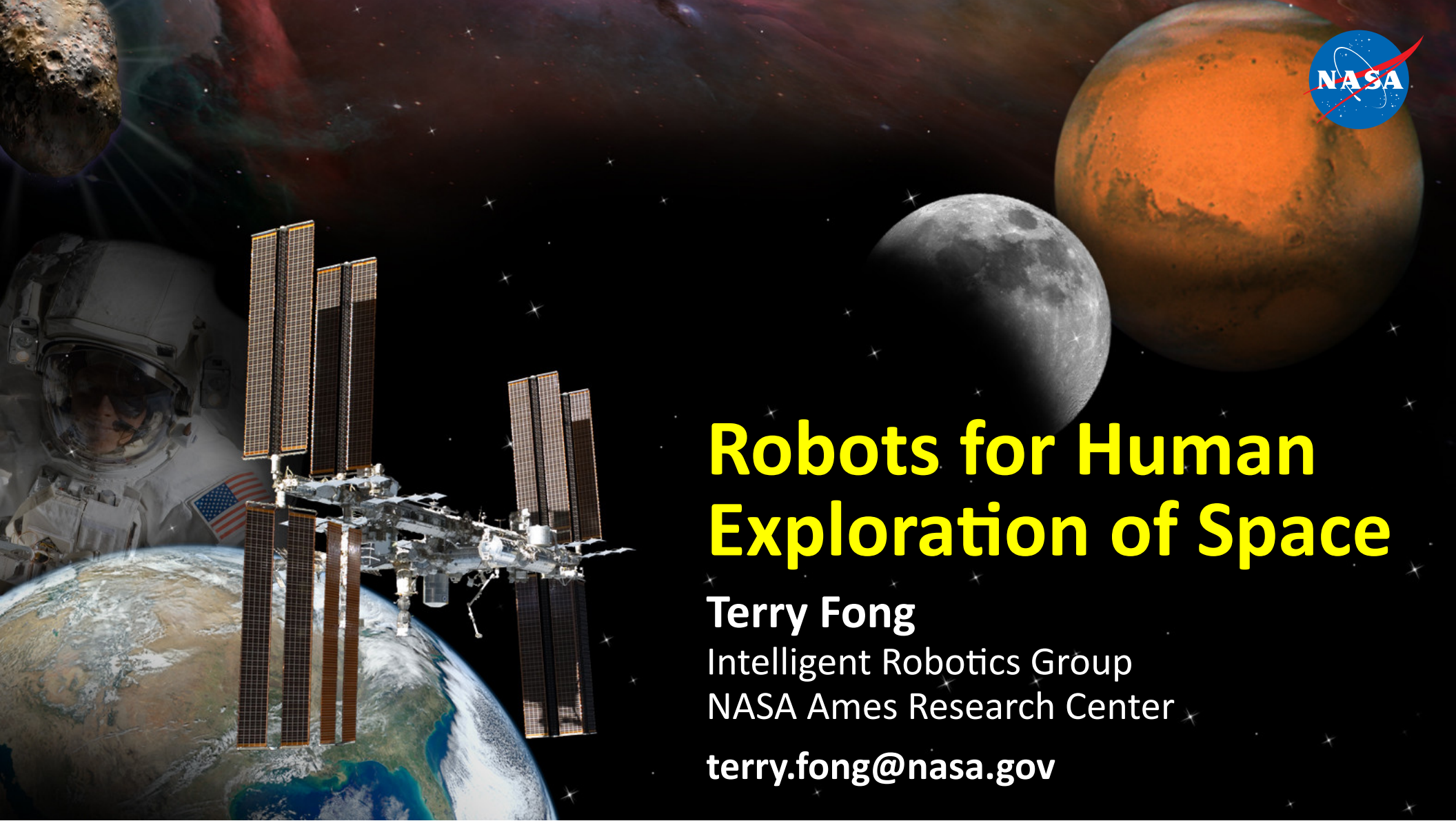

Robots for Human Exploration of Space

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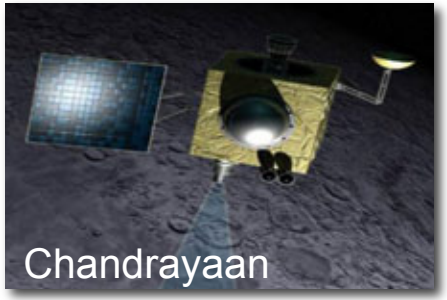
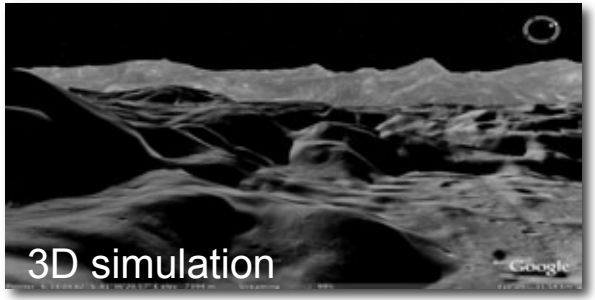
Apollo Surface Operations

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

What's Changed Since Apollo?





EARTH RELIANT

MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS

Mastering fundamentals aboard the International Space Station

U.S. companies provide access to low-Earth orbit

PROVING GROUND

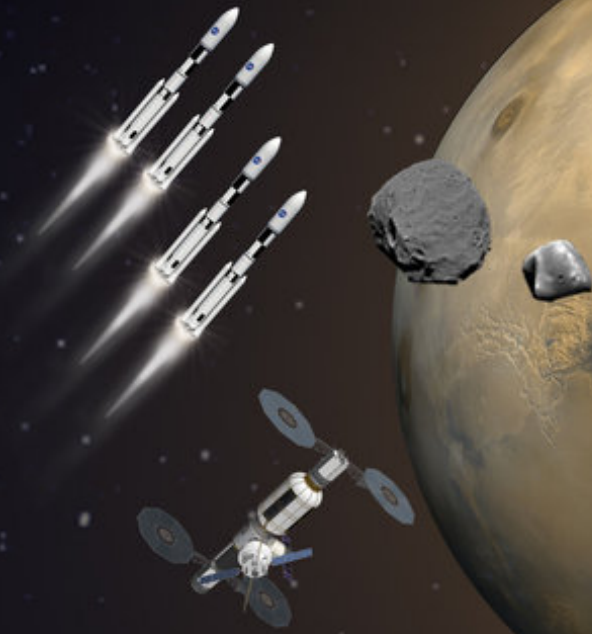
MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS

Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit

The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft

MARS READY

MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS



Developing planetary independence by exploring Mars, its moons and other deep space destinations

www.nasa.gov

Robots for Human Exploration

Purpose

- Increase human productivity
- Improve mission planning & execution
- Off-load routine work to robots

Before Crew

- **Scouting** & prospecting
- Site prep, deploy equipment, etc.

Supporting Crew

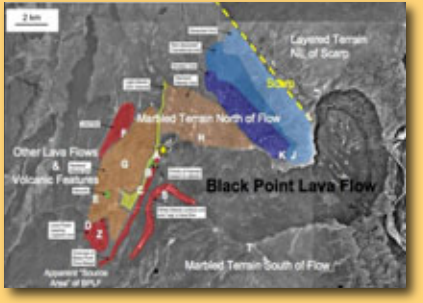
- **Extend human reach**
- **In-flight maintenance**

After Crew

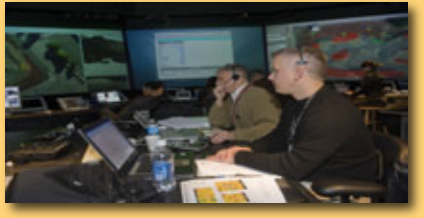
- **Follow-up** & close-out work
- Site survey, supplementary tasks, etc.

Robot Scoutng

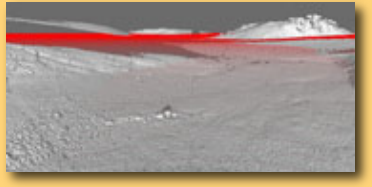
Planning



Robot Mission



Update

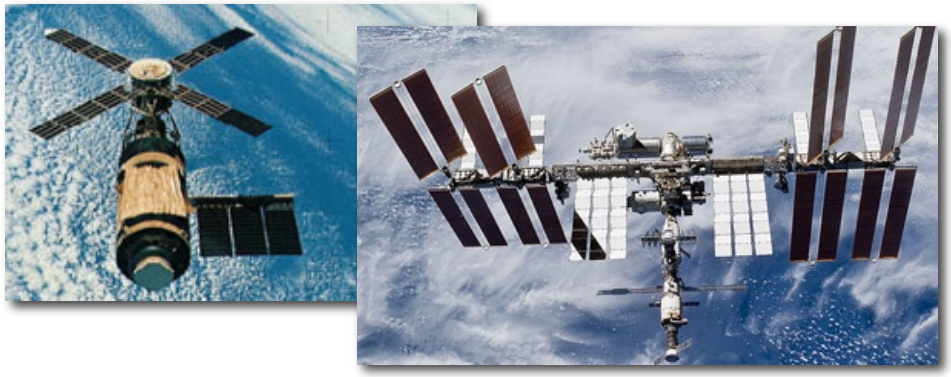


Human Mission

In-Flight Maintenance

Motivation: Skylab

- Micro-meteoroid + sun shield tore off at launch … and took a main solar array with it
- Almost lost the vehicle due to lack of power and overheating … before it was ever used!
- Astronauts had to do emergency repairs
- Future pre-deployments to deep space will need robots to do this type of work



Inspect & monitor
- Conduct routine surveys and inventory
- Check and document payload status

Routine maintenance
- Change air/water filters
- Perform water draw on life support system

Emergency response
- Assess environment after fire event
- Identify, evaluate and repair leaks
- Operate hatches, valves, mechanisms, etc.

Extending Human Reach

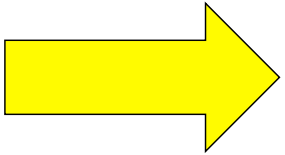
Surface Telerobotics

- Crew in orbit (inside spacecraft) remotely operates a robot on planetary surface
- Some level of “telepresence” (not necessarily immersive, nor high-quality)
- Enables long-duration “sorties” and surface work to be performed by crew

Candidate Missions

- **Lunar Farside**. Orion crew mission (libration point or distant retrograde)
- **Near-Earth Asteroid**. Asteroid dynamics and distance prevent effective manual control of robot from Earth
- **Mars Orbit**. Crew operates from stationary orbit or a Martian moon (e.g. Phobos) when interactive control is needed

Robotic Follow-Up



Challenge #1: Human-Robot Interaction

Key questions

- How to improve **human-robot team productivity** (coordination, task distribution, communication)?
- How to **reduce the # of people** in ground control?
- How to facilitate **crew-control** (training, skills, etc)?
- How to support **proximal interaction** for a variety of users (bystander, teammate, technician, etc)?

Challenge #2: Non-prehensile Manipulation

Key questions

- How can we manipulate the world **without** using a dexterous end-effector (robot hand)?
- How do we plan and control the use of **pushing**, **tapping, dragging, rolling, pivoting**, etc?
- What modeling / understanding of the **interaction physics** (friction, contact, mass, etc) is needed?

Challenge #3: Effective Simulation

Key questions

- How can we use simulation for **research** and **testing** (regression testing, V&V, etc)?
- How can we simulate **human-robot interaction**?
- How can we better simulate **physical phenomena** and unstructured, natural environments (especially when parameters are ill-defined)?