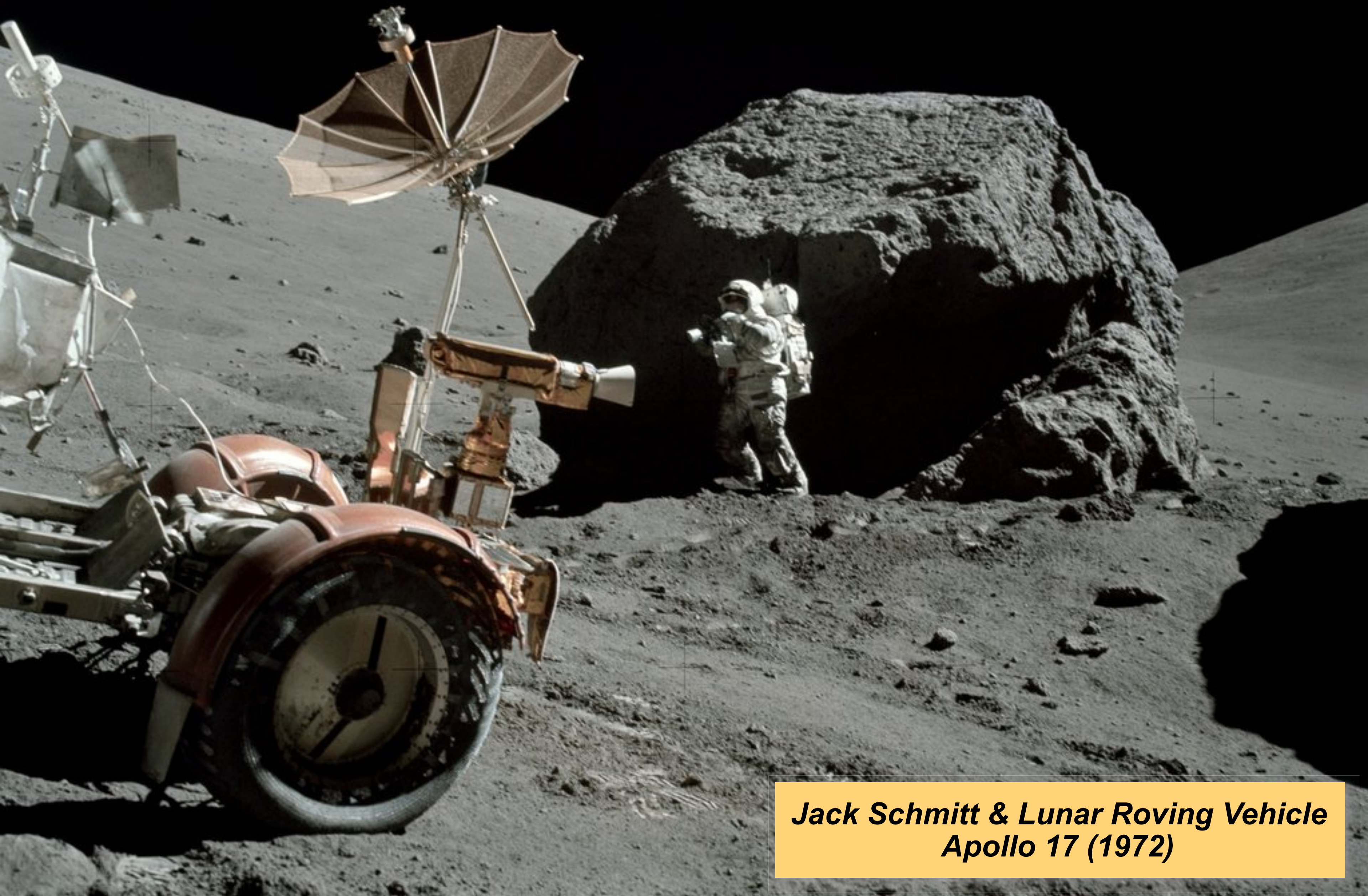
OUR HOME WITH THE ROBOTS

From planetary rovers to self-driving cars

Terry Fong

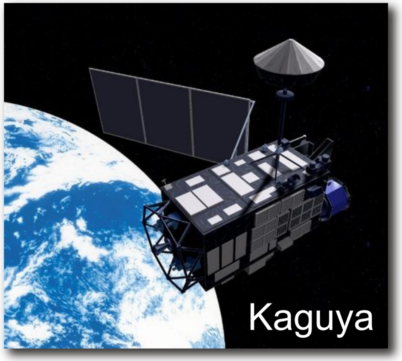
Chief Roboticist
NASA Ames Research Center
terry.fong@nasa.gov

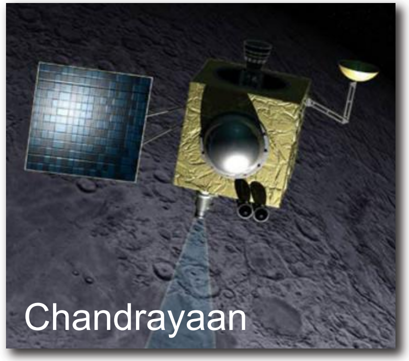
Human Planetary Exploration

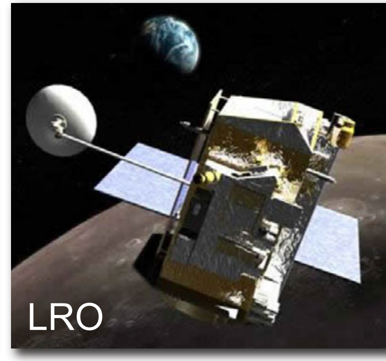


Jack Schmitt & Lunar Roving Vehicle
Apollo 17 (1972)

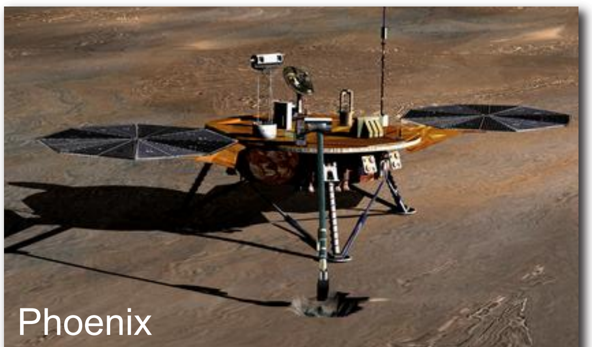
What’s Changed Since Apollo?


Kaguya

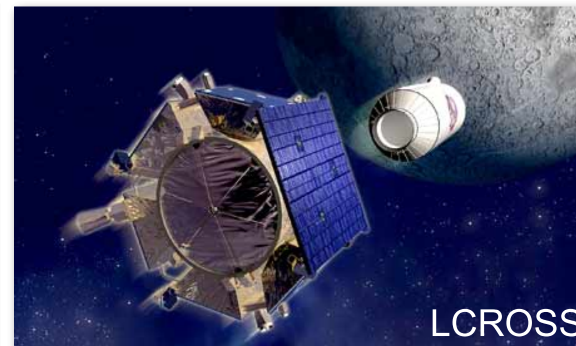

Chandrayaan

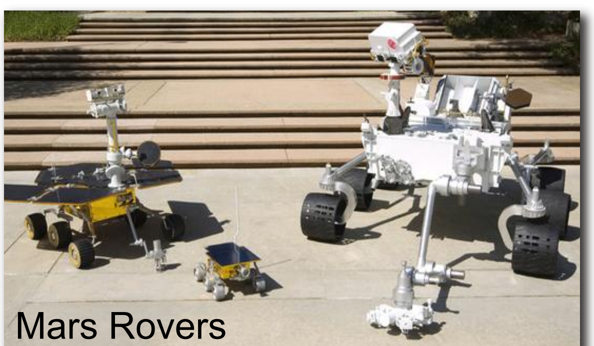

LRO


Space Station


Phoenix


Robonaut 2


LCROSS


Mars Rovers


ATHLETE, K10, Chariot

Human-Robot Teaming for Space

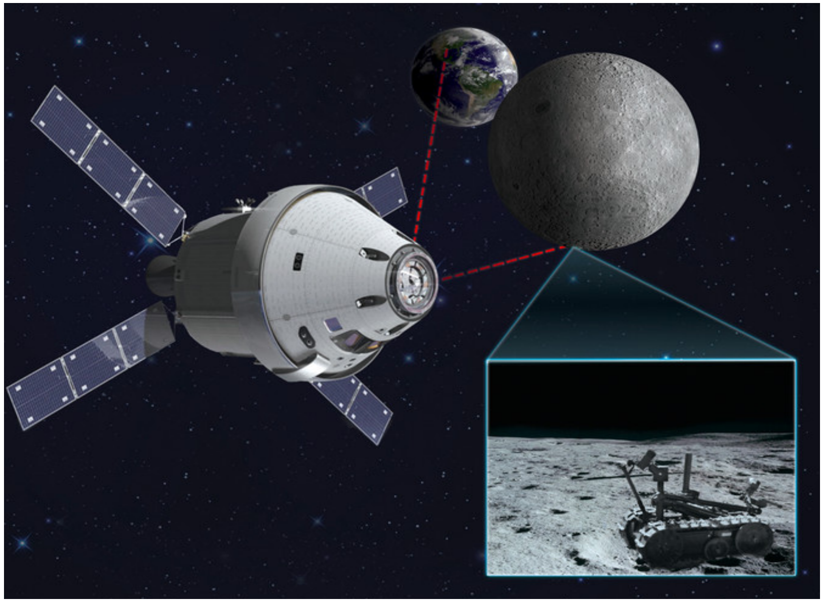
Improve performance

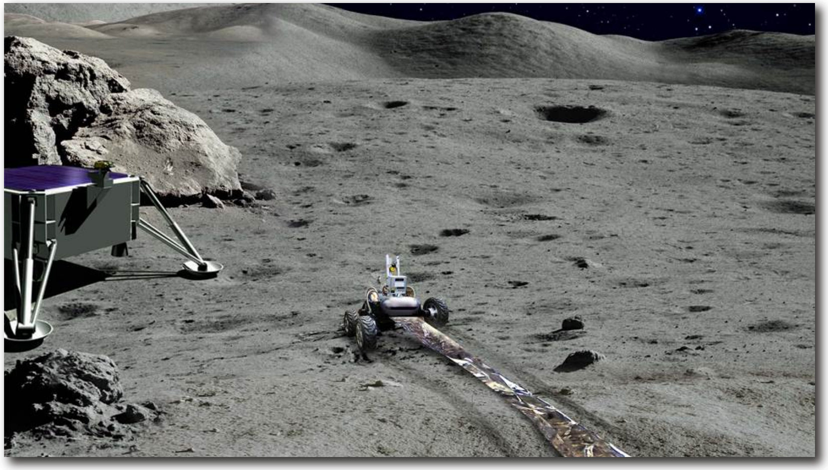
- Study how **humans can remotely support autonomous robots**
- Address the many **anomalies**, **corner cases**, and **edge cases** that require unique solutions, but which are not currently practical to develop, test, and validate under real-world conditions
- Humans provide high-level guidance (not low-level control) to assist when autonomy is inadequate, untrusted, etc.

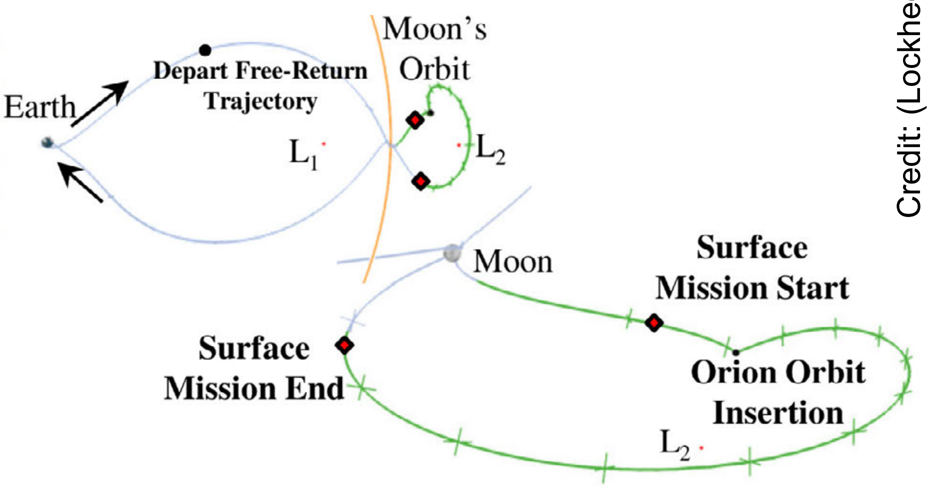
Lunar Mission Concept

Orion at Earth-Moon L2 Lagrange

- Astronaut remotely operates lunar rover from orbiting spacecraft – ***AVATAR in real-life!***
- Spacecraft orbiting 60,000 km beyond lunar farside
- High-bandwidth, low-latency data communication between spacecraft and surface robot







Credit: (Lockheed Martin / LUNAR)

Lunar Mission Simulation

"Surface Telerobotics" Project

- Simulation of the "Orion at Earth-Moon L2 Lagrange" concept
- Astronauts in the International Space Station (ISS)
- K10 planetary rover at NASA Ames
- Data comm via satellite relay with short delay (**750 msec round-trip**)
- Asynchronous bandwidth (**3 Kbps downlink, 800 Kbps uplink**)

ISS Expedition 36 testing

June 17, 2013 – **C. Cassidy**, survey

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

Aug 20, 2013 – **K. Nyberg**, inspect

SURVEY

DEPLOY

INSPECT

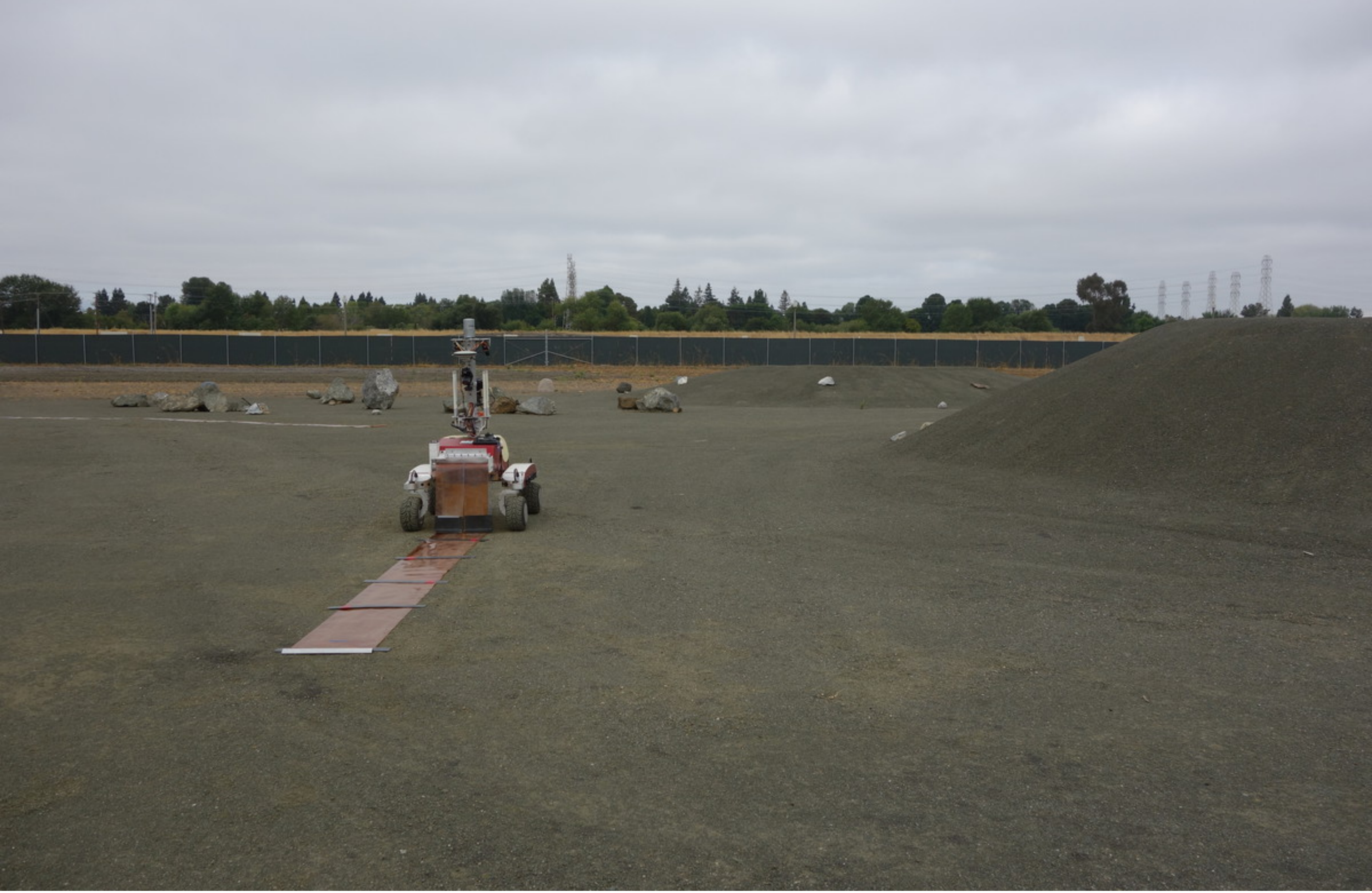
- **Human-robot mission sim**: site survey, telescope deployment, and inspection
- **Telescope proxy**: Kapton polyimide film roll (no antenna traces, electronics, or receiver)
- **3.5 hr per crew session** ("just in time" training, system checkout, ops, & debrief)
- **Robot ops**: manual control (discrete commands) and supervisory control (task sequence)

Astronaut in Space / Robot on Earth

Chris Cassidy remotely operates K10 from the ISS to perform site survey (2013-06-17)

K10 performing surface survey

Luca Parmitano works with K10 to deploy simulated polymide antenna (2013-07-26)



K10 deploying simulated polymide antenna

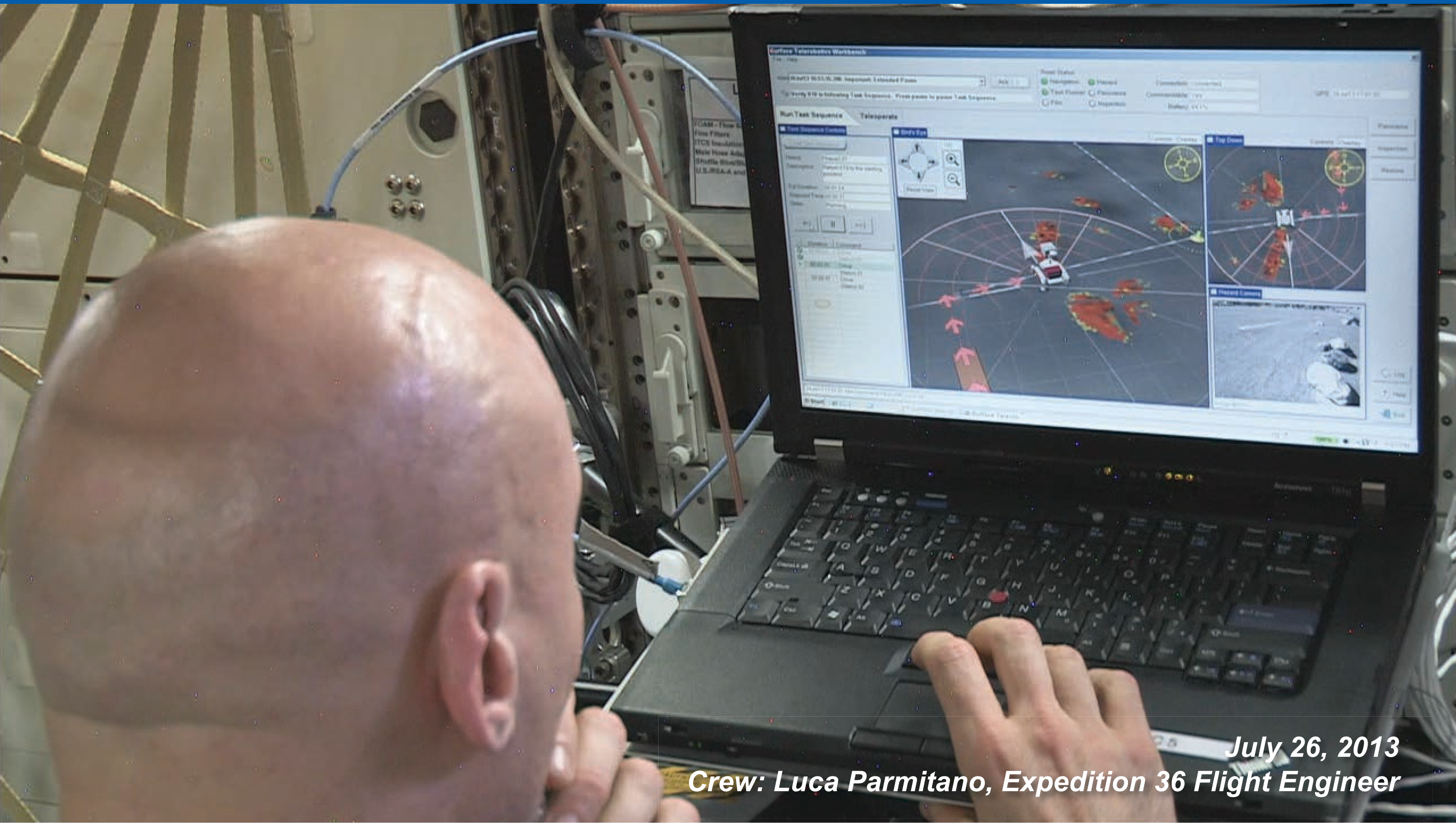
Deployed simulated polymide antenna (three “arms”)

Karen Nyberg works with K10 to document deployed simulated antenna (2013-08-20)

K10 documenting simulated polymide antenna

Astronaut Remotely Helping Space Robot

Astronaut Remotely Helping Space Robot

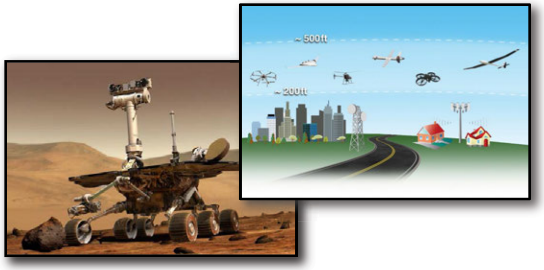


Human Remotely Helping Self-driving Car(s)

Vehicle assist: Situation assessment

Vehicle assist: High-level guidance

NASA and Self-Driving Cars



Common Technologies

Autonomy
Advanced Planning & Scheduling Algorithms, etc.

Human-Autonomy Teaming
Robotic Supervision including Human/Robotic Interactions, etc.

Networked Operations
Remote Vehicle Management, etc.

Prognostics / Diagnostics
Including State Management, etc.

Sensors and Perception
Data Processing / Fusion Methodologies, etc.

Verification and Validation
Methodologies & Application Experiences, etc.

NASA Missions

Planned human-machine interaction

Natural and time delayed environments

Aerial, space, and planetary navigation

On-board and ground control autonomy

Cyber-security for "one-off" systems

…

Self-Driving Cars

Diverse human-machine interaction

Structured environment

GPS & map-based navigation

Distributed and cloud-based autonomy

Cyber-security for consumer product

…

Self-Driving Cars at NASA Ames

Public/private partnerships

- **Google** (2014-15): collaborative testing of sensors and vehicles
- **Nissan** (2014-19): cooperative software development

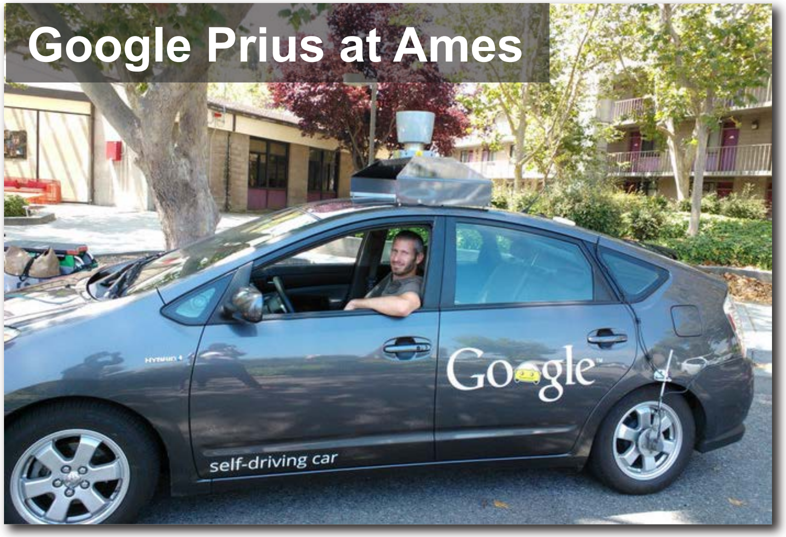
NASA interest

- Expand knowledge of commercial autonomous systems
- Develop protocols and best practices for testing of autonomous systems under **complex real-world conditions**
- Facilitate transfer of NASA technology

Technology maturation

- Safe testing in urban environment
- **Leverage NASA expertise** in autonomy, robotics, safety critical systems, and rigorous testing

Nissan Leaf at Ames



Google Prius at Ames

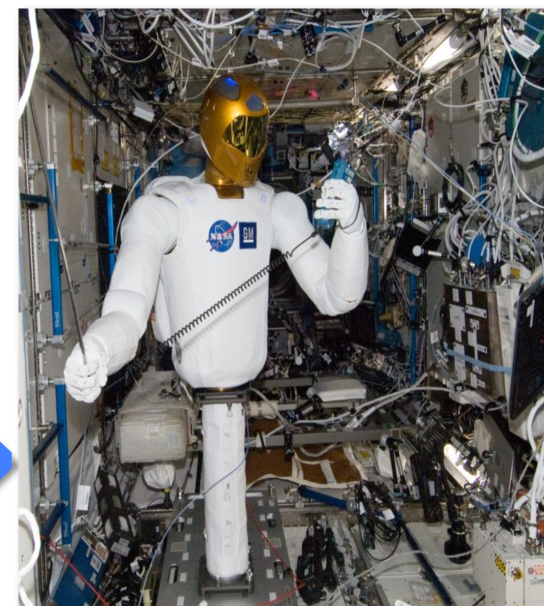
Working with NASA: Small Businesses

SBIR / STTR program

sbir.nasa.gov

- **Adapt** and **mature** terrestrial robotics technology for space use
- **Identify** and **transition** low-TRL technology from academia
- Build commercial products for **economies of scale** & **sustainability**
- Help NASA move beyond “one-off” components and systems
- **Very important to understand NASA relevance before proposing** !!

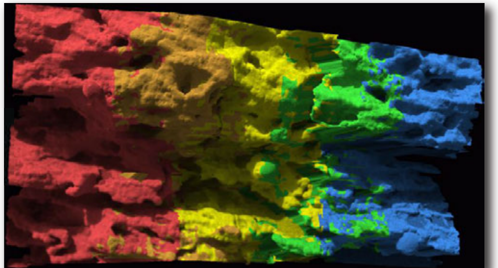
ROS

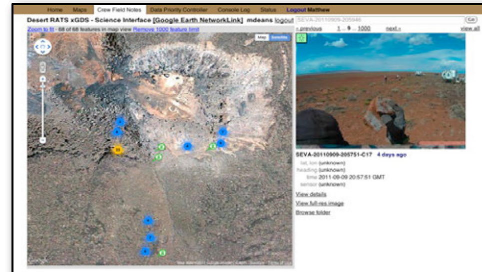


Working with NASA: Software Licensing

Vision Workbench

Apache 2



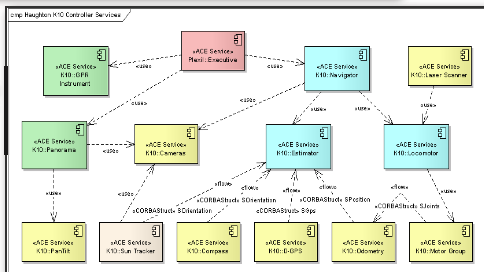


Exploration Ground Data Sys. (xGDS)

Apache 2

RoverSW

NOSA 1.3



Visual Environment for Remote Virtual Exploration (VERVE)

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Neo Geography Toolkit

(Ames Stereo Pipeline)

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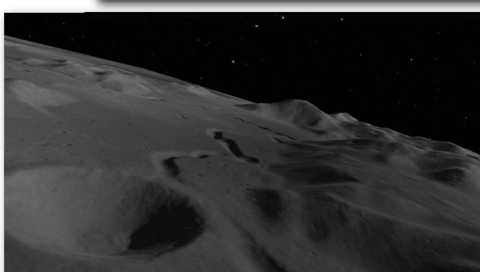

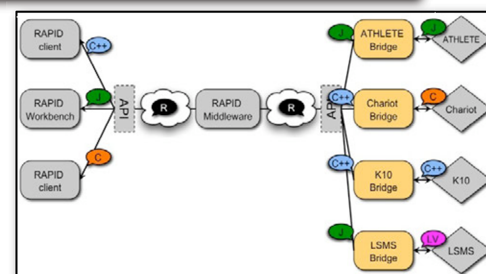

RAPID

(NASA robot middleware)

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NASA Tensegrity Robotics Toolkit

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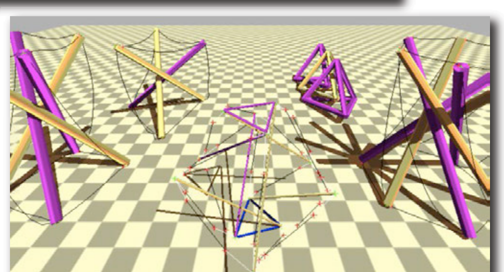

Astrobee Robot Software

Apache 2

Working with NASA: Partnerships

Academic

- The Robotics Institute
- Leland Stanford Junior University
- Vanderbilt University
- MIT
- Case Western Reserve University
- Berkeley University of California
- Rutgers The State University of New Jersey
- University of Idaho
- USC
- Brigham Young University
- Wisconsin University of Wisconsin–Madison
- Cornell University
- Universiteit Gent
- SETI Institute
- KAIST Korea Advanced Institute of Science and Technology 한국과학기술원

Commercial

- Google
- Nissan
- Astrobotic
- SSL
- Energid Robotics and Machine Vision
- Otherlab
- Altius Space Machines
- ProtoInnovations
- TRACLabs

Government

- DARPA
- Marine Corps Warfighting Lab "Semper Fidelis"
- SPAWAR
- NPS Praestantia Per Scientiam 1909
- Naval Research Laboratory Washington, DC
- USGS science for a changing world

Questions?

Intelligent Robotics Group
Intelligent Systems Division
NASA Ames Research Center

irg.arc.nasa.gov