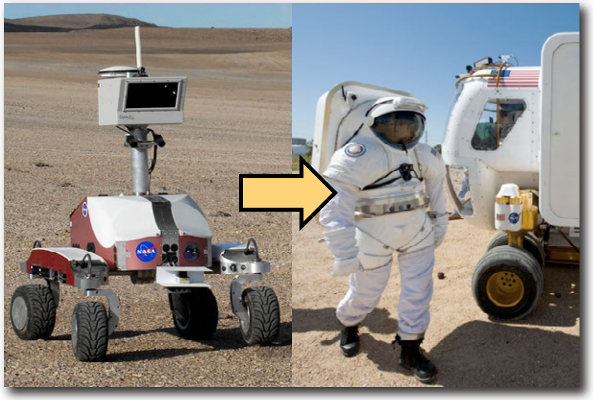
- "Robot as tool" is only **one** model
- Humans and robots do **not** need to be just co-located or closely coupled
- ▸ **Distributed teaming is also important**

Concurrent, interdependent operations

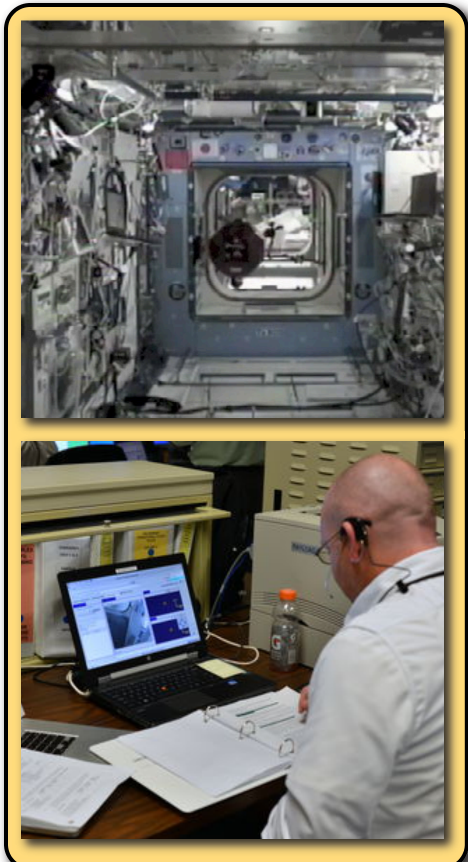
- Human-robot interaction is still **slow** and **mismatched** (compared to human teams)
- Easy for robots to slow down the human
- ▸ **Loosely-coupled teaming (in time and space) should also be employed**

Distributed teams

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



Interactive Exploration Robots



PART 1

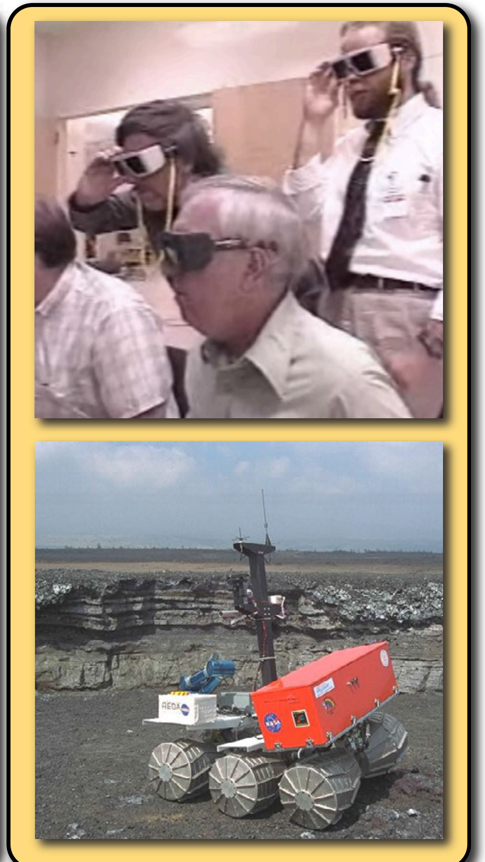
Humans on Earth
Robot in space

PART 2

Humans on Earth
Robot on the Moon

PART 3

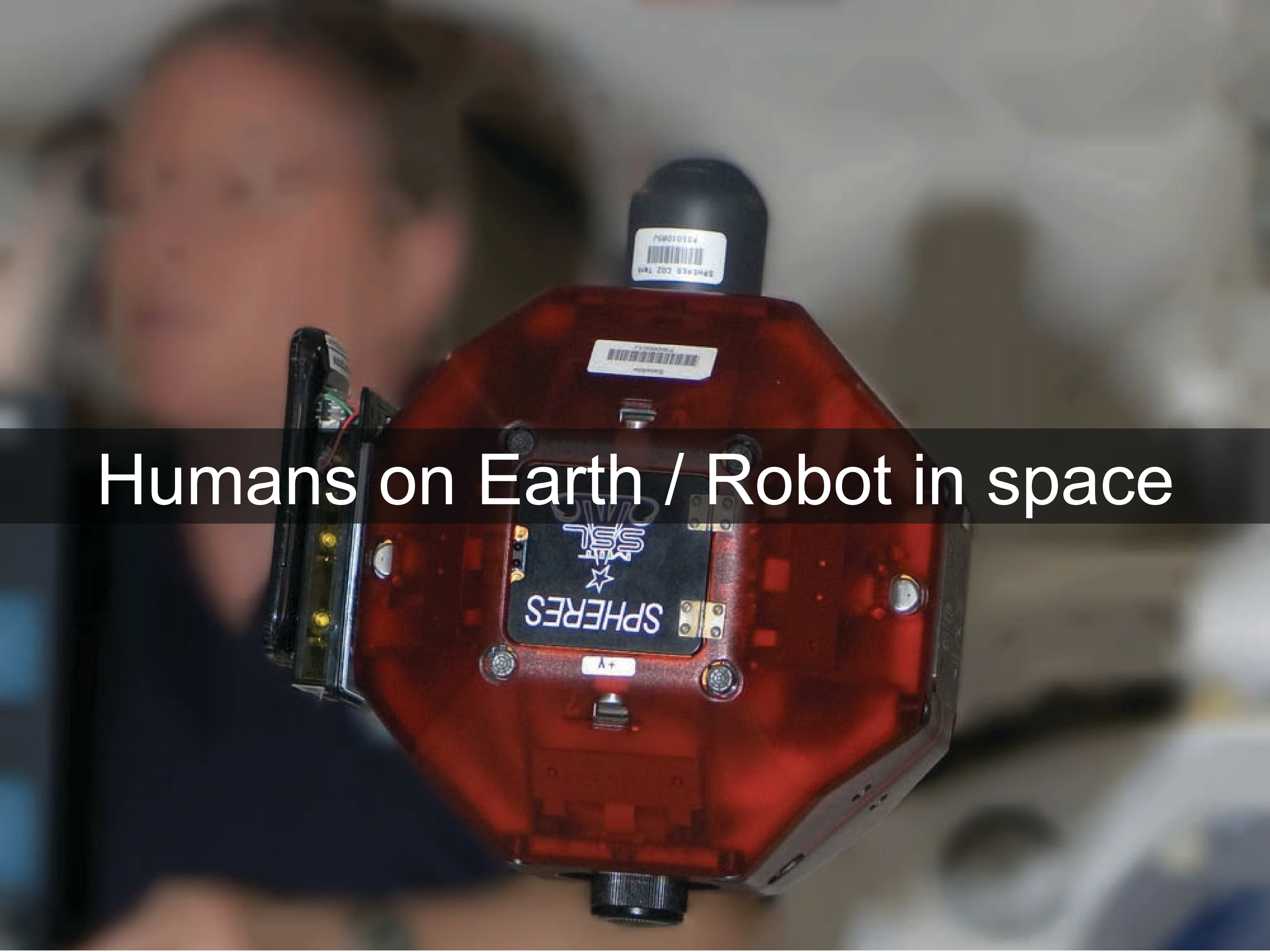
Humans in orbit
Robot on planet



PART 4

Real-time
telerobotics

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.

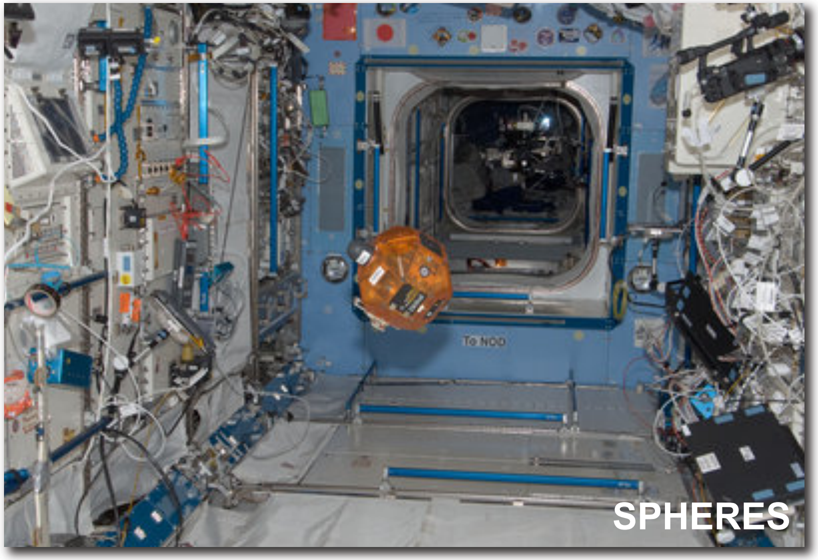
Space Station Robots

Space Station Remote Manipulator System (Canadarm2)

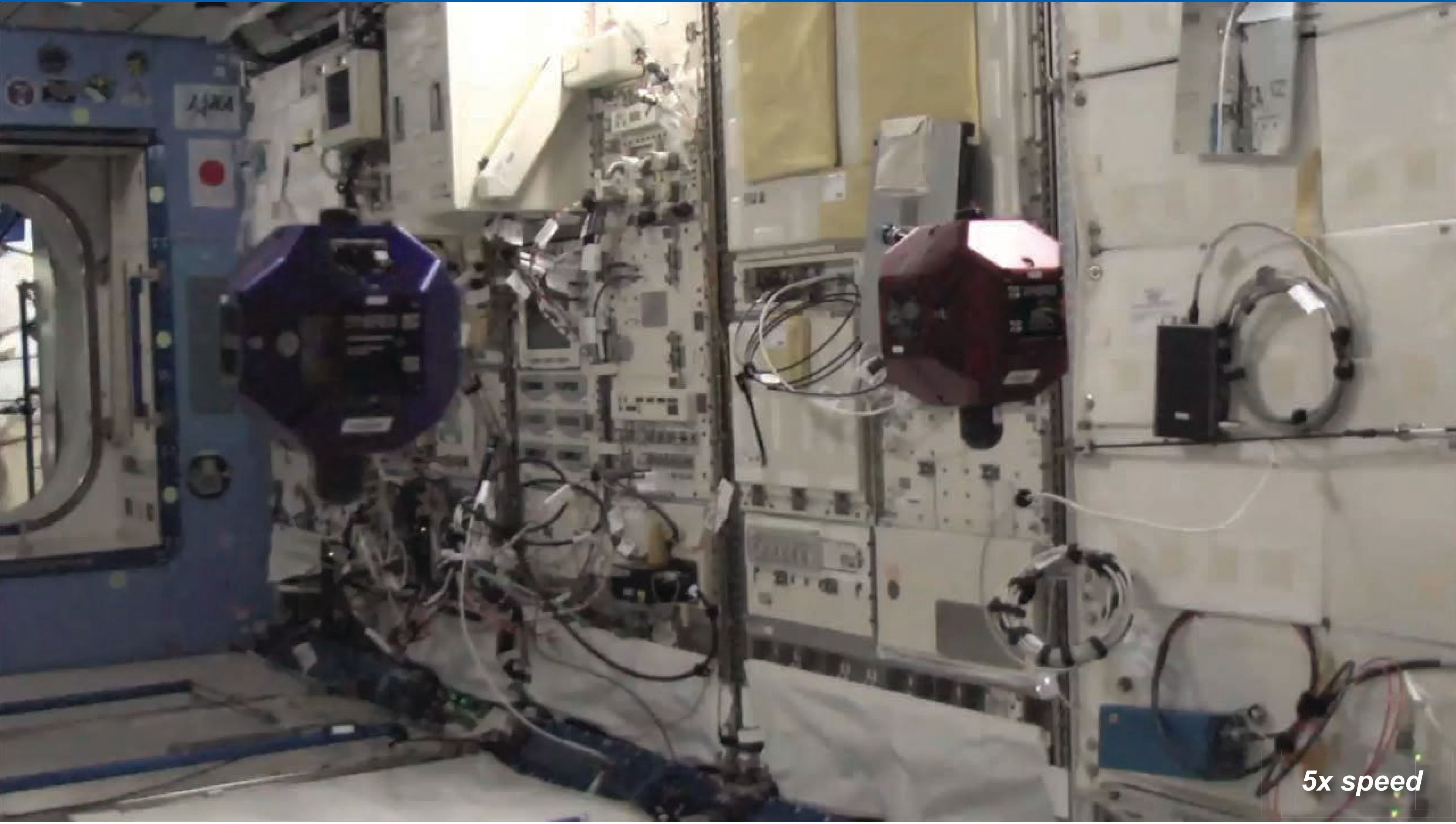
Space Station Robots

Special Purpose Dexterous Manipulator ("Dextre")

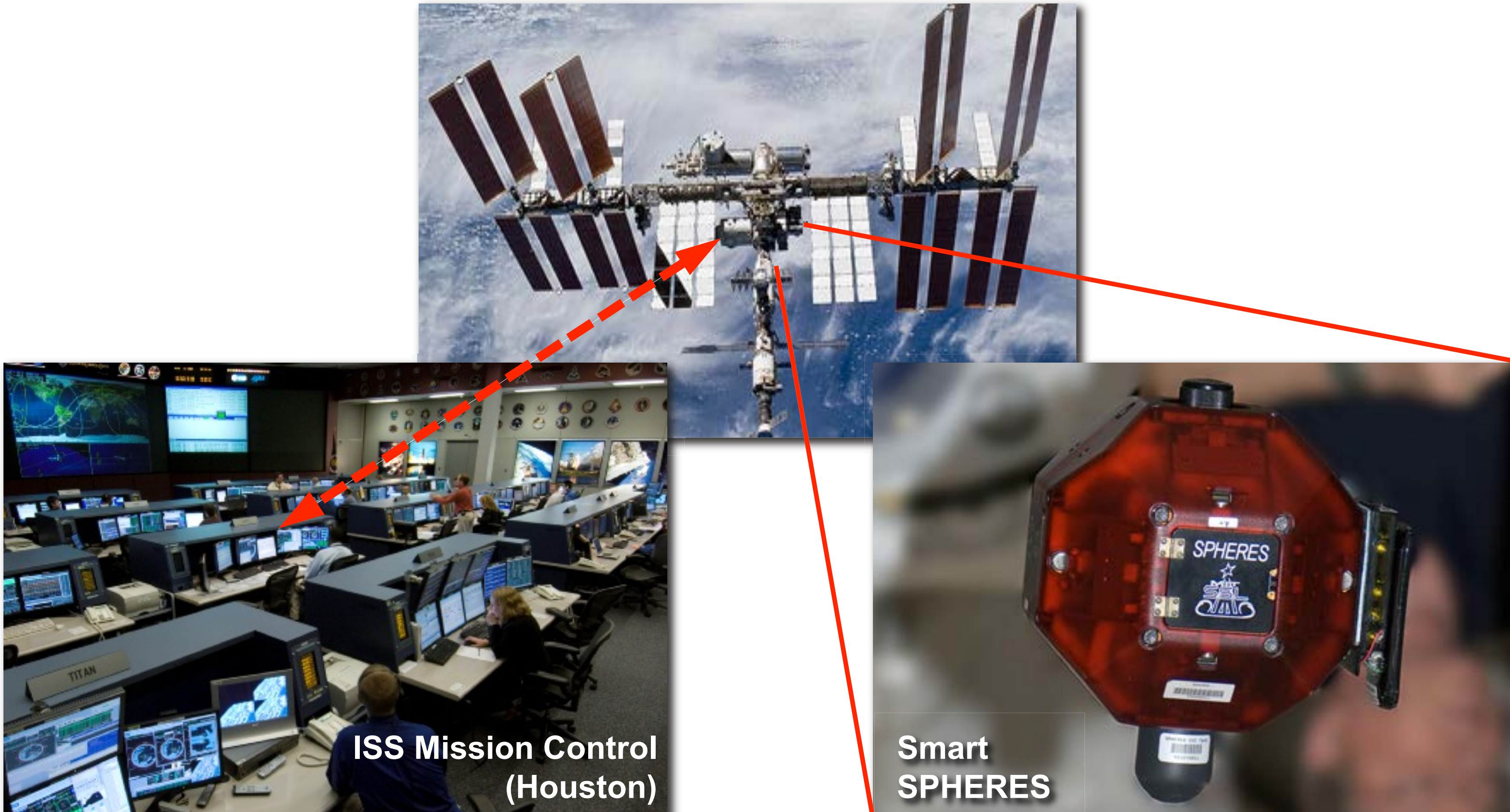
Space Station Robots



SPHERES

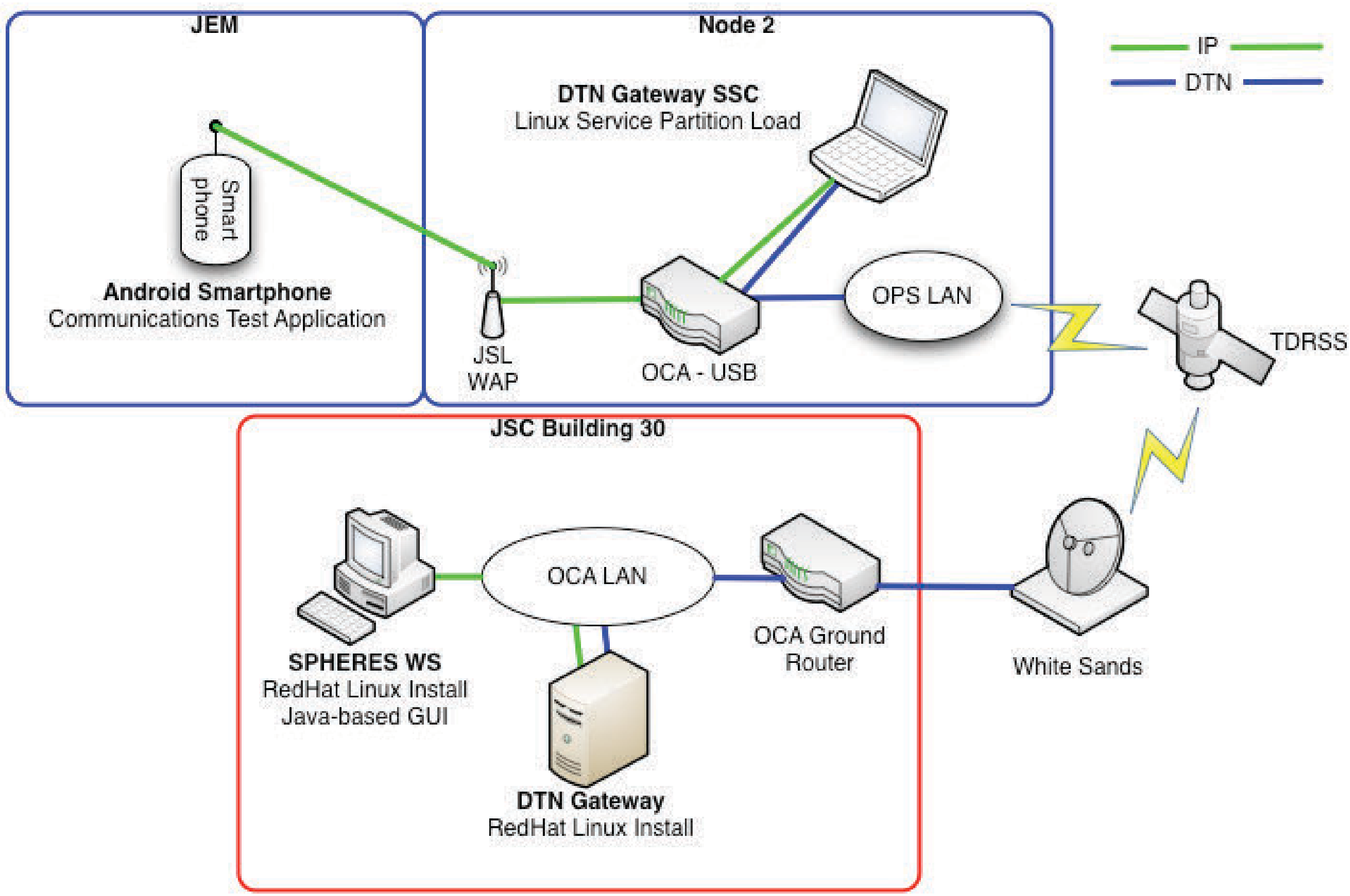


Smart SPHERES



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

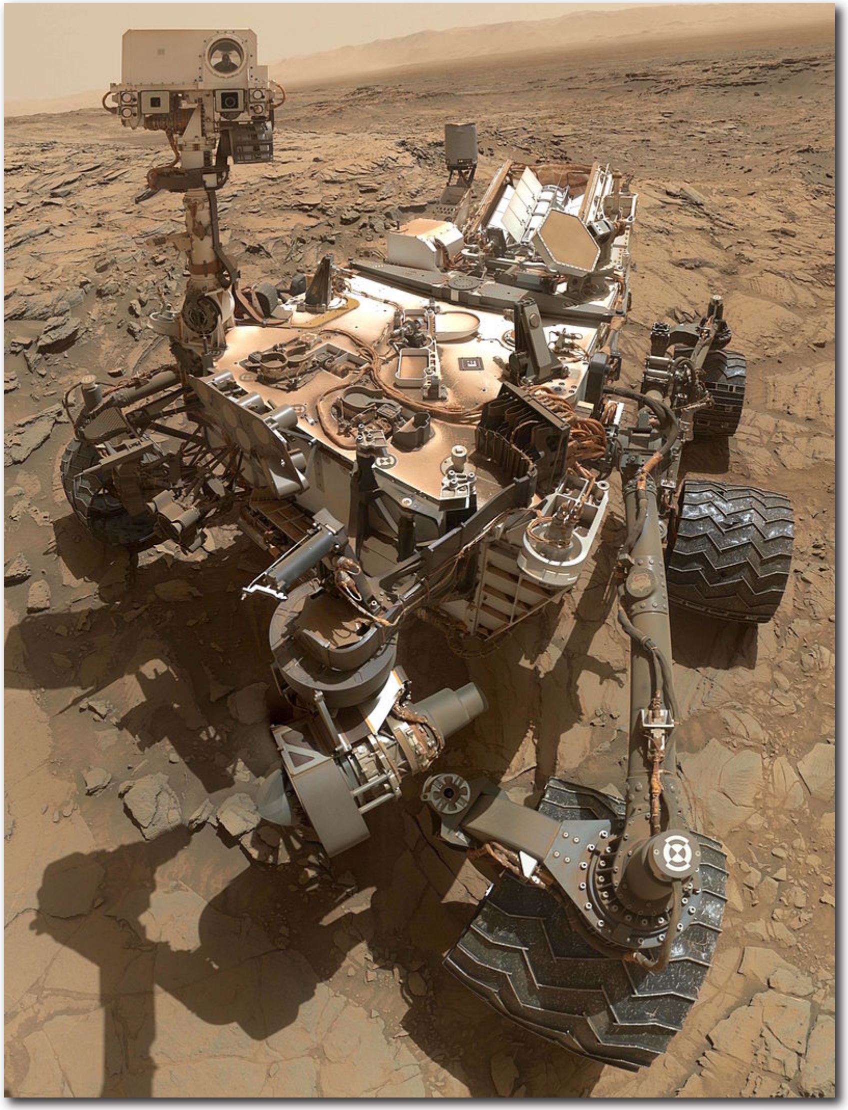


Space Station Interior Survey (2012)


Humans on Earth / Robot on another world

Mars Rovers

Mars Exploration Rover on Mars
(artist concept)



Curiosity at “Big Sky”

Resource Prospector Mission

Mission

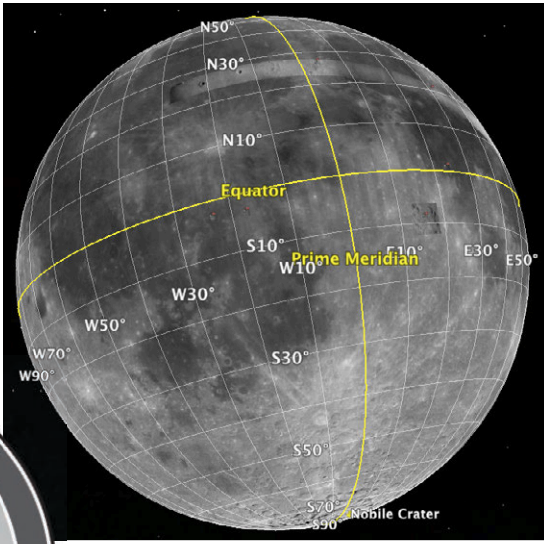
- Characterize the nature and distribution of **lunar polar volatiles**
- Demonstrate **in-situ resource utilization**: process lunar regolith

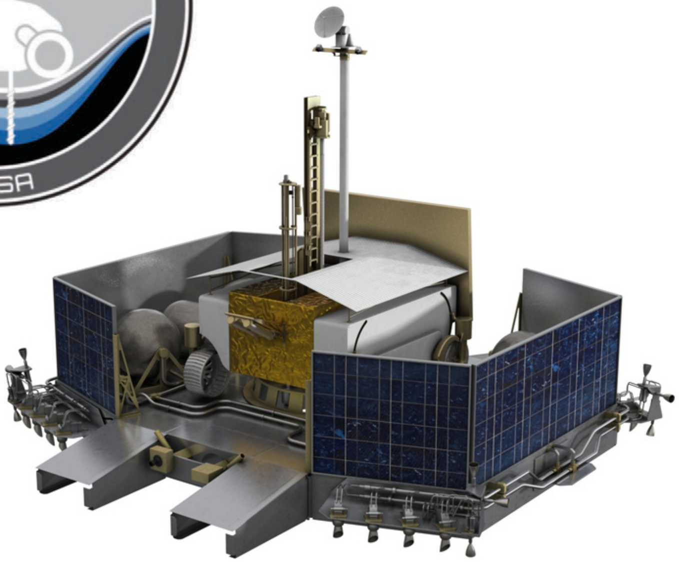
Key Points

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

Rover

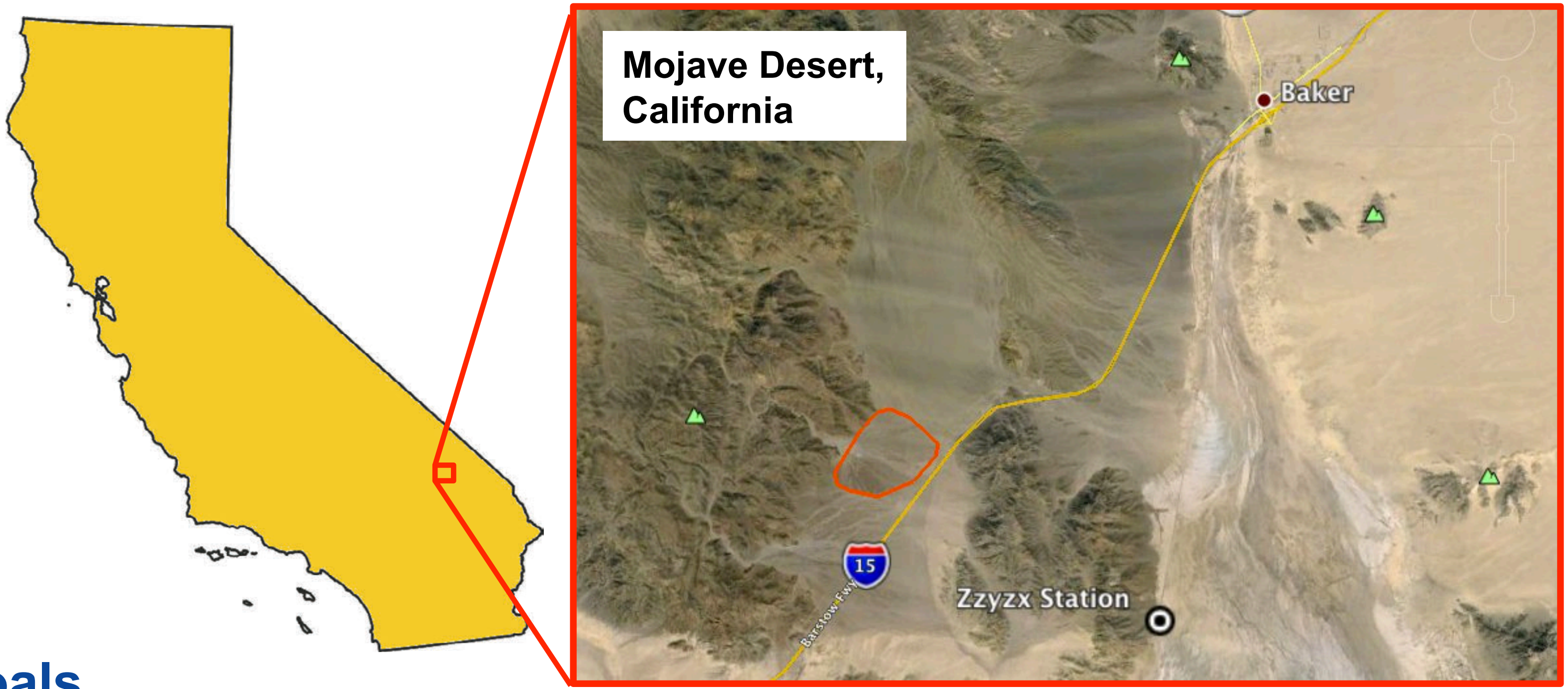
- Mass: 300 kg (including payload)
- Size: 1.4m x 1.4m x 2m
- Max speed: **10 cm/s**
- Speed made good: **0.5 cm/s**





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

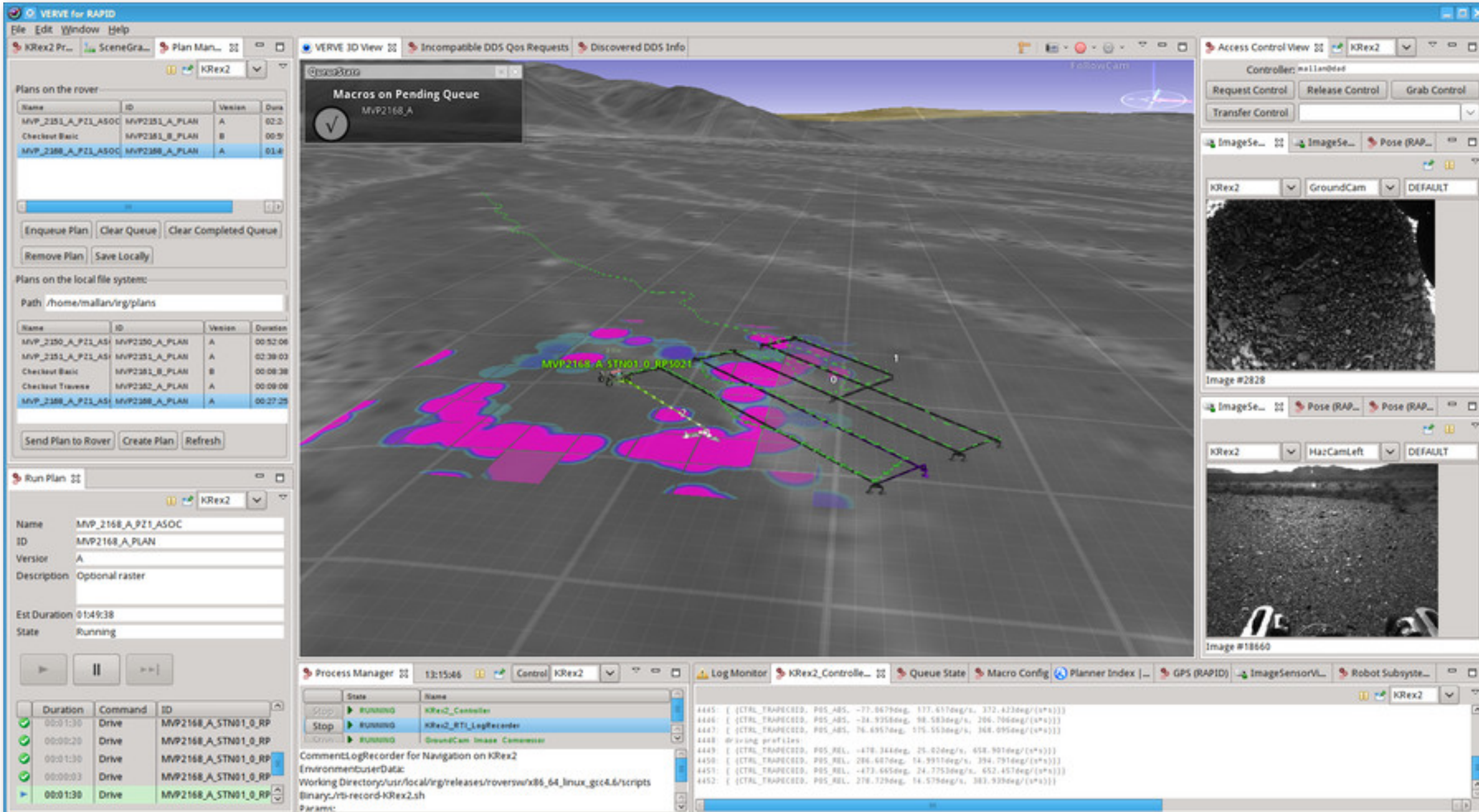
Prospecting Rover and Instruments

Real-time Operations (NASA Ames)

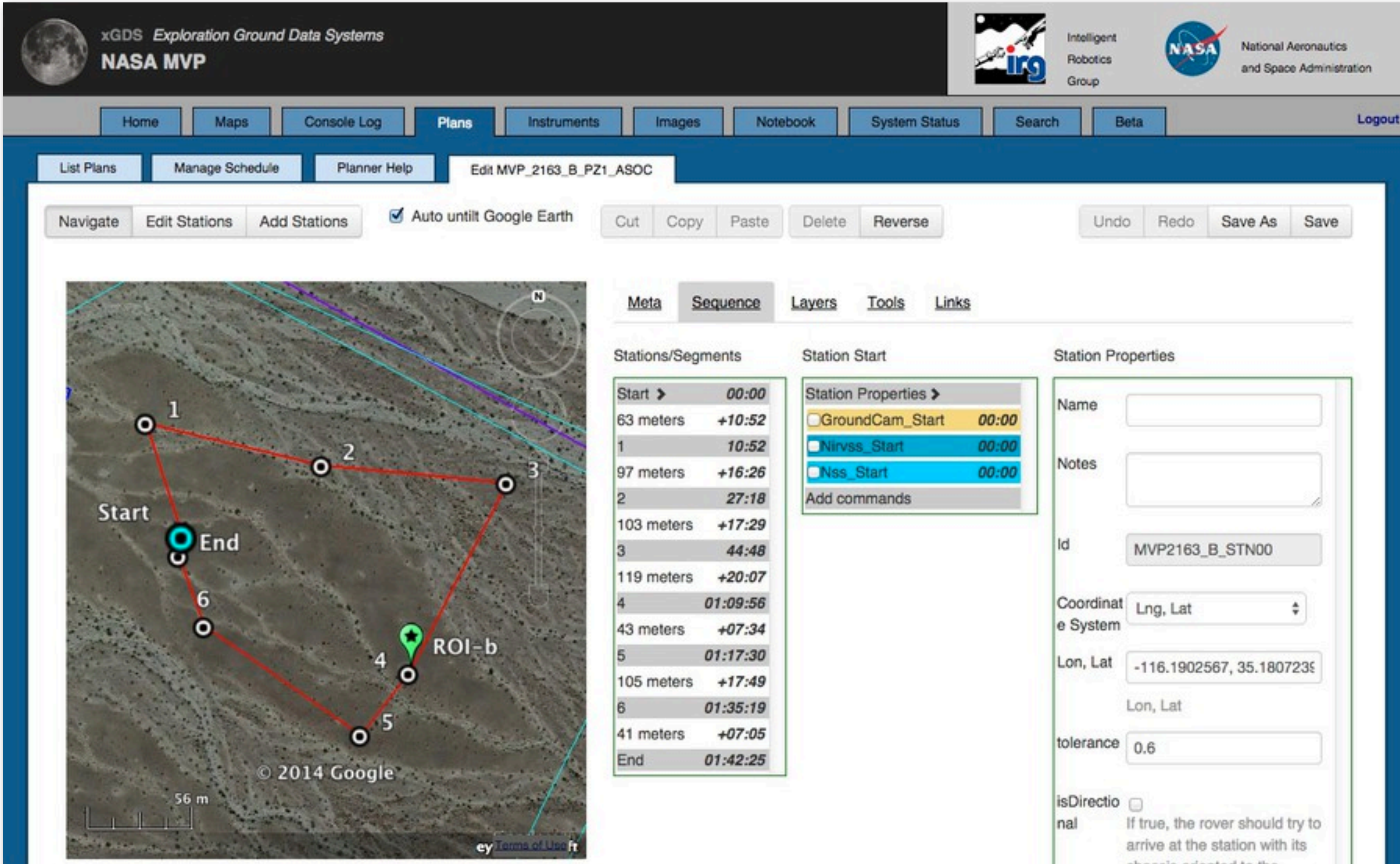
Mojave Volatiles Prospector

Mojave Desert, California
October 2014

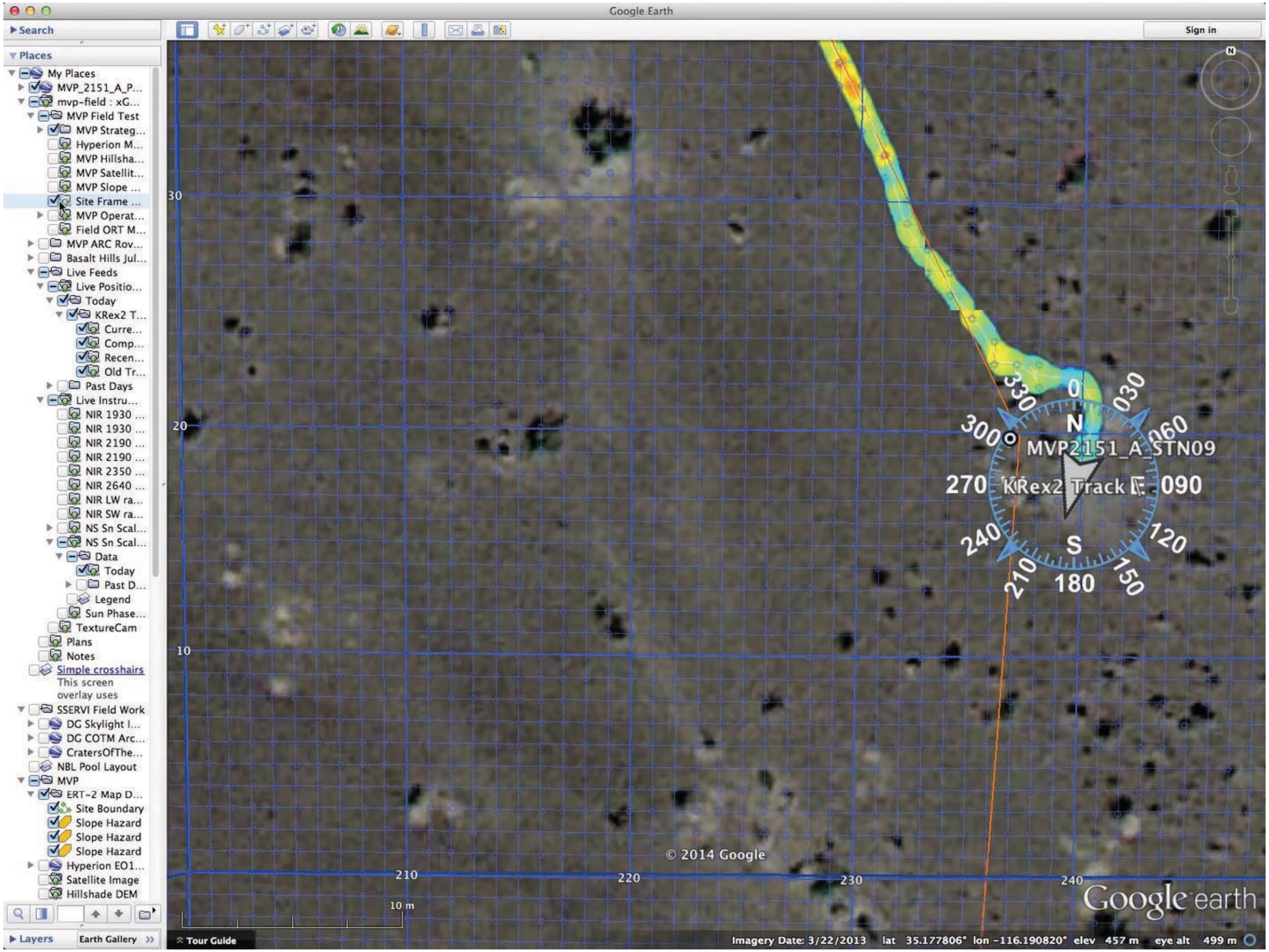
Rover Operator Interface (VERVE)

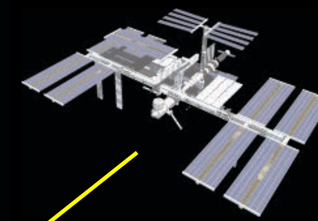


Science Operations Interface (xGDS)



Exploration Ground Data System (xGDS)





Humans in space / Robot on the ground

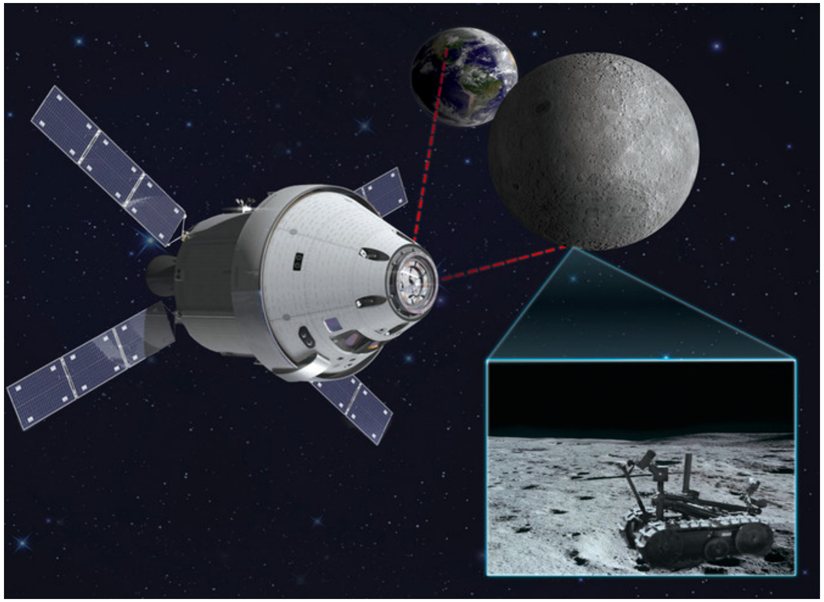
"Fastnet" Lunar Libration Point Mission

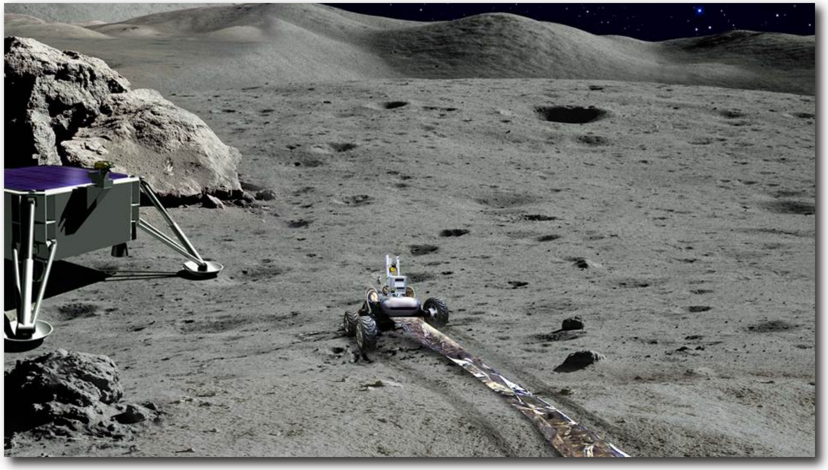
Orion MPCV at Earth-Moon L2 (EM-L2)

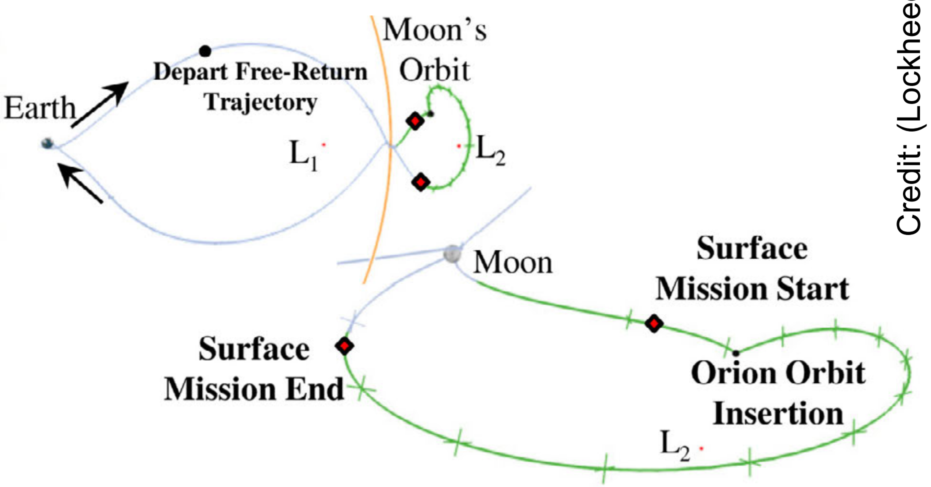
- 60,000 km beyond lunar farside
- Allows station keeping with minimal fuel
- Crew remotely operates robot
- Does not require human-rated lander

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.

Spring 2013

Surveying

Crew gathers information needed to finalize the telescope deployment plan.

Chris Cassidy

17 June 2013

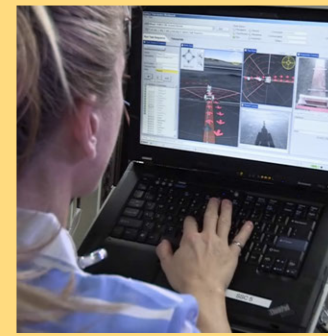
Telescope Deployment

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

Luca Parmitano

26 July 2013

Telescope Inspection

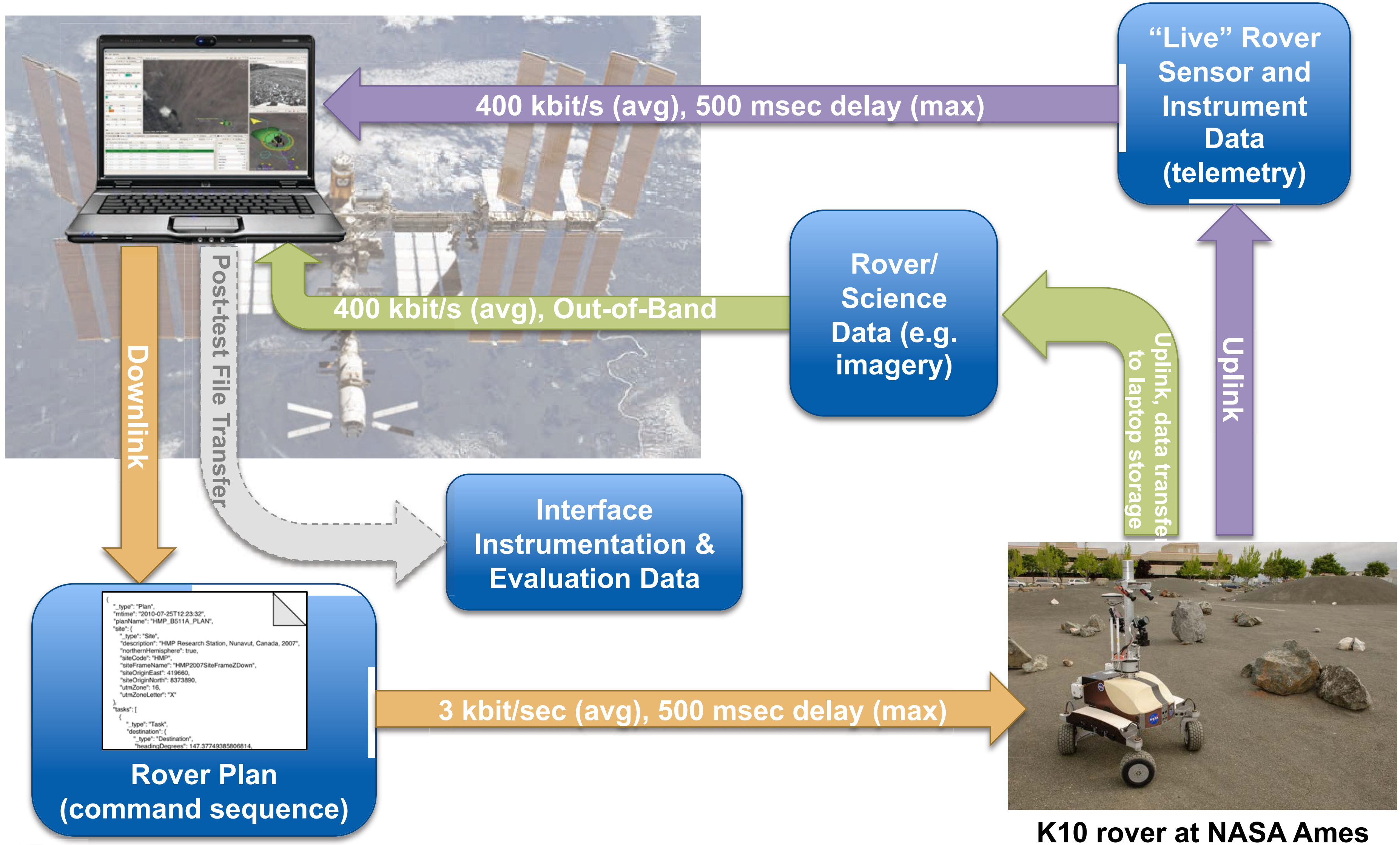


Crew inspects and documents the deployed telescope for possible damage.

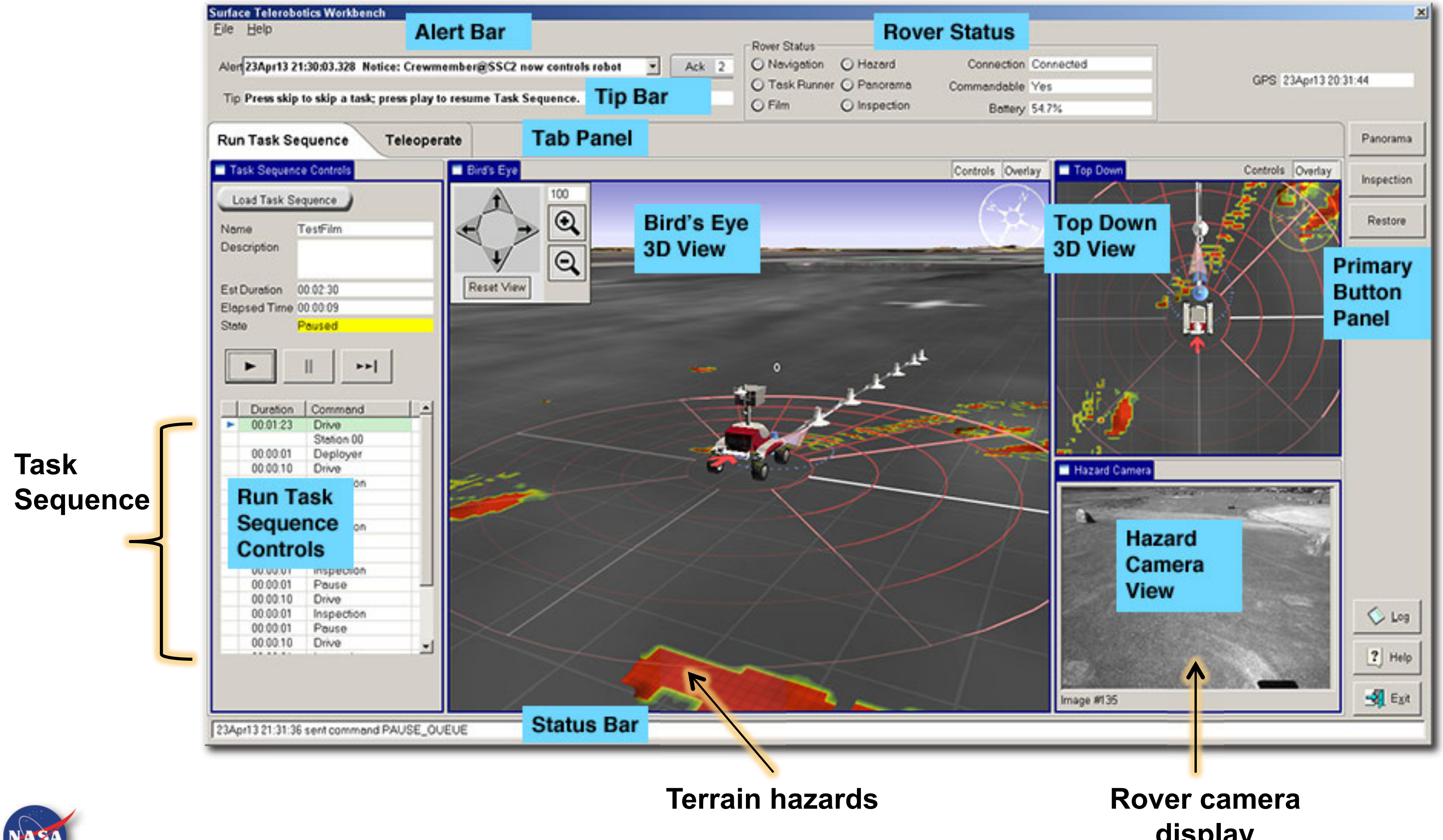
Karen Nyberg

20 August 2013

ISS Test Setup

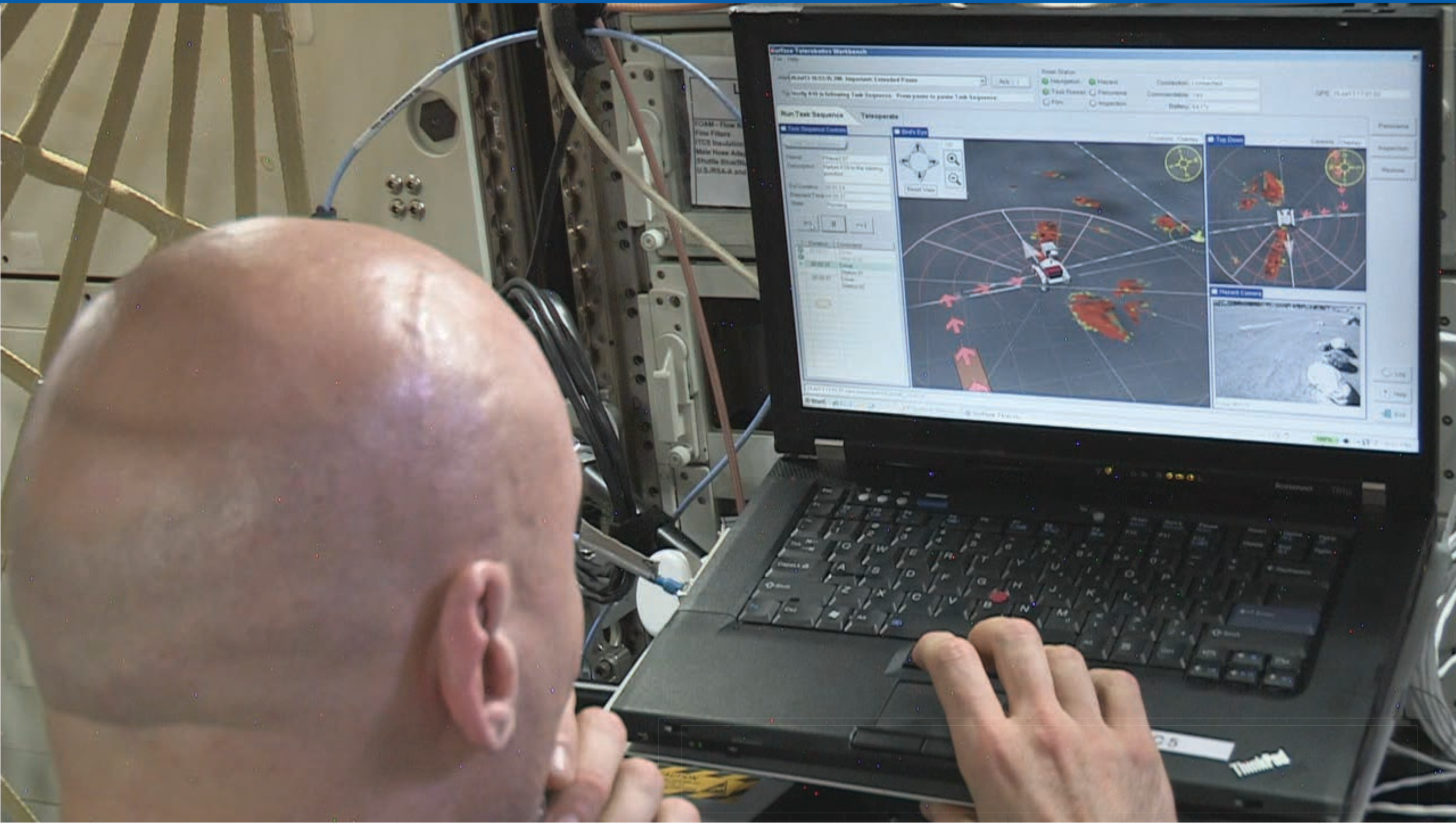


Robot Interface (Supervisory Control)



Crew-controlled Telerobotics (2013)

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)

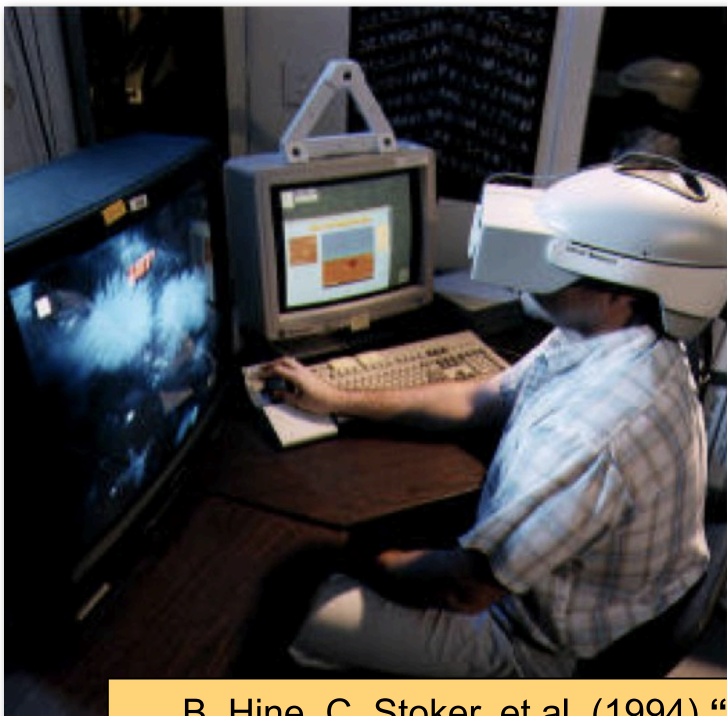
M. Bualat, D. Schreckenghost, et al. (2014) **"Results from testing crew-controlled surface telerobotics on the International Space Station"**. Proc. of 12th I-SAIRAS (Montreal, Canada)

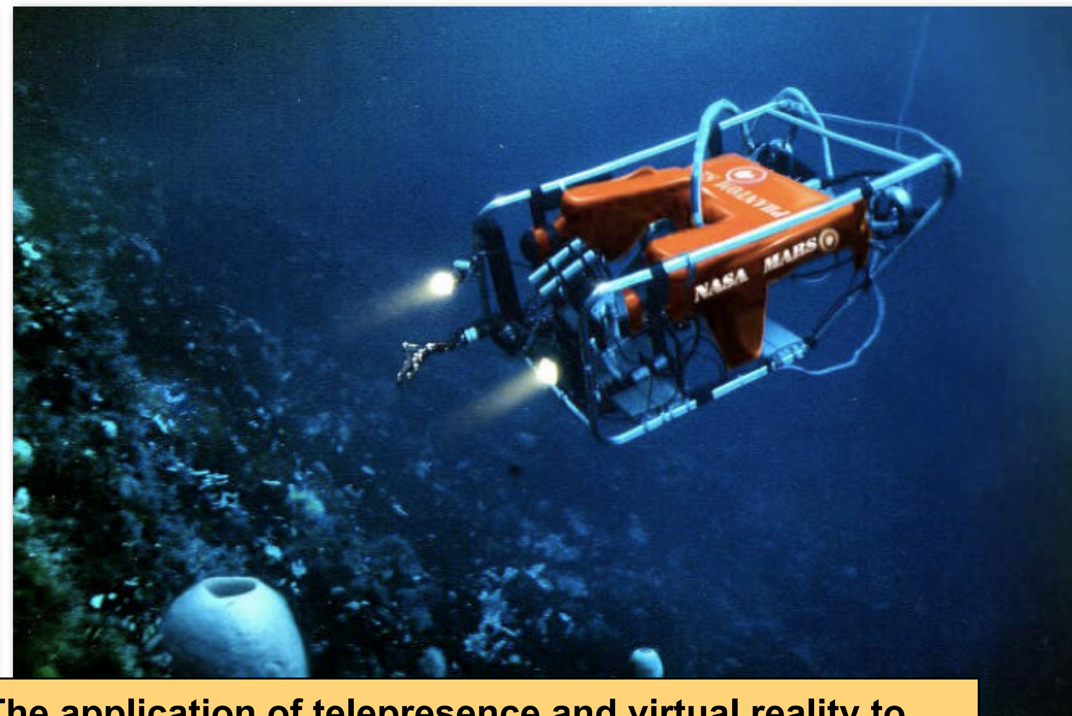

Real-time Exploration Telerobotics

Real-time Exploration Telerobotics

Telepresence Remotely Operated Vehicle (TROV)

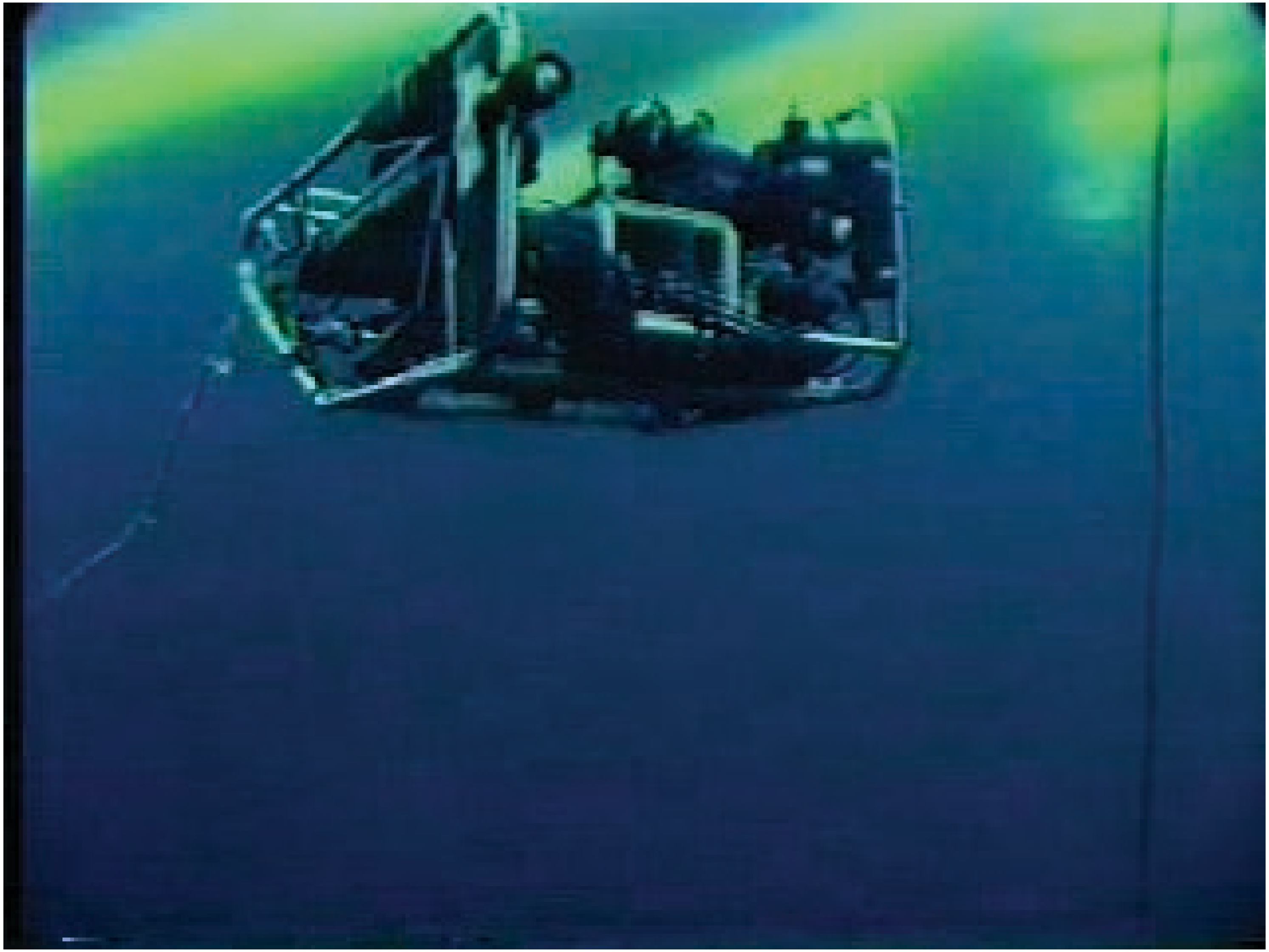
- Benthic ecology survey of McMurdo Sound (Nov-Dec 1993)
- Remote operations from NASA Ames via satellite (832 kbps downlink)
- Virtual environment + telepresence video (head tracked stereo display)





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 (accomodation 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 that efficiency.

Questions?

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