Telerobotics for Human Exploration

Enhancing crew capabilities in deep space

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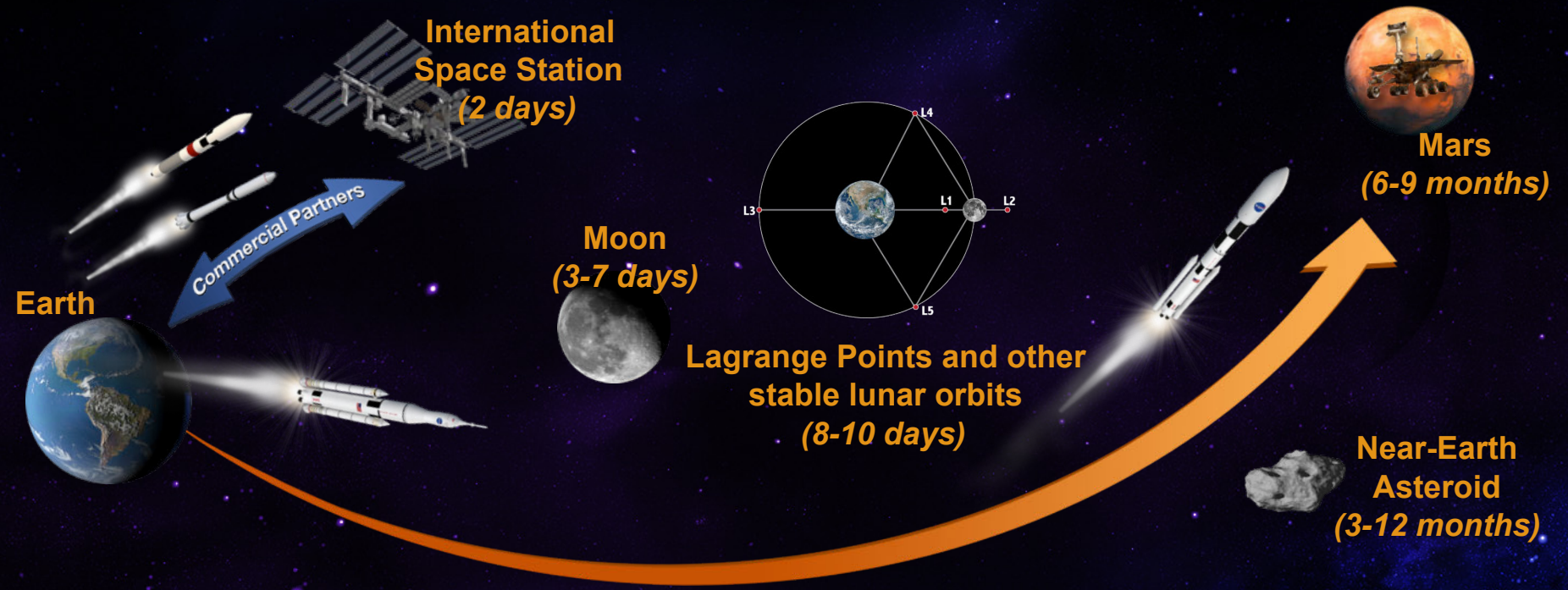
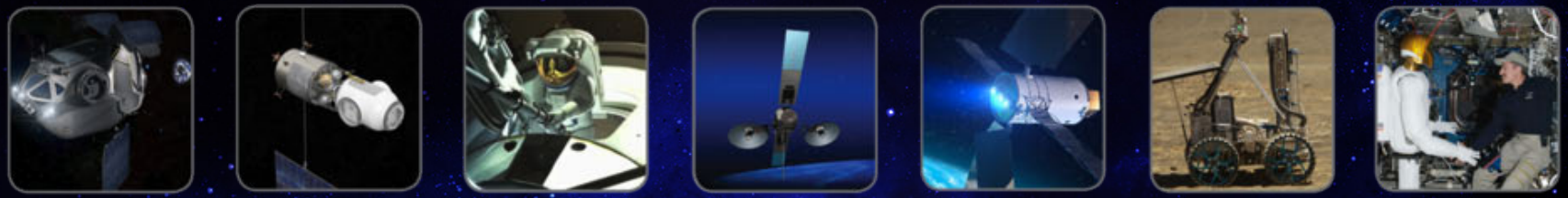
Exploration destinations

(one-way travel times)



Future missions will be longer, more complex, & require new technology

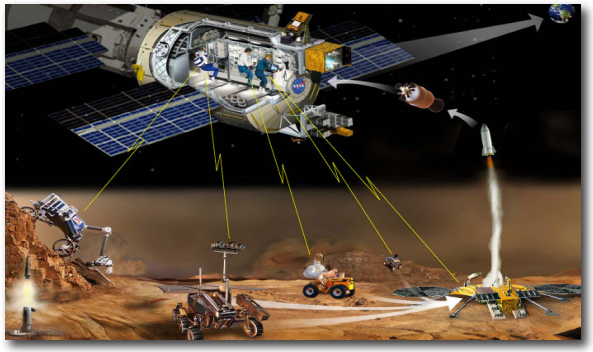


Robotics and Mobility | Deep Space Habitation | Advanced Spacesuits | Advanced Space Comm | Advanced Propulsion | Resource Utilization | Human-Robot Systems

Telerobotics for Human Exploration

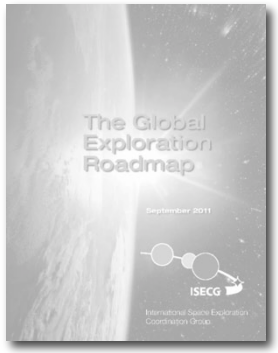
Part 1: Crew Surface Telerobotics

- Crew remotely operates surface robot from spacecraft
- Extends crew capability
- Enables new types of missions



Part 2: Interoperability

- Facilitate systems integration and testing
- Reduce development cost
- Expand international collaboration



Part 3: Common User Interfaces

- Common control modes
- Common interaction paradigms
- Enhance operator efficiency and reduce training time

Surface Telerobotics

Concept of Operations

- Crew remotely operates surface robot from spacecraft
- Proposed by numerous study teams for future missions
- Very little experimental data and validation to date

Candidate Missions

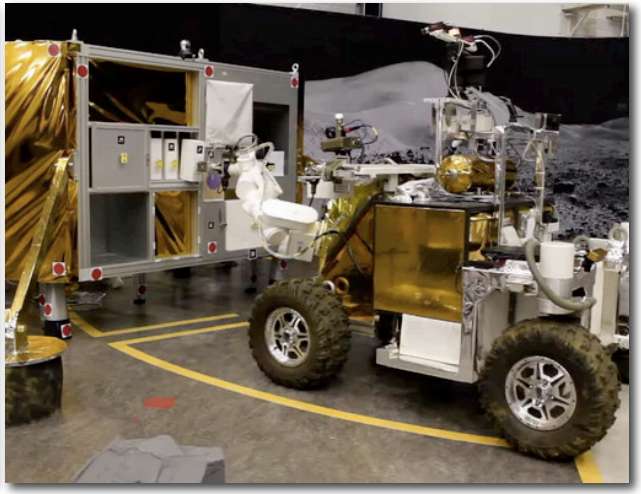
- **L2 Lunar Farside**. Orion MPCV at Earth-Moon L2 and rover on lunar farside surface
- **Near-Earth Asteroid**. NEA dynamics and distance prevent Earth-based manual control
- **Mars Orbit**. Crew operates surface robot when situation precludes Earth control

Credit: NASA GSFC

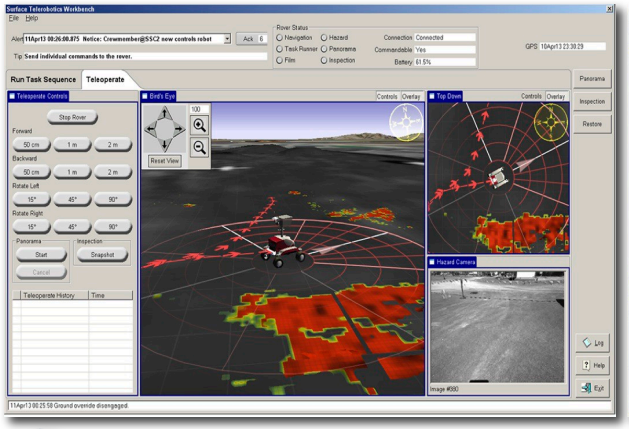
Studies

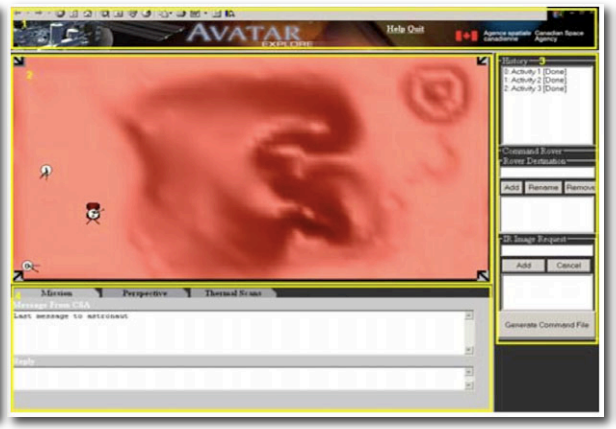
Surface Telerobotics (2012-14, NASA)

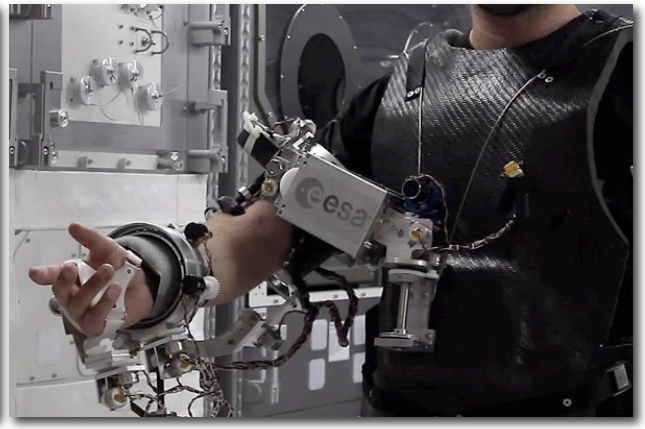
Avatar Explore (2009, CSA)



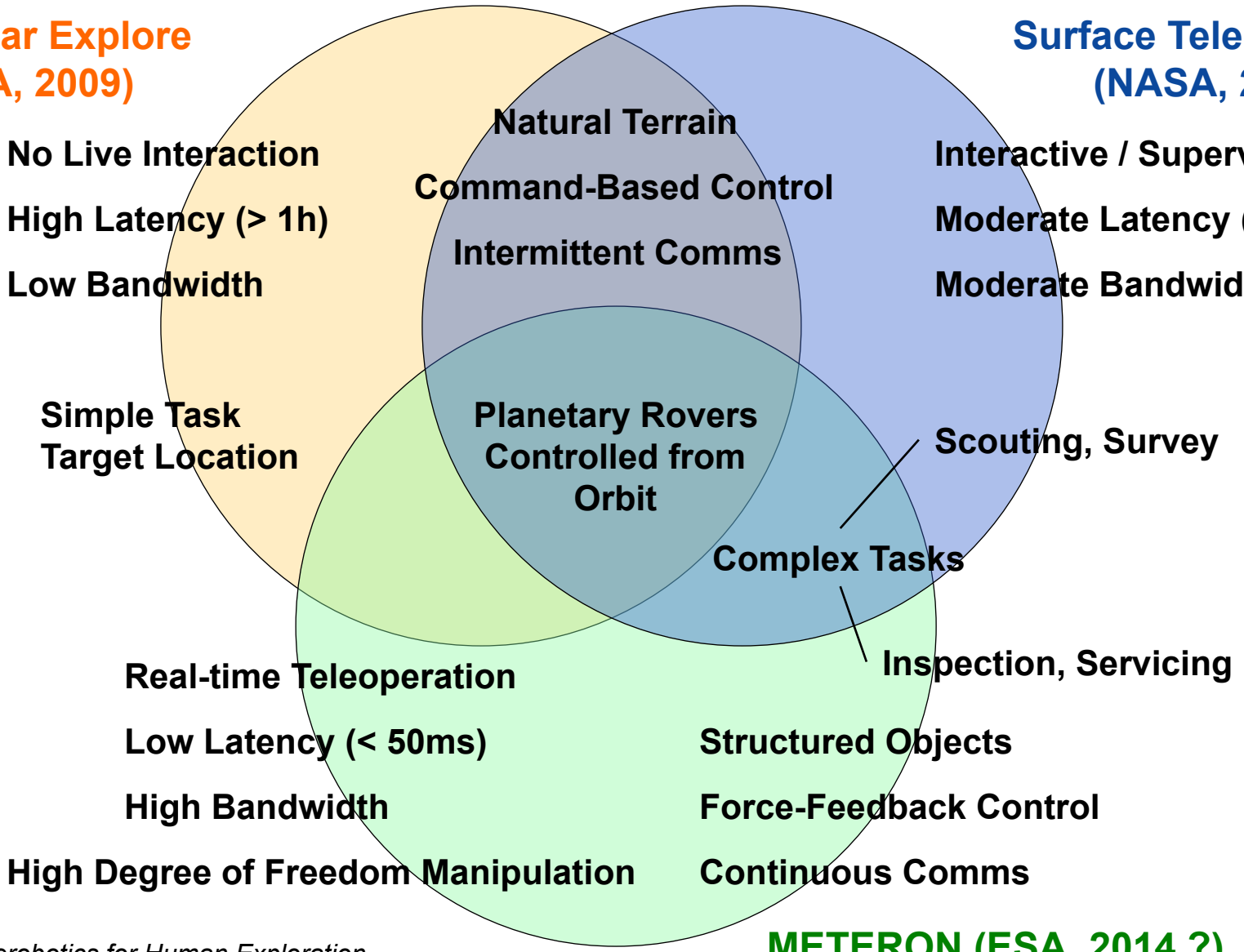
METERON (2014 ?, ESA)







Comparison


Avatar Explore
(CSA, 2009)
No Live Interaction
High Latency (> 1h)
Low Bandwidth
Simple Task
Target Location
Surface Telerobotics
(NASA, 2012-14)
Interactive / Supervisory
Moderate Latency (< 2s)
Moderate Bandwidth
Scouting, Survey
Natural Terrain
Command-Based Control
Intermittent Comms
Planetary Rovers
Controlled from
Orbit
Complex Tasks
Inspection, Servicing
Real-time Teleoperation
Low Latency (< 50ms)
High Bandwidth
High Degree of Freedom Manipulation
Structured Objects
Force-Feedback Control
Continuous Comms
METERON (ESA, 2014 ?)

NASA Surface Telerobotics

Goals

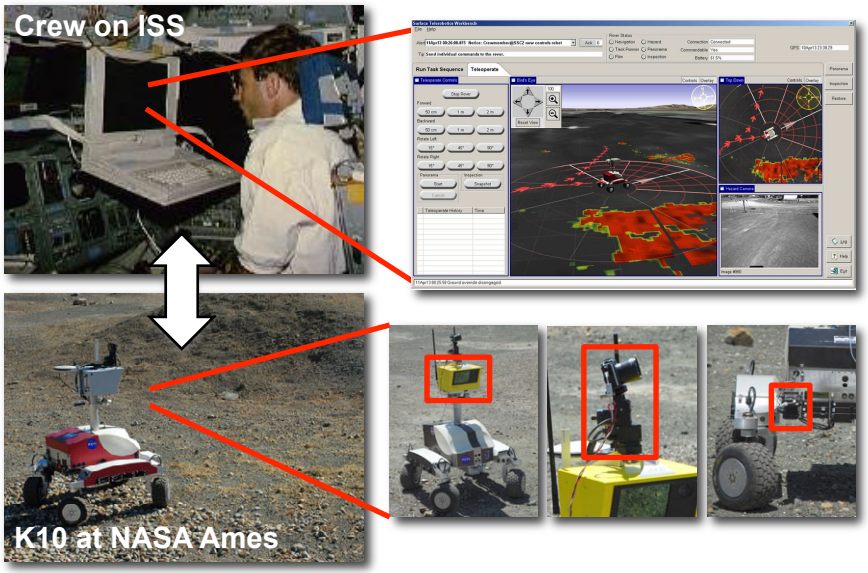
- Demo **crew-centric control** of surface telerobot from ISS (first operational system)
- Test **human-robot "opscon"** for future deep-space exploration mission
- Obtain **baseline engineering data** of system operation

Approach

- Leverage best practices and findings from **prior ground simulations**
- Collect data from robot software, crew user interfaces, and ops protocols
- Validate & **correlate to prior ground sim** (analog missions 2007-2011)

Implementation

- **Waypoint mission simulation**
- **K10 planetary rover** in ARC Roverscape (outdoor test site)
- **Astronaut on ISS**
  (10 hr total crew time, ISS Incr. 36)



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

Waypoint Mission

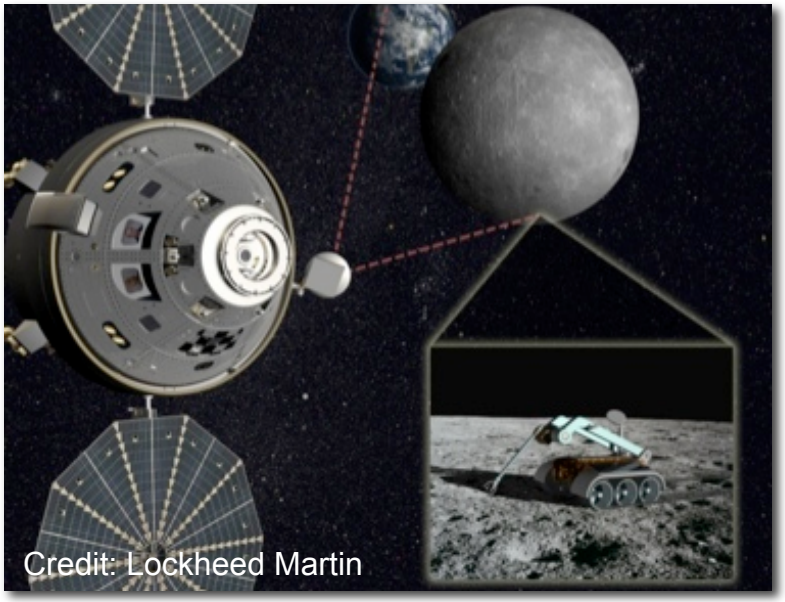
Earth-Moon L2 Lagrange point

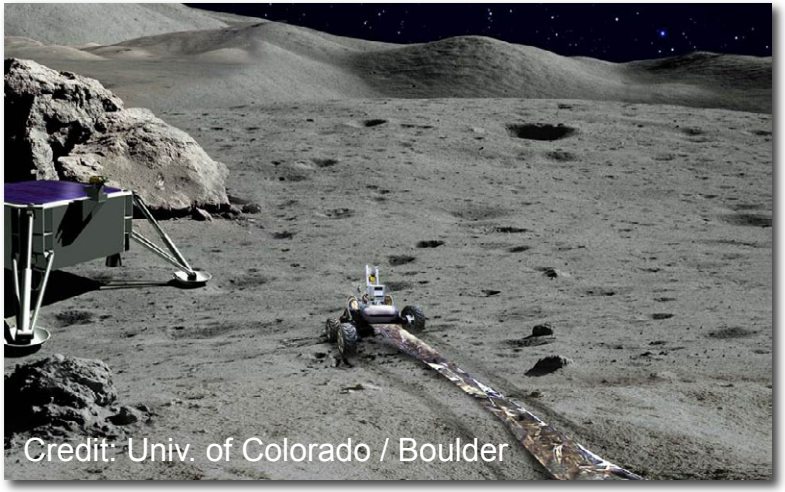
- 60,000 km beyond lunar farside
- Allows station keeping with little fuel
- Crew remotely operates robot on Moon
- Cheaper than human surface mission
- Does not require human-rated lander

Lunar telescope installation

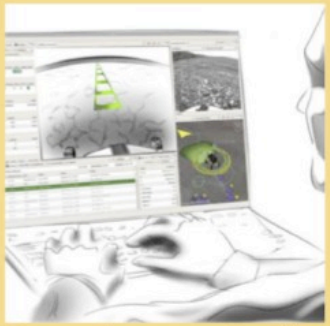
- Use telerobot to setup radio telescope on surface
- Requires surface survey, deployment, and inspection / documentation
- Lunar farside = radio quiet zone for low freq. measurements of cosmic dawn

LUNAR
LUNAR UNIVERSITY NETWORK for ASTROPHYSICS RESEARCH


Credit: Lockheed Martin


Credit: Univ. of Colorado / Boulder

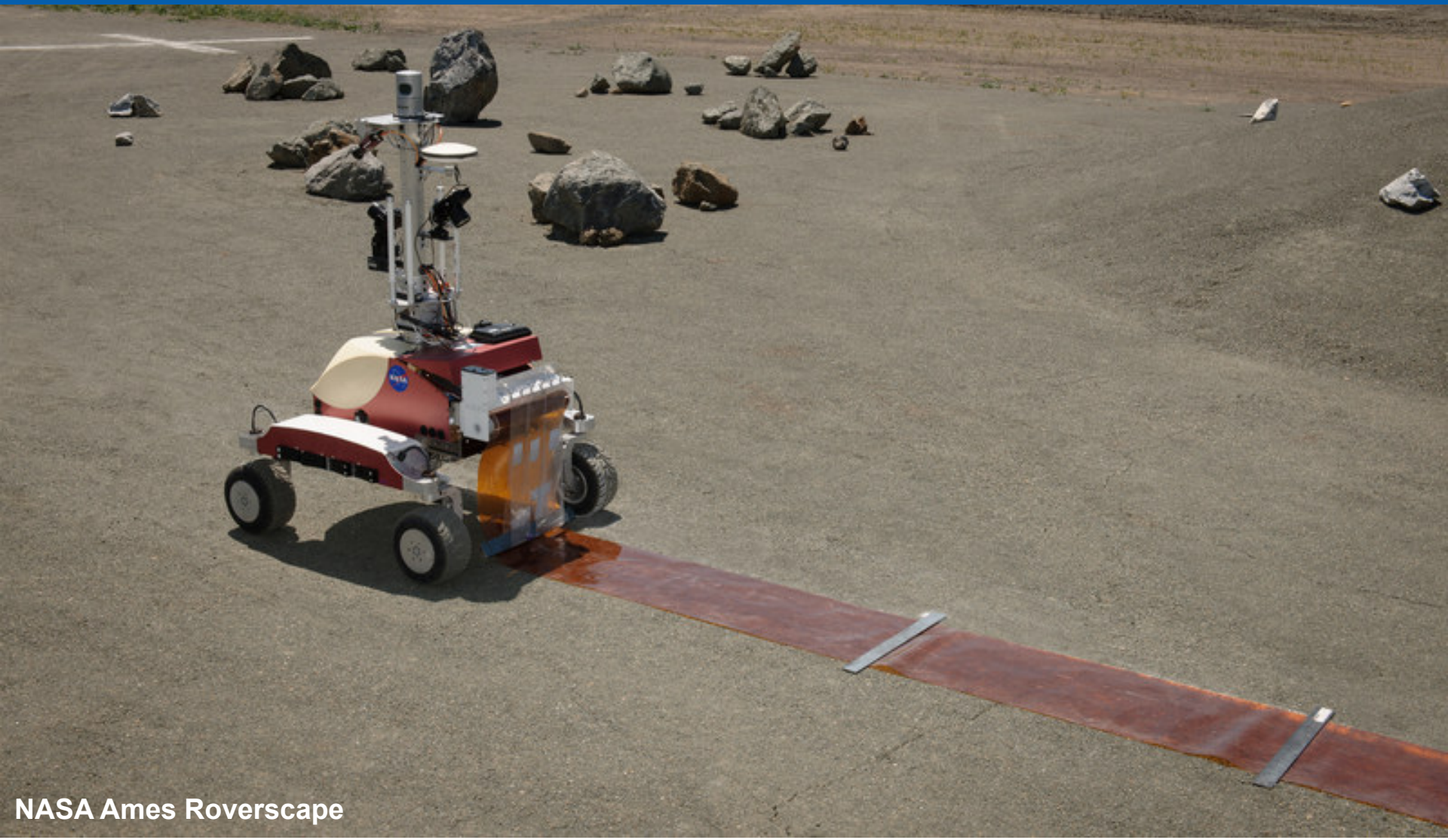
Waypoint Mission Simulation (2013)

Phase 0	Phase 1	Phase 2	Phase 3
Pre-Mission Planning	**Surveying / Scouting**	**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 10***	***August 8***

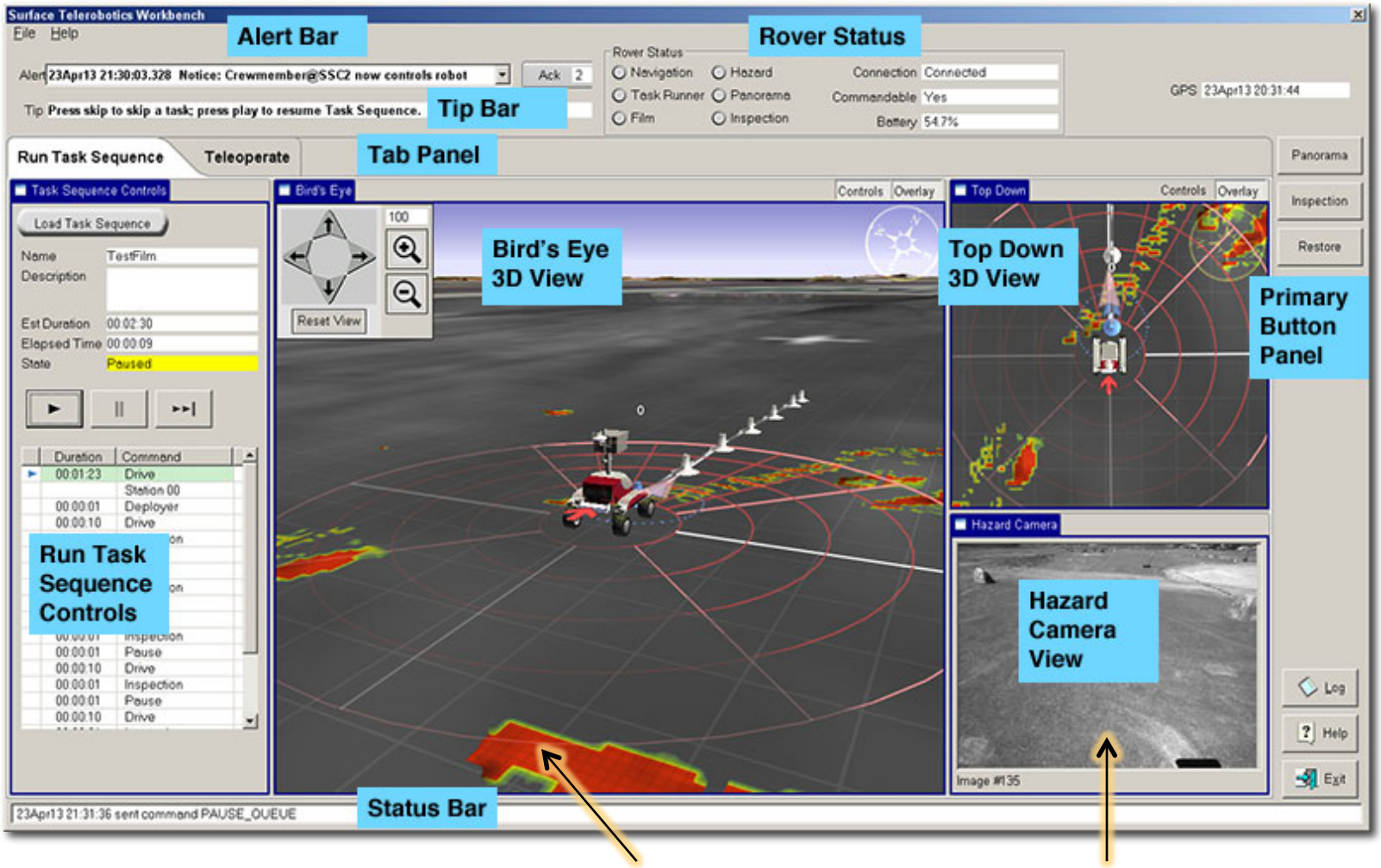
K10 Planetary Rover @ NASA Ames

NASA Ames Roverscape

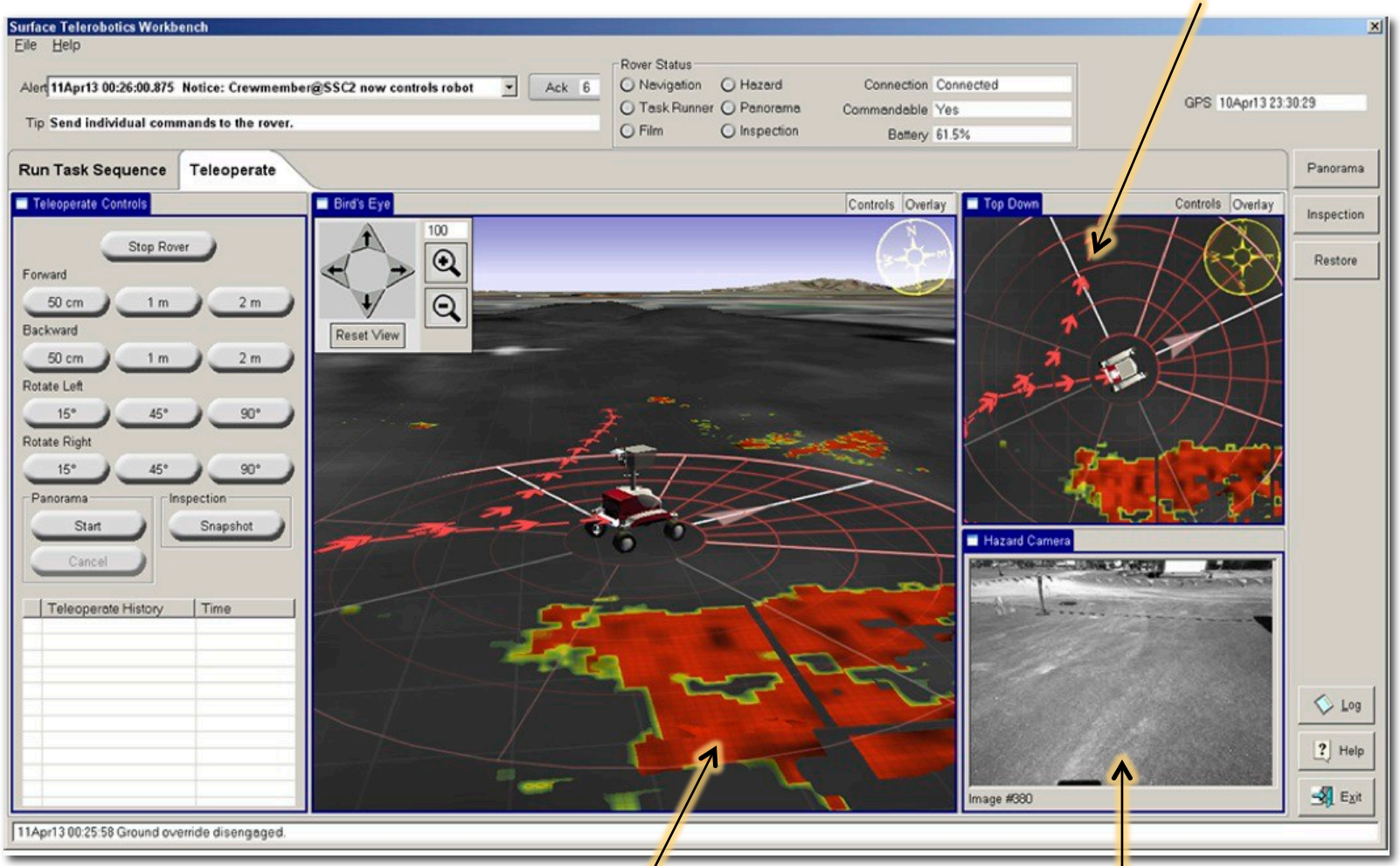
Deployed Telescope Simulation



Robot Interface (Task Sequence Mode)



Robot Interface (Teleop Mode)



Experimental Protocol

Data Collection

Obtain engineering data through automatic and manual 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

manual
- **Crew Questionnaires:** workload, situation awareness, criticial incidents

Metrics

Use performance metrics* to analyze data and assess human-robot ops

- **Human:** Bedford workload & SAGAT (situation awareness)
- **Robot:** MTBI, MTCI for productivity and reliability
- **System:** Productive Time, Team Workload, and task specific measures for effectiveness and efficiency of the Human-Robot system

** Performance metrics used for prior analog field tests: 2009 robotic recon, 2010 lunar suface systems, 2010 robotic follow-up, 2009-2011 Pavillion Lakes research project, etc.*

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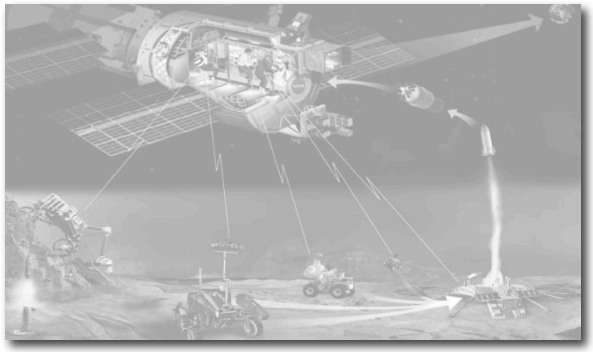
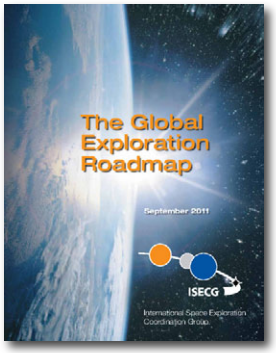
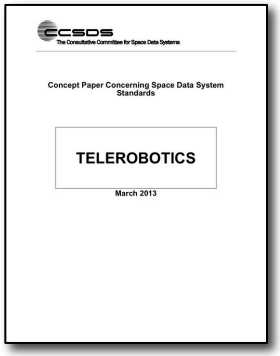


Part 2: Interoperability

- Facilitate systems integration and testing
- Reduce development cost
- Expand international collaboration





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Interoperability

Modern robots are highly complex systems

- Many software modules (on-board and off-board)
- Distributed development team
- Standardized framework facilitates interoperability

Benefits of interoperability

- Facilitate integration and testing
- Reduce cost and risk
- Enhance operational flexibility and capabilities

Robots that do not speak the same "language" are a major obstacle to collaboration in space exploration …

CCSDS Telerobotics Standard

MOIMS-TEL

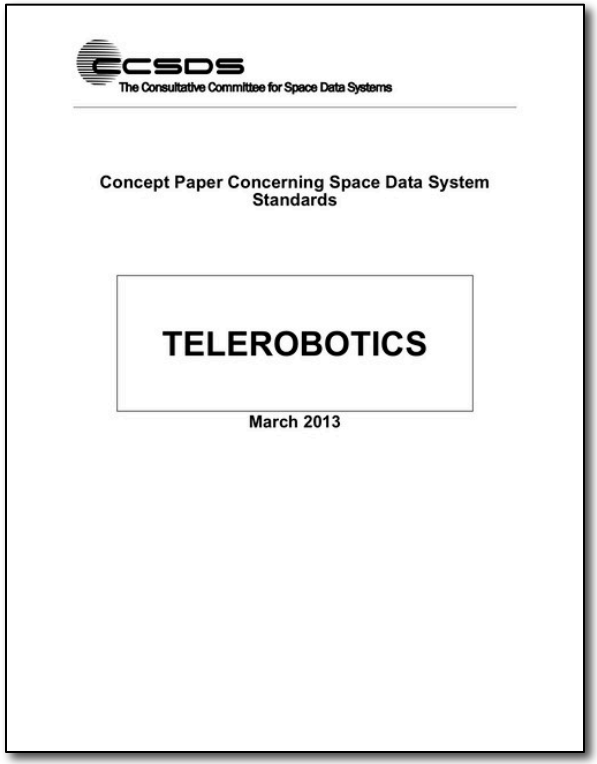
- **M**ission **O**perationa & **I**nfo. **M**anagement **A**rea
- **Tel**erobotics Working Group
- Develop interoperability standards applicable to multiple projects and missions

Focus

- Compatibility "layer" that facilitates **command** and **data** exchange
- Specfication for **software data structures**
  - Message formats
  - Application Programming Interfaces (API)
  - Functional description of standard services

This is NOT …

- All-encompassing system for robot data comm
- Set of standards governing space robotics



Chairs: David Mittman (JPL)
Lindolfo Martinez (JSC)

Interoperability Standard Development

Approach

- Adopt best practices and lessons learned from relevant work
- Develop recommendations based on future mission needs
- Consider existing CCSDS standards (where appropriate)

Relevant work

- CCSDS Asynchronous Message Service (AMS)
- CCSDS Application Support Services (APP)
- CCSDS Mission Operations (MO)
- IETF Delay-Tolerant Networking (DTN)
- OMG Common Object Request Broker Architecture (CORBA)
- OMG Data-Distribution Service for Real-Time Systems (DDS)
- NASA Robot Application Programming Interface Delegate (RAPID)
- SAE Joint Architecture for Unmanned Systems (JAUS)
- etc.

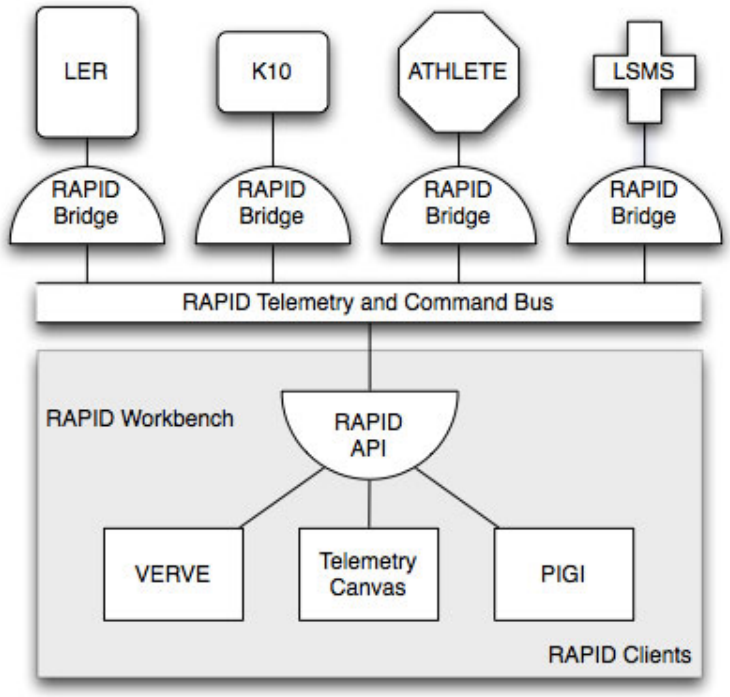
NASA RAPID (2007 – present)

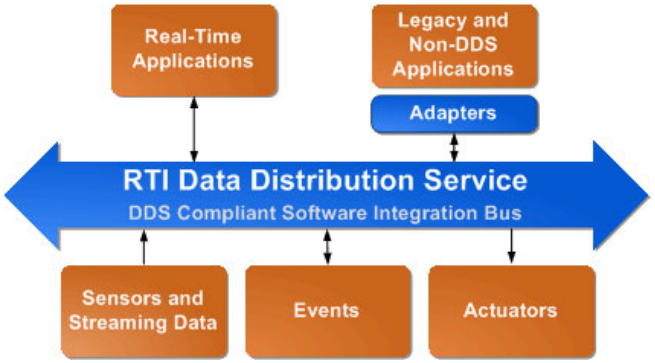
Robot Application Programming Interface Delegate (RAPID)

- Provides Message Definitions & API
- Provides Common Services API
- Developed by ARC, JPL, and JSC with assistance from GRC, LaRC, and KSC

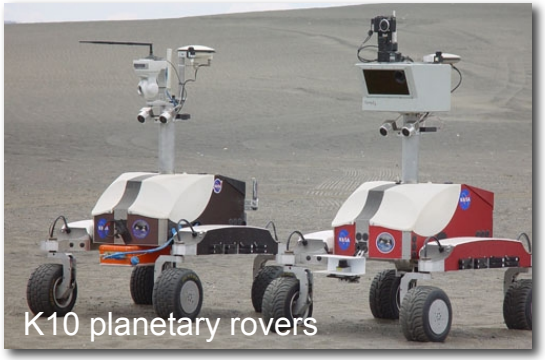
Implementation

- Uses **Data-Distribution Service**
  - International standard (OMG)
  - Publish-subscribe communications
- RTI DDS provides data transport (middleware) layer
- Open-source release (Apache 2)

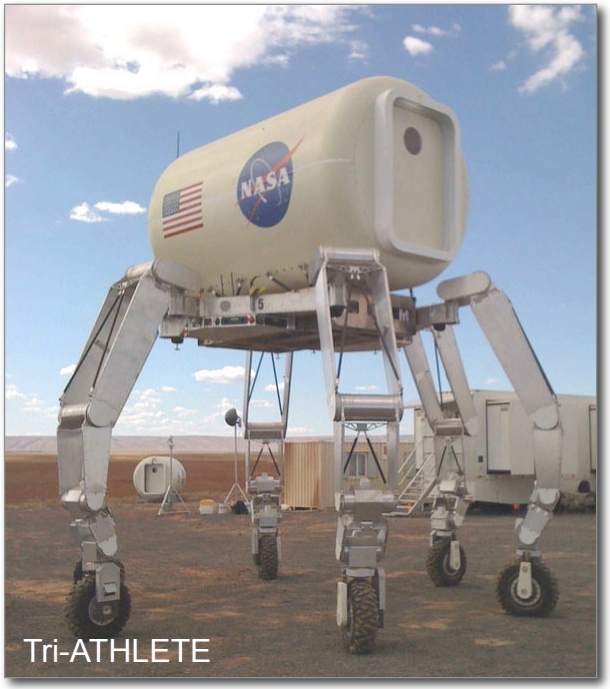




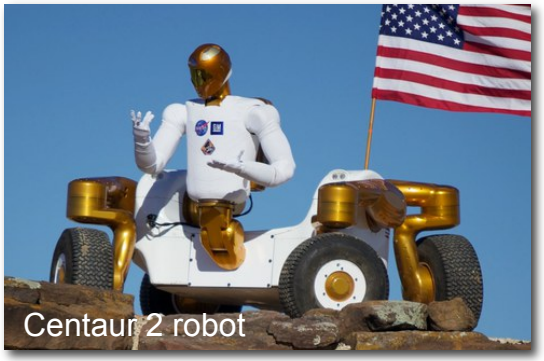
RAPID Robots

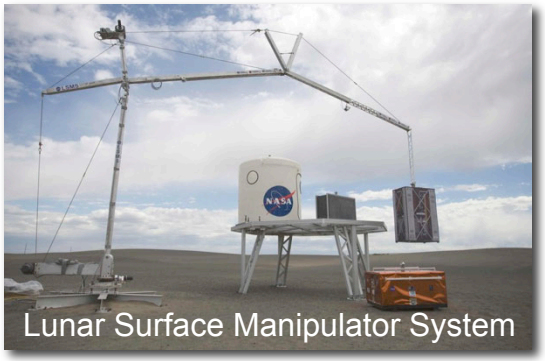

K10 planetary rovers


Smart SPHERES



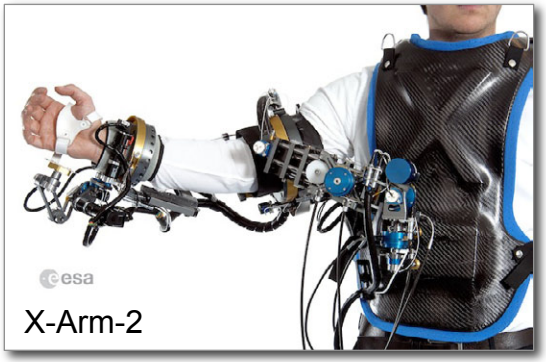
Tri-ATHLETE


Centaur 2 robot



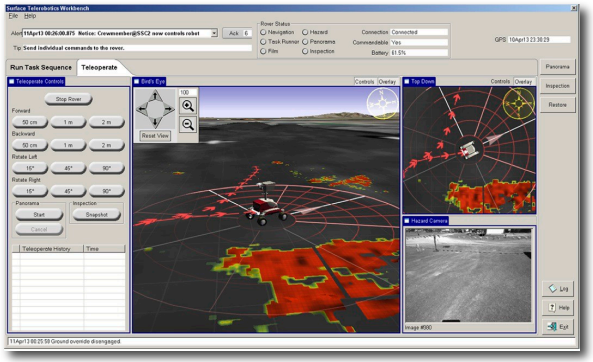
Lunar Surface Manipulator System

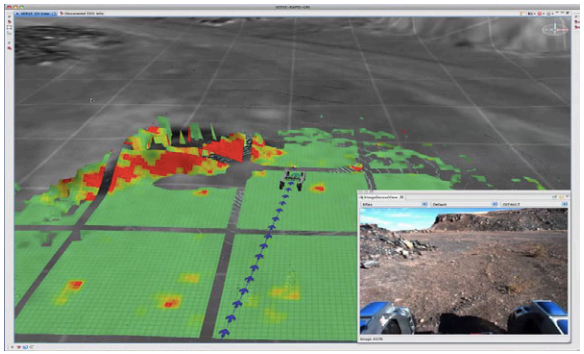
Space Exploration Vehicle

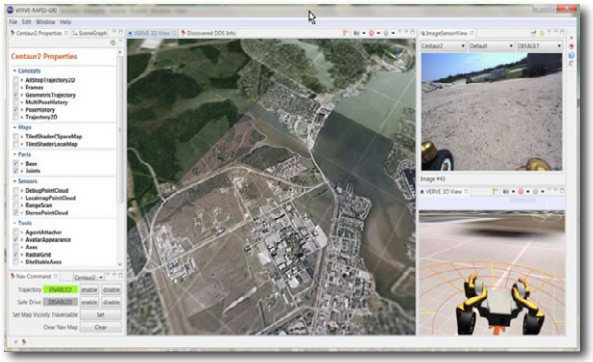


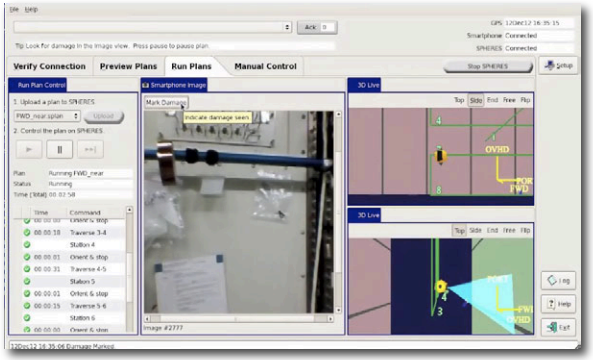
X-Arm-2

RAPID User Interfaces









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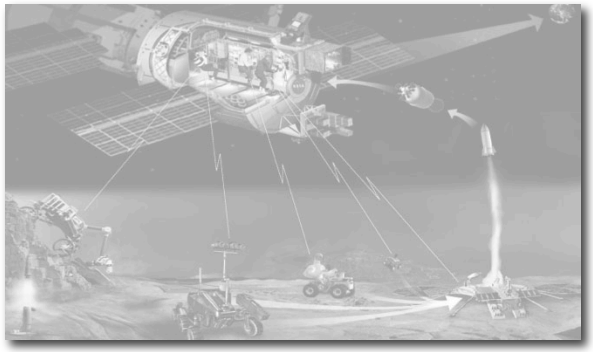

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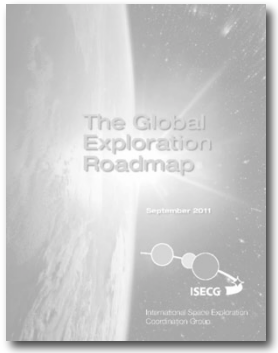

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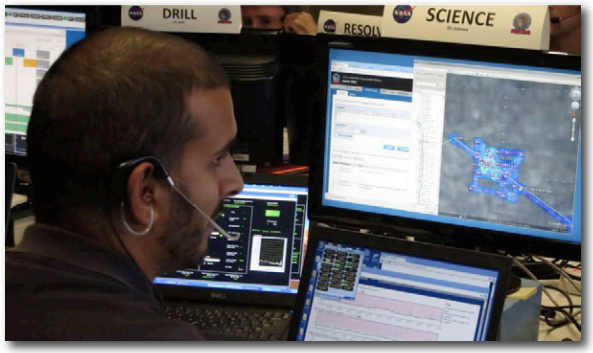


Robot User Interfaces

Space robots

- Space robots have very diverse forms (size, shape, movement, etc)
- Many different control modes (manual to safeguarded to supervisory)
- Broad range of tasks (mobility, field work, positioning, etc.)

User interfaces

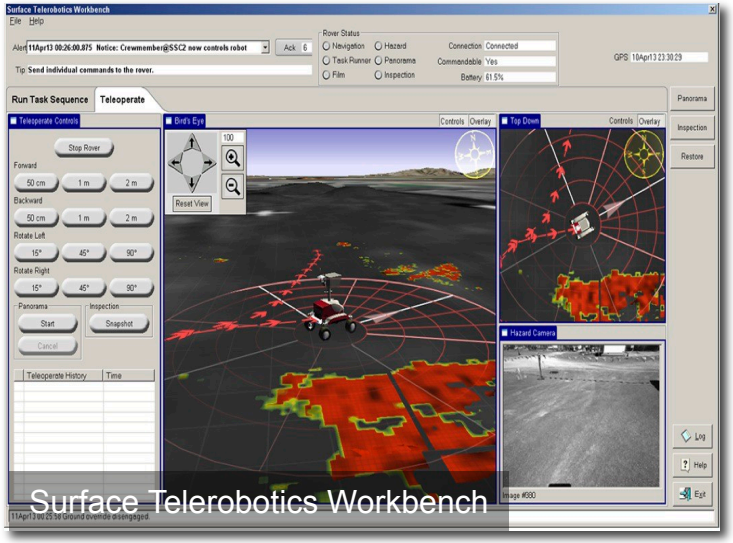
- Robots have custom user interfaces and custom interaction modes
- Users need to relearn control methods for each new robot
- Very difficult to port new control modes from robot to robot

Multiple, complex and/or inconsistent robot user interfaces result in increased training, reduced operational efficiency and higher crew workload

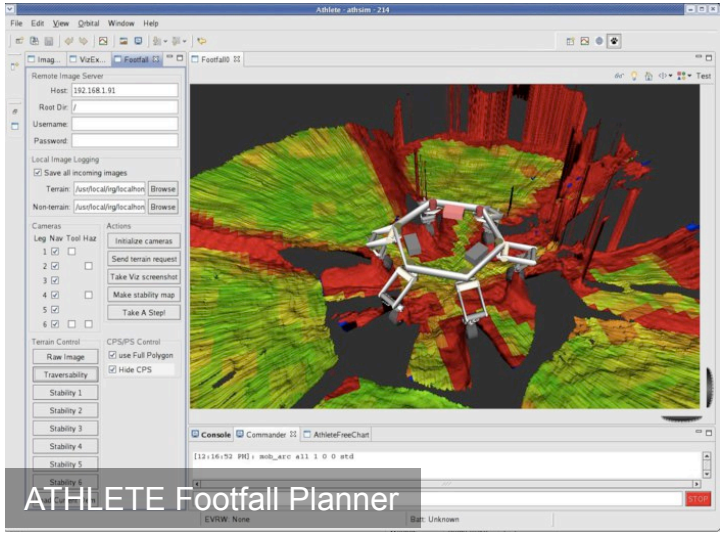
Robot User Interfaces


ISS Robotic Work Station


R2 Teleop UI



Surface Telerobotics Workbench



ATHLETE Footfall Planner

Operator Interface Standards

Industrial Robots

- ANSI/RIA R15.06-1999
  - Guidelines for industrial robot manufacture, installation, and safeguarding for personnel safety
- ANSI/RIA R15.02-1-1990
  - Guidelines for the design of operator control pendants for robot systems

Ergonomics

- NASA Man-Systems Integration Standards
  - Human-systems integration design considerations & requirements
- MIL-STD-1472F
  - General human engineering criteria for military systems

Common User Interfaces

Standardized Interactions

- Common set of commands that will produce **predictable** and **consistent** robot behaviors
- Common **interaction paradigms** (for different control modes)
- Common **information displays** (standard semantics)

Benefits

- Help users avoid inadvertently sending erroneous commands when switching between different types of robots
- Enhance operator efficiency
- Reduce training time (initial & proficiency maintenance)

Common Ground Vehicle Interfaces


Honda Civic


Pontoon boat


Forklift

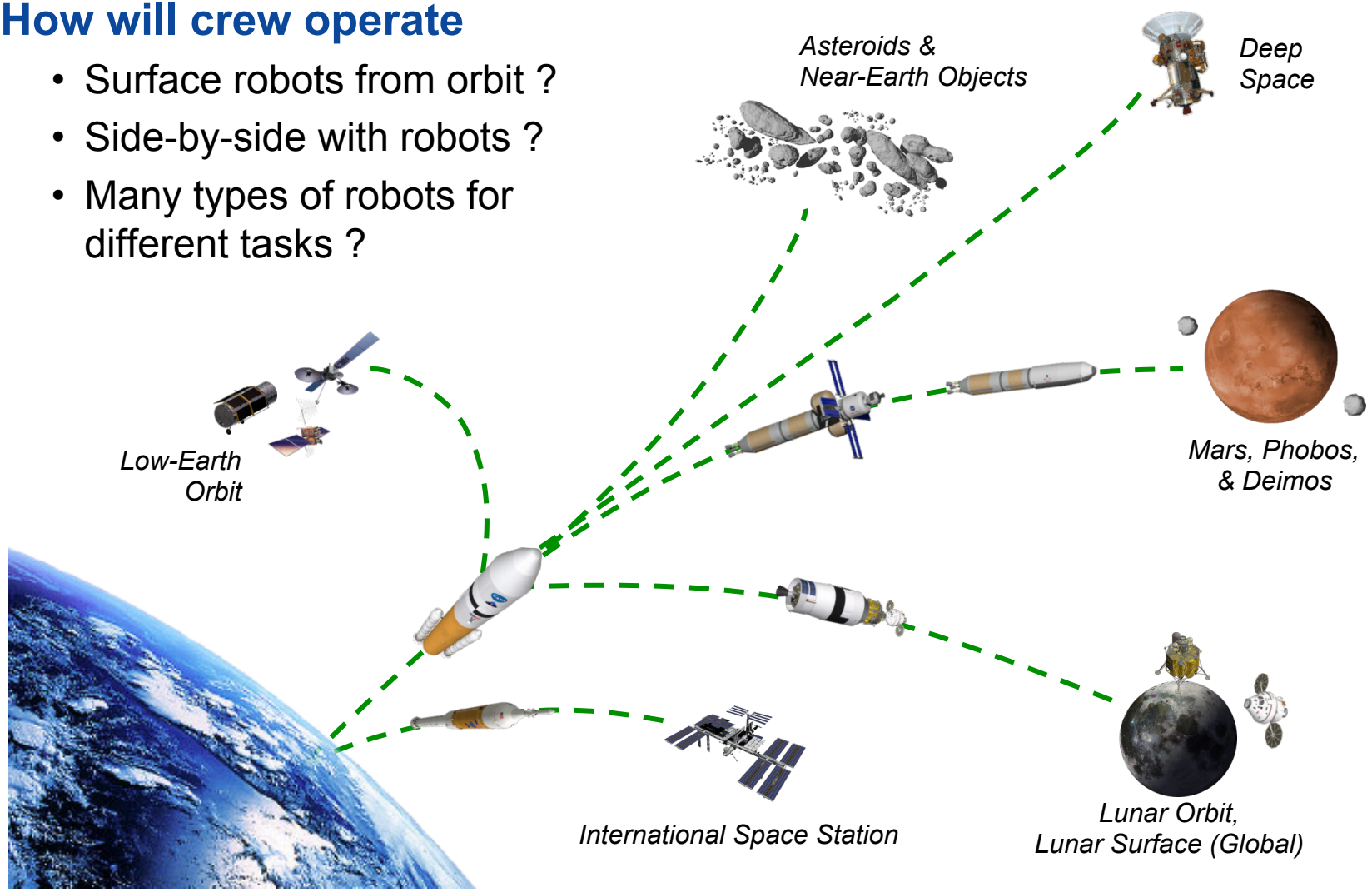

Riding lawnmower


School bus

Common User Interfaces

How will crew operate

- Surface robots from orbit ?
- Side-by-side with robots ?
- Many types of robots for different tasks ?



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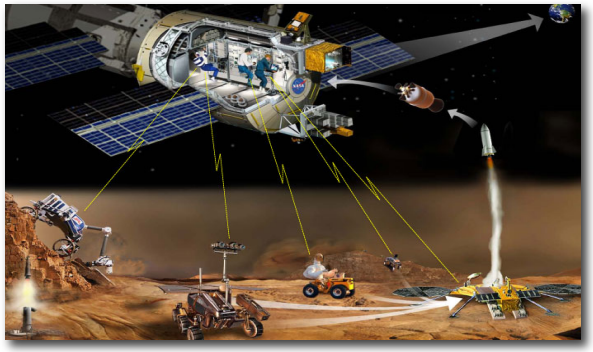

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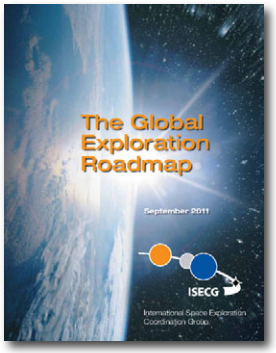

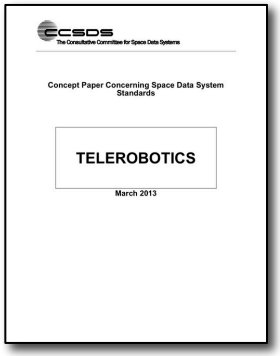

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- Common control modes
- Common interaction paradigms
- Enhance operator efficiency and reduce training time